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SUMMARY

TECHNOLOGY, ENGINEERING AND MODELING

INFLUENCE OF PNEUMATIC CONVEYING ON THE CHARACTERISTICS OF CALCITIC LIMESTONE

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ABSTRACT

Pneumatic conveying is one of the most important techniques for the manipulation of particulate or powdered materials in the industry. This method has many advantages such as greater flexibility, simplicity of operation and lower cost if compared to other techniques of particulate handling. The objective of this work is to check the modification of the characteristics (particle size, angle of repose and apparent density) of calcitic limestone in an industrial scale pneumatic conveying system. It was verified by means of standard tests that the characteristics such as apparent density and effective diameter decreased by 22% and 7%, respectively, from the cycles with the material through the line of the pneumatic conveying system, and the angle of repose, even after abrasion of the material in the system, there were no significant changes.

Keywords: pneumatic conveying, material characterization, calcitic limestone.

Introduction

Pneumatic conveyance is the term used for moving different types of materials from the suspension and mixing in a gas flow through a pipe. Because it presents advantages such as flexibility and low maintenance cost, it is one of the most important materials transfer techniques in a huge variety of industries (LOPES, 2007). The design of a pneumatic conveying system for a solid material is strongly dependent on its physical properties, in particular, those ones involving interaction with air and with the pipeline. Typically, these interactions are a function of basic particles properties such as size, density, and shape. The study of these properties and its correlation with their macroscopic characteristics is what defines the material for its proper application. If there is any change in these properties the material may lose its applicability.

In a pneumatic transfer, intense friction can occur due to the interactions of the material with the air, the pipe and between particles, entailing changes in the characteristics of the material transported such as granulometry, apparent density, and angle of repose, which can lead to losses for industries.

In the mineral industry pneumatic convey is highly used, one of the materials widely used is the limestone. The limestone presents a wide variety of uses, from material for construction, material for aggregates, material for the manufacture of lime (calcium oxide), source of hydraulic binder in the manufacture of cement, and even as ornamental stones (MINISTÉRIO DE MINAS E ENERGIA, 2008). The applicability is associated with the size of the limestone granule, size grains of 40 to 100 mm are used in cement kilns and steel kilns, as small grains of about 100 µm are used in animal feed (FEECO, 2008). For each industrial branch, the size of the limestone affects its application.

The present work deals with the analysis of calcitic limestone characteristics by sieving granulometry, apparent density through a known volume and angle of repose by the funnel method, before and after being transported in a pneumatic system by means of a pressurized ejector, in order to compare the changes in their characteristics, validating or invalidating its applications.

Theoretical Framework

This work presents and discusses the results of calcitic limestone characterization in terms of its angle of repose, bulk density, and granulometry. The angle of repose, among other applications, is relevant to determine the amount of volume loss in collecting equipment, such as a silo or hopper, due to the angle formed on the surface. This test gives directions for deciding the best solution for the material handling required in the company and to make coherent projects for the installation of this chosen solution (ANDRADE, 2016).

Apparent density is the bulk density of the powder. It provides the mass per unit volume of loose-packed powders. This value is a first, low-cost evaluation of powder to determine consistency from lot to lot. A low apparent density can be an indication of fine particles and a high apparent density can be an indication of large particles. A change in apparent density can also indicate a change in the surface roughness of the powder.

The granulometry is important to predict characteristics of the material transport, depending on the granulometry the material may have a greater facility to be transported, the granulometry also influences the fluidization capacity of this particular material, besides its applicability. Some definitions (VARELA, 2017) should be presented for a better analysis of the material:

• Fineness module: The sum of the percentages accumulated in all the sieves of the series used, divided by 100. The larger the modulus of fineness, the thicker the soil will be;

• Maximum diameter: Corresponds to the number of the sieve of the series used in which the cumulative percentage is less than or equal to 5%, provided that this percentage is greater than 5% in the sieve immediately below;

• Effective diameter: the opening of the sieve for which we have 10% in the total mass of all particles smaller than it (10% of the particles are thinner than the effective diameter) and presented by equation 1; This parameter provides an indication of the permeability of the sands.

$$d_{ef} = d_{10} \qquad (1)$$

• Coefficient of non-uniformity: is the ratio between the diameters corresponding to 60% and 10%, taken in the particle size curve and presented by equation 2. This relation indicates the lack of uniformity since its value decreases when the material is more uniform.

$$c_{nu} = \frac{d_{60}}{d_{ef}} \qquad (2)$$

$c_{nu} < 5$ uniform

$5 < c_{nu} < 15$ partially uniformity

$c_{nu} > 15$ not uniform

For the comparison between the limestone before and after transports, the first characterizations were carried out on samples of virgin calcitic limestone. After this data collection, the material was submitted to pneumatic transport in a cyclic system and then the same characterization procedures were performed. The pneumatic conveying system used is described in section 3.

Material and Methods

The mentioned material characterization, as well as the pneumatic conveying process, were performed at the facilities of the Zeppelin Systems Latin America Test Center, located in São Bernardo do Campo. The system in question consists of two hoppers MG-02 and MG-04, two pneumatic guillotine valves (VGP-01 and VGP-02), one manual guillotine valve VGM-01, two butterfly valves for dosing -35) and a butterfly valve for air control (V-28), the blow tank (VP0100), a standard 3" pipe of about 130m, having a 5m height difference between the hoppers, an RT conveyor -01 and flexible for interconnection. In order to control this system a flow meter (FL-01) and two pressure transmitters (PT-01 and PT-09) were used. The transport cycle consists of dosing material into the blow tank by means of butterfly valves, opening of valve V-28 and its subsequent closing. Due to the limited availability of material to perform the tests, it was necessary to recirculate the material in batches through the system. It was defined that at a certain set mass value measured in the upper hopper the system would enter into the lower hopper feedback stage, preventing the opening of the air supply valve V-28, opening the pneumatic valve VGP-02 and RT-01 thread until a certain set value was reached, thus returning the system to its initial operation. Each feedback loop was defined as "mass cycle". The system is shown in Figure 1.

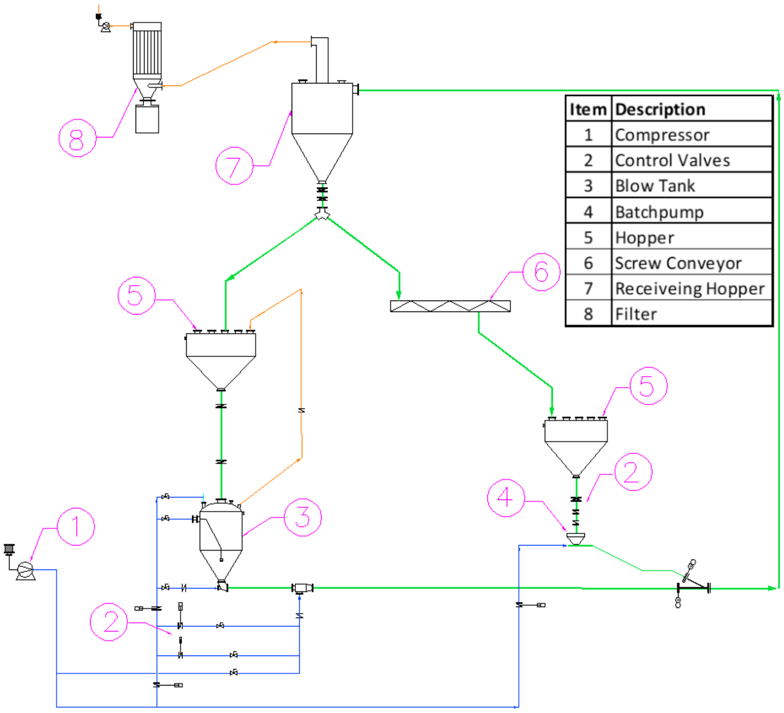

Figure 1. Schematic representation of the pneumatic conveying system.

The funnel method was used in the evaluation of the angle of repose. This method consists of filling a cylinder with a diameter at the exit of at least five times the diameter of the particle (GUZMAN, PELAEZ, 2008). The work makes use of a PVC tube filling up to approximately half its capacity, pouring the material contained in the container slowly and avoiding any vibrations in the cylinder and its bearing surface. The material is then deposited on the surface forming a cone as shown in figure 2, whose angle was measured by using a goniometer positioned at the straightest region of the cone and corresponds to the angle of repose.

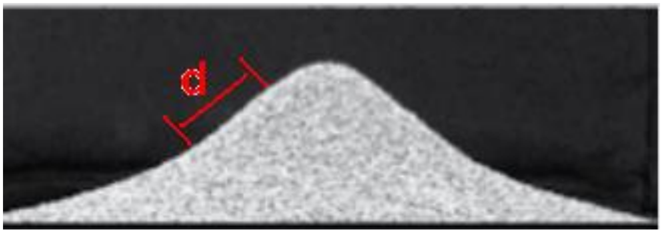

Figure 2. Material deposition and the region of the cone (d) that must be used to evaluate the angle of response.

The method used in the work to determine the apparent density followed the experimental procedure: the material was added in a cylinder of known volume (152 cm³) until it was completely filled slowly so that there was compaction of the material, so as not to leave empty spaces which interfered in the density calculation, and then the mass of that material was measured by repeating this procedure ten times for the minimization of instrumental uncertainties. After these measurements, the obtained value of mass was recorded, and thus the density was calculated dividing the mass contained into the recipient by its volume. The mean value of the bulk density was considered.

The granulometric test carried out in this work was done through the sieving method (SAMPAIO, 2007), where a series of sieves with different openings and previously known masses are stacked and the material is deposited into the top sieve. After submitting the ensemble to ten minutes of vibration, using for this purpose a sieves agitator, the sieve masses were evaluated again. The mass difference corresponds to the amount of material retained at each sieve.

Results and Discussion

Before the passage in the pneumatic transport, the sampled material showed an average apparent density of 970 kg/m³. In terms of the angle of repose, it was obtained a mean value of 44 °. Through the granulometric test it was possible to obtain the values of fineness module, maximum diameter, effective diameter and coefficient of non-uniformity, for future comparison with the limestone that passed through pneumatic transport. After characterization of the blank sample, the material was inserted into the transport line presented in figure 1 and then a sample was drawn for characterization. Its apparent density was 757 kg/m³. The mean value of the angle of repose at this stage resulted in 45 °.

From the granulometric test after the transport, it was possible to analyze the fineness module, maximum diameter, effective diameter and the coefficient of non-uniformity. These results are presented in table 1 comparing the limestone characterization before and after the pneumatic transport. The coefficient of non-uniformity revealed that limestone before the transport process did vary significantly, with an increase of 43%, but remained lower than 5, which corresponds to a considerably uniform material. The maximum diameter increased as well, which means that there was a greater mass accumulation in the sieves of greater aperture if compared to the test gauged out before the conveyance.

Table 1. comparison of the material properties after and before the pneumatic conveyance process.

Property	Before transport	After transport
Angle of repose (°)	44	45
Bulk density (kg/m^3)	970	757
Effective diameter (um)	42	39
Maximum diameter (um)	180	300
Coefficient of non-uniformity	2,14	3,07
Fineness module	0,05147	0,03500

When comparing the obtained values of the tests with the applicability of the limestone (FEECO, 2018), one can verify that, considering only the particle size, the material continues in the same range of application even being submitted to cycles of pneumatic conveyance which are not common in industries, that is, the material is usually transported from a storage device to a destination only once. The influence of the pneumatic transport, by the system used, was that of degradation of the calcareous limestone grain. What can be concluded is that the material conveyance can change the analyzed characteristics of materials and, depending on the particularities of the system and number of cycles, can influence the application.

Conclusion

It can be concluded from FEECO, 2018, that limestone after passage through the pneumatic conveying systems did not show a change in its angle of repose. Already analyzing the densities and the fineness modulus we can see that there was a significant decrease. In the apparent density, there was a decrease of 22% after transport and in the fineness module a decrease of 32%. The effective diameter decreased by 7%. This shows that the limestone has become thinner because of the intense particle-particle, particle-air and particle-pipe interaction that occurs in a pneumatic convey. These interactions cause wear on the material and can cause a decrease in grain diameter.

Acknowledgment

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References

LOPES, Cibele Souza. **Influência do alimentador de sólidos na fluidodinâmica do transporte pneumático**. 2007. 80f. Dissertação (Mestrado) - Curso de Engenharia Química, UFSCar, São Carlos, 2007.

MINISTÉRIO DE MINAS E ENERGIA. **Perfil do calcário**. 2009. Belo Horizonte: J.Mendo, 2018. p.7-8.

FEECO INTERNATIONAL. **Limestone Processing Handbook**. 2018. Green Bay: FEECO US Headquarters, 2018.

ANDRADE, Rafael Antunes de. **Método para a determinação do ângulo de inclinação da tremonha em silos**. 2016. Trabalho de conclusão de curso (Engenharia mecânica) - Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2016.

GUZMÁN, Diana Paola Solaque; PELÁEZ, Arcesio Lizcano; **Ángulo de fricción crítico y ángulo de reposo de la arena del Guamo**. Épsilon, Bogotá, v. 1, n. 11, p. 7-20, julho/dezembro. 2008.

VARELA, Marcio. Granulometria. Tirol: Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte, 2017. Slides.

SAMPAIO, João Alves; FRANÇA, Silvia Cristina Alves; BRAGA, Paulo Fernando Almeida. **Tratamento de minérios: práticas laboratoriais**. 1. ed. Rio de Janeiro: CETEM, 2007. p. 55-79.

D.F. Heaney. Handbook of Metal Injection Molding. Woodhead Publishing Series in Metals and Surface Engineering, 2012.

EVALUATION OF POWER GENERATION CYCLE CONFIGURATIONS IN WASTE-TO-ENERGY PLANTS APPLIED TO A BRAZILIAN SCENARIO

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ABSTRACT

Municipal solid waste (MSW) generation is growing all over the world, and its proper disposal is a problem for all governments. In Brazil, almost 41% of the total MSW collected is improperly disposed in uncontrolled landfills and dumps (ABRELPE, 2018). Thermal technologies are an interesting solution, as they are considered a suitable disposal solution with an energy recovery advantage. The objective of this study is to compare, three different power cycle configurations: simple Rankine cycle, Improved Rankine Cycle with reheating and a Combined cycle. Energy analysis results showed that the combined cycle presented better efficiencies, approximately 45%, now for steam cycles the highest efficiency was 32%, achieved for the improved Rankine Cycle.

Keywords: Manuscript format, Document template, MS Word styles, PDF.

Introduction

The amount of MSW tends to increase over the years, which makes them an inconvenience for the management of municipalities, since the disposal of solid waste in inadequate places causes one of the worst environmental impacts, since the decomposition of materials generates highly toxic substances that directly contaminate the soil, water, air and people. This is an illegal practice, with unquestionable harmful effects, and over the years, presents increasing costs of control measures and remediation. Among the different techniques and technologies used for the correct MSW disposal there are the waste-to-energy (WtE) plants, considered a suitable disposal solution with an energy recovery advantage. These plants are commonly based on the Mass Burning configuration, which is fully developed and has several plants operating on a commercial scale in Europe, USA and Asia.

The aim of this work is to study different steam power cycle configurations based on mass burning technology, from energy point of view. In this way, three configurations were evaluated: a. Simple Rankine cycle, b. Improved Rankine cycle with reheating and c. Combined cycle. Simulations were performed assuming the same MSW amount and composition for the 3 configurations, the MSW composition corresponds to the city of Santo André, São Paulo, Brazil. In order to take into account, the influence of MSW composition, two additional scenarios (II and III) were studied, in which organic matter and sanitary waste fractions change according to the deviations observed in samples studied by GUTIERREZ-GOMEZ; TONELI; NETO (2018). Extreme cases were assumed to show an optimistic (II) and pessimist (III) scenarios according to the MSW low heat value (LHV).

Material and Methods

The gravimetric composition of the MSW of Santo André city was assumed from GUTIERREZ-GOMEZ; TONELI; NETO (2018). The MSW compositions used in all scenarios are presented in Table 1. The simulations were performed using EES® Software. The amount of MSW for all configurations was assumed as 26.44 t/h, which is the amount of waste collected in the city of Santo André in the year 2014, according to the last report. The fuel was used as received, without pre-treatment.

Table 1 Gravimetric composition of all Scenarios

	Organic Matter	Sanitary waste	Plastic	Paper/ cardboard / tetrapak	Textile	Inert (glass, metal and other)	PCI (MJ/kg)
Scenario I (%)	39.7	10.9	14.5	11.0	9.0	14.9	7.2
Scenario II (%)	31.3	15.5	15.6	11.8	9.6	16.2	7.84
Scenario III (%)	47.0	6.8	13.6	10.3	8.4	13.9	6.64

Power Cycles

The Operation parameters used in the simulation of case a. Simple Rankine cycle, were adapted from the most common plants (ISWA, 2013), for case b. Improved Rankine Cycle with reheating, parameters were adapted from AEB plant in Amsterdam, and for case c. Combined Cycle, parameters were adapted from Zabalgardi in Bilbao, Spain (WOOD *et al.*, 2013).

Results and Discussion

Analyzing Table 2, it is possible to highlight that the addition of a reheat stage in case b. generates an increase in cycle efficiency, achieving an increase of approximately 7% compared to the simple cycle (case a). Considering the sensitivity analysis of the gravimetric composition, for Case a, the power generated in Scenario II (optimistic) and Scenario III (pessimistic) were 14.45 and 12.23 MW respectively, while in Scenario I was 13.27 MW. These values represent an increase of 8.8% (Scenario II) and a decrease of 7.8% (Scenario III) in installed capacity, in comparison to Scenario I. This demonstrates the importance of the gravimetric composition of waste in the plant performance. Case c had the best efficiency, due to the use of the gas turbine, which supplies approximately 73% of all the power generated in the plant.

Table 2. Main results of simulations

	Scenario I			Scenario II			Scenario III		
	Case a	Case b	Case c	Case a	Case b	Case c	Case a	Case b	Case c
Energy Analysis									
Gross Power [MW]	13.27	16.9	82.2	14.45	18.46	83.53	12.23	15.63	80.99
Net Power [MW]	12.42	16.11	81.33	13.60	17.62	82.7	11.39	14.79	80.15
Thermal efficiency [%]	25.1	32.08	45.26	25.10	32.08	44.85	25.10	32.08	45.65

Conclusion

Among the alternatives studied in this work, the combined cycle proved its efficiency and great power generation capacity. However, the promotion of this type of installation would not be exclusively from a power plant of MSW, due to the need to use another fossil fuel to supply a greater energy demand.

The other alternatives (single cycle and reheating cycle), which use only MSW as fuel, do not achieve the technical characteristics that can be achieved with the combined cycle, but possible modifications of the steam cycle can promote an improvement in overall efficiency.

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References

ABRELPE. *Panorama dos resíduos sólidos no Brasil 2017 [Solid Waste Panorama in Brazil 2017]. [In Portuguese]*. . Brasilia: 2018.

GUTIERREZ-GOMEZ, Andrea; TONELLI, Juliana; NETO, Ana Maria. Energy recovery of municipal solid waste in Santo André city, SP: case study in natura combustion. 2018, Recife: UFRPE, 2018. p. 243–259.

ISWA. *Waste-to-Energy State-of-the-Art-Report*. . Copenhagen: 2013.

TSILEMOU, Konstantinia; PANAGIOTAKOPOULOS, Demetrios. Approximate cost functions for solid waste treatment facilities. *Waste Management & Research*, v. 24, n. 4, p. 310–322, ago. 2006. Disponível em: <http://journals.sagepub.com/doi/10.1177/0734242X06066343>.

WOOD, Steven *et al. Review of state-of-the-art waste-to- energy technologies. Stage Two – CASE STUDIES*. . London, UK: 2013.

DETERMINATION OF THE EXPERIMENTAL CALORIFIC PERFORMANCE OF PASSION FRUIT SPREADING WASTE

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ABSTRACT

Brazil is the world's largest producer and consumer of passion fruit, being a tropical fruit that produces a lot of waste in its process. As this residue is more than 60% of the mass of the fruit, there is a problem directed to the discard of the same. One way to add economic and financial value to the passion fruit industry would be to use the waste as a source of fuel in a process of converting biomass to energy. The objective of this work was to characterize samples of passion fruit residues by analyzing the moisture content and the experimental calorific value, aiming at its energy utilization, in order to obtain initial information to help define the best conversion path of this biomass: thermochemical or biochemical. After analysis, it was concluded that the most appropriate biomass utilization route would be anaerobic biodigestion due to the high moisture content presented in the samples (greater than 80%). However, the same ones, if in dry basis, also have high calorific value, compared, for example, with sugarcane bagasse. With the results, it was demonstrated that the biomass of the passion fruit pulp presents itself as a potential alternative for the energy utilization.

Keywords: biomass, biomethanation, energy, passion fruit, thermochemical.

Introduction

Passion fruit is a general name given to the fruit and plant of the genus passiflora, a plant of tropical origin rich in vitamin C, calcium and phosphorus. Brazil is the world's largest producer and consumer of passion fruit per year, and the species with the largest commercial expression is *Passiflora edulis* (sour passion fruit) due to its fruit quality and higher industrial yield (FALEIRO, 2016).

In the passion fruit juice processing industry, waste disposal is a growing problem due to its production is increasing each year, as this waste constitutes most of the fruit's weight, about 60 to 70%. total (MELETTI, 2011).

These residues are basically composed of peels and seeds from the pulp extraction process for final destination in juices, soft drinks or sweets. They are a problem for the environment due to the large amount disposed of in landfills or cost problem for being sent as composting inputs. This disposal represents thousands of tons that could generate some economic value for industry.

According to EMBRAPA (2016), it is estimated that 60% of this production of 1 million tons per year of passion fruit is sold in natural, as table fruit or without industrial purposes (FALEIRO, 2016). The other 40% being destined for industrial processing and having an average yield of 35% of pulping due to the high amount of bagasse and seeds, it is possible to reach an estimated amount of 260 thousand tons of waste per year.

Adding value to these by-products is of economic, scientific and technological interest. Seeds and bark may be used for animal feed supplementation, such as feed for cattle and poultry, but without adequate technical information. The seeds, about 6 to 12% of the total weight of the fruit, can be good sources of oil, carbohydrate, protein and minerals, despite the high content of cellulose and lignin that limits their use in animal feed (FERRARI, 2004).

Another way that could add value to this supply and industrialization chain would be to use this waste as a form of energy production through its biomass. Biomass, which contains chemical energy from the conversion of light energy through photosynthesis, has been considered as one of the alternatives to fossil fuels due to its environmental characteristics, renewable, low cost, abundant and has a production potential within the limits of farmland that the planet offers (ROSILLO-CALLE, 2004).

According to EPE (2017), Brazil has about 17.5% of the energy matrix coming from sugarcane biomass (EPE, 2017). If we consider the value presented in this same report for firewood and charcoal, other products also coming from biomass, we would have added 8% more representativeness of renewable sources from biomass in Brazil.

This study aims the utilization of this energy from the passion fruit peel and seed biomass from a fruit pulping industry in the north of Espírito Santo State - Brazil, by characterizing these residues, analyzing their moisture content and determining its experimental calorific value, to obtain initial information to help define the best conversion route for this biomass: thermochemical or biochemical.

Material and Methods

- ✓ Sample Preparation

The residual biomass samples from passion fruit processing were collected from the pulping process step. Three samples were obtained, each within 1 hour interval, to guarantee a representativeness of the residues, whose masses were 1.150 kg, 1.805 kg and 0.6 kg. The collected fractions were mixed, totaling 3,553 kg of samples, which were placed in low density polyethylene (LDPE) plastic bags.

The conditioned and homogenized product was taken from Linhares - ES by air transport to the laboratory of the Federal University of ABC (LACABIO / UFABC) - SP, where some characterization tests were conducted. Thus, the samples were ground in a Philips model RI2034 / 21 device to guarantee the total homogeneity of the residues that possess bark, stems, leaves and seeds.

- ✓ Laboratory analysis

Humidity

The homogenized and ground samples were sent to a forced air circulation oven at 70ºC until constant mass was achieved, since the total solids content is calculated excluding the moisture content.

All mass determinations were performed using a 320g capacity BL-320H semi-analytical balance from the Shimadzu manufacturer. All analyzes were performed in triplicate.

To calculate humidity was used equation 1:

$$\boldsymbol{W = 100 - \left[\left(\frac{m_f - m_c}{m_a}\right) - 100\right]} \qquad (\mathbf{1})$$

M_F is the final mass after drying in grams**;**

M_C is the mass of the crucible, in grams**;**

M_A is the mass of the sample before drying (fresh) in grams.

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Heating Value

HHV (Higher Heating Value) on a dry basis was determined by a calorimetric pump (C2000, IKA) according to ASTM D2015-00 Standard Test Method for Gross Calorific Value of Coal and Coke by the Adiabatic Bomb Calorimeter (**2000)**.

The method consisted of making pellets or small briquettes of 1g of biomass with a press. These pellets were placed in a crucible next to a cotton wire, which is responsible for igniting next to an ignition wire. The pump was pressurized with 30bar oxygen and immersed in water to ensure uniform temperature around the pump.

After this, the process is automatic, only need to enter the data, and with the analyzed biomass, wait about 9 minutes to collect the result.

Results and Discussion

The moisture content of the triplicate samples, as well as its average, is shown in Table 1. According to the literature, the passion fruit peel has 88.37% ± 0.17 humidity, which indicates that the analyzes performed with the sum of bark and seeds has a relatively close value (CORDOVA, 2005).

The result of the analysis of the higher heating value obtained experimentally from the passion fruit residue samples is also presented in Table 1 for its triplicate and the calculated average value.

In Table 2, it is possible to see a comparison of the humidity and higher heating value found in experimental analysis with other biomasses using the same analysis reference. The analyzes show that the biomass in the dry base has a good thermochemical potential due to the high calorific value.

Table 1. Results obtained from moisture content and calorific value analyzes of passion fruit pulping samples**.**

	PARAMETERS	
SAMPLES	HUMIDITY (%)	PCS (MJ KG¯¹)
1	**84,26**	**18,97**
2	**85,51**	**19,23**
3	**82,87**	**19,11**
AVERAGE	84,21	19,10

Table 2. Comparison between studied biomass and other biomass using the same literature procedure.

BIOMASS	HUMIDITY (%)	PCS ($MJ\ KG^{-1}$) IN DRY BASE	REFERENCES
PASSION FRUIT (RIND + SEEDS BEFORE PROCESSING)	**84,52**	**19,1**	**-**
OURIÇO CASTANHA-DO-PARÁ	**9,71**	**18,95**	**RODRIGUES *ET AL.***
RINDS OF CASTANHA-DO-PARÁ	**11,02**	**19,53**	**RODRIGUES *ET AL.***
SOLID URBAN WASTE OF SANTO ANDRÉ (CRAISA)	**71,48**	**-**	**MARANA**
SUGARCANE BAGASSE (AFTER MILLING)	**50,88**	**19,17**	**NIÑO**
SEEDS OF AÇAÍ	**12,43**	**17,93**	**RODRIGUES *ET AL.***
COCONUT SHELL	**-**	**17,69**	**RODRIGUES *ET AL.***

Conclusion

The humidity found, around 84%, is undesirable to thermochemical process and desirable to biochemical route. This makes this last route the most suitable one. However, further studies on this route are needed, since the tests and studies of anaerobic bio digestion and the impacts that biomass pH may interfere in the biological process have not been performed.

For the thermochemical route, it has a higher HHV compared to other biomasses, and close to sugarcane bagasse, an important energy source in the Brazilian energy matrix. Being extracted the humidity, the analyzed biomass has high energetic potential for these processes. Further studies on this route are needed, as an elementary composition example, to assess the full potential use on this route.

References

CORDOVA, KATIELLE R. VONCIK; GAMA, THAIS M. M. TAVARES BASTOS; WINTER, CRISTINA M. GUOLO; NETO, GEORGES KASKANTZIS; FREITAS, RENATO JOÃO SOSSELA. CARACTERÍSTICAS FÍSICO-QUÍMICAS DA CASCA DO MARACUJÁ AMARELO (PASSIFLORA EDULIS FLAVICARPA DEGENER) OBTIDA POR SECAGEM. B.CEPPA, **CURITIBA, V.23, N.2 P. 221-230, JAN./JUN. 2005.**

EMPRESA DE PESQUISA ENERGÉTICA (EPE). MINISTÉRIO DE MINAS E ENERGIAS. BALANÇO ENERGÉTICO NACIONAL. RELATÓRIO SÍNTESE **| ANO BASE 2016 |. RIO DE JANEIRO, RJ, JUNHO DE 2017.**

Faleiro G.F.o, junqueira,N. jUNQUEIRA. T.V., EDITORES TÉCNICOS. MARACUJÁ: O PRODUTOR PERGUNTA, A EMBRAPA RESPONDE. **BRASÍLIA, DF. EMBRAPA, 2016.**

Ferrari, R.A.; Colussi, F.; Ayub, R.a. CARACTERIZAÇÃO DE SUBPRODUTOS DA INDUSTRIALIZAÇÃO DO MARACUJÁ – APROVEITAMENTO DAS SEMENTES. **Rev. Bras. Frutic., JABOTICABAL - SP, V. 26, N. 1, P. 101-102, ABRIL 2004.**

MARANA, K.B.B.; SILVA, C.A.; TONELI, J.T.C.L.; NETO, A.M.P.;ANTONIO,G.C. COMPARATIVO DE METODOLOGIA DE ANÁLISE IMEDIATA VISANDO O PROCESSAMENTO TERMOQUÍMICO DE CONVERSÃO ENERGÉTICA DA FRAÇÃO ORGÂNICA DE RSU DO MUNICÍPIO DE SANTO ANDRÉ. **6TH INTERNATIONAL CONFERENCE ON ENGINEERING FOR WASTE AND BIOMASS VALORISATION – MAY 23-26, 2016 - ALBI, FRANCE.**

MelettI,L.M.M. aVANÇOS NA CULTURA DO MARACUJÁ NO BRASIL. **Rev Bras Frutic, Vol Esp:83-91. 2011.**

NIÑO, A.D.L. CARACTERIZAÇÃO DA BIOMASSA RESIDUAL DE CANA-DE-AÇÚCAR VISANDO SEU APROVEITAMENTO ENERGÉTICO. **UNIVERSIDADE FEDERAL DO ABC, 2014.**

RODRIGUES, D. S.; DE SANTANA, A.R; RÍOS, J.M.G.; GADELHA, M.T.; TONELI, J.T.C.L.; ANTONIO, G.C. PROPRIEDADES FÍSICAS, QUÍMICAS E POTENCIAL ENERGÉTICO DE BIOMASSAS DA REGIÃO AMAZÔNICA. **UNIVERSIDADE FEDERAL DO ABC, 2016.**

RODRIGUES, D.S.; SANTANA, A.R.; RÍOS, J.M.G.; MARANA, K.B.B.; SILVA, C.A.; TONELI, J.T.C.L.; ANTONIO, G.C. ENERGETIC POTENCIAL OF TROPICAL BIOMASS. **UNIVERSIDADE FEDERAL DO ABC, 2016.**

Rosillo-Calle, F. UMA BREVE ANÁLISE DO POTENCIAL DA BIOMASSA NO BRASIL**. Renabio: BIOMASSA & ENERGIA, V. 1, N. 3, P. 225-236, 2004.**

EVALUATION OF THE AEROBIC DEGRADATION OF FOOD WASTE DURING THE STORAGE PERIOD BEFORE BATCH ANAEROBIC DIGESTION PROCESS

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ABSTRACT

Among the technologies available for energy and material recovery of the organic fraction of the MSW, the most important are those based on biological processes, such as anaerobic digestion (AD).This article refers to the aerobic degradation of food waste before being subjected to batch anaerobic digesters. Before starting processes in garage-type reactors, food waste is usually stored under ambient conditions until sufficient mass is obtained to fill the reactor and begin the process. Four samples of food waste were collected at the restaurant of IPT (Instituto de Pesquisas Tecnológicas) in São Paulo, Brazil and it was storage during 5 to 8 day. It was observed that solid to liquid phase changes occurred as a result of degradation processes and a decrease in pH was also observed. To verify a possible mass loss during the stocking process, the mass was estimated at end of the period. The difference found between the initial and final storage period ranged from 0.9 to 9.6%, so it was not possible to state whether this variation is due to material losses or inaccuracies derived from mass estimation.

Keywords: food waste, aerobic hydrolysis, anaerobic digestion, degradation

Introduction

The organic fraction represents around 50% in mass of the Brazilian municipal solid waste (MSW), which depicts an enormous potential for energy and nutrients recovery through biogas and organic compost production.

Although in Brazil landfills are the main form of final disposal for MSW, the recently approved Solid Waste National Policy enforces the hierarchy of no generation, reduction, reuse, recycling and treatment to the MSW management, so, alternative technologies for MSW treatment are to be developed, landfilling just the residues of these treatments.

Among the technologies available for energy and material recovery of the organic fraction of the MSW, the most important are those based on biological processes, such as anaerobic digestion (AD).

Development of commercial scale technologies for anaerobic digestion of food waste in Brazil must be preceded by experimental studies both in laboratory and pilot scales.

Considering sequential batch anaerobic digestion in garage systems, it is usual to observe, before the beginning of the actual anaerobic digestion, a storage period to accumulate the complete charge of the reactor, which varies according to reactor size and technology. During this storage period, some of the initial facultative degradation processes of the feedstocks start. The influence of the storage time in the loss of digestible material for the anaerobic reactor was analyzed in the study.

The amount of leachate generated and the loss of volatiles are very important parameters for the adequate leachate storage system design so that the storage time does not compromise methane generation because of material loss due to aerobic degradation, which would impact in the profitability of a commercial biogas production plant. Due to the technological difficulty to weight the solids in the reactor at the beginning of the anaerobic stage, a methodology based on the mass balance based on the total solids is proposed.

Material and Methods

Four samples of food waste, one from each day of the week, (from Monday to Thursday) were collected at the restaurant of IPT (Instituto de Pesquisas Tecnológicas) in São Paulo, Brazil, both from the kitchen (food preparation residues - FPR) and from the dining room (food leftovers - FL) in the same mass proportion (1:1). Samples of 200 g were collected for each day of the week and were cut into about one-inch size pieces and homogenized. The daily samples were then put into one-liter amber glass bottles, suspended by a tulle fabric to permit separation of the leachate from the solid phase. The substrate was kept at ambient conditions for a period of 5 to 8 days to evaluate the aerobic degradation and leachate production, simulating the period of accumulation of substrate before the beginning of AD processes in garage-type reactors.

Analysis of pH, Solids and volume of leachate generated were performed for samples immediately after collection at the restaurant and for the leachate and the suspended material at the end of the storage period.

The solid materials were crushed using a blender and subjected to extraction and filtration processes. For the extraction process 10g of sample were diluted in 90mL of water and mixed using a magnetic stirrer for 110 minutes. Suspended and diluted solids were separated using a pressure filter with a 0.7 µm pore glass fiber for around 3 hours.

Solids analysis were performed according to the methodology presented in Standard Methods 2005 (APHA, 2005) and the methods presented in INSTITUTO ADOLFO LUTZ (2008).

To verify the degradation through a mass variation of the materials stored for a period, samples were analyzed at the beginning and at the end of a period of 5 to 8 days. The mass in the tulle fabric at the end of the period was evaluated by the fixed solids results and the amount of leachate generated according to equation (1):

$$M_{tulle} = \frac{(TFS_{initial} * 0{,}2 - TFS_{leachate} * M_{leachate})}{TFS_{tulle}} \qquad (1)$$

M_{tulle}	= Mass in the tulle fabric at end of period	[kg]
$TFS_{initial}$	= Total fixed solids at beginning of period	[$kgTFS/kg_{sample}$]
0,2	= Mass of sample at start of the test	[kg_{sample}]
$TFS_{leachate}$	= Total fixed solids in leachate at end of period	[$kgTFS/kg_{sample}$]
$M_{leachate}$	=Mass of leachate	[kg]
TFS_{tulle}	= Total fixed solids in the tulle fabric at end of period	[$kgTFS/kg_{sample}$]

Leachate mass was estimated according to equation (2):

$$M_{leachate} = V_{leachate} * 0{,}001 * d \quad (2)$$

$V_{leachate}$	= Menu leachate volume generated	[mL]
0,001	= Conversion mL para L	[L/1000mL]
D	= Leachate density	[kg/L]

Mass balance, considering that gaseous losses were not significant:

$$M_{initial} = M_{tulle} + M_{leachate} \quad (3)$$

$M_{initial}$ = Mass of sample at the beginning [kg]

Results and Discussion

The results presented in Table 1 were obtained using equations 1, 2 and 3. The initial mass of all menus was 0.2kg. At the end of the process, a change of physical state of the residue was observed, with the solid part retained in the tulle and the leachate collected in the amber glass bottle. The leachate volume was measured with a beaker as shown in Table 1. The leachate mass was estimated according to equation (2) and the suspended tulle mass was estimated according to equation (1).

Table 1. Leachate volume

	Leachate volume (mL)
1	30
2	52
3	36
4	22

The amount of leachate generated during the storage period varied with no correlation with the storage time. This can be explained by the fact that the samples come from different menus and also because they were stored for different periods because the objective was to the accumulation of residues during the period of one week.

To estimate the mass present in the tulle, it was used TFS mean results from each menu as *presented* in equation (1). The mass balance was calculated according to equation (3). The results are shown in Table 2.

Table 2. Parameters at beginning of period

Menu	TFS start	TFS - final (tulle) ($g.kg_{sample}^{-1}$)	SFT - final (leachate) ($g.kg_{sample}^{-1}$)	Calculated mass in the tulle (kg)	Mass of the leachate (kg)	Total Mass (kg)	Difference
1	12.7505	14.3486	2.1833	0.1732	0.0300	0.2032	0.0032
2	8.3024	10.7188	5.3923	0.1288	0.0520	0.1808	-0.0192
3	11.9462	13.3395	4.3000	0.1623	0.0360	0.1983	-0.0017
4	11.0967	12.0587	0.2864	0.1828	0.0220	0.2048	0.0048

The difference found between the initial mass and the mass resulting from the sum of the calculated mass of solid material in the tulle fabric and the leachate ranged from 0.9 to 9.6%, so it was not possible to state whether this variation is due to material losses or inaccuracies derived from mass estimation. Food waste has a great variability in its composition, having different degradability levels. Thus, it is considered that in order to verify the occurrence of possible mass loss, mass measurements of the mass of solids before the beginning of the anaerobic stage (represented by the mass in the tulle fabric at the end of period) are very important and the use of estimate by only in cases where it is not possible to measure.

A decrease of the pH and a change of physical state could be noticed during the degradation process, indicating the beginning of the hydrolysis and acidogenesis processes.

The mean initial pH of the residues was 5.8 and after the storage period it reached the value of was 4.68.

Conclusion

Considering a storage period of 5 to 8 days, when storing organic waste under ambient conditions, physical state change, from solid to liquid could be evidenced by the generation of leachate which was easily measured, as well a decrease in material pH observed after this period, indicating the beging of the hydrolysis process. To establish mass balances for evaluation of the loss of organic matter in gaseous form, it is necessary to weight the solid content before the beginning of the anaerobic stage.

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References

APHA. **Standard Methods for the Examination of Watar and Wastewater**. 21ª ed. Washington, DC: APHA / AWWA / WEF. 2005.

INSTITUTO ADOLFO LUTZ (São Paulo). **Métodos físico-químicos para análise de alimentos** /coordenadores Odair Zenebon, Neus Sadocco Pascuet e Paulo Tiglea – São Paulo: Instituto Adolfo Lutz. 2008. p. 1020

ANALYSIS OF THE DISTRIBUTION SYSTEM CONSIDERING PV PENETRATION WITH OPTIMIZED POWER FACTOR CONTROL

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ABSTRACT

Distributed Generation (DG) is very convenient, because it can delay or even avoid load reinforcing investments in distribution networks. In particular, we can mention the Photovoltaic Generation (PV), which is currently growing quickly and it is available all over the planet. With this large increase, it is necessary to worry about the control of technical losses in the network and the voltage levels at each bus. The goal of this paper is to find the optimal adjustment for the Power Factor (PF) in the PV inverters, which minimizes the technical losses and improves the voltage profile. To solve the problem, an Optimal Power Flow (OPF) was modeled considering the hourly variations of load and PV power availability. The equations were modeled in AMPL software and the Knitro solver was used. The algorithm was tested on a 10-bus system and the results are presented and discussed. It is demonstrated that the optimal control of the PF is more efficient when compared to others PV inverters operating mode.

Keywords: distributed generation; losses minimization in distribution network; optimal power flow; photovoltaic generation; power factor control of PV inverter;

Introduction

In Brazil, the main sources of electricity are hydroelectric (60%) and thermoelectric (24%) (Aneel, 13-Jul-2019).

Large power plants, such as hydroelectric plants, are usually located far away from urban centers or even in remote locations. Therefore, it is necessary to build extensive transmission/distribution lines to dispatch the generated power to the urban centers. In these two stages, there are active power losses. According to (Ng, Salama, & Chikhani, 2000), 13% of all the power generated is consumed as active losses in distribution networks.

Currently, there is a concern to meet the growing demand for electricity, but in a sustainable way that does not cause significant environmental impact. Therefore, the development of renewable energy sources such as solar, wind, biomass, etc., has been growing gradually. These types of energy sources are known as Distributed Generation (DG) (Paludo, 2014).

Solar energy systems stand out in the national scenario compared to other renewable power sources. In the last years, they have shown an exponential growth in installed capacity, from 54 MW in Jan/2017 to over 900 MW in Jul/2019 (Aneel, 30-Jul-2019). The decrease of implementation costs, the development of new inverter technologies, low environmental impact rates and the growing incentive policy are responsible for this growth (Carvalho, 2012).

Most of the residential and commercial consumers are connected in the distribution networks. These networks are generally radials, theoretically there is only one-way power flow. Under a large penetration of DG, there is the possibility of two-way power flow in the network, because sometimes the generated power may be greater than the consumed at bus, causing reverse flow in the network.(Paludo, 2014). This reverse power flow may cause an increase in bus voltage levels. Generally, PV systems operate with unity power factor (PF), i.e. there is no generation or absorption of reactive power by PV inverter at the connection point. Reactive power control is a very useful solution for voltage profile improvement and loss reduction in distribution networks.

Many papers have studied the impact of PV generation in the distribution networks. Several techniques have been proposed to study the problem, such as the use of voltage regulators and reactive management of inverters. In (Solanki, Ramachandran, & Solanki, 2012), the impact of PV on 3 levels of penetration is analyzed. The analysis is done in steady state and evaluates the voltage levels, unbalance and losses in a feeder. For the simulation, it is considered a unity power factor and that there is not any kind of voltage regulator along the grid.

The paper (Eichkoff, Marques, & Mello, 2018) presents an analysis of the voltage profile with a reactive power control (Volt/Var). This control is done to minimize active power losses. The paper proposes a Volt/Var control of the solar inverter, which basically, makes the inverter inject or absorb reactive power depending on the voltage level in the bus. The reactive limit was proposed respecting the PF control curve according to ABNT (Abnt, 2013). It was also considered the hourly load and intermittency profile of the PV generation.

The integration between voltage regulators and the PV system is studied in (Selim, Abdel-Akher, Aly, & Kamel, 2016). The aim is minimize the voltage deviation in the bus together with the minimization of voltage regulator operations. The problem is solved by injecting PV power into the network.

Analyzing this information, it is intuitive to conclude that it is very important to optimize the operation and planning of distribution network in the presence of high PV penetration. The goal of this paper is to develop an optimal power flow (OPF), aiming to improve the voltage profile and minimize active power losses. This goal is achieved by optimizing the PF adjustment to be set in the solar inverters at buses, thus it is possible to control the reactive power in the grid. The load profile and the PV hourly curve were considered for this paper.

Material and Methods

An OPF algorithm was implemented using the programming language AMPL(AMPL., 2019). The load flow equations were modeled in the AMPL language according to (Monticelli, 1983). The objective function and the restrictions to be imposed in the system as well. The software Knitro (Knitro., 2019) was applied to solve the problem and find the optimal PF to achieve the target function.

The target function of the problem was the minimization of the losses, which is described as follows:

$$Minimize\ Losses = \sum_{km \in \Omega} g_{km}\left(V_k^2 + V_m^2 - 2V_k V_m \cos\theta_{km}\right) \tag{1}$$

In this equation, g_{km} is the series conductance between the buses $k - m$, V_k is the voltage magnitude at the bus k, V_m is the voltage magnitude at the bus m, θ_{km} is the difference of the voltage angle at the terminal buses $k - m$ and Ω is the set of all distribution lines.

The constraints applied to the problem were:

a-) Active (2) and reactive (3) power balance at the bus

$$S_{FV}PF + P_k - P_{Lk} = V_k \sum_{m \epsilon \Omega_k} V_m(G_{km}\cos\theta_{km} + B_{km}\sin\theta_{km}) \tag{2}$$

$$\sqrt{S_{FV}^2 - (S_{FV}PF)^2} + Q_k - Q_{Lk} + Q_k^{sh} = V_k \sum_{m \epsilon \Omega_k} V_m (G_{km} \sin \theta_{km} - B_{km} \cos \theta_{km}) \quad (3)$$

The term S_{FV} is the PV apparent power injected at the bus k by inverters, PF is the Power Factor to be set in the PV inverter, P_k and Q_k are the active/reactive power generated by conventional generators at the bus k, P_{Lk} and Q_{Lk} are the active/reactive power of the load connected at the bus k, Q_k^{sh} is the injection of reactive power by shunt component at the bus k, G_{km} and B_{km} are the real/imaginary part of the admittance matrix from the branch $k - m$, and Ω_k is the set of all buses neighboring the k bus.

b-) PF limits

$$PF_{min} \leq PF \leq PF_{max} \quad (4)$$

$$S_c \geq 0.5 S_n \quad (5)$$

The limit described in equation 4, defines the range of the available settings to the PF to be set in the PV inverter connected to the bus. The terms FP_{min} and FP_{max} are the minimum and maximum possible set in the inverter. Equation 5 defines whether the PF control can be activated or not, because with the inverter loading power below 50% of the nominal, the PF control cannot be done (Enel, 2019). S_c is the loading power of the inverter and S_n is its rated power.

c-) Voltage limits

$$V_{k_{min}} \leq V_k \leq V_{k_{max}} \quad (6)$$

The terms $V_{k_{min}}$ and $V_{k_{max}}$ are the maximum and minimum limits respectively, the slack bus voltage is fixed in 1 pu.

The load hourly variation was considered according to (Neto, 2016) and the intermittency of PV generation like the curve presented in (Selim, Abdel-Akher, Aly, & Kamel, 2016). The algorithm was tested on a 10-bus system of (Rao & Narasimham, 2008). The loads have an inductive characteristic, each bus has a nominal active/reactive power connected. The specification at each bus was assumed as its maximum demand. The period from 06:00 am to 06:00 pm was studied, because it is the period which has some contribution from PV system. The PV penetration level considered (S) was 50% of the maximum demand at each bus, except at the slack bus. Figure 1 represents the PV systems at each bus. This PV allocation was defined to stand out the effects of a high PV penetration. The tests were made considering:

- System operating without any PV generation;
- PV generation working with unity power factor;
- PV generation working with variable power factor between 0,90 ind to 0,90 cap;

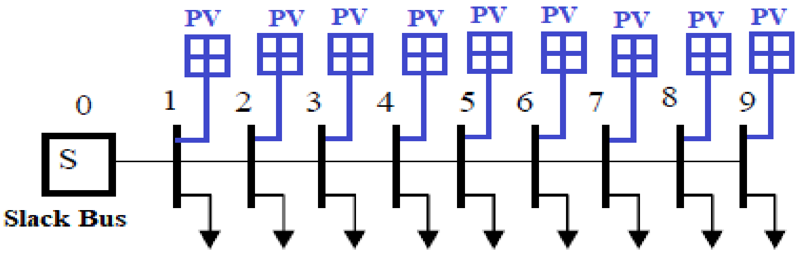

Figure 1. 10-Bus system with the PV considered

Results and Discussion

After all the simulations, the results are shown below. The hourly OPF in Table 1, the voltage profile results can be seen in Table 2 and the losses in Table 3.

Table 1. Optimal Power Factor

	TIME												
Bus	AM						PM						
	6	7	8	9	10	11	12	1	2	3	4	5	6
2	1,00	1,00	1,00	0,93	0,93	0,93	0,93	0,93	0,93	0,93	0,93	1,00	1,00
3	1,00	1,00	1,00	0,91	0,92	0,92	0,92	0,92	0,92	0,92	0,91	1,00	1,00
4	1,00	1,00	1,00	0,91	0,90	0,90	0,91	0,90	0,90	0,91	0,92	1,00	1,00
5	1,00	1,00	1,00	0,91	0,90	0,90	0,90	0,90	0,90	0,90	0,91	1,00	1,00
6	1,00	1,00	1,00	0,95	0,95	0,95	0,95	0,95	0,94	0,95	0,95	1,00	1,00
7	1,00	1,00	1,00	0,96	0,96	0,96	0,97	0,96	0,96	0,97	0,97	1,00	1,00
8	1,00	1,00	1,00	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	1,00	1,00
9	1,00	1,00	1,00	0,98	0,99	0,99	0,99	0,99	0,99	0,99	0,98	1,00	1,00
10	1,00	1,00	1,00	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	1,00	1,00

The PV converters need to work according to their nominal apparent power. So, if you need to inject/absorb reactive power, it´s necessary to avoid the solar inverter overload keeping the equality below:

$$S_{pv} = \sqrt{P_{pv}^2 + Q_{pv}^2} \tag{7}$$

In this equation, S_{pv} is the apparent power available by the PV arrangement, P_{pv} and Q_{pv} are the active and reactive power dispatches by the solar inverter to the network. Therefore, when you are working with a PF different than 1, it´s necessary cut the active power to avoid the converters overload. This cut of active power is known as Power Curtailment.

Table 2. Voltage Profile

Bus	Maximum voltage deviation - pu		
	No PV installed	PV PF=1	PV OPF
2	0,9956	0,9969	0,9979
3	0,9923	0,9940	0,9963
4	0,9775	0,9846	0,9890
5	0,9680	0,9791	0,9842
6	0,9491	0,9695	0,9760
7	0,9430	0,9665	0,9735
8	0,9319	0,9613	0,9688
9	0,9136	0,9526	0,9609
10	0,9008	0,9466	0,9554

Table 3. Total Losses in the Period

Case	Power Curtailment (MWh)	Losses (MWh)
No PV installed	0	3,7955
PV with PF=1	0	1,5979
PV with OPF	2,3397	1,5233

It can be noted in Table 1 that the voltage profile has a large deviation without any PV systems connected. Considering the PV systems connected with unity PF an improvement of voltage magnitude at each bus, but the increase is better with the system operating with optimal power factor adjustment, as a lower voltage deviation can be noticed in the results.

A lower energy loss at the distribution network can be noticed in Table 2. The column identified as Power Curtailment (Table 3) was inserted to show how much active energy curtailment was necessary to dispatch the reactive power.

Depending on the topology and loads of the system, there may be a big active power curtailment, what can make the PV systems investment less attractive. Therefore, each system must be studied very carefully.

Conclusion

This paper presented an algorithm based on OPF to determine the optimal system's operation point considering the variation of the solar inverter’s power factor.

The PV system by itself decreases the power losses and improves the voltage profile at the grid, but it was demonstrated that the reactive power control is very important to improve even more the voltage profile and decrease even more the losses at the distribution network. So, the optimal power factor adjustment presented in this paper is an effective technique to optimize the planning or operation of the distribution network. But its necessary to worry about the active power curtailment, because the higher the curtailment, the lower will be the revenue with the PV systems. The grid needs reactive power, so it is necessary to study a way to compensate the users for the reactive power injected/absorbed by their PV systems. This subject will be treated in other works.

Acknowledgment

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References

Abnt. (2013). NBR 16149: Sistemas Fotovoltaicos - características de interface de conexão com a rede elétrica de distribuição. Rio de Janeiro.: ABNT.

AMPL. (04 de 08 de 2019). *A Modeling Language for Mathematical Programming.* Fonte: A Modeling Language for Mathematical Programming.: http://www.artelys.com/uploads/pdfs/ampl-book.pdf

Aneel. (13-Jul-2019). *Banco de Informações de Geração*. Acesso em 13 de Jul de 2019, disponível em http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

Aneel. (30-Jul-2019). *Sistema de Registro de Geração Distribuida*. Acesso em 30-Jul-2019, disponível em http://www2.aneel.gov.br/scg/gd/VerGD.asp

Carvalho, K. J. (09 de 2012). Sistemas Fotovoltaicos Distribuídos e Integrados à Rede Elétrica: Condições de Operação e Seus Impactos. Dissertação de Mestrado. Universidade Federal do Rio de Janeiro. *Tese de Mestrado. UFRJ.* Rio de Janeiro, RJ, Brasil.

Eichkoff, H., Marques, R., & Mello, A. (2018). Análise da Geração Distribuída Para o Controle de Tensão e Potência Reativa em Sistemas Modernos de Distribuição. *VII Congresso Brasileiro de Energia Solar.* Gramado.

Enel. (04 de 2019). Nota Técnica 6.012. *Requisitos Mínimos Para Interligação de Micro e Minigeração Com a Rede de Distribuição*. São Paulo, SP, Brasil.

Garcia, A., Mastromauro, R., & Sanchez, T. (2017). Reactive Power Flow Control for PV Inverters Voltage Support in LV Distribution Networks. *IEEE Transactions on Smart Grid, 8*(1), 447-456.

Knitro. (08 de 04 de 2019). *Manual Knitro.* Acesso em 2019, disponível em http://www.artelys.com/uploads/pdfs/Knitro80_UserManual.p df

Monticelli, A. J. (1983). *Fluxo de Carga Em Redes de Energia Elétrica.* Campinas: Edgar Blucher Ltda.

Neto, A. F. (2016). Avaliação do Impacto de Sistemas Fotovoltaicos Conectados à Rede de Distribuição de Baixa Tensão.Dissertação de Doutorado. Universidade de São Paulo. *Tese de Doutorado. USP.* São Paulo.

Ng, H., Salama, M., & Chikhani, A. (1 de 01 de 2000). Classification of Capacitor Allocation Techniques. *IEEE Transactions on Power Delivery*, pp. 1-6.

Paludo, J. A. (2014). Avaliação dos Impactos de Elevados Níveis de Penetração da Geração Fotovoltaica no Desempenho de Sistemas de Distribuição de Energia Elétrica em Regime Permanente. Dissertação de Mestrado. Universidade de São Paulo. *Tese de Mestrado. USP.* São Carlos.

Rao, R., & Narasimham, S. (2008). Optimal Capactior Placement in a Radial Distribution System using Plant Growth Simulation Algorithm. *World Academy of Science, Engineering and Technology, 45*, 1-8.

Selim, A., Abdel-Akher, M., Aly, M., & Kamel, S. (2016). Efficient Time Series Simulation of Distribution Sysstems with Voltage Regulation and PV Penetration. pp. 1-6.

Solanki, S. K., Ramachandran, V., & Solanki, J. (2012). Steady State Analysis of High Penetration PV on Utility Distribution Feeder. *IEEE*, pp. 1-6.

STUDY OF MACHINE LEARNING IN POWER GENERATION

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ABSTRACT

The aim of this work is present the predictive model in order to calculate the value of distributed generation technology composed by four types of power generation such as photovoltaic, wind, thermal and biomass. The developed objective function is constrained and the problem here is solved by using the method of machine learning (ML) by Matlab. The machine learning decides about the appropriate model from the best type of power generation. This was achieved by using Gaussian Process Regression. In order to verify the performance of the ML optimization model, this study concludes, for example, that depending on generation type, it is possible to achieve energy and money savings.

Keywords: machine learning, power generation, distributed generation, energy optimization, network.

Introduction

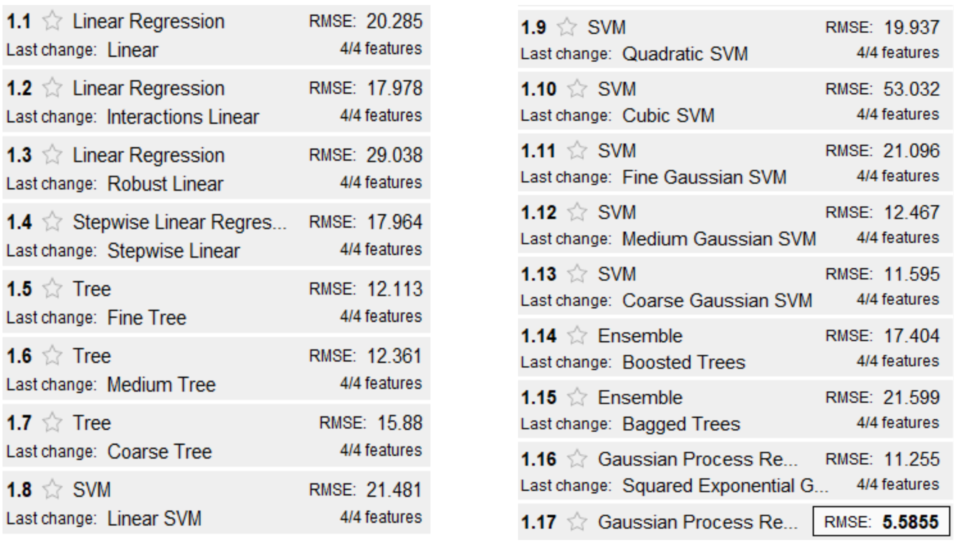
An important enabling technology for artificial intelligence (AI), machine learning (ML) has been successfully applied in many areas, including computer vision, medical diagnosis, search engines and speech recognition [1]. ML is a field of study that gives computers the ability to learn without being explicitly programmed. ML techniques can be generally classified as supervised learning, unsupervised learning and reinforcement learning. In supervised learning, the aim of the learning agent is to learn a general rule mapping inputs to outputs with example inputs and their desired outputs provided, which constitute the labeled data set. In unsupervised learning, no labeled data is needed, and the agent tries to find some structures from its input. While in reinforcement learning, the agent continuously interacts with an environment and tries to generate a good policy according to the immediate reward/cost fed back by the environment. For ML, it has the following advantages to overcome the drawbacks of traditional resource management, networking, mobility management and localization algorithms [2].

The advantage is that ML can learn useful information from input data, which can help improve network performance [4]. For instance, by using the deep neural network has proven to be a universal function approximator, traditional high complexity algorithms can be closely approximated, and similar performance can be achieved but with much lower complexity [3], which makes it possible to quickly respond to environmental changes. In addition, reinforcement learning can achieve fast network control based on learned policies [5]. At last, by involving transfer learning, machine learning has the ability to quickly solve a new problem. Hence, it is possible to transfer the knowledge acquired in one task to another relevant task, which can speed up the learning process for the new task. However, in traditional algorithm design, such prior knowledge is often not utilized. The basics of some ML algorithms along with their applications it was obtained in [6].

Distributed generation (DG) technology refers to power generation facilities on the customer side connected to a nearby low voltage grid or multi-generation systems for integrated gradient utilization (including wind, solar, and other distributed renewable power generation), multi-generation equipment for residual heat, residual pressure and residual gas generation, and small natural gas-fired systems with combined cooling and heating capabilities. In essence, it is a small-capacity generating unit for development, grid connection, and energy consumption based on the proximity principle [7]. In this work, four types of power generation are possible to analyses such as DG.

Material and Methods

In this section was used the ML app of Matlab, including 19 optimization models, such as linear regression, SVM, tree, ensemble and Gaussian models [8]. In Figure 1, it is possible to observe all models that it was simulated. From this ML app, it was possible to define the best predictive model to change the energy type to use in DG technology.



A B

Figure 1. ML app of MATLAB. (A) ML models from 1.1 to 1.8. (B) ML models from 1.9 to 1.17. Source: Authors (2019).

From this ML app of MATAB it is possible to model the best predictive model and train accordingly to new table data.

$$yfit = trainedModel.predictFcn(T) \qquad \text{eq.1}$$

where: T=readtable ('data').

Results and Discussion

In this section, the performance of the ML app is evaluated by computer simulation. In Figure 2 it is possible to observe all data table versus power generation from the sources.

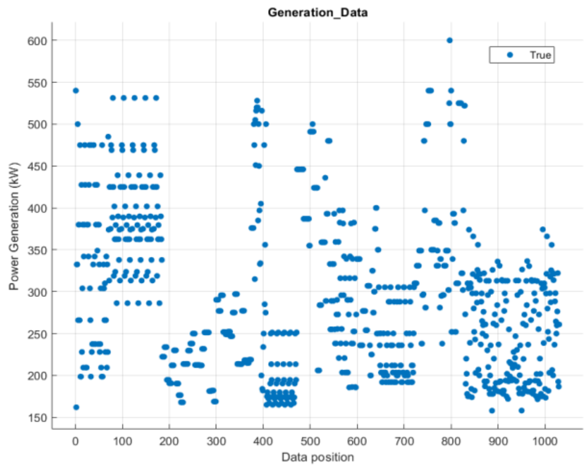
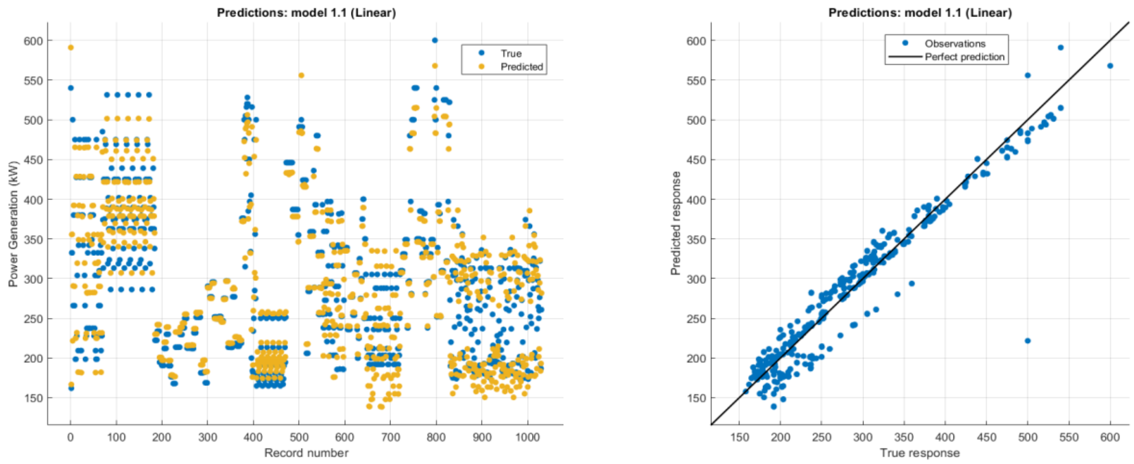


Figure 2. Power generation versus data position of four types of power generation (photovoltaic, wind, thermal and biomass). Source: Authors(2019).

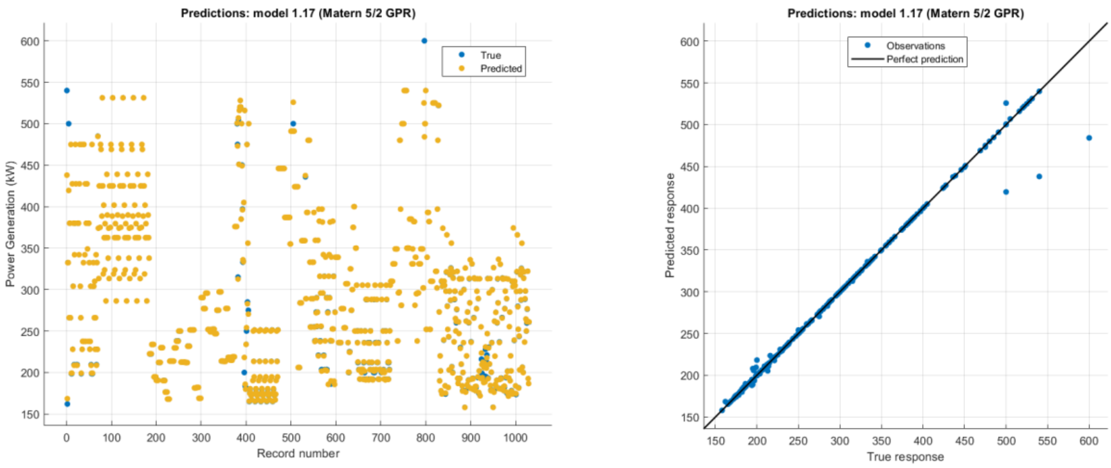
According to Figure 3, it is possible to observe in A that the linear prediction model is close to the original data, however in B data points are outside proper linear regression. Thus, the best model that fitting all data was the Gauss Process Regression because the behavior of collected data is clearly similar to GPR according to Figure 4, A and B.



A

B

Figure 3. ML using Linear prediction model . A. Data from four types of power generation. B. prediction linear model fitting. Source: Authors(2019).



A

B

Figure 4. ML using Gauss Process Regression (GPR). A. Data from four types of power generation. B. prediction GPR model fitting. Source: Authors(2019).

From these results, it is possible to classify according table 1 the new data for the maximum power generation. Therefore, it is possible to observe which type of power generation is the best use in GD system. However is important to consider the cost to assign priorities in ML analysis or other optimization relative to time.

Table 1. Estimated data to ML analysis. Source: Authors (2019).

time (minutes)	Photovoltaic (kW)	Wind (kW)	Thermal (kW)	Biomass (kW)	Maximum power generation	Classification
1	540	0	0	540	540	biomass
2	162	0	0	162	162	biomass
3	332.5	142.5	0	228	332.5	photovoltaic
4	332.5	142.5	0	228	332.5	photovoltaic
5	198.6	132.4	500	192	500	thermal

Conclusion

In this work, it was possible to test the use of ML app to analyze four types of power generation. From the simulation was obtained the best prediction model that fitting all data and for future work, it is important to analysis the impact of energy cost in DG technology.

Acknowledgment

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References

[1] R. S. Michalski; J. G. Carbonell; T. M. Mitchell. “Machine learning: An artificial intelligence approach”. Springer Science & Business Media. 2013.
[2] Y. Sun et al. “Application of Machine Learning in Wireless Networks: Key Techniques and Open Issues”. IEEE Communications Surveys & Tutorials, pp. 1–37, Jun. 2019.
[3] H. Sun et al. “Learning to optimize: Training deep neural networks for interference management”. IEEE Trans. Signal Process, vol. 66, no. 20, pp. 5438–5453, Oct. 2018.
[4] G. Cao, Z. Lu, X.Wen, T. Lei, and Z. Hu. “AIF: An artificial intelligence framework for smart wireless network management” IEEE Commun. Lett., vol. 22, no. 2, pp. 400–403, Feb. 2018.
[5] R. Li, Z. Zhao; X. Chen; J. Palicot, and H. Zhang. “TACT: A transfer actor-critic learning framework for energy saving in cellular radio access networks”. IEEE Trans. Wireless Commun., vol. 13, no. 4, pp. 2000– 2011, Apr. 2014.
[6] C. Jiang et al. “Machine learning paradigms for next-generation wireless networks”. IEEE Wireless Commun., vol. 24, no. 2, pp. 98–105, Apr. 2017.
[7] K. Ramalingam; C. Indulkar. “Distributed Generation- Design, Operation and Grid Integration”. Science Direct, pp. 69-147, 2017.
[8] G. Ciaburro. “MATLAB for Machine Learning”. UK: Packt Publiching. 2017.

OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION IN A RADIAL DISTRIBUTION SYSTEM FOR LOSS MINIMIZATION

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ABSTRACT

This paper proposes a Flower Pollination Algorithm (FPA) for optimal placement of Distributed Generation (DG) in a radial distribution system (RDs) for minimization of active power loss. The main objective is to find the optimal DG point in RDs, in order to achieve power losses reduction and voltage improvement, respecting the RDs characteristics. Simulations are carried out on 69-bus test system and compared with other optimization algorithms. The results demonstrate that the proposed FPA gives superior solutions than other stochastics algorithms in relation to the execution time and accuracy.

Keywords: Active Power Loss Reduction; Distributed Generation Placement; Flower Pollination Algorithm; Radial Distribution System.

Introduction

Losses in transmission and distribution systems constitute the largest consumption of energy produced (SUVARCHALA; YUVARAJ; BALAMURUGAN, 2018). According to (DA ROSA; TEIXEIRA; BELATI, 2018), the amount of power losses in the Brazilian system over a year is equivalent to hydroelectric power plant production of Itaipu. This quantity is due to the high distances between the consumers and generators in Brazil. In order to minimize power losses various techniques have been applied, such as: capacitor placement; feeder reconfiguration; and DG placement (RAMADAN; BENDARY; NAGY, 2017). In recent years, the high penetration of renewable DG sources have been used as an important solution to keep power system sustainable and ensure energy supply security (LI et al., 2018). Installation and integration of DG in RDs can provide several technical, economical, and environmental benefits. This is due to DG modify the power flow, as consequence reducing the technical losses (FURLAN et al., 2018). Despite of, their valuable benefits, DG may led to some challenges, for instance, RDs were originally designed and constructed to handle uni-directional power flow, while the addition of DG can led to bi-directional power flow. In DG integrated the island may happen. The inappropriate placement and sizing of DG may lead to overvoltage and excessive power losses (REZAEE JORDEHI, 2016). In (ATWA; EL-SAADANY, 2010), the authors emphasizing that high penetration level of intermittent DG in a RDs (about 20%-30%), can cause negative effects on the system.

Generally the placement problem formulation of DG is non-convex and nonlinear optimization problem. Usually, in all formulations the objective function is to minimize the real power losses and improve voltage; considering physical constraints equations in terms of voltage and power (MORADI; ABEDINI, 2012).

Many techniques have been applied to handle this problem, and can be classified into classical and approximate methods. The first group, namely deterministic is composing into analytical e numerical programing such as in (ACHARYA; MAHAT; MITHULANANTHAN, 2006) the authors solved the optimal placement and sizing of DG by using an analytical approach. The objective function were modeled in order to minimize the total power losses and applied in three distribution systems with contingences and complexity. In (ACHARYA; MAHAT; MITHULANANTHAN, 2006), developed a Mixed Integer Non-Linear Programming (MINLP) formulation for loss minimization for optimal placement of multiple DG on 33-bus and 69-bus RDs. The proposed approach simplifies the problem in two phases, namely Siting Planning Model (SPM) and Capacity Planning Model (CPM) this reducing the search space and computational time. The SPM selects the candidate buses to place and in CPM optimal sizes are obtained. The second group, approximate methods heuristics and meta-heuristics these algorithms may not to obtain global optimality in the case of large-scale DG placement, but their performance in terms of efficiency depends on the adjustments of some parameters. Even with carefully chosen parameters, these algorithms may lead to the same or approximate solutions. (BELATI et al., 2016), proposed a methodology based on the genetic algorithm of Chu-Beasley (GACB) and first-order sensitivity (FOS) to minimize active power losses in RDs. The results show computational time gain and good solutions applied on 34, 70 and 126-bus. In (SANJAY et al., 2017), the authors used a recent metaheuristic Grey Wolf Optimizer applied on 33 and 69 and Indian 85-bus to minimize power losses. The research shows that proposed method outperformed all other stochastic algorithms.

In this paper, a recent algorithm Flower Pollination Algorithm developed by (YANG, 2012) has been proposed to find out the optimal placement of DG in RDs, in order to achieve power losses reduction and voltage profile with less execution time and better accuracy. Each DG size as considered as 50 kW, and 5 and 10 number of DG has been placed on 69-bus RDs, according to (PAL et al., 2018).

Material and Methods

The proposed objective function is used to reduce the power losses and improve the voltage profile. The DG placement can be obtained optimally by solving the equation (1) as in (PAL et al., 2018).

$$Min. f = min(P_{loss}) \tag{1}$$

Where:

f Represents the total active power losses;

P_{loss} Represents the total active power loss in RDs.

$$P_{loss} = \sum_{i=1}^{nl} I_i^2 * R_i \tag{2}$$

Where:

nl Represents number of branchs;

$I_i = i^{th}$ Represents branch current;

$R = i^{th}$ Represents branch resistance.

The objective function (1) is subject to the following constraints as (PAL et al., 2018):

- *Load Flow Constraints*
- *Bus Voltage Constraints*
- *DG penetration level*

Application Methodology Optimal Placement of DG Problem

This section indicates the application and implementation of FPA to solve Optimal Placement of DG in RDs. Many steps have been followed as follows:

- **Initial Steps**
1. Input system data;
2. Input the quantity of DG and capacities of DG;
3. Input FPA data (population size, maximum iteration and parameter p);
4. Give the initial FPA solution $x_i^t(x_i)$ is a vector that corresponds the flower pollen by random solution;
5. Calculate the initial value objective function via Power Flow (back forward sweep);
6. Update the initial current best g_*;
- **Iterative Step**
7. If random $< p$ do global pollination, otherwise do local pollination;
8. Calculate the value objective function via Power Flow (back forward sweep);
9. Update the current fittest solution g_*;
10. If iteration $<$ maximum iteration, go to step 6 otherwise stop and update the best solution.

Results and Discussion

The proposed FPA is programmed in Matlab (R2017B) language on a computer having 4 GHz Intel core ™ i3 CPU M 350 with 4-GB RAM.

The FPA was tested on 69-bus RDs this system has a total load of 3802.2 kW and 2300 kVAr at a voltage level of 12.66 kV. The system data are presented in (BARAN; WU, 1989). The parameters considered in simulations are presented in Table 1. The Power Flow was executed using a back forward sweep algorithm (RUPA; GANESH, 2014).

Simulations:

1. 5 DG to place
2. 10 DG to place

Table 1 Parameters simulation

Simulations	*Population Flowers*	*Iterations*	*Parameter* p	*Quantity of DG to place*
1	15	100	0.2	5
2	25	100	0.2	10

In this work the each DG as considered as fixed 50 kW according (PAL et al., 2018). The FPA is as approximate technique, so the algorithm was 30 runs. The best, medium, and worst solutions, considering active power losses are shown in Table 2.

Table 2 Summary results tested system

Simulations	*Best Solution (Losses kW)*	*Medium Solutions (Losses kW)*	*Worst Solution (Losses kW)*	*Runs*
1	186.92	188.33	191.15	30
2	167.58	173.66	175.84	30

The simulation 1 consists in allocate 5 DG units, each DG injected 50 kW. Without DG placement, the active losses in the system are obtained as 225.01 kW, and the minimum voltage is found to be (0.90 p.u). The reference bus voltage at the substation is assumed to be as (1.0 p.u) and the lower and upper limits of voltage magnitude at the buses are chosen as (0.90 p.u) and (1.0 p.u) respectively.

Then, the FPA as compared as Grey Wolf Optimization (GWO), One by One Search Algorithm (OBOSA), and Ant Lion Optimization (ALO) proposed in (PAL et al., 2018). Optimal placement obtained from FPA are 62, 63, 64, 65, 66. The power losses are minimized to 186.92 kW with percentage reduction of 16.93%. The minimum voltage is improved to (0.92 p.u). Thus, the FPA outperforms other algorithms in terms of minimizing losses and better computational time as presented in Table 3.

Table 3 DG Placement on 69 bus RDs, 5 DG

Algorithm	ALO	GWO	ABOSA	FPA
DG	5	5	5	5
buses	31;60;63;64;65	60;61;62;63;64	61;62;63;64;65	62;63;64;65;66
Losses (kW)	195.18	188.97	187.71	186.92
Time (seconds)	472	1442	31	9

In the second case, simulation 2 consists to applied 10 DG units at system injected the same active power the first tested case. The losses without injection of DG are 225.01 kW and are decreased to 167.58 kW due to installation of DG, as shown in Table 4. Moreover, the minimum voltage has been enhanced from (0.90 p.u) to (0.92 p.u). The value of installed capacity of active power is 500 kW. In addition, the FPA found the good solution with lower computational cost.

Table 4 DG Placement on 69 bus RDs, 10 DG

Algorithm	ALO	GWO	ABOSA	FPA
DG	10	10	10	10
buses	35;55;56;57;58	11;13;26;36;59	16;20;21;26;60	20;21;59;60;62;
	59;60;61;63;68	60;61;62;63;64	61;62;63;64;65	63;64;65;66;70
Losses (kW)	183.87	176.05	170.33	167.58
Time (seconds)	439	1749	62	13

Execution time graph for GWO, ALO, ABOSA, and FPA is presented in Figure 1. It is clear that proposed algorithm FPA outperformed in less execution time than other approximate methods to placed 5 DG, and 10 DG in RDs.

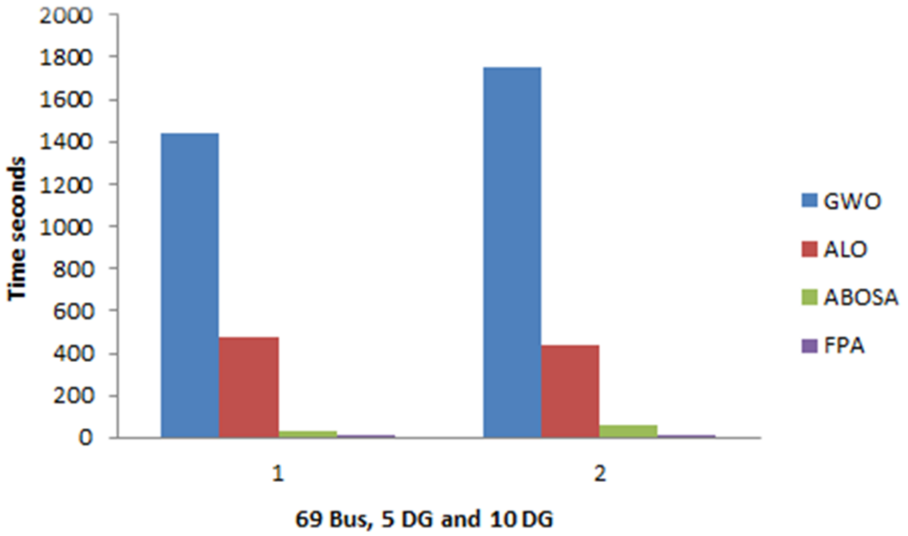

Figure 1 Comparison execution time between algorithms

Conclusion

This paper presented an efficient metaheuristic FPA, to solve the non-convex, discrete, optimal DG problem applied on 69-bus RDs. It aims to minimize the total power losses, improve voltage profile with less execution time and better accuracy. Two simulations have been used to show the impact on system related 5 DG, and 10 DG placed. It is observed that, the obtained results with proposed algorithm proved good performance and effectiveness in finding good solutions. Also, the FPA not only reduce the technical losses but also allocate DG with low computational time when compared with other similar approach.

Acknowledgment

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References

ACHARYA, N.; MAHAT, P.; MITHULANANTHAN, N. An analytical approach for DG allocation in primary distribution network. **International Journal of Electrical Power and Energy Systems**, v. 28, n. 10, p. 669–678, 2006.

ATWA, Y. M.; EL-SAADANY, E. F. Optimal allocation of ESS in distribution systems with a high penetration of wind energy. **IEEE Transactions on Power Systems**, v. 25, n. 4, p. 1815–1822, 2010.

BARAN, M. E.; WU, F. F. Optimal capacitor placement on radial distribution systems. **IEEE Transactions on Power Delivery**, 1989.

BELATI, E. et al. Distributed Generation Allocation Using the Genetic Algorithm of Chu-Beasley and Sensitivity. **Przegląd Elektrotechniczny**, v. 1, n. 8, p. 196–201, 2016.

DA ROSA, W. M.; TEIXEIRA, J. C.; BELATI, E. A. New method for optimal allocation of distribution generation aimed at active losses reduction. **Renewable Energy**, v. 123, p. 334–341, 2018.

FURLAN, R. H. et al. **Optimal allocation of distributed generation in a radial distribution network for losses reduction and voltage profile improvement**. SBSE 2018 - 7th Brazilian Electrical Systems Symposium. **Anais**...2018

LI, Y. et al. Optimal distributed generation planning in active distribution networks considering integration of energy storage. **Applied Energy**, v. 210, n. July 2017, p. 1073–1081, 2018.

MORADI, M. H.; ABEDINI, M. A combination of genetic algorithm and particle swarm optimization for optimal distributed generation location and sizing in distribution systems with fuzzy optimal theory. **International Journal of Green Energy**, v. 9, n. 7, p. 641–660, 2012.

PAL, A. et al. **Optimal DG allocation for minimizing active power loss with better computational speed and high accuracy**. Proceedings of the 4th IEEE International Conference on Recent Advances in Information Technology, RAIT 2018. **Anais**...IEEE, 2018

RAMADAN, H. S.; BENDARY, A. F.; NAGY, S. ET AL. Particle swarm optimization algorithm for capacitor allocation problem in distribution systems with wind turbine generators. **International Journal of Electrical Power and Energy Systems**, v. 84, p. 143–152, 2017.

REZAEE JORDEHI, A. Allocation of distributed generation units in electric power systems: A review. **Renewable and Sustainable Energy Reviews**, v. 56, p. 893–905, 2016.

RUPA, J. A. M.; GANESH, S. Power Flow Analysis for Radial Distribution System Using Backward / Forward Sweep Method. **International Journal of Electrical and Computer Engineering Vol:**, v. 8, n. 10, p. 1628–1632, 2014.

SANJAY, R. et al. Optimal allocation of distributed generation using hybrid grey Wolf optimizer. **IEEE Access**, v. 5, p. 14807–14818, 2017.

SUVARCHALA, K.; YUVARAJ, T.; BALAMURUGAN, P. **A brief review on optimal allocation of Distributed Generation in distribution network**. 4th International Conference on Electrical Energy Systems. **Anais**...2018

YANG, X.-S. **Bio-inspired optimization algorithms - Book**. [s.l: s.n.]. v. 118

ENERGY INTEGRATION OF SOLAR WATER HEATING SYSTEM IN POWDER MILK PRODUCTION

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ABSTRACT

The transformation of raw milk into powdered milk is energy intensive, requiring steam heating, refrigeration and electrical utilities for its main stages: separation, heat treatment, evaporation and drying. Energy efficiency can be improved by increasing the concentration of milk solids in evaporation stage, reducing the energy load of the dryer, which has not been studied in detail. This work aims to study the heat recovery in the evaporation stage, and to integrate a solar heating system to provide hot water to the process, reducing external utility costs. We used the case study of an article published about an industry in New Zealand, the application of the Pinch Analysis Method, with the aid of EES software - version 10.458. The projected network of heat exchangers resulted in 10 heat exchange units, with an area of 1,337.09m² and a heat exchange of 31,129 kW, the total process heat recovery was 20,833 kW (66.9%) and the energy supplied the solar heating system was 4,447kW (14.3%), which represented 25,280 kW (81.2%) of energy savings, which reduced 5,849 kW of the need for external steam utility, that means only 18.8% of the total heat exchanged in the process.

Keywords: Process Integration, Pinch Analysis, Solar Heating, Dairy, Milk Powder.

Introduction

Converting raw milk into powdered milk is an energy-intensive process and has four main processing steps: milk separation, heat treatment, evaporation and spray drying. These processes are serviced by steam at 40 bar, chiller to generate chilled water and compressor to generate compressed air. Improvements in energy efficiency in the process can be achieved by concentrating milk solids in the evaporation step before final spray drying. For Walmsley et al. (2017), evaporation systems have not yet been studied in detail.

Milk comes from the farm to the dairy at 7°C to 10°C. After rapid testing, it is transferred to the cooling tank at 4°C to 5°C, the fat content is standardized (different dairy products require different fat content). Homogenization is performed to prevent the formation of cream in pasteurized milk, to improve consistency and taste and to decrease whey loss in fermented products. Heat treatments are employed to eliminate the microbial load of milk (SILVA, SILVA and FERREIRA, 2012).

According to Walmsley et al. (2016), milk enters the heat treatment process at about 8 ° C and heats up to 95°C. Conventional heat recovery typically heats milk to about 80°C. A direct steam injection (DSI) quickly heats milk to 95°C to limit its contact with the equipment, it oscillates between 80°C and 85°C for instant cooling and low pressure steam generation. The multi-effect evaporation system follows the heat treatment and concentrates milk from about 12% to 52% solids. An upper temperature limit of 73ºC aims to avoid further protein denaturation so as not to affect the taste of milk powder.

According to Kemp (2007), evaporators are a simple separation system where a volatile solvent is vaporized to remove it from a solution containing an involuble solute. The heat required for evaporation is provided by condensation of hot steam or vapors in a heat exchanger immersed in the evaporating liquid. The amount of water to be evaporated is usually fixed by the process flow chart. There are three methods for reducing the system power requirement while maintaining the required evaporation rate: multistage evaporation (effects); mechanical steam recompressor - MVR and thermal steam recompressor - TVR. Walmsley et al. (2016) and Walmsley et al. (2017) used double effect evaporator, the first effect with MVR and the second with TVR.

After leaving the final evaporator effect, the concentrated milk is heated in the spray dryer to about 75°C and homogenized before spraying and spray drying using hot air (210°C) to form milk powder. The partially dried powder leaving the spray dryer main chambers is cooled to about 35 ° C in the final fluidized bed. Dry air from the dryer is discharged into the atmosphere at about 75 ° C, before passing through cyclones and /or baghouses for particle removal.

The evaporator, spray dryer and auxiliary equipment are washed clean-in-place (CIP) with water heated from room temperature to 85 ° C (WALMSLEY at al., 2017).

Process thermal currents and available plant utilities are shown in Table 2 and Table 3, respectively.

Table 1 - Process Thermal Currents

Corrente	T_{supply} (°C)	T_{target} (°C)	Energy (kW)	Mcp (kW/°C)
Cold Milk	8	95	23,557	272
HT flash vapour	83	83	3,231	
E1 vapour bleed	73	73	5,733	
E2 Condenser	56	56	1,677	
COW	73	13	14,103	237
CIP Water	25	85	540	9

Source: adapted from Walmsley et al. (2016).

Table 2 - Available Plant Utilities

Corrente	Tipo	T_{supply} (°C)	T_{target} (°C)
HPS	Quente	250	250
MPS	Quente	180	180
HTHW	Quente	80	65
LTHW	Quente	55	35
Cooling Water	Fria	25	30

Source: adapted from Walmsley et al. (2016).

Process Energy Integration techniques can be applied to new projects or retrofit plants in a variety of industrial sectors, including dairy, to ensure that before using external energy supplies, all heat is used and harnessed. existing in the process itself. Among the most used methodologies is Pinch Analysis, according to which the minimum energy consumption can be calculated from a graphical method and an algorithm, before the design of the exchanger network. The graphical calculation for a given process, and for each temperature range, adds the enthalpy variations for hot and cold currents, represented in a Temperature versus Available Thermal Power graph, where two composite curves are constructed, one for hot currents and one for cold currents, showing the division of the temperature axis at different intervals, defined by the initial and final temperatures of the currents. The simultaneous graphical representation of both curves, for a certain ΔT_{min} of distance between the temperature of hot and cold currents, locates the Pinch Point, dividing the process into two zones: above the Pinch, where hot currents are cooled by cold currents; below Pinch, where all cold currents are warmed by hot currents. Additional heat or cold needs are met by external utilities. (FERNANDES, 2012). In energy integration, the supply, which starts cold and needs to be heated, is known as the cold current and the hot product that must be cooled is called the hot current. To perform heating and cooling, a steam heater can be placed in the cold stream and a water chiller in the hot stream. Energy consumption can be reduced if some hot stream heat can be recovered and used to heat cold stream in a heat exchanger. The challenge is to know how much heat can be recovered, size of the heat exchanger, and the temperatures around it (KEMP, 2007).

A hypothetical solar evacuated pipe water heating system of 1,000m² has been proposed by Quijera et.al (2011) and Quijera and Labidi (2013) as a hot utility for a dairy plant in the Basque countries by combining a boiler system with the forced circulation solar thermal unit and indirect water heating, as shown in Figure 1. The system provides hot water at 95°C, the same milk heating temperature at the beginning of the milk powder production process presented in the case study. by Walmsley et al. (2016). This paper aims to quantify, through Pinch Analysis, the potential energy savings resulting from heat recovery in the evaporation stage of milk powder production, from the integration of a solar heating system as an external hot utility. It will be a reference for the development of research for the author's doctoral thesis.

Material and Methods

This article was produced based on the case study of the industrial milk evaporation system for powdered milk production, according to (Walmsley et al., 2016) and (Walmsley et al., 2017) in New Zealand dairy plants. Direct steam injection (DSI) was not considered in the heat treatment of milk, we assumed the use of an MVR recompressor for both evaporator stages, as shown in Figure 1. For the cleaning water (CIP), we assumed an ambient temperature of 25°C.

Figure 1 presents the evaporation system to increase the solids concentration in milk and the integration of the solar water heating system as a hot process utility.

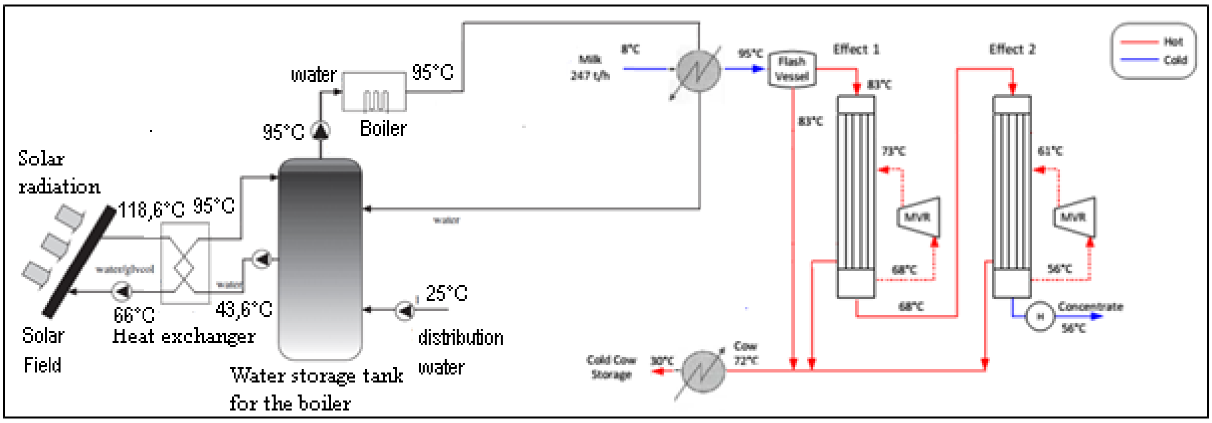

Figure 1 - Integration of solar heating to the milk evaporation system

Source: Quijera et.al (2011); Quijera and Labidi (2013); Walmsley et al. (2016) and Walmsley et al. (2017)

The heat exchanger network was defined with support from the Microsoft Excel® program provided as an appendix to Kemp's book (2007). Then, the minimum number of heat exchangers and the minimum heat exchange area of the network were calculated, according to Smith (2005). For this stage of the study, data on the temperature of the process thermal currents, presented in Tables 1 and 2, were entered in the excel spreadsheet, in the tab INPUT. The values of the quantities not provided in the article Walmsley et al. (2016) were calculated with the aid of the EES software - Version 10.458, based on the energy balance and mass balance equations and tabulated enthalpy values (CENGEL and BOLES, 2015). To determine the enthalpy of milk at different temperatures and concentrations, the equation $\int dh = \int c.dT$ was used, where "c" is the specific heat of cow's milk, obtained according to Costa (2014). The minimum number of grid heat exchange units is calculated by the following equation:

$$N_{units} = [S_{above\ pinch} - 1] + [S_{below\ pinch} - 1] \qquad \text{(Eq. 1)}$$

Where Nunits is equal to the number of units (lines) and S is equal to the number of chains including utilities (points). The total area of the entire changer network is determined by the equation:

$$A_{Network} = \frac{1}{U} \sum_{K}^{Intervals\ k} \frac{\Delta H_k}{\Delta T_{LMk}} \qquad \text{(Eq. 2)}$$

Where Anetwork = heat exchange area for the value "k"; ΔHk = enthalpy variation in "k"; ΔTLMk = logarithmic mean difference in "k"; U = overall heat transfer coefficient, and

$$\Delta T_{LMk} = \frac{[(\mathrm{TQ\ i} - \mathrm{TF\ f}) - (\mathrm{TQ\ f} - \mathrm{TF\ i})}{\ln\left(\frac{(\mathrm{TQ\ i} - \mathrm{TF\ f})}{\mathrm{TQ\ f} - \mathrm{TF\ i})}\right)} \qquad \text{(Eq. 3)}$$

Smith (2005) presents coefficient values for calculating the global heat transfer coefficient with Equation 4. By adopting intermediate values of the various coefficients and stainless tube (do = 25mm) and (di = 20mm), we obtain U = 816 (W / m².K) assumed for this work.

$$\frac{1}{U} = \frac{1}{h_S} + \frac{1}{h_{SF}} + \frac{d_o}{2k} ln\left(\frac{d_o}{d_i}\right) + \frac{d_o}{d_i} \cdot \frac{1}{h_{TF}} + \frac{d_o}{d_i} \cdot \frac{1}{h_T} \qquad \text{(Eq.4)}$$

For this study, the modification of the process with the use of MVR recompressors in both evaporator effects, the results obtained for energy and currents with the support of the EES software and the excel spreadsheet were changed, as shown in Figure 2. Thus, It was possible to identify the process point for the integration of the hot utility provided by the solar heating system.

Results and Discussion

Processing with the provided spreadsheet resulted in a Pinch Point at a temperature of 54°C, as well as the following energy targets: Minimum Hot Utility = 60,621.71 kW and Minimum Cold Utility = 51,610.71 kW. However, the use of MVR recompressors in both evaporator effects, as shown in Figure 1, reduced the demand for hot utility to 8,226 kW.

It can be seen from the GCC tab of the Kemp excel spreadsheet (2007) that the energy associated with the temperature of 90°C is 6,000 kW, the energy required for the solar heating system.

Using the Grid tab of the spreadsheet and Equation 1, we obtained Nunits = 10 units. The Composite Curves define the temperature ranges, whose sum of the swap areas for each interval obtained with Equations 2, 3 and 4, results in the A_Network = 1,337.09 m² network swap area, shown in Figure 2. The TC9 heat exchanger heats Cold Milk through the warm utility of the solar heater.

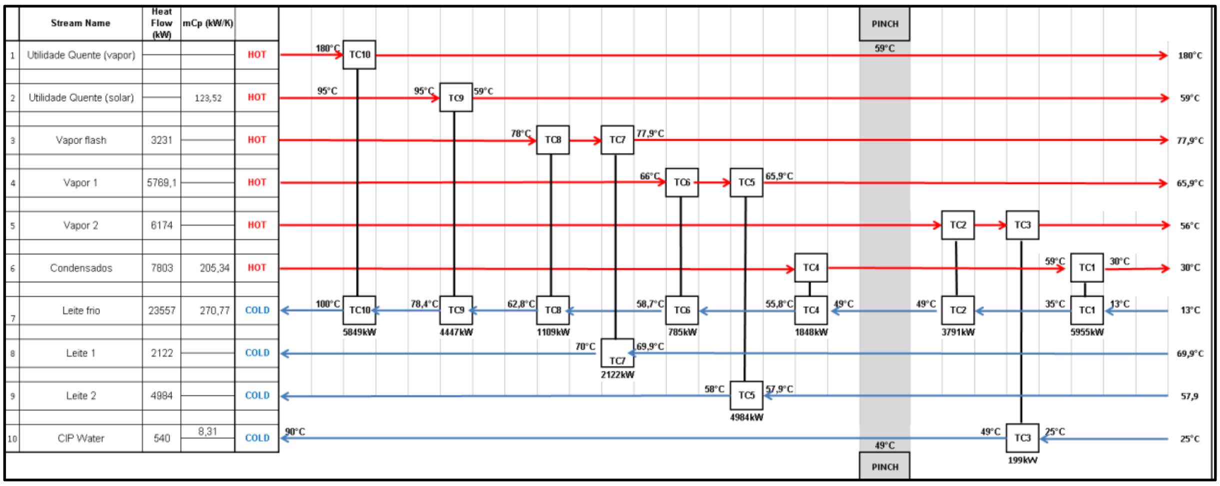

Figure 2 - Heat Exchanger Network

Source: the authors

All the hot currents in the process gave all their heat to the cold currents except Steam V2. The energy exchanged in the TC9 heat exchanger is 4,447 kW between Cold Milk and hot water from the solar heater.

Conclusion

The Pinch Method analysis of a 247 ton/hour raw milk powder production process, focusing on the evaporation process, increased the milk solids concentration from 12% to 52%, producing the concentrate that will go to the spray dryer to finish the process.

According to the demands of the process the necessary utilities for the process were estimated, the minimum number of heat exchangers, the minimum exchange area and the network of exchangers was designed.

The total amount heat exchanged in the heat exchanger network was 31,129kW, the total amount heat recovery energy was 20,833 kW, ie 66.9% of all total heat exchanged in the grid and the energy supplied by the solar heating system was 4,447kW, ie 14.3% of all total heat exchanged in the network.

Thus, the total amount of heat recovery and solar hot utility represented 25,280kW, which represents 81.2% of all total heat exchanged in the grid, which is the energy savings generated by the proposed solutions, and the energy spent on the external steam utility was 5,849 kW, which represented 18.8% of the total heat exchanged in the process.

References

CENGEL, Yunus A.; BOLES, Michael A. **Thermodynamics: an engineering approach.** 8th ed, McGraw-Hill Education, 2015.

DA COSTA, Angelica Ribeiro. Thermophysical, rheological and interfacial properties of bovine milk and whey concentrated in vacuum evaporator. 2014. Doctoral Thesis. Federal University of Viçosa.

FERNANDES, Maria Cristina S. Process Integration - University of Lisbon, Department of Chemical Engineering, 2012. Available at: https://fenix.tecnico.ulisboa.pt/downloadFile/1689468335557233/sebenta_IP%20(1).pdf Access in: November 2018.

KEMP, Ian C. **Pinch analysis and process integration: a user guide on process integration for the efficient use of energy**. 2nd ed. Elsevier, 2007.

QUIJERA, José Antonio; ALRIOLS, María González; LABIDI, Jalel. Integration of a solar thermal system in a dairy process. Renewable Energy, v. 36, n. 6, p. 1843-1853, 2011.

QUIJERA, José Antonio; LABIDI, Jalel. Pinch and exergy based thermosolar integration in a dairy process. Applied Thermal Engineering, v. 50, n. 1, p. 464-474, 2013.

SILVA, Gilvan; SILVA, Angélica Maria Araújo Dias; FERREIRA, Maria Presciliana de Brito. Produção alimentícia. **Processamento do Leite. Recife: EDUFRPE, 2012.** Disponível em: http:// http://pronatec.ifpr.edu.br/wp-content/uploads/2013/06/Processamento_de_Leite.pdf. Acesso em: novembro, 2018.

SMITH, Robin. **Chemical process: design and integration**. John Wiley & Sons, 2005.

WALMSLEY, Timothy G. et al. Appropriate placement of vapour recompression in ultra-low energy industrial milk evaporation systems using Pinch Analysis. **Energy**, v. 116, p. 1269-1281, 2016.

WALMSLEY, Timothy G. et al. Process and utility systems integration and optimisation for ultra-low energy milk powder production. **Energy**, v. 146, p. 67-81, 2017.

POWER FACTOR PREDICTION USING ANN

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ABSTRACT

Correcting power factor is critical in any industrial installation. Voltage drops, losses and overloads are some of the consequences of a low power factor in an installation. With lower throughput due to excess reactive, we have an increase in circuit current that leads to additional wiring heat losses. With the advancement in studies on artificial intelligence, the LSTM (Long Short Term Memory) neural network model capable of performing speech recognition and text translation emerged. In this paper, the LSTM was applied and analysed to predict the power factor of an electric power grid. To perform the experiment were used energy meters and commercial controllers to measure the power factor of an electric grid. The measurements were stored in database on cloud server. LSTM algorithms were developed and applied in Python. Testing with the LSTM for power prediction resulted in an error rate mean of 0.0037 and absolute error rate of 0.0446 and was able to predict power factor values with 99.63% accuracy.

Keywords: LSTM, Power Factor, ANN.

Introduction

Recurrent Neural Networks (RNN) have in their hidden layers a link to itself, which in addition to carrying the activation function result to subsequent (next layer) neurons, it transmits the data to itself, resulting in a loop. In RNN the representation of a single node is composed of layers that can contain several neurons. The hidden layer is connected to itself, sending a response forward as well as feedback. In order to train recurrent neural networks, the Backpropagation algorithm is usually applied, rolling out the RNN a standard neural network [1]. Finally, in RNN, weights are shared, memory is fast, short and reminiscent of what happened only in the last interactions [2].

To find the value of the minimum global error (gradient drop), at each interaction with the network, the Backpropagation algorithm multiplies the current weight value by the learning rate defined in the RNN and updates the weights. In RNN with thousands of layers the weight values can be so small that it do not change the results. This fact results in a problem called Vanish Gradient. There are algorithms like Backpropagation Through Time (BPTT) and Xavier Initialization that work around this problem.

Another problem that can happen with RNN is that the weight values become too large to not find the global minimum error value [3]. One of the techniques applied to avoid this problem is not to visit all hidden layers, but this technique can compromise the learning of the RNN. Another technique to avoid the problem with weight values is to use the RMSProp optimizer, which divides the learning rate by an exponentially decreasing average of the gradient square [4]. The LSTM are used for future prediction based on past information by adding memory cells to the neural network and manipulating these cells. The RNNs end up copying multiple neural networks, which makes the algorithm slower.

Material and Methods

To perform the experiment initially were chosen the following hardware ESP-WROOM-32 Kit, DDS238-4 W Power Meter, Serial Converter (TTL) to RS485 (Click RS485) e PC (Windows 8 Core 7 8G RAM computer).

The ESP-WROOM-32 is a low-cost educational kit made up of a dual-core ESP32 32-bit microcontroller. The choice of using this kit was motivated by the fact that it supports the use of FreeRTOS real-time operating system, which has several important tools for application development, and by allowing connection to other devices over a Wi-Fi network.

The DDS238-4 W power meter [3] operates in class 1 according to IEC62053-21 and allows the measurement of various quantities of a single-phase power grid, including total energy (sum of energy consumed / imported with energy generated / exported), voltage, current and power factor of the mains, besides presenting the values of the active and reactive power measurements and the frequency of the mains. Figure 1 shows the energy meter, RS485 converter and ESP32 microcontroller used in the experimental tests.

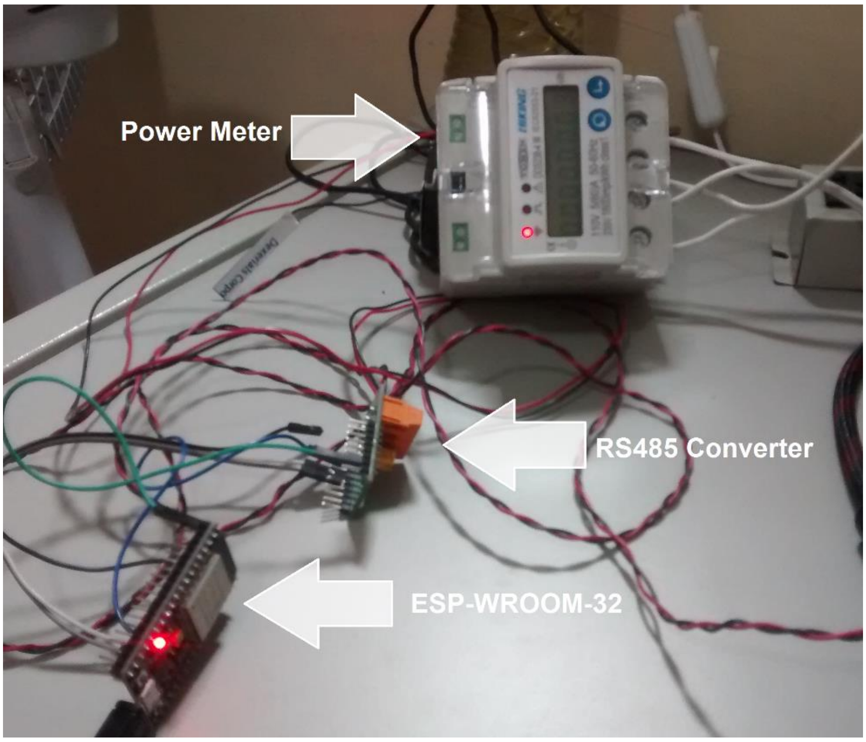

Figure 1 - Hardware used in experimental laboratories.

All measurements made by the power meter can be read via an RS485 communication channel via the Modbus RTU (Remote Terminal Unit) protocol, a condition that favours the connection of this equipment to an industrial network and to a Supervisory Control and Data Acquisition (Scada) supervisory. The DDS238-4 W operates on single-phase 120V to 240V 50 or 60 Hz networks and supports a maximum current of 60 to 100 Amps, depending on the mains voltage chosen. To connect the ESP-WROOM-32 to the power meter DDS238-4 W was using a serial converter module to RS485.

The program developed for the ESP32 microcontroller is responsible for reading the values of the measurements made by the power meter through an RS485 wired network using Modbus RTU protocol. Every 10 seconds the power factor is read by ESP32 and stored in database on cloud server. Measured values (power factor) are read by ESP32, stored in memory, and later sent via the MQTT (Message Queuing Telemetry Transport) protocol to a server on cloud containing an internet of things platform responsible for receiving and storing measurements in a database. Thus, being the measurements stored in a database in the cloud, it is possible to apply to monitor the forecasts and analyses of the RNN over the internet.

To perform LSTM simulations, Python 3.6 was used in conjunction with the Keras neural network library, the Pandas data structuring library, Matplotlib for graphing, Scikit-learn for linear regression and data normalization, and the library math and vector structure NumPy. All software used is free and open source found in the Python Package Index (PyPI) repository [5]. The table 1 shows the LSTM network configuration.

Table 1. The LSTM network configuration.

Number of Power Factor Measurements	3672
Number of Neural Network Training Measurements	3472
Number of Neural Network Test Measurements	200
Activation function	Sigmoid
Number of Provisioning Measurements	90
Input Memory Unit	1
RNN First Layer: Number of Memory Units	100
RNN Second, Third and Fourth Layers	30
Optimizer	RMSProp
Batch size	100
Epochs	20
Output Memory Unit	1

After including the Keras, Sklean, Numpy, Pandas and Matplotlib libraries in the program, the RNN training databases were loaded. From this database, the power factor field was extracted and its values were normalized on a scale from zero to one.

To start training the values of the last 90 measurements from this database were loaded. Then, the LSTM network layers containing 100 memory units were added, as the unit value preferably has to be large to capture the trend. In LSTM, the setting was maintained so that the memory unit can pass information to the subsequent layers. Therefore, the first layer of LSTM is ready. To avoid RNN overfitting problems, the repressor has been set to a value of 0.3 that clears 30% of the inputs. Three hidden layers have been added because a neural network with few layers may not find a satisfactory result (error rate). Then the output layer has been defined, and consequently the last hidden layer will be linked to that output layer. Since there is only one output (power factor), there will be only one memory unit in the output.

Results and Discussion

After RNN training 200 power factor measurements are predicted. The RNN forecasts are compared to field measurements. Initially, 3672 power factor measurements were stored in a database. The first sample was taken on 5/12/2018 17:29 and the last on 5/12/2018 23:18, resulting in a sampling every 10 seconds approximately.

The total base with the measurements was divided into two parts, the first part responsible for the training base, consisting of 3472 power factor measurements and the second part, responsible for the LSTM model test, consisting of 200 records. The training database was normalized to factors between zero and one and thereafter, and to initiate RNN training 90 initial measurements were warranted. The RNN training took about 10 minutes to complete and resulted in an error rate of 0.0037 with an average and absolute error rate of 0.0446. This means that the RNN model was able to predict the power factor values for within the 23hs range with 99.63% accuracy.

Figure 2 shows the result of the simulation with the RNN with the power factor values measured by the power meter and shows the curve with the forecasts measured and forecasted by the RNN.

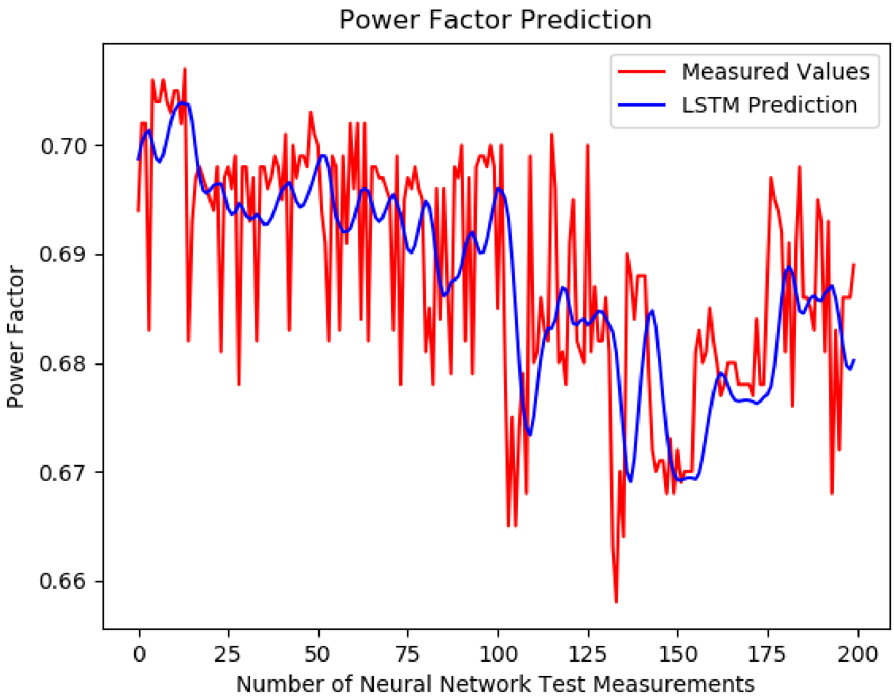

Figure 2. Graph containing the curve of the power factor measurements made by the energy meter and the curve with the power factor forecasts calculated by the RNN.

Conclusion

The LSTM model proved to be very useful for power factor prediction, since in the tests performed the RNN responded with 99.63% accuracy.

References

[1] CHOI, Keunwoo; FAZEKAS, George; SANDLER, Mark. Text-based LSTM networks for automatic music composition. arXiv preprint arXiv:1604.05358, 2016.

[2] LIU, Yang et al. Learning natural language inference using bidirectional LSTM model and inner-attention. arXiv preprint arXiv:1605.09090, 2016.

[3] WILLIAMS, Jason D.; ZWEIG, Geoffrey. End-to-end lstm-based dialog control optimized with supervised and reinforcement learning. arXiv preprint arXiv:1606.01269, 2016.

[4] ZHENG, Jian et al. Electric load forecasting in smart grids using long-short-term-memory based recurrent neural network. In: Information Sciences and Systems (CISS), 2017 51st Annual Conference on. IEEE, 2017. p. 1-6.

[5] Ketkar, Nikhil. Deep Learning with Python. Apress, 2017.

ELECTRIC POWER SCHEDULE CONSIDERING THE PRESENCE OF INTERMITTING SOURCES

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ABSTRACT

This work proposes the development of a model for the hourly dispatch of energy produced by intermittent sources of electric wind and solar power generation. For this, the Optimal Power Flow problem is incremented by the time variable (t), representing the hourly basis and the characteristics of electric wind and solar power generation were considered. For the proposed model, it was considered as objective functions the minimization of active losses and generation costs. In addition, the generation limits of the other generation sources, the voltage limits of the system buses and the limit of transformer tapping were considered. Mathematical modeling was performed using AMPL (Modeling Language for Mathematical Programming) software, using Knitro software as solver. In this work stage, in order to validate the proposed model, simulations were performed from the minimization of active losses, considering wind and solar generation data from generator groups located in the Northeast region of Brazil associated with the IEEE 30-buses test system.

Keywords: Hourly dispatch; Optimal Power Flow; Solar Generation; Wind Generation.

Introduction

Considering the information published by official agencies, it is possible to observe the great relationship between population growth, technological and socioeconomic evolution and the increased demand for electricity. With the growing supply of energy from renewable sources, studies by the Brazilian Energy Research Company (EPE), in conjunction with National System Operator (ONS), which serve as the basis for the National Energy Plan (PNE) indicate that the population increase in Brazil will continue at a rate of 0.6% per year until 2026. This population increase, according to EPE and ONS, will result in a 3.7% increase in electricity consumption (EPE, 2017).

In this sense, investments in the electricity sector, as well as energy supply, follow the trend of increasing demand. In 2018, for example, the Internal Electric Energy Supply (OIEE) in Brazil was 636.4 TWh, 1.7% higher than the OIEE of 2017 (625.7 TWh), where 83.3% correspond to renewable sources, two percentage points higher than the previous year. Table 1 illustrates the variation in the supply of electricity by source, where is is observed the increase in the supply of intermittent renewable sources (the solar source increased by 871% in the previous year) with a decrease in the supply of fossil sources (MME, 2019).

Table 1: Variation in domestic electricity supply in Brazil, 2018 - 2019

Source	**OIEE Brazil variation**
Wind power	↑ 14,4 %
Solar	↑ 316,1 %
Nuclear	↓ 0,4 %
Hydraulics	↑ 4,8 %
Fossil oil	↓ 25,4 %
Natural gas	↓ 16,7 %
Mineral coal	↓ 12,6 %

Source: Brazilian Ministry of Mines and Energy (MME), 2019

Also, in relation to the data presented in Table 1, a greater participation of intermittent sources in the Brazilian energy market impacts the models of planning, operation and commercialization of electric energy, and these themes are extremely important for researchers linked to the energy sector. Thus, the present work proposes the development of a model of hourly dispatch of electric energy considering the characteristics of generation of intermittent, solar and wind sources.

Material and Methods

For the development of this work, a bibliographical review about the methodologies and mathematical formulations used for the dispatch of electric energy and a study about the characteristics of the intermittent wind and solar generation were initially performed. From the studies performed, it was proposed a mathematical modeling for time dispatch, considering the characteristics of intermittent sources generation.

For the simulations, it was chosen data from the Lagoa do Barro wind farm and the Nova Olinda photovoltaic plants, both connected to the Northeast subsystem of SIN. Table 2 illustrates the generation profile of the Lagoa do Barro wind farm where it is possible to notice that the highest generation rates occur at night and in the morning. On the other hand, the period where there is less wind generation occurs around 14:00hs.

Table 2: Average hourly energy generation data - every day June / 2019 - Lagoa do Barro Wind Farm - Northeast Subsystem (Source: ONS, 2019).

H (time of day)	Generated MW	H (time of day)	Generated MW
00:00	164,3	12:00	124,0
01:00	161,1	13:00	114,7
02:00	156,8	14:00	109,6
03:00	153,5	15:00	108,6
04:00	154,6	16:00	108,1
05:00	154,6	17:00	107,5
06:00	156,2	18:00	104,4
07:00	160,6	19:00	119,0
08:00	161,6	20:00	141,7
09:00	156,9	21:00	154,5
10:00	146,3	22:00	159,3
11:00	134,3	23:00	164,2

Table 3 illustrates the average hourly photovoltaic solar generation graph of the Nova Olinda Photovoltaic plant, where it can be noted that the highest generation rates occur between 08:00 and 16:00, and in the period between 18:00 and 05:00hs, the power generation from this source is zero.

Table 3: Average hourly solar photovoltaic generation data - June / 2019 - Nova Olinda Photovoltaic Set - Northeast Subsystem (Source: ONS, 2019).

H (time of day)	Generated MW	H (time of day)	Generated MW
00:00	0	12:00	142,1
01:00	0	13:00	130,6
02:00	0	14:00	113,1
03:00	0	15:00	86,8
04:00	0	16:00	47,3
05:00	0	17:00	4,9
06:00	13,7	18:00	0
07:00	72,5	19:00	0
08:00	111,9	20:00	0
09:00	135,7	21:00	0
10:00	146,6	22:00	0
11:00	147,2	23:00	0

In the implementation of the FPO (Optimal Power Flow), we defined the objective functions as the minimization of hourly generation costs (represented by Equation 1) and active losses (represented by Equation 2).

$$\text{Minimize } f(x,u,t)=\sum_{t=0}^{23}\sum_{k=1}^{NB}[(Peol_{k,t}.\rho eol_{k,t})+(Psol_{k,t}.\rho sol_{k,t})+(Pterm_{k,t}.\rho term_{k,t})+(Phidr_{k,t}.\rho hidr_{k,t})] \quad (1)$$

with $j = 1, \dots, NB$, where NB is the number of buses of the electrical system; t: is the time of day;

$\rho eol_{k,t}$: Cost of MWh produced by wind source in bus k at time t;

$\rho sol_{k,t}$: MWh cost produced by photovoltaic solar source at bus k at time t;

$\rho term_{k,t}$: MWh cost produced by the thermal source in bus k at time t;

$\rho hidr_{k,t}$: MWh cost produced by the hydraulic source in bus k at time t;

$Peol_{k,t}$: Power in MW produced by the wind source at bus k at time t;

$Psol_{k,t}$: Power in MW produced by the photovoltaic solar source at bus k at time t;

$Pterm_{k,t}$: Power in MW produced by the thermal source in bus k at time t;

$Phid_{k,t}$: Power in MW produced by the hydraulic source in bus k at time t.

$$\text{Minimize } f(x,u,t)=\sum_{t=0}^{23}\sum_{k=1}^{NL}(g_{km}(V_{k,t}^{2}+V_{m,t}^{2}-2V_{k,t}V_{m,t}\cos\theta_{km,t}) \quad (2)$$

with K = 1, … , NL where NL is the number of lines in the electrical system; t: is the time of day;

g_{km}: Serial conductance between buses k - m;

$V_{k,t}$: Bus voltage in bus k at time t;

$V_{m,t}$: Bus voltage in bus m, at time t;

$\theta_{km,t}$: Voltage angle between buses k-m at time t.

Equations 3 and 4 represent the equality constraints, representing the active and reactive power balance equations, respectively. Equations 5 through 8 illustrate the inequality constraints, representing the limits of active and reactive power generation, bus voltages, and transformer tapping, respectively.

$$Pi_{k,t}=P_{Gk,t}-P_{Lk,t}=V_{k,t}\sum_{m\in k}V_{m,t}[G_{km}\cos\theta_{km,t}+B_{km}\,\text{sen}\,\theta_{km,t}] \quad (3)$$

$$Q_{k,t}=Q_{Gk,t}-Q_{Lk,t}=V_{k,t}\sum_{m\in k}V_{m,t}[G_{km}\,\text{sen}\,\theta_{km,t}-B_{km}\cos\theta_{km,t}] \quad (4)$$

$$P_{Gk_{\min},t}\leq P_{Gk,t}\leq P_{Gk_{\max},t} \quad (5)$$

$$Q_{Gk_{\min},t} \le Q_{Gk,t} \le Q_{Gk_{\max},t} \quad (6)$$

$$V_{k_{\min},t} \le V_{k,t} \le V_{k_{\max},t} \quad (7)$$

$$Tap_{k_{\min},t} \le Tap_{k,t} \le \mathrm{Tap}_{k_{\max},t} \quad (8)$$

In order to validate the proposed methodology, some simulations were considered by the wind and photovoltaic generations associated with the modified IEEE 30 bus test system, presented in Figure 3, consisting of:

- Bus 1: Slack bus (Vθ type) - Generation bus, angular reference;
- Buses: 2, 5, 6, 11 e 13 are generation buses, PV type;
- Bus 6: also, PV type - Wind plant inserted in the system;
- Bus 11: also, PV type - Solar photovoltaic plant inserted in the system;
- The rest of the buses are load buses (PQ type).

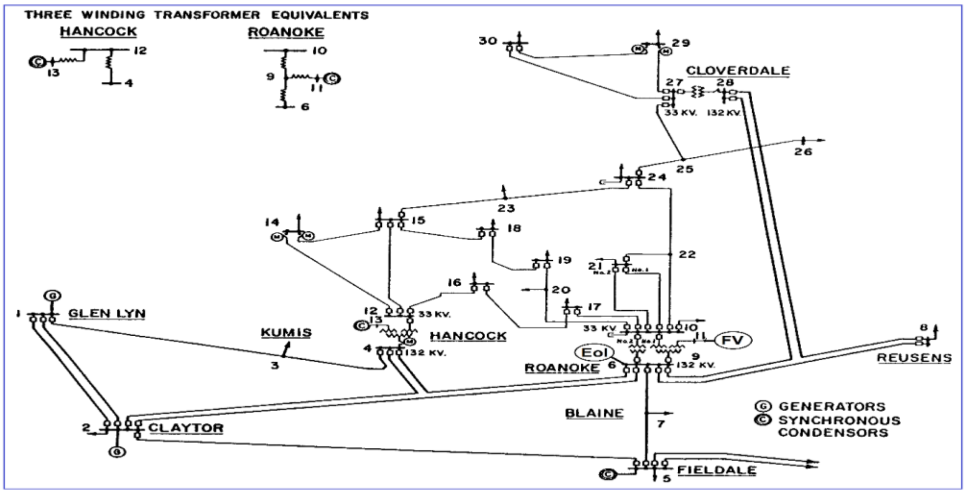

Figure 3: Modified IEEE 30-Bus System. Adapted from Christie (1993)

From the previous system, two cases were initially simulated. For Case 1, the simulations were performed based on a set of wind generators with generation capacity of P = 150 MW and with a photovoltaic solar plant installed in the system with generation capacity of P = 0 MW, (representing the solar plant operation at nighttime). In Case 2, the simulations were performed based on a set of wind generators with generation capacity of P = 50 MW and with a photovoltaic solar plant installed in the system with generation capacity of P = 100 MW, (in this case, representing the operation of the solar plant in a period with high solar radiation).

Results and Discussion

In Case 1, the active power losses were 5.07 MW and the wind plant accounted for 58.03% of the active power and 57.22% of the reactive power produced.

In Case 2, the active power losses were 7.67 MW, with the wind power plant accounting for 19.15% of the active power and 13.99% of the reactive power produced. The solar plant accounted for 28.01% of the active power output.

When the system operated with the wind farm with active power production capacity reduced to 1/3 of total capacity, and with the solar plant operating at 100% of its capacity (100 MW), both sources produced 47.25% of the total active power of the system. A small increase in active power losses was noted, since the power required to meet the demand was generated by different buses, far from the loads.

Conclusion

In this work, it was presented a model for the hourly dispatch of electric energy, which considered the characteristics of intermittent renewable sources, solar and wind. The simulations were performed initially considering the minimization of the active losses of the system, demonstrating a complementarity of solar and wind sources in the electrical system. From the results obtained, it was possible to verify that the wind source produced the maximum of its capacity to supply reactive power to the system, which contributed to the reduction of technical losses.

The proposed modeling considered the presence of thermal and hydraulic sources, as well as wind and solar sources. In the next stage it will be considered the generation costs for each of these sources, which may be different and fluctuate at each hour of the day, due to several factors, including irradiation, wind speeds, water reservoir availability or fuel costs variations.

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References

EPE. Série estudos da demanda – Projeção da demanda de energia elétrica para os próximos 10 anos (2017 – 2026). Nota Técnica. DEA 001/17. Rio de Janeiro, Jan. 2017.

BRASIL. MME. **Resenha Energética Brasileira – Exercício 2018.** Edição: maio de 2019. Disponível em: http://www.mme.gov.br/documents/1138787/1732840/Resenha+Energ%C3%A9tica+Brasileira+-+edi%C3%A7%C3%A3o+2019+v2.pdf/66a837a8-4164-4b37-be4a-59a5ad270c50?version=1.0Acesso em: set. 2019.

CHRISTIE, R., **Power Systems Test Case Archive.** University Of Washington Electrical Engineering. Disponível em: https://labs.ece.uw.edu/pstca/ . Acesso: 08/2019.

ONS. Resultados da Operação. Boletins da Operação. Disponível em http://ons.org.br/Paginas/resultados-da-operacao/boletim-geracao-eolica.aspx Acesso em: 06/2019.

______Resultados da Operação. Boletins da Operação. Disponível em http://ons.org.br/Paginas/resultados-da-operacao/boletim-geracao-solar.aspx Acesso em: 06/2019.

GOVBR, **Sistema Interligado Nacional atende 98% do território brasileiro.** Disponível em: http://www.brasil.gov.br/noticias/infraestrutura/2011/12/sistema-interligado-nacional-atende-98-do-mercado-brasileiro Acesso em: 12/2018.

OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION USING A FLOWER POLLINATION ALGORITHM

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Abstract –

This paper presents a methodology for optimal placement Distributed Generation (DG) in distribution system using an efficient metaheuristic Flower Pollination Algorithm (FPA). The proposed methodology was applied on two systems containing 34 and 70 buses, respectively. The proposed method was validated with other techniques found in literature. As a main result, the manly objective function as power loss minimization is considerate in this algorithm. Numerical results show that the performance of the proposed FPA method is better than other methods compared.

Keywords: Distributed Generation, Flower Pollination Algorithm, Load Flow, Radial Distribution Systems.

Introduction

The losses in transmission lines and distribution systems constitute great part of the consumption of the system´s energy (SUVARCHALA; YUVARAJ; BALAMURUGAN, 2018). Particularly in Brazil the yearly energy loss is equivalent to the major hydroelectric power plant in the country, Itaipu. This is consequence of the great distances between charges and generators (DA ROSA; TEIXEIRA; BELATI, 2018). According to (BELATI et al., 2018), the insertion of distributed generation (DG) in the distribution system alters the potency flows, modifying the losses by Joule effect and contributing to an improvement in in the tension profile. Another fact, not less important, is that these renewable resources as wind energy, solar, biomass and others are ecologically correct (BELATI, 2016). In (QUEZADA et al., 2006) the author emphasizes that the high participation of DG in distribution networks is a new challenge to the traditional power systems. This has led to great amount of research on this important issue. In literature several methodologies for DG allocation were proposed, as sensitivity analysis associated to the optimal power flow (BELATI et al., 2018). To analyze the impact of wind energy in the distribution system the Genetic Algorithm of Chu-Beasley (GACB) (BELATI, 2016) was applied with the objective of reduce the active losses, in three distribution systems 34, 70 and 126 buses. OBOSA (PAL et al., 2018) presented a method to allocate DG in networks of 33 and 69 buses of IEEE to minimize the active losses with low computational cost. *Ant Lion Optimization Algorithm* (ALOA) is proposed to allocate and find the optimal size of DG (ALI; ABD ELAZIM; ABDELAZIZ, 2017), in (XIE et al., 2013) the authors proposed a modified version of PSO (*Improved Reinitialized Social Particle Swarm Optimization* - IRS-PSO)to find a better place to allocation and sizing of DG considering several alternative sources like photovoltaic, wind and biomass.The motivation for choosing the flower pollination algorithm (FPA) is the fact of that being a recent technique , in which several variations can be made, and for having one single parameter **p,** what turns this algorithm of easy implementation. The FPA has also shown itself effective in other areas of knowledge (ZHOU; WANG; ZHOU, 2018) and (ABDELAZIZ; ALI; ABD ELAZIM, 2016).This paper is divided in the following manner: in section II is demonstrated the mathematic formulation of the problem; in III the Flower Pollination Algorithm (FPA) is presented; in section IV the tests and results are presented and finally in V the conclusions of the work are presented.

Material and Methods

I. Mathematic formulation

The problem of optimal placement of distributed generation (DG) consists in determine the best place to the DG, with the intent to reduce the technical losses in the electrical grid and improve the profile of tension, satisfying the operational restrictions of the electrical grid. The objective function is commonly formulated to minimize the technical losses in lines (DA ROSA; TEIXEIRA; BELATI, 2018). The objective function may be represented according to the equation:

$$Min\ f(x) = \sum_{1}^{NL} g_{km}[V_k^2 + V_m^2 - V_k V_m \cos(\theta_k - \theta_m)] \qquad (1)$$

where:

$f(x)$	Represents the total of active losses in the system;
g_{km}	Represents the conductance between buses *k* and *m*;
V_k	Represents the magnitude of tension in the *k* bus;
V_m	Represents the magnitude of tension in the *m* bus;
θ_k, θ_m	Represents the angular difference between buses *k* and *m*;
NL	Represents the total number of lines in the system.

The objective function (1) is exposed to the following restrictions:

- Power flow restrictions

Exposed to restrictions of active and reactive balance of power according to equations (2) and (3);

$$P_{Gk} - P_{Lk} - V_k \sum_{m \in k} V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] = 0 \qquad (2)$$

$$Q_{Gk} - Q_{Lk} - V_k \sum_{m \in k} V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] = 0 \qquad (3)$$

Where:

G_{km}, B_{km}	Represent the elements of admittance of the electrical grid matrix;
P_{Gk}, Q_{Gk}	Represent the active and reactive power generation in the *k* bus;
P_{Lk}, Q_{Lk}	Represent the active and reactive power demand in the *k* bus;
k	Represents the set of buses adjacent to the *k* bus, including the *k* bus itself.

- Restrictions of levels of tension

The tension profile in each bus (V_k) must be in the range of acceptable levels, between the minimum and maximum;

$$V_k^{min} \leq V_k \leq V_k^{max} \qquad (4)$$

$$V_k^{min} = 0{,}90 \text{ p.u.}$$

$$V_k^{max} = 1{,}00 \text{ p.u.}$$

II. Flower Pollination Algorithm (FPA)

The main objective of a flower is the reproduction by pollination. The pollination is typically associated to the pollen transfer, such transfer occurs by pollinators as insects, birds, bats, and other animals. The pollination can occur in two ways: biotic and abiotic. Around 90% of pollination in nature belongs to the biotic form, which means, the pollen is transferred by pollinators like insects and other animals. The other 10 % belong to the abiotic form which does not require any kind of pollinator. In this case wind and diffusion in water are responsible for the pollination, according to (YANG, X.-S, 2012).

The flower pollination algorithm characteristcs are:

The biotic and crossed pollinations are considered as global processes of pollination;

The pollinators move in a way to obey to the Levy flights;

Abiotic pollination and auto pollination are considered local pollination;

Local and global pollination are controlled by an exchange probability $p \in [0; 1]$.

From the characteristics of the pollination process we can have an idea of how the flower pollination algorithm works.

There are two fundamental steps in this global and local pollination algorithm. In the global pollination, the pollens of the flowers are transported by pollinators, for example insects, this ensures the pollination and the reproduction to global optimization, which can be mathematically modelled as below:

$$x_i^{t+1} = x_i^t + L\left(x_i^t - g^*\right) \quad (5)$$

where:

x_i^t Represents the pollen i or vector soluction x_i;

t Represents the number of iterations;

g^* Represents the better current sollution found among all the sollutions in the current generation/iteration;

L Is the force parameter of pollination that is essentially the size of the step that obeys to the Levy flights.

$$L \sim \frac{\lambda \Gamma(\lambda)\, sin(\pi\lambda/2)}{\pi} \frac{1}{S^{1+\lambda}}, (S \gg S_0 > 0) \quad (6)$$

Where:

$\Gamma(\lambda)$ is a standard gama function, and this distribution is valid to values of $S > 0$. For this paper we used $\lambda = 1.5$ according to (YANG, 2012).

And for local pollination we have:

$$x_i^{t+1} = x_i^t + \varepsilon\left(x_j^t - x_k^t\right) \quad (7)$$

Where:

x_j^t *and* x_k^t are pollens of different flowers from the same or similar species;

ε Is the parameter of the local pollination force, generates two random flowers, if they are from the same or similar species then they can be pollinated, otherwise no action **should take place.**

As seen the flower pollination activity can occur in a global as well as in a local scale. For such are used the probability of exchange or proximity $p[0;1]$ to alternate between local and global pollination, providing a wide and intelligent scanning through the search space. The complete algorithm of the proposed methodology is presented in figure 2:

1. Enter the data of the distribution system: as the data of the electrical grid and the charges;
2. Inform the size of the population of n flowers, maximum number of iterations, number of DG for placement and the power of the generators to be placed;
3. Give the initial solution x_i^t (x_i é um vetor) that corresponds to the pollen of a flower provided by a random solution;
4. If the random number $< p$ then perform the global pollination, otherwise make the local pollination;
5. Calculate the initial objective function based in the equations (1), (2), (3) and (4);
6. If the number of iterations is > k show the results, otherwise make another iteration.

Results and Discussion

The main objective of this paper is to show the performance of the FPA to solve the problem of optimal placement of distributed generation in the electrical grid. However, as the FPA is an approximate methodology that does not guarantee the convergence to an optimal place, the validation of the proposed method is necessary. Therefore, to validate the technique, the systems of radial distribution of 34 (SU; TSAI, 1996) and 70 (BARAN; WU, 1989)] buses were studied and compared with another technique available in the literature.

For each system the FPA found the optimal placement. The power insertion of the DG was considered fix, injecting active and reactive power in the system (DA ROSA; TEIXEIRA; BELATI, 2018) with the objective to reduce the active losses of the system.

- 530 kW and 530 kVAr;
- 1 MW and 1 MVAr;
- 3 MW and 3 MVAr.

The proposed methodology was implemented in MATLAB®, using a computer DELL Inspiron 7000 processor Intel® Core™ i7-7700HQ CPU @ 2.80 GHz, 8GB of RAM, operational system

Windows 10 Home - 64 Bits.

To the tested systems we used the parameters according to table 1.

TABLE 1

CONSTANTS USED IN THE TESTS

n flowers	15
Iterations	50
Inserted power of DG	530 kW; 1 MW; 3 MW
Placed DG quantity	1

A - Placement of one DG in the system of 34 buses

The first simulated system was the 34 buses. The data of the lines and charges can be consulted in (SU; TSAI, 1996). The tension of the substation and the minimal tension of the bus #27 were 1,0 and 0,94 (p.u) respectively. In the first test a DG of fixed power 530 kW, 530 kVAr was placed and the impacts on the network were analyzed.

The result was compared with the sensitivity analysis technique (AS) proposed by (DA ROSA; TEIXEIRA; BELATI, 2018). The value of active and reactive power injected by each DG were 0,53 MW; 0,53 MVAr ; 1 MW; 1 MVAr; 3 MW; 3 MVAr respectively. The total active losses with the proposed methodology was lower than with the compared method. The lower tension for this system, 0,94 p.u, was found in the bus #27. There was improvement on the tension profile, after DG placement, to 0,95 p.u. the results are in table 2.

TABLE 2

TEST 1 – SIMULATION 34 BUSES SYSTEM

34 buses	**Initial System**	**Compensated System**	
		AS	FPA
Total Losses kW	222,29	144,37	144,04
Reduction (%)		35,05	35,20
Local and size		27	26
DG in kW		530	530
Maximum Tension in p.u. #1	1,00	1,00	1,00
Minor Tension in p.u. # 27	0,94	0,95	0,95

Table 3 presents the results of test two allocating a DG with fixed capacity of 1MW; 1 MVAr. It can be noticed that the FPA had a slight advantage when compared to the AS. The tension on bar 27 was equal in both methods.

TABLE 3

TEST 2 - SIMULATION 34 BUSES SYSTEM

34 buses	**Initial System**	**Compensated system**	
		AS	FPA
Total losses kW	222,29	101,23	100,12
Reduction (%)		54,46	54,95
Local and Size		26	24
DG in kW		1000	1000
Maximum Tension in p.u. #1	1,00	1,00	1,00
Minor Tension in p.u. # 27	0,94	0,96	0,96

In table 4 are presented the results of test , allocating a DG with fixed capacity of 3MW and 3MVAr respectively. In this simulation, there was an expressive reduction in the active losses, in the order of 71,96% in the system.

TABLE 4
TEST 3 - SIMULATION 34 BUSES SYSTEM

34 buses	Initial System	Compensated System	
		AS	FPA
Total losses kW	222,29	68,11	62,32
Reduction (%)		69,35	71,96
Local and Size		21	9
DG in kW		3000	3000
Maximum Tension in p.u. #1	1,00	1,00	1,00
Minor Tension in p.u. # 27	0,94	0,99	0,98

In figure 3 is presented the comparison of active losses in the 34 buses system, in the four cases: without the DG insertion, allocating 530kW; 530 kVAr in the bar 26, 1MV; 1MVAr in the bar 24 and 3MW; 3 MVAr in the bar 19. It is possible to notice that as more active power is allocated, the active losses are considerably decreasing.

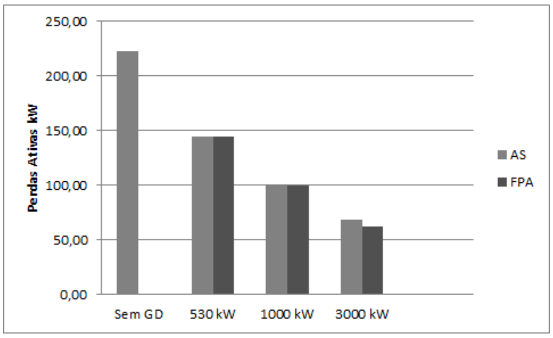

Figure 1- Comparative between AS and FPA in the 34 buses system

B - Placementof one DG in the 70 buses system

The second simulated system was the 70 bars, the data of lines and charges can be consulted (BARAN; WU, 1989). The tests in this system followed the same logic as in the previous simulation. An 530 kW; 530 KVAr DG was placed in the distribution network and compared with the result from the AS technique, then inserted a DG of 1 and 3 MW; 1 and 3 MVAr respectively. The substation tension values and minor tension are 1,0 and 0,90 p.u. respectively.

In the forth test there was a reduction in the active losses through the proposed methodology, in the order of 51,59% in relation to the initial losses, being better than the AS. The tension profile has also improved in the worse system bus #66, to 0,93 p.u. The simulation result is found in table 5.

TABLE 5
TESTE 4 - SIMULATION 70 BUSES SYSTEM

70 buses	Initial System	Compensated System	
		AS	FPA
Total Losses kW	225,00	112,90	108,92
Reduction (%)		49,82	51,59
Local and size		66	63
DG in kW		530	530
Maximum Tension in p.u. #1	1,00	1,00	1,00
Minor Tension in p.u. # 66	0,90	0,94	0,93

In table 6 are presented the results of test five, placing a DG with fixed capacity of 1 MW; 1 MVAr. In this simulation, there was an reduction in the active losses, being 76,60% with the AS technique and 77,35% with the FPA, in comparison to the initial system without DG. There was also an increase in the tension profile in the worse bus of the system, from 0,90 to 0,96 p.u.

TABLE 6
TESTE 5 - SIMULATION 70 BUSES SYSTEM

70 buses	**Initial System**	**Compensated System**	
		AS	FPA
Total losses kW	225,00	52,63	50,95
Reduction (%)		76,60	77,35
Local and size		64	62
DG in kW		1000	1000
Maximum tension in p.u. #1	1,00	1,00	1,00
Minor Tension in p.u. # 66	0,90	0,96	0,96

In test seven is considered a DG with power of 3 MW; 3 MVAr respectively in the system of 70 buses. The results demonstrated that the FPA found lowers losses than the compared method. The results are available in table 7.

It is interesting to notice that with the insertion of maximum power of DG, the active losses for this system were not reduced, as it was happening with the incremental of power previously, this owns to the fact that de 70 buses network has considerably lower charges for this injected power.

TABLE 7
TEST 6 - SIMULATION OF 70 BUSES SYSTEM

70 buses	**Initial System**	**Compensated system**	
		AS	FPA
Total Losses kW	225,00	158,17	141,10
Reduction (%)		29,70	37,28
Local and size		63	58
GD in kW		3000	3000
Maximum Tension in p.u. #1	1,00	1,00	1,00
Minor Tension in p.u. # 66	0,90	1,05	1,0

The figure 4 presents the behavior of active losses facing the insertion of DG, that is, as the DG offers more power to the system there is direct relation with the decrease of total losses.

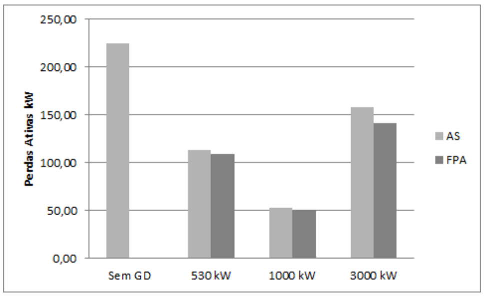

Figure 2 – comparative between AS and FPA in the 70 buses system

C - Placement of two DG in the system of 34 buses

For the tested systems were used the parameters shown on table 8(ABDEL-BASSET; SHAWKY, 2019)

TABLE 8
TESTE 8 - SIMULATION OF THE 34 BUSES SYSTEM

n flowers	15
Iterations	20;25
Inserted DG power	1 MW; 1 MVAr
Quantity of placed DG	2

In table 9, is presented the comparative between the techniques Genetic Algorithm of Chu-Beasley and First Order (GACB-FOS) and the FPA for the placement of two DG with the objective of evaluating the active losses in 10 simulations. The table demonstrates the number of simulations, the bus candidate to placement, the number of iterations and the active losses between the methods.

The DG were dispatched with fixed power of 1 MW; 1 MVAr respectively, according to (BELATI, 2016).

The first simulated system was of 34 buses and the GABC-FOS found the lower losses in four of ten possible tries, with bigger number of iterations. In contrast, the FPA had 100% of harnessing finding lower losses with smaller number of iterations.

TABLE 9
TEST 9 – COMPARATIVE BETWEEN GACB-FOS AND FPA

	GACB-FOS			**FPA**		
Sim	Buses	Losses (kW)	Iter.	Buses	Losses (kW)	Iter.
1	9 e 24	44,16	24	9 e 24	44,16	20
2	10 e 24	44,25	49	9 e 24	44,16	20
3	9 e 24	44,16	27	9 e 24	44,16	20
4	9 e 24	44,16	46	9 e 24	44,16	20
5	9 e 25	44,27	25	9 e 24	44,16	20
6	10 e 24	44,25	41	9 e 24	44,16	20
7	9 e 25	44,27	46	9 e 24	44,16	20
8	9 e 26	45,23	39	9 e 24	44,16	20
9	9 e 25	44,27	31	9 e 24	44,16	20
10	9 e 24	44,16	33	9 e 24	44,16	20

The last test was performed in the system of 70 buses, considering the same previous parameters. The results of the simulation are presented in table 10. Again the FPA demonstrated better results than the GACB-FOS with great assertiveness and low number of iterations.

TABLE 10
TEST 10 – COMPARATIV BETWEEN GACB-FOS AND FPA

	GACB-FOS			**FPA**		
Sim.	Buses	Losses (kW)	Iter.	Buses	Losses (kW)	Iter.
1	11 e 64	30,05	33	12 e 62	27,80	25
2	11 e 64	30,05	44	12 e 62	27,80	25
3	10 e 64	33,39	23	12 e 62	27,80	25
4	62 e 67	30,16	28	62 e 67	30,16	25
5	9 e 63	33,24	33	12 e 62	27,80	25

6	11 e 63	29,04	37	12 e 62	27,80	25
7	12 e 64	29,42	38	12 e 62	27,80	25
8	11 e 63	29,04	44	62 e 67	30,16	25
9	11 e 63	29,04	49	62 e 67	30,16	25
10	14 e 63	33,83	24	13 e 62	28,21	25

Conclusion

This article presented a proposal to placement of DG in distribution grids based on the flower pollination algorithm (FPA). The objective function was formulated with the purpose of minimizing the active losses and improving the tension profile, always attending to the operational restrictions of the grid.

It was demonstrated that the placement of DG with the proposed methodology proportionated decrease in the technical losses of the grid with consequent improvement in the tension profile of the system. The result was compared with other methodologies found in the literature, with superior performance of FPA.

It was observed that in the system of 70 buses, with the allocation of 1 DG of 3MW, provocated the violation of the tension profile, overtaking the allowed level of tension and the losses increased instead of decreasing.

Finally, the proposed method represents an excellent tool to the planning and operation of power electrical systems, with the objective to reduce technical losses

References

ABDEL-BASSET, M.; SHAWKY, L. A. Flower pollination algorithm: a comprehensive review. **Artificial Intelligence Review**, v. 52, n. 4, p. 2533–2557, 2019.

ABDELAZIZ, A. Y.; ALI, E. S.; ABD ELAZIM, S. M. Flower pollination algorithm for optimal capacitor placement and sizing in distribution systems. **Electric Power Components and Systems**, v. 44, n. 5, p. 544–555, 2016.

ALI, E. S.; ABD ELAZIM, S. M.; ABDELAZIZ, A. Y. Ant Lion Optimization Algorithm for optimal location and sizing of renewable distributed generations. **Renewable Energy**, v. 101, p. 1311–1324, 2017.

BARAN, M. E.; WU, F. F. Optimal capacitor placement on radial distribution systems. **IEEE Transactions on Power Delivery**, 1989.

BELATI, E. Distributed Generation Allocation Using the Genetic Algorithm of Chu-Beasley and Sensitivity. **Przegląd Elektrotechniczny**, v. 1, n. 8, p. 196–201, 2016.

BELATI, E. A. et al. Distribution System Analysis with Wind Generation by Means of Sensitivity Technique. **IEEE Latin America Transactions**, v. 16, n. 2, p. 476–481, 2018.

DA ROSA, W. M.; TEIXEIRA, J. C.; BELATI, E. A. New method for optimal allocation of distribution generation aimed at active losses reduction. **Renewable Energy**, v. 123, p. 334–341, 2018.

PAL, A. et al. Optimal DG allocation for minimizing active power loss with better computational speed and high accuracy. Proceedings of the 4th IEEE International Conference on Recent Advances in Information Technology, RAIT 2018. **Anais**...IEEE, 2018

QUEZADA, V. H. M. et al. **Assessment of Energy Distribution Losses for Increasing Penetration of Distributed Generation**. v. 21, n. 2, p. 533–540, 2006.

SU, C. T.; TSAI, C. C. New fuzzy-reasoning approach to optimum capacitor allocation for primary distribution systems. **Proceedings of the IEEE International Conference on Industrial Technology**, p. 237–241, 1996.

SUVARCHALA, K.; YUVARAJ, T.; BALAMURUGAN, P. A brief review on optimal allocation of Distributed Generation in distribution network. **Proceedings of the 4th International Conference on Electrical Energy Systems, ICEES 2018**, p. 391–396, 2018

.

XIE, S. et al. Impacts of different wind speed simulation methods on conditional reliability indices. **International transactions on electrical energy systems**, v. 20, n. May 2010, p. 1–6, 2013.

YANG, X.-S. **Bio-inspired optimization algorithms**. [s.l: s.n.]. v. 118

ZHOU, G.; WANG, R.; ZHOU, Y. Flower pollination algorithm with runway balance strategy for the aircraft landing scheduling problem. **Cluster Computing**, v. 21, n. 3, p. 1543–1560, 2018.

FAULT LOCATION USING INDEPENDENT COMPONENT ANALYSIS AND WAVELET TRANSFORM

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ABSTRACT

Fault location in transmission lines is an important subject when discussing the continuity of the power supply to final consumers. In an attempt to improve the accuracy of the fault location function in transmission systems, many works have been presented in the literature, including the ones based on travelling waves. These methods use travelling waves, produced by fault events, and their respective reflection times, for estimating the fault distance in transmission lines. As the detection of the reflection times by means of wavefronts is still a challenge, the main goal of this work is to use Independent Component Analysis (ICA) to precisely detect wavefronts, created by fault events, thus improving the fault location function. All obtained results by using ICA are compared to a method based on Wavelet Transform for detecting wavefronts and so estimating the fault distance. The proposed method based on ICA showed a better performance against many different fault cases, when comparing to the method based on Wavelet Transform.

Keywords: Fault Location, Independent Component Analysis, Wavelet Transform.

Introduction

Power availability is an important parameter commonly used to measure the power quality performance of a given electrical system. However, any electrical system is vulnerable to interruptions, which can be mainly caused by faults in transmission lines, as they have the highest failure rate in power grids. Therefore, the fault location function is essential to restore the power service as soon as possible, currently becoming a subject of many studies that have been proposed in the literature.

In a general way, fault location methods can be divided into two groups, i.e., the first one using fundamental frequency (phasors) and the second one using high frequencies. The second group, discussed in this work, is based on travelling waves theory and uses high frequencies produced during fault events (BEWLEY, 1963). These methods take into account the light speed and its propagation time over a particular medium (lines or cable). According (ZIMMERMAN; MURILLO-SANCHEZ; THOMAS, 2011) these methods are more accurate and reliable than the ones based on fundamental frequency.

Travelling waves can arise in transmission lines due to faults or atmospheric discharges (lightning), going from the fault point to the ends of the line in both directions, repeatedly. At each end of the transmission line the waves are refracted and/or reflected, depending on the equivalent impedance connected at that bus. This process lasts until the total dissipation of the travelling waves, which depends on the line characteristics.

Figure 1 shows the Lattice diagram for a case where the length of the transmission line is L (km) and the fault point is located d (km) from the bus 1. As can be observed in this figure, the fault event produces two waves going to the ends of the line and then being reflected to the fault point. Considering this process repetitively, the standard shown in Figure 1 is reached.

The main purpose of methods based on travelling waves is to determine the instant when the wavefronts arrive at the ends of the transmission line, making possible to estimate the fault distance, since the wave propagation speed is known.

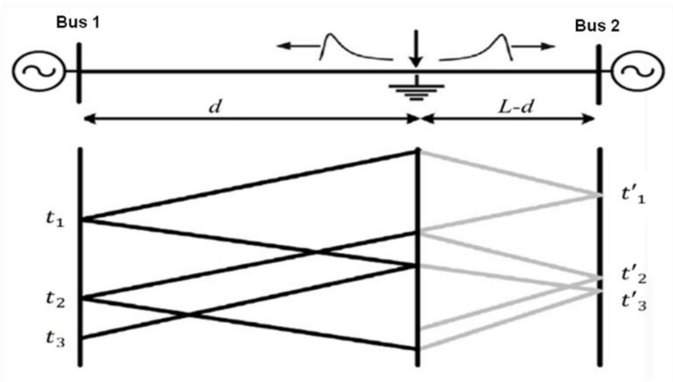

Figure 1. Lattice diagram for a faulted transmission line.

Wavelet Transform is a technique commonly employed for fault location, where wavelet functions are used considering time and frequency domains simultaneously. This technique is suitable when non-periodic and high frequency signals are present, being useful to deal with fault signals. This is a technique already consolidated for fault location application and many works can be found in the literature.

Another less common method for fault location in transmission lines is the so-called Independent Component Analysis (ICA), developed in the 90s for dealing with problems of blind source separation (HYVARINEN; KARHUNEN; OJA, 2003).

Some works considering the application of ICA in electrical power systems can be found in the literature, as for example: (AI; ZHANG, 2013) where ICA is used for harmonic content separation; and (ARIFF; PAL, 2013) where ICA is used for grouping coherent generators.

The work presented by (NAGATA et al., 2018) employs a variation of ICA, so-called Single Channel ICA (SCICA), for dealing with problems of voltage sag and swell detection and segmentation. This variation was proposed by (DAVIES; JAMES, 2007) and it is based on time-delayed signals. In (ALMEIDA et al., 2017) the authors propose an algorithm based on FastICA and Support Vector Machine for fault location and classification.

Considering the importance of a fast and accurate fault location scheme to restore the power system as soon as possible when faults take place in transmission lines, the main goal of this work is to propose a new methodology based on ICA (with temporal structure and single channel) for precisely detecting wavefronts during fault events.

Material and Methods

In terms of fault detection methods based on travelling waves, two different strategies can be adopted, i.e., voltage signals can be measured at only one terminal of the transmission line or voltage signals can be measured at both terminals of the transmission line. When using measures from a single terminal, only the first and second incident wavefronts are of interest. In this sense, for determining the arrival instant of the second wavefront, a pre-location of the fault point could be needed, depending on the fault type (with or without ground involved). On the other hand, in case of synchronized measures from both terminals the fault location process is simplified, not requiring a pre-location step, as only the arrival instants of the first wavefront at both terminals are needed. Despite the simplicity of the second option, in this case a more sophisticated communication infrastructure is required.

For the purpose of this work, that is a comparison between ICA and Wavelet Transform for detecting wavefronts, a scheme for fault location considering synchronized signals from both terminals is adopted.

The Wavelet Transform basically consists in applying low pass filters and high pass filters, in different levels, thus allowing obtaining the approximation and detail coefficients. The Inverse Wavelet Transform is applied to the detail coefficients, making possible to identify the wavefronts. In this work, it was employed the wavelet function Symlet3, while the detail coefficients are from the first level.

As for the ICA, we propose to use a single channel method based on second order statistics, which is able to exploit the temporal structure of the signals being considered. The *M* signals used as inputs are given by delayed versions of the l Using the Second Order Blind Identification (SOBI) algorithm (BELOUCHRANI et al., 1997), we obtain *M* outputs from which we are able to estimate the wavefronts arrival instants. This work considered *M*=3.

Results and Discussion

To evaluate the fault location schemes proposed in this work, the power system shown in Figure 2 was modeled and simulated in PSCAD. The voltage system is 500 kV, while the length of the transmission line is 200 km. The equivalent systems connected in each bus are also represented by $\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{Z}_1$ and $\mathbf{Z}_2$.

Many fault cases were simulated by applying faults in different points of the transmission line. For each new fault case the voltage signals from both terminals were stored, thus allowing analyzing the performance of the proposed schemes against different situations, in terms of fault location and fault resistance. While the power system was simulated in PSCAD, the proposed schemes based on ICA and Wavelet Transform were implemented in MATLAB. For the purpose of this work, only the fault location function is evaluated, considering that the fault was previously and correctly detected and classified by specific algorithms for fault detection and classification.

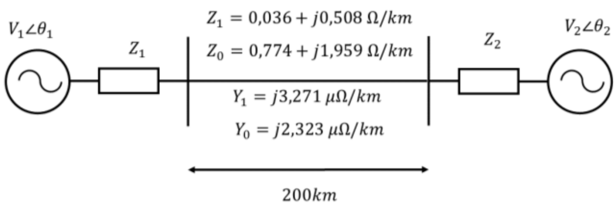

Figure 2. Power system adopted.

To simulate different fault conditions the following parameters were changed during the simulations: a) fault distance (from 5 km to 195 km, adopting the bus 1 as a reference); b) equivalent systems conditions ($\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{Z}_1$ and $\mathbf{Z}_2$); c) type of fault (single-phase, double-phase, and three-phase); d) fault angle. The simulations were divided into two groups, where the first one contains only solid faults ($R_f = 0\ \Omega$), while the second one contains faults through 50 Ω or 100 Ω. The obtained results are shown in Figure 3 and Figure 4, respectively. They are presented in terms of fault resistance versus percentage error (considering the total length of the transmission line). In red color are the results obtained when the proposed scheme is implemented by using Wavelet Transform. In blue color are the results obtained when the proposed scheme is implemented by using ICA. By means of these figures it is possible to conclude that both methods are very accurate in detecting the wavefronts, as both scheme present errors lower than 2%. Moreover, it is possible to observe that the errors obtained with ICA are lower than the ones obtained with Wavelet Transform, mainly for faults in the middle of the transmission line. With respect to fault resistance, it was verified that the schemes' performances practically are not affected, regardless the value considered (0 Ω, 50 Ω or 100 Ω).

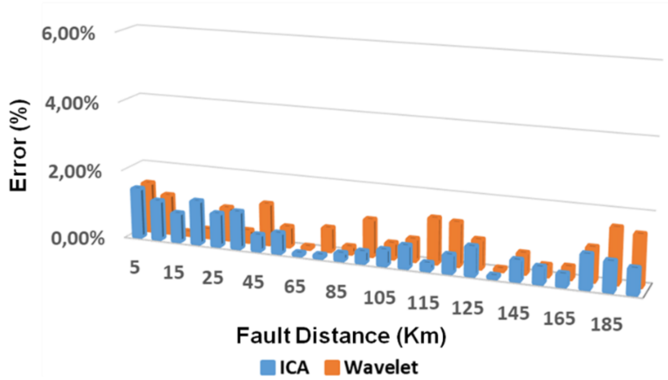

Figure 3. Results considering $R_f = 0\ \Omega$.

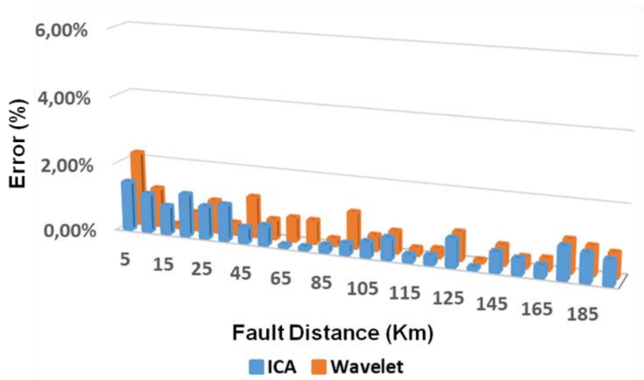

Figure 4. Results considering $R_f = 50\ \Omega$ and $R_f = 100\ \Omega$.

Conclusion

This work presented a comparison between two different methods for locating faults in transmission lines, where the first method is based in ICA and the second is based on Wavelet Transform. The adopted transmission system was simulated in PSCAD, while the mentioned methods were implemented in Matlab. By changing the power system parameters (fault distance. fault resistance, equivalent sources, and fault angle) many fault cases were generated, thus allowing comparing both algorithms in terms of fault location, when using synchronized measures from the two terminals of the transmission line.

As can be seen by means of the presented results, both algorithms are able to accurately locate faults in transmission lines. However, the algorithm based on ICA presents better results for faults in the middle of the transmission line, when compared to the algorithm based on Wavelet Transform. As shown by the results, fault resistance does not affect significantly the algorithms' performances.

Acknowledgment

The authors would like to thank the UFABC and its Postgraduate Program in Energy.

References

AI, Y.; ZHANG, H. Harmonic separation based on independent component analysis method. **Journal of Computers (Finland)**, v. 8, n. 2, p. 433–440, 2013.

ALMEIDA, A. R. et al. ICA feature extraction for the location and classification of faults in high-voltage transmission lines. **Electric Power Systems Research**, v. 148, p. 254–263, 2017.

ARIFF, M. A. M.; PAL, B. C. Coherency identification in interconnected power system - An independent component analysis approach. **IEEE Transactions on Power Systems**, v. 28, n. 2, p. 1747–1755, 2013.

BELOUCHRANI, A.; ABED-MERAIM, K.; CARDOSO, J.F.; MOULINES, E. - A blind source separation technique using second-order statistics. **IEEE Transactions on signal processing**, v. 45, n. 2, pp. 434–444, 1997.

BEWLEY, L. V. **Traveling waves on transmission systems**. John Wiley & Sons, 1963.

DAVIES, M. E.; JAMES, C. J. Source separation using single channel ICA. **Signal Processing**, v. 87, n. 8, p. 1819–1832, 2007.

HYVARINEN, A.; KARHUNEN, J.; OJA, E. **Independent Component Analysis**. J. Wiley, 2003.

NAGATA, E. A. et al. Voltage sag and swell detection and segmentation based on Independent Component Analysis. **Electric Power Systems Research**, v. 155, p. 274–280, 2018.

ZIMMERMAN, R. D.; MURILLO-SANCHEZ, C. E.; THOMAS, R. J. MATPOWER: Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education. **IEEE Transactions on Power Systems**, v. 26, n. 1, p. 12–19, 2011.

FOUCAULT BRAKE TORQUE CONNECTED TO A VERTICAL AXIS WIND TURBINE ON A SMALL AERODYNAMIC CHANNEL

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ABSTRACT

In this paper a method was developed for using the Foucault brake on a rotating aluminum disc, connected to the axis of a savonius vertical axis wind turbine in a small aerodynamic channel. Thus, it was proposed a theoretical model of calculation of magnetic torque as a function of the distance of the permanent magnet with the disk, aiming to validate the experimental torque measurements through the developed methodology. Through the algorithms in the simulations, it was possible to obtain validation with a result acceptable of a torque comparison.

Keywords: aerodynamic channel, savonius turbine, foucault brake, measurements.

Introduction

New forms of electricity generation through renewable sources have emerged in recent decades because of the oil crisis and the issue of global warming (GWEC, 2018). In Brazil, the environmental issue coupled with its great potential in the generation of energy through solar and wind energy, has also strengthened the importance of these new renewable sources in the generation of electricity (PEREIRA, 2012).

In the case of wind energy, much of the wind generation happens through horizontal axis wind turbines in wind farms. With the growth of decentralized generation in the country, vertical axis wind turbines such as the savonius turbine (SAVONIUS, 1930), offer great potential for power generation in turbulent urban areas and in rural areas. They also provide other advantages over horizontal axis turbines such as lower cost to make, low noise, operate in any direction wind, low maintenance etc(TUMMALA, 2016; KUMAR, 2018, AKWA 2012; AKWA 2017).

Experimental work with wind turbines can be done either in the field or in aerodynamic channels. The experimental results found in the literature present many divergences between the data presented by different authors. They arise due to the different experimental methods adopted, such as different ways of torque measurement (BLACKWELL et al., 1977; MOJOLA, 1985).

Considering the utility and importance of small turbines in the current scenario, this work aims to validate a theoretical model of a magnetic brake using a permanent magnet on an aluminum disc and to calculate the magnetic torque as a function of angular velocity of the disc. They are part of the development of the test system for measuring aerodynamic torque using the Foucault brake, which is connected to a savonius vertical axis wind turbine in a small aerodynamic channel.

Material and Methods

For the assembly and installation of the aerodynamic channel, a workbench was used inside the Renewable Energy Laboratory; block A, room 801-1 at the Federal University of ABC (UFABC), Campus de Santo André. It is formed by transparent acrylic walls, which provide easy viewing and low friction. They were made by laser cutting of acrylic plates (Figure 1).

The vertical axis turbine was made by 3D printing. Figure 2 shows inside the aerodynamic channel with the turbine in the tests section. The vertical turbine has a diameter of 0.05 m, with blades in semicircular profile of 0.002 m. It is made so that there is an overlap between the blades of 0.006 m. The turbine has 0.146 m in height in order to reduce the spade tip flow effect, as explained in (AKWA, 2014).

A device consisting of Foucault brake and sensor for dynamic torque measurement was developed, for the experimental tests, according to Figure 3. The brake was used to vary the load on the turbine shaft and the sensor of torque captured the average torque produced by the turbine. The magnetic brake system is made with an aluminum disc connected to the upper tip of the turbine shaft and a neodymium magnet positioned on the disc. When the disc is rotating, a current induced in the aluminum also generates a magnetic field, consequently causing a force on the magnet.

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Figure 1. Small aerodynamic channel.

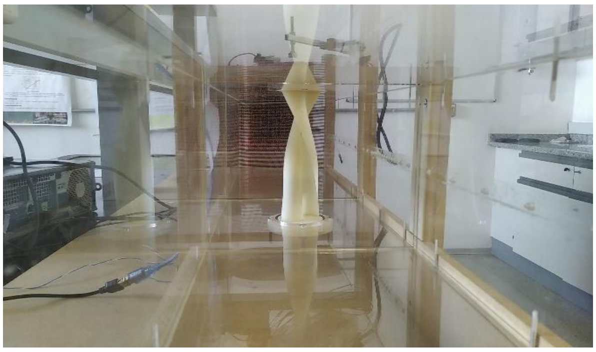
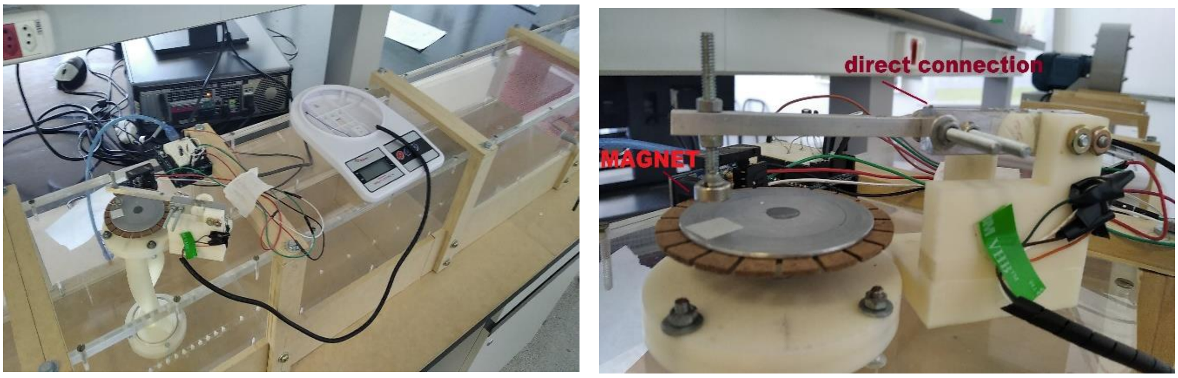


Figure 2. Vertical axis wind turbine.

The force applied on the magnet is transferred to the rod connected directly to the load cell, as shown in Figure. 3-b. In the measurements, the magnet can be approached or distanced from the disc by a set of screws. Varying the distance of the magnet with the surface of the aluminum disc, the force that produces the Foucault brake torque by the induced magnetic field, is a function of distance and angular velocity.

After a calibration process using the rod directly connected to the load cell, the adapted weight balance provided a measure of the useful torque on the turbine shaft, T_{sensor}, given by Equation 1.The calibration data are shown in Figure. 4.

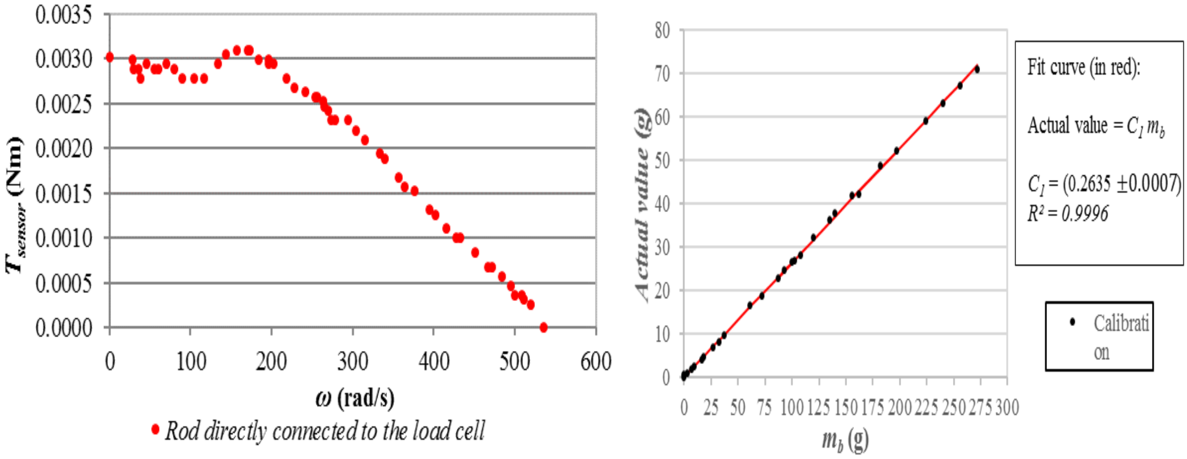
$$T_{sensor} = R_1 \cdot \left[\frac{(C_1 \cdot m_b)}{1000}\right] \cdot g = 0.0204 \cdot \left[\frac{(0.2635 \cdot m_b)}{1000}\right] \cdot 9.7856 \quad (1)$$



(a) (b)

Figure 3. Magnetic brake and sensor: (a) showing the value of the m_b (Equation 1) by the sensor, (b) the brake system.

For the terms in equation 1: m_b : grams-force on the weight balance screen , C_1 is a coefficient equal to 0.2635, R_1 is the force application radius equal to 0.0204 m and g is the local gravity acceleration value, in Santo André, SP, which according to Lopes (2008) can be approximated to 9.7856 m/s².



(a) (b)

Figure 4. (a) Method for measuring the useful torque on the turbine shaft T_{sensor} *versus* the angular velocity ω*:* (b) calibration.

The theoretical model for the calculation of the magnetic torque of a permanent magnet in an aluminum disc comes from a model for the calculation of the magnetic field B of a cylindrical magnet. The calculation of B produced by the magnet could also have been calculated by the FEMM (Finite Element Method Magnetics) software, but only if there was axial symmetry. However, to validate the theoretical model with the experimental torque, the magnet disk will not be centered on the aluminum disk, but rather on the so-called effective radius (r_{effe}) on the disk from the center of the disk to the center of the magnet disk.

The proposed model is based on magnetic charges to determine the field created by a cylindrical magnet over any point in space. The magnet and disk will be discretized by (ΔR and Δθ), and the position of this point will be in cylindrical coordinates (θ, R, Z), as shown in Figure 5. For the calculation of the distance between the magnetic charge ("C") and the point of interest on the aluminum disc ("P") was calculated from the resulting vector, which can be seen in Figure 5.The center of the magnet will be defined by (I), the center of the disc defined as (O) will be the center of the general coordinates of the model, which can also be this in Figure 5. Therefore, in order to operate with the sum of the vectors, it was necessary to change to Cartesian coordinates.

(a) (b)

Figure 5. Illustration of the discretization of space on the magnet and disk (a); Cartesian coordinates for the sum of vectors, in equation 2, of the aluminum disc (major disc) and magnet (minor disc) (b).

$$\overrightarrow{CP} = \overrightarrow{IC} + \overrightarrow{OI} - \overrightarrow{OP} \quad (2)$$

Several authors have used the Coulomb model for magnetic field calculation created by a magnetic charge (*Jr*) (AMJADIAN, 2016; JANSSEN, 2011; ENGEL-HERBERT, 2005). In the external region of the magnet, the focus of this model, the charge surface density (σ_{magnet}) can be calculated by equation 3. For the charge q_k in a discretized piece on the magnet, it is obtained by equation 4. For the calculation of the field B_p anywhere outside the magnet was obtained through equation 5, where the direction $\vec{k}$ of the field being the direction of the vector CP_k. These equations were entered into an algorithm, along with equation 6 for the calculation of magnetic torque, where σ is the aluminum conductivity, ω angular velocity.

$$\sigma_{magnet} = \frac{J_r}{4\pi} \quad (3)$$

$$q_{k=}\sigma_{magnet}.\Delta R.(R_k.\Delta\theta) \quad (4)$$

$$\overrightarrow{B_p} = \iint_{S magnet+and\, -} \frac{q_k}{|CP_k|^2}\vec{k}\,drd\theta \quad (5)$$

$$T_{mag} = B_{normal}{}^2\sigma_{al}\omega R_p \quad (6)$$

Results and Discussion

To validate the experimental torque with the model torque, a distance of 0.0054 m from the magnet in relation to the aluminum disc was used, as shown in Figure 6.

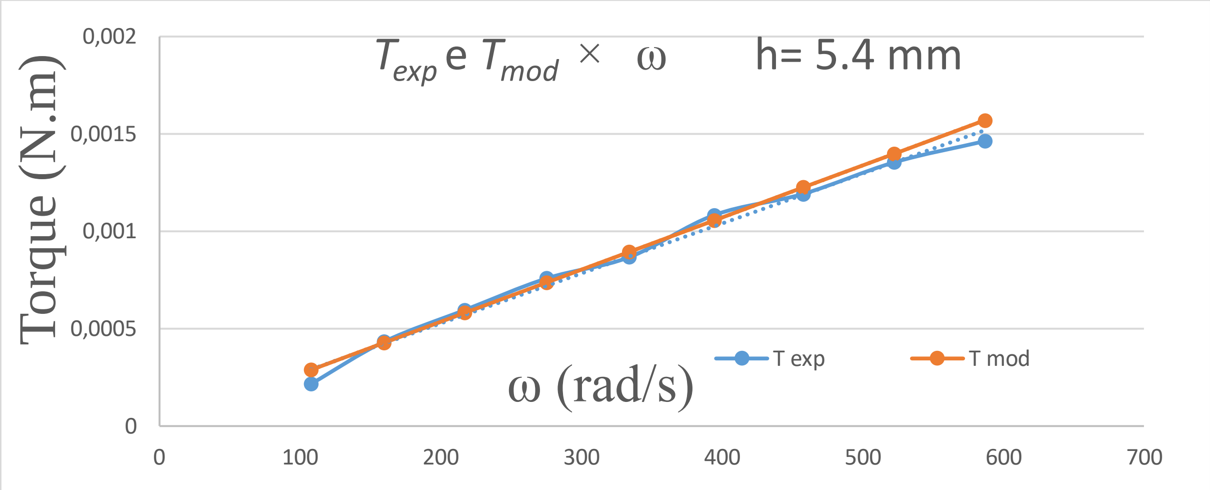


Figure 6. Results with the graphic of torque versus angular velocity.

Conclusion

The methodology to obtain the experimental torque of the eddy brake showed that it is possible to carry out experiments in the field of small scale and low cost wind energy. The proposed model of magnetic field calculation by magnetic charges calculates the fields well for the case of a permanent magnet on a circularly moving aluminum disc. Thus, it was possible to obtain acceptable comparative results of the experimental magnetic torques and theoretical model, seeking a contribution in the study and improvement of the performance of the savonius vertical axis wind turbine.

Acknowledgment

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References

AKWA, J. V. Estudo Numérico e Experimental do Escoamento Sobre um Rotor Eólico Savonius em Canal Aerodinâmico com Alta Razão de Bloqueio, **Tese de Doutorado, Programa de Pós-Graduação em Engenharia Mecânica, Escola de Engenharia, Universidade Federal do Rio Grande do Sul**, 2014.

AKWA, J. V. VIELMO, H. A. PETRY, A. P. A review on the performance of Savonius wind turbines. **Renewable and Sustainable Energy Reviews** 16, p. 3054– 3064, 2012.

AKWA, J. V. ; FALCÃO, C. E. G., Aerodynamic Design Analysis Of A Hybrid Vertical Wind Turbine For Decentralized Power Generation. **24th ABCM International Congress of Mechanical Engineering**, 2017.

AMJADIAN, M.; AGRAWAL, A. K.; A new formulation for calculating magnetic flux density of a cuboidal permanent magnet**. ResearchGate**. Available on: (https://www.researchgate.net/ publication/ 303365467_A_new_formulation_for_calculating_magnetic_flux_density_of_a_cuboidal_permanent_ magnet), 2016 (Accessed July, 2019).

BLACKWELL, B. F.; SHELDAHL, R. E.; FELTZ, L. V.;Wind Tunnel Performance

Data for Two- and Three-Bucket Savonius Rotors, **Final Report SAND76-0131**, Sandia Laboratories, Albuquerque, USA, 105 p., 1977.

ENGEL-HERBERTA, R.; HESJEDAL, T.; Calculation of the magnetic stray field of a uniaxial magnetic domain. **Journal of Applied Physics 97**, 074504, doi: 10.1063/1.1883308, 2005.

GLOBAL WIND ENERGY COUNCIL. **Global wind energy statistic**s. Available on: (http://www.gwec.net/global-figures/wind-in-numbers); 2015 (Accessed July, 2019).

JANSSEN, J. L. G. Extended analytical charge modeling for permanent-magnet based devices : practical application to the interactions in a vibration isolation system. **Eindhoven: Technische Universiteit Eindhoven**, DOI:10.6100/IR719555, 2011.

KUMAR, R.; RAAHEMIFAR, K.; FUNG, A. S., A critical review of vertical axis wind turbines for urban applications**. Renewable and Sustainable Energy Reviews**, Vol. 89, pp. 281–291, 2018.

LOPES, W.; Variação da Aceleração da Gravidade com a Latitude e Altitude. **Caderno Brasileiro de Ensino de Física, Vol. 25**, No. 3, pp. 561–568, 2008.

MOJOLA, O. O. On The Aerodynamic Design of The Savonius Windmill Rotor, **Journal**

of Wind Engineering and Industrial Aerodynamics, v. 21, p. 223-231, 1985.

PEREIRA, M. G.; CAMACHO, C. F.; FREITAS, M. A. V.; DA SILVA, N. F.; The renewable energy market in Brazil: Current status and potential. **Renewable and Sustainable Energy Reviews** 16, p. 3786– 3802, 2012.

SAVONIUS, S. J.; Wind Rotor **– Patent 1,766,765**, United States Patent Office, 1930.

TUMMALA, A.; VELAMATI, R. K; SINHA, D. K.;INDRAJA, V.;KRISHNA, V. H.; A review on small scale wind turbines. **Renewable and Sustainable Energy Reviews** 56, p. 1351– 1371, 2016.

ALGORITHM BASED ON ARTIFICIAL NEURAL NETWORKS AND FOURTH-LEVEL DISCRETE WAVELET TRANSFORM FOR ISLANDING DETECTION IN AN AC GRID WITH PHOTOVOLTAIC GENERATION SYSTEM

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ABSTRACT

With the increase of distributed generation, the concern of a possible non-detection of isolated operation increases. This concern is due to the safety risks that this condition imposes on people and equipment. Therefore, this work proposes a method based on Artificial Neural Networks (ANN) and Discrete Wavelet Transform (DWT) for islanding detection of photovoltaic generation systems. To accomplish this task, AC voltage signals are used to detect the islanding condition. Firstly, a large number of fault cases are generated in the adopted distributed generation system (DG) with photovoltaic (PV) array. Then, the voltage signals of the fault cases are processed employing a DWT to generate the ANN input patterns. After the training process, different cases are generated in the adopted DG system to evaluate the performance of the ANN. Subsequently, an analysis of the algorithm performance is carried out, and the results are compared with the operating parameters established by IEEE standards and also different works in literature. Finally, the conclusions are presented. The results show that the use of artificial neural networks together with a wavelet preprocessing offers an appropriated combination for islanding detection of PV generation systems. Both the photovoltaic DG system and the ANN processing algorithm are modeled in Matlab.

Keywords: Distributed Generation, Artificial Neural Networks, Islanding Detection, Discrete Wavelet Transform.

Introduction

Islanding condition is known as the continued operation of a distributed generation system (e.g., photovoltaic system) when the mains grid fails, and the generation system does not notice the condition and continues functioning without rapid disconnection (VERHOEVEN, 2002). Given this, the rapid detection and disconnection of islanding operation through suitable protective devices is of the utmost importance. Due to the increase of distributed generation (DG) systems in the electricity grid such as; wind generators and photovoltaic (PV) systems, a shutdown of the power grid may not be noticed by protective devices and leaving the generation systems in operation, extending the operating time in islanding condition. Given this scenario, protective devices must be able to detect and shut down the islanding operation as soon as possible to avoid damage on the electrical system and consumers (YANG et al., 2017), (DO et al., 2016).

Figure 1, shows the diagram of parallel connection between a PV generation system and a power grid. During regular operation, the real power and reactive power required by the loads are provided by the PV generation system and the power grid at the same time. Consequently, the power at the common coupling point (CCP) is balanced (HONG et al., 2012). When the utility grid is disconnected, and islanding condition are observed, the power at the CCP is unbalanced due to the utility grid is no longer providing power. Thus, the voltage and frequency at the CCP become abnormal. Under these circumstances, the PV generation system can be disconnected from loads using four types of protection relays; overvoltage relay, under-voltage relay, over-frequency relay, and low-frequency relay (BALAGUER et al., 2008). However, when the output power of the PV generation system is almost equal to the power consumption of the loads, the power at the CCP remains balanced. The frequency and voltage patterns generated by the PV generation system are similar to those of normally-functioning power grid, preventing the protective relays from working correctly. Given this scenario, more robust and effective island detection methods are required to disconnect the system under these circumstances.

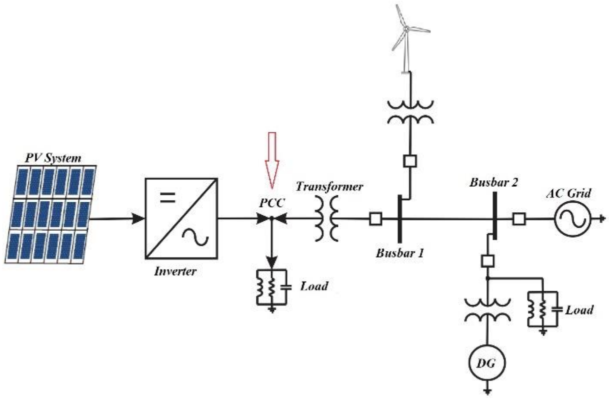

Figure 1. PV system connected in parallel to an AC grid.

Conventional islanding detection methods can be divided into passive and active detection methods. Passive detection methods primarily monitor the voltages, frequencies, and phases at the end of the load to identify islanding operations. Passive methods include the phase jump detection method, harmonic voltage detection method, under and over voltage methods, and under and over frequency methods. However, when the difference between the power output of the photovoltaic system and the total power consumption is indistinguishable, variations in system voltage or frequency are not evident enough for relay detection. Therefore, the disadvantage of passive detection methods is that they have a non-detection zone, which makes immediate and effective detection of islanding condition during mains interruptions difficult. Active detection methods involve entering an interference signal into the power grid and observing whether system voltage or frequency is affected. Under normal conditions, interference should not influence the stability of the power grid. However, when islanding operations occur, the power grid is not available as a reference (ABOKHALIL et al., 2018). Therefore, regardless of whether the system's total output power and total load power consumption are balanced, an actively initiated interference disturbs the balance and generates significant voltage and frequency variations to detect islanding operations.

In an effort to develop a fast and accurate method for islanding detection, this work presents an islanding detection scheme of PV generation systems. To perform this task, AC voltage signals are processed through a fourth level DWT, to then apply the wavelet coefficients as Artificial Neural Networks (ANN) inputs responsible for detecting islanding condition.

Methodology

A.- Artificial Neural Networks

Artificial neural networks are biologically inspired computational tools designed to simulate how the human brain processes information. As ANNs gather their knowledge by detecting patterns and relating data through the training process and experience, not programming. An ANN is made up of units, artificial neurons or processing elements, connected with coefficients (weights) creating a neural structure and organizing in layers. ANNs advantages comes from the connection of neurons in a network, each weighted input processing element, transfer function, and output. The behavior of ANNs are determined by the transfer functions of its neurons, the learning process method, and the architecture itself. Weights are adjustable, in this sense, ANNs are parameterized system (DE PÁDUA BRAGA; DE LEON FERREIRA; LUDERMIR, 2007).

B.- Discrete Wavelet Transform

Wavelet Transform is an efficient tool for local analysis of non-stationary and fast transient signals (ADDISON, 2017). Wavelet Transform provides multiresolution analysis with dilated windows, enabling robust frequency analysis. Unlike Fourier analysis where is possible to determine the frequencies contained in a signal in exchange for the loss of temporal information, because the Fourier Transform does not inform when the frequencies appear. Since frequency and time information are coupled, a tool for this kind of analysis becomes essential. Given this, wavelet analysis presents essential differences compared to fourier analysis, since it provides simultaneous information of time and frequency. A large number of wavelet functions can be used to perform a wavelet analysis, resulting in different wavelet transformations (SABLÓN; MENDEZ; IANO, 2010). A wavelet transform can be described by the Equation 1.

$$x(t) = \sum_{k=-\infty}^{\infty} C_{J,k}\Phi_J(t-k) + \sum_{k=-\infty}^{\infty}\sum_{j=-\infty}^{\infty} d_{j,k}\psi\left(2^j - k\right) \tag{1}$$

Where $x(t)$ represents the original function of the signal, J indicates the initial resolution of the function. The value $d_{j,k}$ represents the dilatation and detail coefficients, $\Phi(t)$ is the orthogonal base scaling function and $\psi(t)$ is the mother wavelet. To perform a Discrete Wavelet Transform (DWT), it has to be used a discrete wavelet function. To perform this procedure, the mother wavelet value in the Equation 1 must be discrete.

C.- Adopted Electrical System

The electrical system adopted for this study, observed in Figure 1, was modeled in Matlab and it is composed of a 250kW PV generation system connected to an AC network through a three-phase DC-AC converter in the CCP. The converter uses a Maximum Power Point Tracking controller to control the power output. The main objective of this work is islanding detection of the PV generation system when a grid disconnection occurs. Therefore, the following considerations were adopted to model the islanding condition:

- AC grid quantities larger than PV generation system quantities;

- The system does not have a battery bank, which means that power delivery directly dependent on the irradiance of the system;

- The DC-AC converter has been modeled with a frequency of 5kH of firing pulse and with a nominal DC voltage of 500V;

- The Three-phase VSC converts the voltage from 500V DC to 260V AC. It uses two types of control: an external control for DC voltage and an internal control for currents I_d and I_q. This allows to independently control the active and reactive power of the PV generation system. The control is based on the Pulse Width Modulation technique;

- A 10 kVar capacitor bank is used as a filter after the DC-AC converter outputs.

- A 260V/25kV and 1MVA transformer is used to couple the PV generation system to the grid;

- A 250kW load is directly connected to the system at the CCP.

D.- Proposed Detection Scheme

This work proposes an algorithm that uses the CCP three-phase AC voltage signals and perform a multiresolution analysis using a fourth level DWT. In a multiresolution analysis, the signal characteristics, that is, the approximation and detail coefficients, are characterized according to the state of the system (normal operation, load shifting, and islanding). After characterization, the coefficients are placed as ANN inputs.

To perform the ANN training process the fourth level approximation and detail wavelet coefficients were considered as ANN input. Moreover, in the training process of the algorithm, only the approximation and detail coefficients of the AC voltage signal at the CCP are used to detect the islanding. A sampling rate of 10 kHz (100 ms) is used to sample the voltage signal while a sliding window of 83 samples (8.33 ms) is used to generate the ANNs input patterns. Each input pattern is decomposed by a fourth level DWT and the coefficients are extracted. This wavelet level criterion was adopted after observing a large number of simulations and tests. Thus, the ANN receives input patterns with 80 values relative to the approximation and detail coefficients of the voltage signal. The processing scheme is shown in Figure 2.

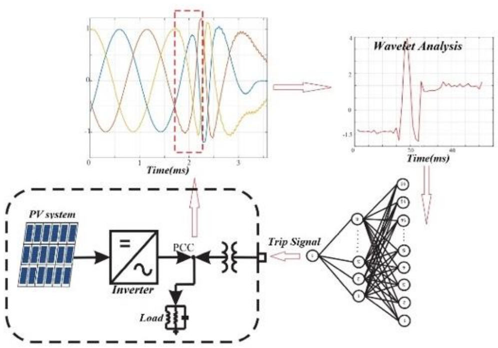

Figure 2. Scheme to detect the islanding condition.

Results and Discussion

To test the ANN for islanding detection, 60 different cases of the cases used in the training process were performed. Figure 3 shows the responses of the algorithm in six islanding cases with different system operation conditions. It is noteworthy that all tested cases were successfully detected. Some inaccuracies in detecting islanding condition were observed, for instance, when the islanding conditions voltage signals are very similar to regular operations voltage signals with small load changes, in this situation the ANN output is not stable enough to be considered a clear islanding condition output. This is reasonable due to the lack of a strong training process. Thus, for an adequately detection of these system operating conditions, and a more detailed analysis of the islanding voltage signals, different types of system operation conditions should be considered in the training process.

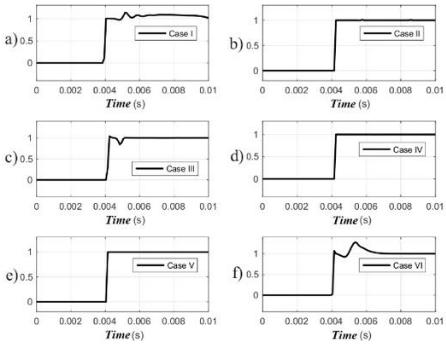

Figure 3. Response of the algorithm in different cases of islanding condition.

]Figure 3 shows that the algorithm developed for islanding detection works within the established parameters. Although, for reasons of limitations, only a few results are presented. The algorithm has shown to perform well for 52 of the 60 test cases used, which represents an 87% efficiency. Even so, when it comes to islanding detection, which is a critical situation in the operation of electric power systems, the algorithm still presents a low performance but promising to be improved and implemented in hardware. DWT analysis makes it possible to identify more clearly the condition involved when a photovoltaic generation system islanding occurs.

Conclusions

This work showed that the application of ANNs in the task of detecting photovoltaic systems islanding is very promising. Dozens of cases were realized to evaluate the performance of the presented proposal. It was found that, despite the answers of the algorithm within the accepted limits, some inaccurate responses were observed. The work presented a new scheme for islanding detection of a photovoltaic generation systems based on ANNs and fourth-level DWT. The use of the DWT presented an advantage in the implemented ANN size, which means that instead of placing a time vector of AC voltage signals as input to the ANN, only the most representative approximation and detail coefficients of the conditions are placed. Thus, in simple terms, DWT allows filtering of the most significant components of the original signal, thus reducing the size of the ANN.

Acknowledgments

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References

ABOKHALIL, Ahmed; AWAN, Ahmed; AL-QAWASMI, Abdel-Rahman. Comparative Study of Passive and Active Islanding Detection Methods for PV Grid-Connected Systems. *Sustainability*, 2018, vol. 10, no 6, p. 1798.

ADDISON, Paul S. The illustrated wavelet transform handbook: introductory theory and applications in science, engineering, medicine and finance. 1. ed. rev. [S. l.]: CRC press, 2017. v. 1.

BALAGUER, Irvin J et al. Survey of photovoltaic power systems islanding detection methods. Industrial Electronics, 2008. 34th Annual Conference of IEEE: IECON 2008., [S. l.], 1 jun. 2008. IEEE, p. 2247-2252.

E PÁDUA BRAGA, Antonio; DE LEON FERREIRA, André Carlos; LUDERMIR, Teresa Bernarda. Redes Neurais Artificiais: Fundamentos e Aplicações (2a edição ed.). 2. ed. rev. [S. l.]: LTC Editora, 2007. v. 46.

DO, Hieu et al. Passive-islanding detection method using the wavelet packet transform in grid-connected photovoltaic systems. IEEE Trans. Power Electron, [S. l.], v. 31, n. 10, 1 out. 2016. IEEE, p. 6955-6967.

HONG, Ying-Yi et al. Nonintrusive energy monitoring for microgrids using hybrid self-organizing feature-mapping networks. Energies, [S. l.], v. 5, n. 7, 5 jul. 2012. IEEE, p. 25-78-2593.

SABLÓN, Vicente I Becerra; MENDEZ, Luiz Róulo; IANO, Yuzo. A Transformada wavelet no processamento e compresssão de imagens. Revista Ciência e Tecnologia, [S. l.], v. 6, n. 9, p. 1-6, 8 jan. 2010.

VERHOEVEN, Bas. Probability of islanding in utility networks due to gridconnected photovoltaic power systems. KEMA Nederland: Report IEA PVPS T5-07, Neterland, p. 01-06, 1 jul. 2002.

YANG, Fuwen et al. Event-based networked islanding detection for distributed solar PV generation systems. IEEE Transactions on Industrial Informatics, [S. l.], v. 13, n. 1, 1 jan. 2017. IEEE, p. 322-329.

DETERMINATION OF AVAILABLE ELECTRICAL ENERGY FROM ORGANIC FRACTION OF MUNICIPAL SOLID WASTE BY ANAEROBIC BIODIGESTION

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ABSTRACT

Observing the world scenario, it is noted the simultaneous needs for environmental preservation and diversification of the energy matrix. Municipal Solid Waste (MSW) represents a challenge to environmental preservation as well as public health, while being materials with high energy content, they can become an interesting alternative to serve both sectors. The objective of this article is to estimate the available electrical energy potential in the organic residues of Santo André, from laboratory tests of biochemical methane potential (BMP) of the organic fraction of the MSW (OFMSW), according to gravimetry. The methodology used was Biochemical Methane Potential Test (BMP) and, based on its results, to estimate the annual electricity generation potential through available equations, which resulted in $2.07x10^7$ kWh, representing 0.7352% of the electricity consumption from the Santo André city. The importance of OFMSW segregation was evidenced, corroborating with the National Solid Waste Policy (NSWP) in mitigating the environmental impacts from the disposal of waste to landfills, as well as benefiting the biodigestion process and, consequently, increasing the participation of renewable energy sources in the Brazilian energy matrix.

Keywords: anaerobic biodigestion; organic fraction; MSW; energy.

Introduction

Municipal Solid Waste (MSW) is a subject with implications in several sectors, especially in the environmental and energy sectors, both connected in an inversely proportional way, ie, what causes damage in one sector, is a very interesting alternative in the other. According to the Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais - ABRELPE (2018), a brazilian citizen generates an average of 1.035 kg of waste per day and such generation is economically related to the country's Gross Domestic Product (GDP), as well as to the increasing energy demand in recent decades. The current Brazilian energy matrix may not meet this increase, since it is essentially based on hydr sources and climate change has an important impact on the availability of this source.

In this sense, aiming at an integrated alternative solution of the energy and environmental sectors, since of all the waste generated in the country, only 2% is recycled, and respecting the guidelines established by the National Solid Waste Policy (NSWP), the MSW presents a high potential of energy recovery while promoting environmental preservation, minimizing the amount of waste sent to landfills, extending the useful life of these areas and mitigating disease vectors.

The energy recovery from waste can occur through two processes: thermochemical and biochemical. In this article, the process analysed is the biochemical process that consists mainly of the degradation of the organic fraction of the waste by microorganisms in the absence of oxygen, producing a gas called biogas, which is mainly composed of methane and carbon dioxide, being highly harmful when released into the atmosphere in uncontrolled dump sites. Anaerobic digestion that occurs naturally in landfills and dump sites is optimized when it occurs in biodigesters with the organic fraction of MSW in the presence of an inoculum (rich in microorganisms).

Regarding the consumption of electricity in the Santo André city, it is currently one of the highest in the state of São Paulo, representing 1.7% of state consumption. According to SEMASA (2015), about 750 tons of waste are collected daily and non-recyclable waste is disposed of in the Municipal Sanitary Landfill, without any previous treatment, as proposed by the (NSWP).

Therefore, the main objective of this paper is to determine the available electrical energy from the anaerobic digestion of the organic fraction of Municipal Solid Waste (OFMSW) from the gravimetric campaign carried out in the municipality between 2015 and 2016.

Material and Methods

For the Biochemical Methane Potential Test, in laboratory scale, the following materials were used:

- Five compositions of organic fractions of municipal solid waste (OFMSW) from the Santo André city (SP), obtained from the gravimetric campaign (2015/2016), deriving from the undifferentiated collection of different areas of the municipality: comercial/central (A), domestic/urban (B), industrial/suburban (C), free markets and food distribution center of Santo André (CRAISA);
- Inoculum from UASB reactor that treats food industry sewage from a soft drink company (Coca-Cola FEMSA);
- Automatic Methane Potential Test System II (AMPTS II), whose system is mechanically agitated and allows the automatical monitoring of the biomethane production profile, under control of the software.

The steps that made up the methodology of the experimental essay were:

- Sampling

Statistical studies by Drudi et al (2014) considered the generation of waste and the population size of the city as the main variables to determine the sampling of MSW disposed of in the Santo André municipal landfill, since the collection in the city was divided in zones/sectors, presenting direct interference in the result of the local gravimetric composition. Based on ASTM D 5231-92, a sample of 36 waste collection trucks (24 tonnes each) was defined, considering a confidence interval between 90% and 95% and a margin of error of 10%, as well as residues from free markets and CRAISA (DRUDI et al, 2014).

- Sample Preparation

It was performed according to these steps: homogenization, quartering, separation, re-quartering, milling, cooling, drying, packaging and storage for a later stage of laboratory testing, as shown in Figure 1.

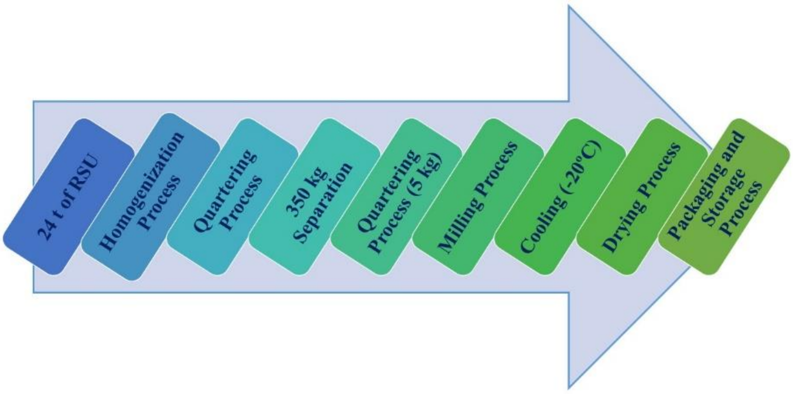

Figure 1. Methodological flowchart of the sample preparation step. Source: Adapted from (MARANA, 2017).

- Laboratory tests for the characterization and methane production potential steps.

The main laboratory tests were the contents of total solids (TS), volatiles (VS) and moisture, pH and alkalinity before and after the anaerobic digestion process aiming the characterization of the substrate (OFMSW) and the mix (substrate + inoculum) using standard methodologies such as EPA 2540B, EPA 2540 G and VDI 4630 (Biochemical Methane Potential Test).

Estimating the experimental biomethane production potential over a period of one year, equation 1 was used:

$$\mathbf{Q_{CH_4} = wc_{MSW} * OFMSW * VS * BP} \quad (1)$$

Where:

Q_{CH4} is the volume of methane generated per year, expressed in [Nm^3 of CH_4/year];

wc_{MSW} is the mass of MSW collected per year, expressed in [t/year];

OFMSW is the organic fraction of MSW in the gravimetric analysis, expressed in [%];

VS is the volatile solids content, expressed in [%];

BP is the biochemical methane potential of the OFMSW, expressed in [Nm^3 of CH_4/t of OFMSW].

From the volume of methane generated per year, the available thermal power was calculated based on equation 2:

$$\boldsymbol{P_t = \frac{(Q_{CH_4} \cdot LHV_{CH_4})}{31536000} \cdot \eta_{collect}} \quad (2)$$

Where:

P_t is the available thermal power expressed in [kW];

Q_{CH4} is the volume of methane generated per year, expressed in [Nm^3 of CH_4/year];

LHV_{CH4} is the lower calorific value of methane, expressed in [kJ/ Nm^3 of CH_4];

$\eta_{collect}$ is the gas collection efficiency, expressed in [%].

It was then possible to calculate the corresponding electric power, considering an internal combustion engine as a conversion technology, according to equation 3:

$$\boldsymbol{P_{el} = P_t \cdot \eta_{motor}} \quad (3)$$

Where:

P_{el} is the corresponding electrical power, expressed in [kW];

P_t is the available thermal power expressed in [kW];

η_{motor} is the efficiency of the internal combustion engine expressed in [%].

Finally, the amount of electric energy available for the volume of methane produced was estimated according to equation 4:

$$\boldsymbol{E_{available} = P_{el} \cdot 8000} \quad (4)$$

Where:

$E_{available}$ is the available electrical energy, expressed in [kWh];

P_{el} is the corresponding electrical power, expressed in [kW];

Results and Discussion

From the BMP Tests and using the equation, it was possible to obtain the results shown in Table 1.

Table 1. Experimental biomethane generation potential. Source: Adapted from (MARANA, 2017).

	Composition A	Composition B	Composition C	Free Market	CRAISA
BMP [Nm³ of CH4/t of VS]	264,83	191,48	194,52	170,85	163,93
VS	0,6478	0,7926	0,726	0,8766	0,8438
TS	0,4415	0,362	0,3206	0,2812	0,1839
TOTAL [Nm³ of CH4/t of OFMSW]	48,70				

From the estimation of the methane volume produced by of the MSW from Santo André city produced in one year, using equations 2, 3 and 4, it was possible to estimate the corresponding available electric energy, as shown in Table 2.

Table 2. Parameters used to determine the corresponding available electrical energy. Source: Own elaboration, 2019.

Biometane Production [Nm³ of CH4/t of MSW]	MSW Generation in Santo André [t/day]	MSW Generation in Santo André [t/year]	RSUf [%]	Biometane Production [Nm³ of CH4/year]	Metane LHV [kJ.Nm³ of CH4]	AMPTS II Eficiency [%]	Thermal Power [kW]	Motor Eficiency [%]	Electric Power [kW]	Energy [kwh]
48,70	750	273750	44,3	5,91E+06	35530	98	652080,9	39,6	258224	2,07E+07

It is important to highlight that for the calculations performed in Table 2, it was considered that during the gravimetric campaign, according to SEMASA (2015), the amount of waste received by the municipal landfill was on average equal to 750 t/day. Thus, in one year, 273.75 kt of waste was received. Of this amount, according to data from the same gravimetric campaign, about 44.3% corresponded to OFMSW, being possible to estimate biomethane production per year. Considering also that the Lower Calorific Value (LHV) of methane is equal to 5.91×10^{6} Nm³ of CH_4/year and that, according to the equipment manufacturer AMPTS II, the gas collection efficiency is 98%, it was possible to calculate the corresponding thermal power. Finally, considering the efficiency of the internal combustion engine as 39.6%, according to data from the Guatapará thermal power plant (2014), it was possible to estimate the electric power and consequently the corresponding available electric energy.

Considering that in 2018, Santo André's city was responsible (SIMA, 2019) for 1.7% of the electric energy consumption of the state of São Paulo, ie $2{,}81.10^{7}$ kWh, it is noted that from the results obtained in this work, the energy available electricity corresponding to the amount of OFMSW, using the biochemical process of energy conversion, is capable of supporting 0,7352% of the municipality's electricity consumption.

Conclusion

With the study carried out in this work it was first possible to conclude that the separation of the OFMSW is essential since the biochemical energy conversion process is optimized when the anaerobic biodigestion substrate is exclusively organic. With the use of this technology, it was possible to estimate that in the Santo André city, the available electricity estimated from OFMSW's anaerobic digestion is capable of meeting 0,7352% of the municipal electricity consumption.

Thus, in addition to diverting a significant amount of waste from landfills, mitigating the environmental impacts likely to be caused by MSW, it is possible to energetically harness such waste, corroborating with the NSWP, since energy recover is the penultimate stage - waste treatment, of the pyramid of priority actions prior to the final destination, as well as collaborating with the diversification of the Brazilian energy matrix based on renewable sources.

Acknowledgment

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References

ABRELPE - Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. **Panorama de Resíduos Sólidos no Brasil – 2018**. São Paulo, 2018.

Drudi, K.C.R., Drudi, R., Martins, G., Antonio, G.C., Toneli, J.T.C.L. – **Physical analysis methods of Municipal Solid Waste of Santo André**. Apresentação de Trabalho/Simpósio. Santo André, 2015.

EPA – **Standard Methods EPA 2540B – Total Solids Dried at 103 – 105ºC** – Approved by SM Committee: 1997.

EPA – **Standard Methods EPA 2540G – Total, Fixed and Volatile Solids in Solid and Semisolid Samples** – Approved by SM Committee: 1997.

Marana, K. B. B. **Caracterização da fração orgânica dos Resíduos Sólidos Urbanos do município de Santo André (SP) para avaliação do potencial de produção de biometano**. Dissertação de Mestrado. Universidade Federal do ABC. Santo André, 2017.

SIMA - Secretaria de Infraestrutura e Meio Ambiente. **Anuário Energético por Município no Estado de São Paulo – 2019 / ano base 2018.** São Paulo, 2019.

Verein Deutscher Ingenieure (VDI). **VDI 4630 -** Vergärung organischer Stoffe 2006:92

REAL-TIME RECONFIGURATION OF ELECTRICAL DISTRIBUTION SYSTEMS THROUGH GRAPH THEORY-BASED ALGORITHM

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ABSTRACT

Non-renewable energy sources traverse irreversible depletion and cause damage to the environment with release of pollutants, being essential to optimize the use of renewable sources, such as electricity. Among existing techniques for optimizing electrical power systems, the most economical is the reconfiguration of the switches because it allows, without causing expenses with new equipments, reduce the joule effect. Currently there are several heuristics to reduce the search space resulting from the combinatorial explosion, but a considerable part does not have the ability to provide a real-time response, being more suitable for operation planning. In this work is presented a method based on graph theory, deterministic, but that does not employ exhaustive search, able to deliver in real time the optimized solution of the problem of reconfiguration, based on the generating tree of the graph that represents the electrical distribution system. The algorithm has been tested in one widely known system in scientific publications, which contains 33 buses and 37 switches. It is noteworthy that solutions were obtained in just 15 ms, characterizing the method as apt to, in addition to minimizing the joule effect, to solve contingencies in the system or even control remote equipment.

Keywords: Optmization; Electrical distribution systems; Real-time reconfiguration; Graph theory.

Introduction

Electrical distribution systems (EDS) are planned both to reduce the cost of investment and the operating cost in the supply of electricity (Torres, 2013). Operators need to reconfigure the EDS topology through maneuvers on the switches in certain situations such as:

A. Interruption of supply due to planned maintenance (preventive/corrective) in the EDS equipments.

B. Interruption due to unplanned maintenance resulting from extreme environmental conditions (disasters), human errors, accidents, equipment breakage etc.

C. Balancing operation of the consuming loads.

D. When demand exceeds the supply capacity of the substation (blackout) or the operational limit of the EDS (overload).

E. Relocation (control) of the inconstant power flows resulting from the injection of assets or reactive from distributed generators.

F. Minimization of the active power losses resulting from the joule effect (optimization).

All the above items imply reconfiguration problem of distribution systems (RPDS), meaning test all possible combinations of the states of the switches installed on the distribution lines and at the same time satisfy the operating restrictions of the system. Thus, the aim of the lowest active power loss is sought with the maintenance of the radiality, the connectivity and the rated voltage profile (except for the allowable tolerances), the three fundamental constraints of a EDS. The RPDS has combinatorial nature due to the binary state that each switch can assume: open or closed. Although it is easy to understand, the combinatorial explosion results in extreme difficulty to test all possible solutions when attempting to optimize EDS. Each possible switching state implies the execution of a load flow for obtaining the state variables. In a EDS that has *n* switches, the total possible amount of switching states to reconfigure it is equivalent to 2^n. Even for small systems the amount of switching states makes the optimization process too slow (Silva, 2014). If all possible solutions (exhaustive search) are tested, the location of the optimal global solution can become unfeasible even with the use of hardest computation.

Among the pioneering works in the RPDS, Merlin and Back (1975) proposed two methods for small systems. One of the exact methods and the other heuristic, this second known by the method name of the sequential opening of switches (branch and bound). This method was not suitable for larger EDS due to the large computational effort imposed by the algorithm. Civanlar et al. (1988) presented a heuristic branch exchange method. Starting from a radial topology, the closure of each switch must always be compensated by the opening of another, maintaining radial topology. Two small systems were used for testing the algorithm, with 12 and 16 buses. The first was achieved the optimum overall value in the RPDS, in the second only a local optimal solution.

Baran and Wu (1989) modified the branch exchange algorithm of Civanlar et al. (1988) and with the scanning method (backward forward sweep) to obtain the power flows managed to resulting in a optimal local solution of very good quality, although the work has not addressed issues related to computational time spent. According to Gomes et al. (2005), the solution presented by Baran and Wu (1989) is not the optimal global solution for the EDS in question, containing 33 buses and 37 switches. Near the beginning of the years 2000 began to emerge studies considering the variables as being dynamic and the EDS as unbalanced three-phase, as for example the work of Opazo et al. (2008). Opazo, García-Santander and Pezoa (2012) published another method to deal with dynamic loads, but without employing inductive statistics, but based on descriptive statistics.

Even with the increase in the number of publications of papers of this nature, still the vast majority of publications, including current studies, treats the variables of EDS as static and loads as balanced. Zhaia et al. (2018) stated that most approaches aimed at simplifying RPDS consider the EDS three-phase balanced, that is, as a unifilar system. The authors contributed by inferring that the effectiveness of the mathematical methods of numerical calculus used to calculate the power flows depend heavily on the degree of unbalance between the phases. Thus, reconfiguration methods for unbalanced systems may not function correctly when there is moderate or strong inequality between the consuming loads present in the phases. In this case, the authors point out the difficulty of convergence of iterative methods regarding the determination of the state variables of the EDS. Gerez et al. (2019) recently published a reconfiguration method that considers the three-phase balanced system, this is, as if it were unifilar, as in this proposed work.

This paper presents a reconfiguration method that applies graph theory aiming at decreasing the computational time spent on the optimization of the EDS. It is also possible to eliminate the weakness of many metaheuristic methods that do not always guarantee the determination of the overall optimal solution for the RPDS, notwithstanding merely providing optimal local solutions. The component of casuality, even if small, present in probabilistic methods, was successfully replaced in this work due to the causality of an exact method that provides conservative results. In addition to locating the optimal global solution, it is also possible to solve the RPDS in real time, allowing the application of the method in EDS equipped with remote controlled equipment.

Material and Methods

Graph theory is a branch of mathematics that studies the relationships between objects in a particular group. A graph is an abstract representation of a set of objects that relate to each other. A vast amount of realistic structures can be represented by means of graphs, according to Bondy (1982). In the present work, the EDS buses were associated to the vertices (V) and the lines to the edges (A), thus representing a physical system by means of a graph.

A path in a graph is a stroll in which all vertices are distinct from each other. The length of a path between two vertices is the amount of edges present in this path. In the case of the valued graph, the length of a path is given by the sum of the values (weights) of the edges or vertices present in this path. In a EDS represented by a graph, it is considered as the whole path between the substation and the last bus, passing through all the other buses. A closed path (circuit) in a graph is a path in which the initial vertex and the final vertex are equal, that is, the starting vertex is equal to that of arrival. It can be considered that circuits are made of edges. A circuit in which all vertices are distinct from each other, except the first and the last, is called a cycle. In the EDS cycles are not admitted because this implies in the formation of meshes. Therefore, all EDS is represented by an acyclic graph.

A graph is dense if it has many arches (directed edges) relative to its quantity of vertices and sparse if it has few arches. A graph can be considered dense if it satisfies the inequality (1):

$$NA \geq NV^2 \tag{1}$$

A graph representing a EDS is shown to be sparse, considering the radial nature of the topology. Even though it may contain a few more lines, in the case of contingencies, the relationship between lines and buses does not satisfy the inequality (1). This characteristic is fundamental in the processing of data from the adjacencies matrix of a graph that represents a EDS, giving computational speed to the proposed method. In a EDS each bus does not present many adjacent links, namely, there are not many buses directly connected in some common bus. Thus, the representation of these links through the adjacencies matrix becomes a more eaware implementation than through the adjacencies list, because there is no need to see multiple connections made at the same vertex of the graph.

Kruskal's Algorithm (KA), whose goal is to seek a minimal generating tree for a connected graph and with valued edges, was used in this work together with a specific technique to solve RPDS. The correction of the KA can be demonstrated by induction (Poggi, 2018). The KA grows generating a forest F until it becomes connected (Feofiloff, 2017). Thus F grows in order to meet the criterion of minimal generating trees based on circuits. In the literature, the programming structures that perform the tasks of creating, fetching, and uniting disjoint sets are known as union-find. This programming technique, present in the KA, has excellent performance with respect to the amount of operations to create, search and unite disjoint subsets in a graph (Donadelli, 2016). The amount of operations is determined by equation (2):

$$\mathrm{Op} = 2(\mathrm{A} + \mathrm{V}) \tag{2}$$

In addition, if the graph has V vertices, the optimum solution has the amount of edges given by the equation (3):

$$\mathrm{A} = \mathrm{V} - 1 \tag{3}$$

When a EDS is associated with a graph, relating buses and lines with vertices and edges, respectively, it is noted that the equation (3) comes against the one described by Silva (2014) as the equation that determines the amount of open switches (SWop) in the EDS so that the even if it is radial and related, NL being the total quantity of lines and NB the total quantity of buses in equation (4):

$$\mathrm{SWop} = \mathrm{NL} - \mathrm{NB} + 1 \tag{4}$$

Thus, we can rewrite the equation (2) depending on the amount of buses and lines of the EDS, implying that the amount of operations of the algorithm in relation to the graph will be the function of NB and NL, as shown in equation (5). It is noted that, given the combinatorial complexity in the RPDS, with a total of 2^n operations to examine the entire search space, equation (5) evidences a very significant decrease in computational processing in the method proposed. The amount of operations no longer increases exponentially, but rather in a linear way.

$$\mathrm{Op} = 2(\mathrm{NL} + \mathrm{NB}) \tag{5}$$

Must provide the graph database, edges and vertices values, from two pre-processings. The first one uses a optimal power flow (OPF) and the second employs a load flow (LF), both to calculate the active power losses on the EDS lines. The tests of this work were performed on hardware endowed with Intel I7-8700 processor with 3.2 GHz with 12 cores and 16 GB RAM (DDR4 2400 MHz). Ten computational simulations were performed, and the processing time is the simple arithmetic average of the times recorded by the Matlab software. The time spent varied (in a negligible way) to each simulation due to the state of the Windows 10 operating system also vary every instant.

Results and Discussion

An 37 switches EDS, shown in Figure 1, whose best optimal solution is previously known in the specialized literature, was used in the test of the algorithm proposed in this work. This system shows up in the works of Baran (1989), Pereira (2010) and Silva (2014), where buses and line databases can be found. The total amount of switching possibilities is $2^{37} \cong 137 \cdot 10^9$, that is, about 137 billion switches settings to search in the search space. The best value for the ohmic losses presented in the literature determines that the switches 7, 9, 14, 32 and 37 should be opened in order for the topology to be radial and the minimum total active power loss is 139,55 kW. Under these conditions, the lowest voltage found is presented in buses 31 and 32, Vmin = 0.938 p.u. To obtain this solution, the present method used data from the preprocessing of the OPF and LF and then performed the combination of the two sets of opened switches, inducing a disturbance in the system. The average computational time spent was 15 ms. In the paper of Ramos (2013), regarding automatic real-time reconfiguration of EDS, it is shown that the time of operation of the protection and command equipment requires at least 200 ms in a real system of the Distributor AES Sul that operates in Southern region of Brazil. In the said EDS there are remote controlled equipment installed for the switches maneuvering.

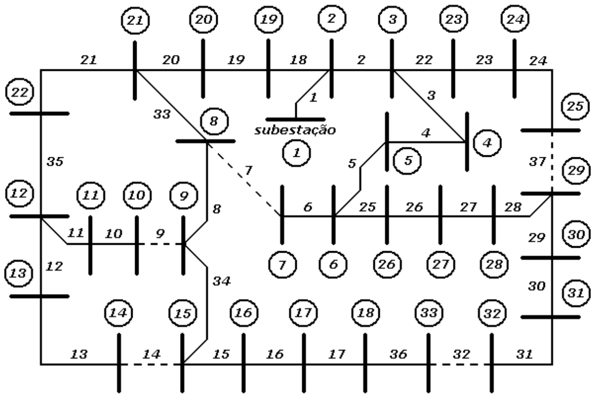

Figure 1. 33 buses and 37 switches EDS unifilar diagram. Dashed line represents open switch.

According to the behavior observed in the computational simulations performed in this work, a comparison can be made between the proposed method and the methods used by other authors cited in the introduction section of this work, according to the Figure 2.

Technique	Computational time	Accuracy	Precision	Sensitivity to parameters
Exhaustive search	Time consuming, can last for hours, days, weeks or months.	Global optimum	Conservatives results.	There isn't.
Metaheuristic	Targeted search, implying in time savings, but depending on the size of the system can become lengthy, consuming many seconds or minutes.	There is no guarantee of achieving the best results found in the literature.	Non-conservatives results due to probabilistic components.	Considerable.
Branch and Bound	If the problem presents a large number of decision variables, this implies high computational cost.	The best results found in the literature are obtained.	Conservatives results.	Considerable.
Proposed work	From the order of tens of milliseconds, resulting from the simplification of exponential to linear complexity.	Obtained the best result found in the literature.	Conservatives results.	Despicable.

More efficient

Moderate efficiency

Less efficient

Inefficient

Figure 2. Merit figures for qualitative comparison between reconfiguration techniques.

Conclusion

The computational time (15 ms) observed showed that the present algorithm is apt to be applied in RPDS with the presence of remote controlled equipment (smart grids). Due to the current stage of scientific advancement in the design and construction of remote-controlled equipment applied to power systems, the development of algorithms that reconfigure EDS in real time is the trend in research to advance in the knowledge frontier. In addition to minimizing the power losses caused by the joule effect, it was still possible to combine the prompt response that can be used in cases of contingencies in the system. Algorithms endowed with these caracteristics have the potential to solve technical issues of the system without the need for frequent human intervention.

Acknowledgment

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References

BARAN, M. E.; WU, F. F. Network reconfiguration in distribution systems for loss reduction and load balancing. IEEE Transactions On Power Delivery, v. 4, n.2, p. 1401-1407, 1989.

BONDY, J. A.; MURTY, U. S. R. Graph theory with applications. 5. ed. Nova Iorque: Elsevier, 1982.

CIVANLAR Seyhan *et al*. Distribution reconfiguration for loss reduction. IEEE Transactions on Power Delivery, v. 3, n. 3, p. 1217-1223, 1988.

FEOFILOFF, Paulo. Algoritmos para grafos em C via Sedgewick. Departamento de Ciência da Computação do Instituto de Matemática e Estatística da Universidade de São Paulo, 2017. Disponível em < https://www.ime.usp.br/~pf/algoritmos_para_grafos/index.html#contents > Acesso em 03 mai. 2019.

GEREZ, Cassio *et al*. Distribution network reconfiguration using selective firefly algorithm and a load flow analysis criterion for reducing the search space. IEEE Access, v. 7, 2019.

GOMES, Flavio Vanderson *et al*. A new heuristic reconfiguration algorithm for large distribution system. IEEE Transactions On Power Systems, v. 20, n. 3, p.1373-1378, 2005.

MERLIN A., BACK H. Search for a minimum-loss operating spanning-tree configuration in a urban power distribution system. Proceedings of 5th. Power System Computation Conference – PSCC, v. 1, p. 1-18, 1975.

OPAZO, Hugo *et al*. Minimal loss reconfiguration considering random load: applications to real networks. Ingeniare Revista Chilena de Ingeniería, v. 16, n. 1, p. 264-272, 2008.

OPAZO, Hugo; GARCÍA-SANTANDER, Luis; PEZOA, Jorge E. Minimal loss reconfiguration of power distribution networks under time-varying demand. 2012. Disponível em: <http://cursos.die.udec.cl/jpezoa/papers/2012-CESA1.pdf> Acesso em: 18 mai. 2019.

POGGI, Marcus. Grafos e algoritmos via indução. Departamento de Informática da PUC-Rio. Disponível em <http://www-di.inf.puc-rio.br/~poggi//ED-Ind-Algs-Grafos-C04.pdf> Acesso em: 25 mai. 2019.

RAMOS, M. J. S. *et al*. Analysis of coordination and selectivity of protection systems during reconfigurations of distribution energy systems in real time. Innovative Smart Grid Technologies Latin America (ISGT LA), 2013.

SILVA, Lindenberg Isac. Reconfiguração de sistemas elétricos de distribuição por meio de aproximação heurística com a equação de movimento do vaga-lume. Dissertação (Mestrado em Engenharia Elétrica) - Universidade Federal do ABC, Santo André, 2014.

TORRES, J. *et al.* A genetic algorithm based on the edge window decoder technique to optimize power distribution systems reconfiguration. Electrical Power and Energy Systems, n. 45, p. 28-34, 2013.

ZHAIA, H. F. *et al*. Dynamic reconfiguration of three-phase unbalanced distribution networks. Electrical Power and Energy Systems, n. 99, p. 1-10, 2018.

DETERMINATION OF BIOCHEMICAL METHANE POTENTIAL IN THE ORGANIC FRACTION OF THE SOLID WASTE FROM CRAISA (SANTO ANDRÉ)

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ABSTRACT

The constant increase in municipal solid waste generation has intensified the search for alternatives to an environmentally appropriate destination for these materials, through reuse, treatment, or energy recovery. In supply centers, open markets and even supermarkets, the organic fraction of the solid waste produced corresponds to a very significant portion of the total. This study aims to determine the biochemical methane potential from the organic fraction of the solid waste generated at the Santo André Regional Integrated Supply Company (CRAISA) through batch anaerobic reactor assays. The experimental part was divided into 2 phases and consisted of the characterization of the organic fraction samples and determination of the biochemical methane potential (BMP). At the beginning and at the end of the BMP assays, the pH, alkalinity and total and volatile solids were analyzed. The monitoring of the methane production was performed over a period of 41 days for both experiments. An average cumulative methane production of (197.74 ± 8.40) Nml/gVS for experiment 1 and (180.44 ± 9.92) Nml/gVS for experiment 2 was obtained.

Keywords: anaerobic digestion; municipal organic waste; biomethanation.

Introduction

The treatment of the organic fraction of the municipal solid waste remains a challenge from an environmental point of view. Energy recovery through biomethanation is a way of reducing the amount of waste to be sent to landfills, as well as diversifying the energy matrix. Solid waste from supply centers, open markets and even supermarkets has very favorable characteristics as substrate in anaerobic digestion systems, since they are basically composed of fruit, vegetables and fish residues, which are easily biodegradable.

The anaerobic digestion process consists of the decomposition of organic matter (biomass) by various types of microorganisms (fermentative, acidogenic, acetogenic and methanogenic) in the absence of oxygen, producing biogas that can be directly used for heat production by direct combustion, used for electricity generation in internal combustion engines, or can be purified to biomethane and used as automotive fuel or inserted into natural gas pipelines. The digestate , which is the effluent of the digestion process can be used as a biofertilizer, resulting in a sustainable procedure, meeting the premises established in Law No. 12.305 /10, the National Solid Waste Policy, which establishes in its objectives the eradication of inappropriate solid waste disposal in Brazil, and the disposal in landfills only of waste that cannot be reused, recycled or used for energy recovery (BRASIL, 2010).

In this study, anaerobic digestion studies were performed to determine the biochemical methane potential (BMP) of the organic fraction of the municipal solid waste generated in CRAISA, through assays in batch anaerobic reactors.

Materials and methods

The experimental analysis was carried in the Laboratory of Biogas Production Processes, located at the São Bernardo do Campo campus of UFABC.

CRAISA is Santo André's municipal company responsible for controlling the marketing and distribution of fresh produce in the municipality. It commercializes approximately 10,000 tons of food per month (CRAISA, 2018).

The samples used in this study were obtained from this company, collected on three different dates (12/15/2015, 01/06/2016 and 01/21/2016). Immediately after collection the samples were sent to the laboratory, ground and dried at 105ºC until constant weight. The dried and ground samples were vacuum packed and stored at room temperature for use in further analysis.

The experimental part consisted in the characterization of the organic fraction samples, through pH, alkalinity and solids series analysis, performed in triplicate at the beginning and at the end of the BMP assays. Total and volatile solids analysis were performed following the methodology described in the Standard Methods for the Examination of Water and Wastewater (APHA 2540 G, 2005). The pH analysis was conducted using the methodology proposed in APHA Technical Standard 4500 - H + pH Value, B (APHA, 2005). For the determination of the intermediate alkalinity (Al) and partial alkalinity (AP) the method described by Ripley et al. (1986) was used.

The biochemical methane potential (BMP) test was performed on the AMPTS II equipment (BIOPROCESS CONTROL, 2014), according to the methodology proposed by the recommendations of the Association of German Engineers VDI-4630:2006. The experiment was carried out in 2 phases:

Experiment 1: the three dried samples collected at CRAISA on different dates were analyzed individually. Each sample was mixed with the inoculum and placed in a 500mL reactor flask, in triplicate, resulting in 9 reactors containing the samples (substrate + inoculum).

Experiment 2: a composite mixture was analyzed, containing the three CRAISA samples used in experiment 1 mixed in equal proportions by mass. Each sample was placed in a 500mL reactor flask, together with the inoculum, in triplicate.

The inoculum used in the experiment consisted of a mixture from three sources: sludge from an anaerobic reactor that treats the industrial effluent from a soft drink company (Coca-Cola FEMSA); granular sludge from a poultry slaughterhouse effluent UASB reactor (Dacar, Tietê) and cattle manure from a FZEA stable (USP - Pirassununga College of Zootechnics and Food Engineering). For the constitution of the composite inoculum, the three components were mixed at a 1:1:1 volume ratio. The inoculum was acclimated in the laboratory for a period of 11 months; kept at a temperature of 35ºC; fed daily, except on weekends, with a nutrient mix, established according to Steinmetz et al. (2016), maintaining a balanced diet in order to provide a better adaptation of the inoculum with the substrate in the anaerobic digestion process.

For both experiments, a sample containing the negative control (only inoculum) and a sample containing the positive control (microcrystalline cellulose + inoculum) were also performed in a triplicate system.

BMP assay monitoring was performed over a period of 41 days for both experiments, at a temperature of 35ºC ± 1ºC (mesophilic range).

Results and discussion

According to the results obtained in the series of solids, it can be observed that there was a reduction of total solids and volatile solids in all samples after the digestion period. The mean value of volatile solids (VS) and total solids (TS) found in the 2 experiments are shown in Table 1.

To obtain the reduction of the volatile solids (biodegradable part) of the substrate of each sample, one has to deduct the reduction of the volatile solids due to the inoculum (negative control) from the reduction of the mixture (inoculum + substract). The last two columns of table 1 show these results.

In the first experiment the third sample obtained the highest volatile solids reduction (39.4%) while the positive control obtained the 62.0% of VS reduction. In the second experiment, the reduction of VS of the composed sample reached 54.5%, while the positive remained at the 77.9%.

Figures 1 and 2 presents the data regarding the daily accumulated gross methane production of each triplicate of the samples, as well as the positive (microcrystalline cellulose) and the negative (only inoculum). It can be observed that the methane production of the samples and inoculum started immediately after inoculation, and finished after 10 to 11 days, except for some triplicates of samples 1 and 2, while for the positive control it took about 4 days to start methane production and about 24 days to stop.

We can also observe that the production of the third sample in figure 1 is the highest, which is in accordance with the results of VS reduction on table 1.

The specific net (discounting the inoculum production) accumulated methane production for the first experiment were 209.8, 144.0 and 239.4 Nml/gVS respectively for the 3 samples, with an average of 197.74 ± 8.40 Nml/gVS and for the second experiment the value obtained was 180.44 ± 9.92 Nml/gVS, while for the positive control the results were 317.3 and 377.8 Nml/gVS in the first and second experiments which represent respectively 76.4 and 91% of the theoretical stoichiometric methane production (415 Nml/gVS).

Table 1. Mean value of VS and TS in the BMP analyses.

Experiment	***Samples***	*Before the BMP analyses*		*After the BMP analyses*		*Substrate reduction*	
		VS *(g VS / kg mixture)*	***TS*** *(g VS / kg mixture)*	***VS*** *(g VS / kg mixture)*	***TS*** *(g VS / kg mixture)*	*(g VS)*	*%*
1	CRAISA 1	34.6 ± 0.02	48.9 ± 0.01	26.0 ± 0.00	37.0 ± 1.00	1.9	28.8
	CRAISA 2	34.6 ± 0.09	49.0 ± 0.04	26.0 ± 0.00	36.7 ± 0.58	1.9	28.8
	CRAISA 3	34.6 ± 0.02	48.9 ± 0.01	25.3 ± 0.58	35.7 ± 0.58	2.6	39.4
	Negative	28.0 ± 0.00	41.3 ± 0.58	21.3 ± 3.79	30.0 ± 5.20	-	-
	Positive	35.9 ± 0.07	49.1 ± 0.07	24.3 ± 1.15	34.3 ± 1.15	4.9	62.0
2	CRAISA	30.6 ± 0.10	43.6 ± 0.00	25.0 ± 0.00	35.7 ± 0.58	3.6	54.5
	Negative	24.0 ± 0.00	36.0 ± 0.00	22.0 ± 0.00	32.3 ± 0.58	-	-
	Positive	31.7 ± 0.03	43.9 ± 0.00	23.7 ± 0.58	34.7 ± 0.58	6.0	77.9

The pH measured at the beginning and at the end of the biomethanation process, in both experiments, remained practically stable, without significant variations, presenting values above 7.0, which indicates that there was no acidification process, ensuring the buffering of the mixture in the reactor, as well as the stabilization required for methane production.

As to the analysis of alkalinity, the obtained results show that the reactors reached the necessary stability for both experiments, with values of AI / AP ratio around 0.35, very close to the values of 0.3 reported by Ripley et al (1986).

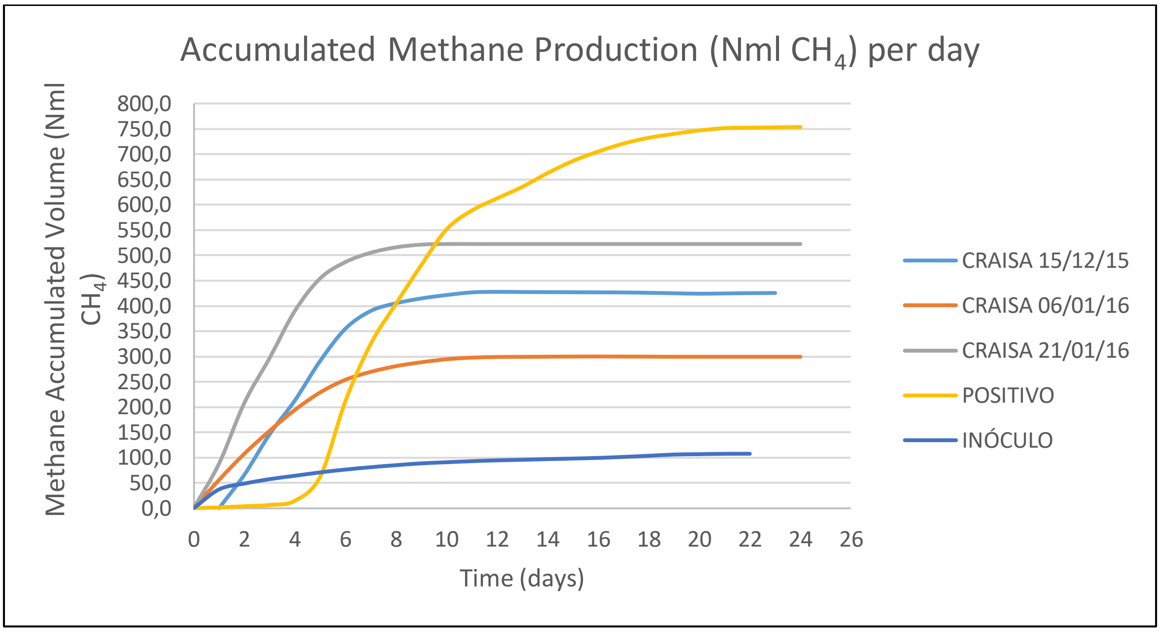

FIGURE 1. Cumulative gross daily methane production obtained in Experiment 1.

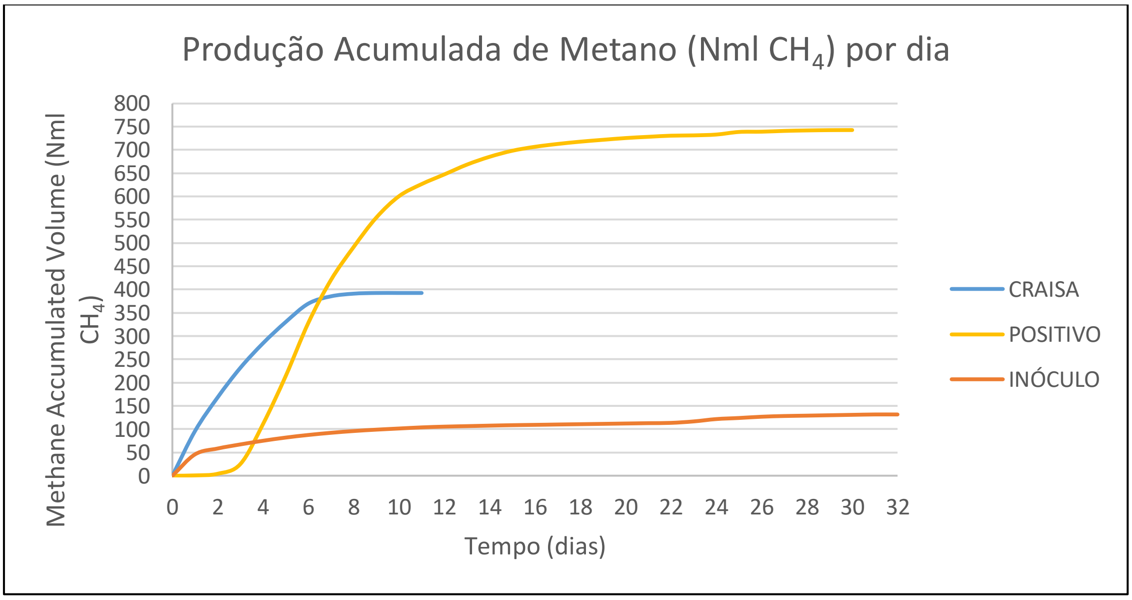

FIGURE 2. Cumulative gross daily methane production obtained in Experiment 2.

Conclusion

The residues used in the tests proved to be very promising substrates for biogas production, having a high concentration of organic matter available to be digested, although the low reduction of SV indicates the presence of lignocellulosic material, which is very difficult to be degraded. The inoculum used showed good interaction with the substrate and a very rapid acclimatation to it.

The pH tests and the relationship between alkalinity presented satisfactory values, proving to be an efficient tool for monitoring reactor stability resulting in high methane yields.

In general, the research proved that the anaerobic digestion process of the organic fraction of municipal solid waste from CRAISA consists of a viable alternative for its treatment and stabilization, as well as its energy recover.

References

APHA. **Standard Methods for the Examination of Water and Wastewater**. 21ª ed. Washington, DC: APHA / AWWA / WEF, 2005.

BRASIL, Law n. 12.305, August 2, 2010. National Policy on Solid Waste; amends the law no. 9.605, February 12, 1998; and makes other arrangements. 2010.

BIOPROCESS CONTROL. Automatic Methane Potential Test System. **Operation and Maintenance Manual**. Versão 2.0. Suécia, 2014.

CRAISA – **Companhia Regional de Abastecimento Integrado de Santo André**. <http://www.craisa.com.br/> - último acesso 24 de junho de 2018.

CORTEZ, Luís Augusto Barbosa; LORA, Electo Silva. **Biomass to Energy Conversion Technologies.** Manaus: EDUA/EFEI, 1997. 540 p. (Energy Systems, v.2).

CRAISA – **Companhia Regional de Abastecimento Integrado de Santo André**. <http://www.craisa.com.br/> - último acesso 24 de junho de 2018.

EPA – **Standard Methods EPA 2540 G, Total, Fixed, and Volatile Solids in Solid and Semisolid Samples** - Approved by SM Committee: 1997.

RIPLEY, L. E., BOYLE, W. C. & CONVERSE, J.C. **Improved alkalimetric monitoring for anaerobic digestion of high-strength wastes**. Journal (Water Pollution Control Federation): 58, p. 406-411. May 1986.

VDI. 4630. **Fermentation of organic materials - Characterization of the substrate, sampling, collection of material data and fermentation tests.** Verein Deutscher Ingenieure, 2006.

ENERGY AND EXERGY COST ANALYSIS OF TWO DIFFERENT ROUTES FOR VINASSE TREATMENT WITH ENERGY RECOVERY

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ABSTRACT

The vinasse, produced as the bottom product of the distillation column in the distillation step of the ethanol production process, is the main liquid residue of this industry. It is a dark brown liquid of acidic nature and high organic matter content, thus making it a polluting effluent. Currently, it is used to fertilise and irrigate sugarcane fields, taking advantage of its nutrients and high water content. However, its disposition is still a problem because of the high production rate in which it is produced, which ranges from 10 to 15 litres of vinasse per litre of ethanol produced. This way, this work addresses the vinasse problem by a preliminary exergy cost analysis of two alternatives for vinasse disposition with energy recovery; being these two alternatives the vinasse concentration with subsequent incineration, and the vinasse biodigestion aiming at the biomethane production. The preliminary results show the biomethane as the product with the highest exergy cost, indicating that important irreversibilities are associated to the biogas production route.

Keywords: vinasse, concentration, incineration, biodigestion, exergy cost.

Introduction

Brazil is the biggest producer of sugarcane in the world (FAO, 2018); and the sugar and ethanol industry is one of the most important sectors of the national economy. The Brazilian ethanol owes its success to its economic competitiveness, which was achieved through economies of scale and technological advances over time (GOLDEMBERG et al., 2004). Nowadays, the Brazilian government is presenting the RenovaBio Program, seeking to expand the biofuel production (COELHO, 2017), being the ethanol among the biofuels contemplated. Nonetheless, the main liquid residue of this production process, or vinasse, still represents a problem for the industry, because of its difficult and costly disposition due to the large volume in which it is generated. Furthermore, with an increasing ethanol production, encouraged by the RenovaBio Program, the vinasse generated will increase as well.

The vinasse, produced as the bottom product of the distillation column in the distillation step, is a dark brown liquid of acidic nature and high organic matter content, thus making it a polluting effluent. However, its solid content is also rich in nutrients such as potassium, sodium, calcium, phosphorous, manganese and nitrogen, among others, which can be used as fertilisers. This way, the fertirrigation, current vinasse disposition, takes advantage of the nutrients in the solid content, and the high water content to fertilise and irrigate at the same time by aspersing the vinasse over the sugarcane crops (FREIRE; CORTEZ, 2000). Still, the main problem for its disposition is the high production rate, which ranges from 10 to 15 litres of vinasse per litre of ethanol produced (FREIRE; CORTEZ, 2000).

This way, this work addresses the vinasse problem by a preliminary exergy cost analysis of two alternatives for vinasse disposition with energy recovery. Being these two alternatives the vinasse concentration with subsequent incineration, and the vinasse biodigestion aiming at the production of biomethane.

This type of analysis (exergoeconomics) is a tool to identify the location, magnitude and source of thermodynamic losses in an energy system (irreversibilities). Furthermore, it calculates the cost associated with the exergy destruction and exergy losses; besides assessing the production costs of each product in an energy-conversion system that has more than one product. The thermoeconomic analysis (exergoeconomics) is also used to compare technical alternatives and facilitates feasibility and optimization studies (TSATSARONIS, 1993).

Material and Methods

This work performed an exergy cost assessment of the two alternatives proposed, and a Base Case for comparison purposes. The Base Case, or Case i, was considered as a conventional ethanol, sugar and electricity production process. Figure 1 shows a simplified flowsheet of the Base Case.

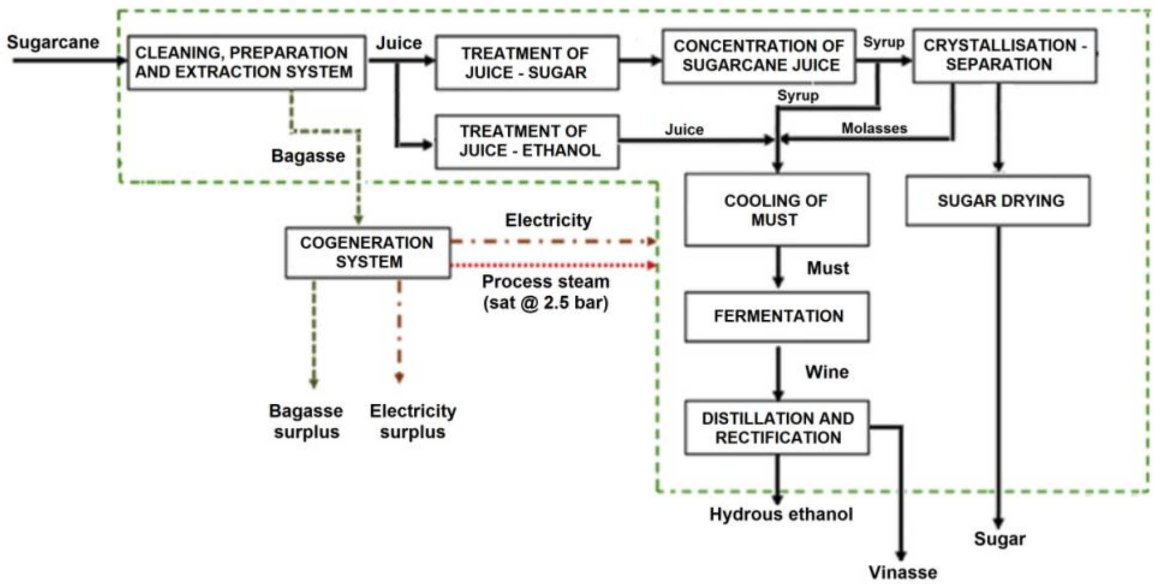

Figure 1. Flowsheet of Case i: Base Case. Modified from Pina et al. (2017).

The vinasse concentration and incineration route, or Case ii, was considered as a Base Case coupled to a vinasse concentration system, sending the concentrated vinasse to the boiler of the cogeneration system. A seven-effect evaporation system and a concentration up to 65 Brix was considered. Finally, the vinasse biodigestion alternative, or Case iii, considers a Base Case coupled to a biodigestion system, a desulphurisation system for biogas cleaning, and a purification system for biomethane production. Figures 2 and 3 depict the flowsheets of Cases ii and iii, respectively.

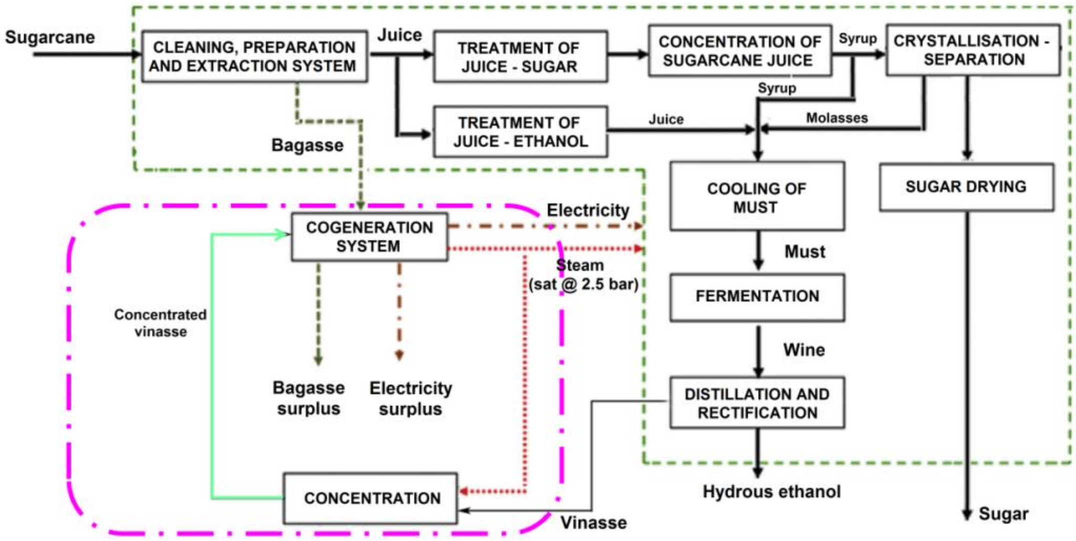

Figure 2. Flowsheet of Case ii: Base Case + vinasse concentration system. Modified from Pina et al. (2017).

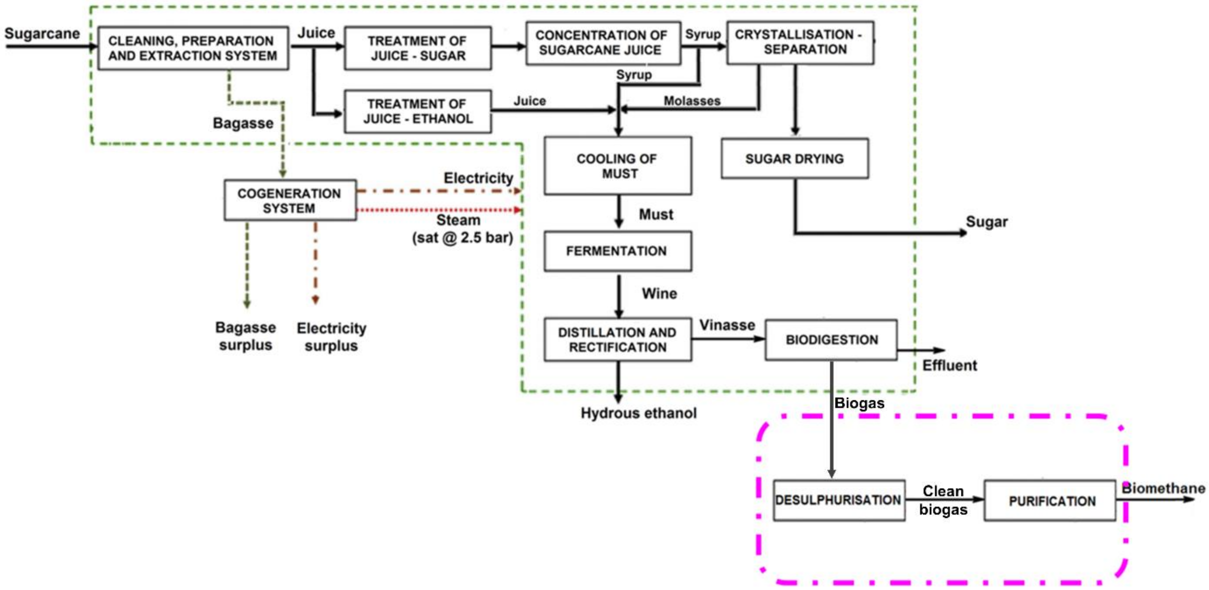

Figure 3. Flowsheet of Case iii: Base Case + biodigestion + desulphurization + purification systems. Modified from Pina et al. (2017).

The conventional production process (Base Case) was simulated using the software Aspen Plus™ V9, according to previous studies (DIAS, 2008; ENSINAS, 2008; PALACIOS-BERECHE, 2011). The modelling of the alternative technologies (vinasse concentration, biodigestion, desulphurisation, purification) was performed using the EES® software, because of its facility of use and faster convergence, according to previous works (PALACIOS-BERECHE; PALACIOS-BERECHE; NEBRA, 2018; PALACIOS-BERECHE et al., 2018).

The cogeneration system was based on a Rankine cycle, producing steam at 65 bar and 520°C (SOSA-ARNAO, 2018); it was also modelled using the EES® software. A configuration considering back-pressure steam turbines (BPST), producing only the required steam for the process, thus maximising the bagasse surplus, was adopted Figure 4 presents the schemes of the configuration system adopted.

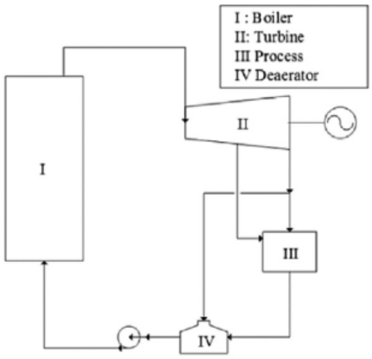

Figure 1. Configuration of the cogeneration system (BPST)

The exergy analysis used data from the process simulations to determine the exergy of each process stream, according to a previous study (PALACIOS-BERECHE; PALACIOS-BERECHE; NEBRA, 2018), and the guidelines presented in Szargut et al. (1988), Ensinas e Nebra (2009), and Modesto et al. (2005).

The exergy cost assessment was performed using the Exergy Cost Theory presented by Lozano e Valero (1993). An exergy cost balance was accomplished for each subsystem assumed in the exergy analysis (PALACIOS-BERECHE; PALACIOS-BERECHE; NEBRA, 2018), taking into account the particular productive function of each subsystem in order to determine the unit exergy cost of each stream.

Results and Discussion

The main results of the preliminary exergy cost assessment, the unit exergy costs of the main products of the evaluated cases, are presented in Table 1.

Table 1. Unit exergy costs (k)

	Base Case	**Case i: Concentration-Incineration**	**Case ii: Biomethane production**
	Conf. 1: BPTS	**Conf. 1: BPTS**	**Conf. 1: BPTS**
	k	**k**	**k**
Ethanol	2.058	2.109	2.058
Açúcar	1.55	1.588	1.55
Concentrated vinasse (65 Brix)	-	1.984	-
Biogas	-	-	6.209
Desulphurised biogas	-	-	6.848
Biomethane	-	-	6.948
Steam	3.457	3.767	3.457
Electricity	4.238	4.618	4.239

From Table 1, it can be observed that the exergy costs of the main products: ethanol, sugar and electricity do not present significant differences when the alternative processes for vinasse treatment are incorporated to the conventional process; the unit exergy costs for electricity and steam resulted in the range of 4-4.6 and 3.4-3.7, respectively. However, it can also be observed that Case i presents slightly higher costs for all products because of the increase of irreversibilities in vinasse concentration and incineration. Regarding the results of Case ii, the unit exergy costs of conventional products resulted almost the same as in the Base case. The most expensive product in this case is the biomethane, with an exergy cost of 6.9, followed by the electricity and steam, these results show that important irreversibilities are associated to the biogas production.

Conclusion

This preliminary exergy cost analysis indicates the impacts in unit exergy costs caused by the introduction of alternative process to treat vinasse with energy recovery; from the evaluated cases, the biomethane is presented as the product with the highest exergy cost.

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References

COELHO, José Mauro. **Apresentação sobre a EPE e o programa RenovaBio**Santo André, 2017.

DIAS, Marina Oliveira De Souza. **Simulaçao do Processo de Produçao de Etanol a Partir do Açúcar e do Bagaço, Visando a Integraçao do Processo e a Maximização da Produção de Energia e**

Excedentes do Bagaço. 2008. Universidade Estadual de Campinas, [s. l.], 2008.

ENSINAS, Adriano V. **Integração térmica e otimização termoeconômica aplicadas ao processo industrial de produção de açúcar e etanol a partir da cana-de-açúcar**. 2008. Universidade Estadual de Campinas, [s. l.], 2008.

ENSINAS, Adriano V.; NEBRA, Silvia A. Exergy Analysis as a Tool for Sugar and Ethanol Process Improvement. In: PÉLISSIER, Gaston; CALVET, Arthur (Eds.). **Handbook of Exergy, Hydrogen Energy and Hydropower Research**. [s.l.] : Nova Science Publishers, 2009. p. 125–160.

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. **FAOSTAT**. 2018. Disponível em: <http://www.fao.org/faostat/en/#data/QC/visualize>. Acesso em: 13 dez. 2018.

FREIRE, Wesley Jorge; CORTEZ, Luís Augusto Barbosa. **Vinhaça de Cana-de-açúcar**. 1. ed. Guaíba: Agropecuaria, 2000.

GOLDEMBERG, José et al. Ethanol learning curve - The Brazilian experience. **Biomass and Bioenergy**, [s. l.], v. 26, n. 3, p. 301–304, 2004.

LOZANO, M. A.; VALERO, A. Theory of the Exergetic Cost. **Energy**, [s. l.], v. 18, n. 9, p. 939–960, 1993.

MODESTO, M.; NEBRA, Silvia A.; ZEMP, Roger J. A Proposal to Calculate the Exergy of Non Ideal Mixtures Ethanol-Water Using Properties of Excess. In: 14TH EUROPEAN BIOMASS CONFERENCE 2005, Paris, France. **Anais**... Paris, France

PALACIOS-BERECHE, Milagros C.; PALACIOS-BERECHE, Reynaldo; NEBRA, Silvia A. Comparison through exergy assessment of two alternatives for the energy use of vinasse : Concentration with incineration vs . Biodigestion. In: PROCEEDINGS OF ECOS 2018 - THE 31ST INTERNATIONAL CONFERENCE ON EFFICIENCY, COST, OPTIMISATION, SIMULATION AND ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS 2018, Guimarães. **Anais**... Guimarães

PALACIOS-BERECHE, Milagros C.; MEDINA-JIMENEZ, Ana C.; PALACIOS-BERECHE, Reynaldo; NEBRA, Silvia A. Comparison between two alternatives for the energy use of vinasse: Concentration-Incineration vs Biodigestion. In: PROCEEDINGS OF THE 17TH BRAZILIAN CONGRESS OF THERMAL SCIENCES AND ENGINEERING 2018, Águas de Lindóia, SP, Brazil. **Anais**... Águas de Lindóia, SP, Brazil

PALACIOS-BERECHE, Reynaldo. **Modelagem e integração energética do processo de produção de etanol a partir da biomassa de cana-de-açúcar**. 2011. Universidade Estadual de Campinas, [s. l.], 2011.

PINA, Eduardo A. et al. Reduction of process steam demand and water-usage through heat integration in sugar and ethanol production from sugarcane – Evaluation of different plant configurations. **Energy**, [s. l.], v. 138, p. 1263–1280, 2017.

SOSA-ARNAO, Juan Harold. **Personal communication**. São Paulo

SZARGUT, Jan; MORRIS, David R.; STEWARD, Frank R. **Exergy Analysis of Thermal, Chemical, and Metallurgical Processes**. New York, USA: Hemisphere Publishing Corporation, 1988.

TSATSARONIS, George. Thermoeconomic analysis and optimization of energy systems. **Progress in Energy and Combustion Science**, [s. l.], v. 19, n. 3, p. 227–257, 1993.

EFFECT OF FOOD-TO-MICROORGANISM RATIO ON METHANE YIELD WITH SUGARCANE VINASSE AS SUBSTRATE

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ABSTRACT

Anaerobic digestion has been highlighted as a potential alternative for the management and energetic valorization of vinasse in Brazil. Consequently, research in this regard has increased significantly in the last decade. However, few researches evaluated the food-to-microorganism (F/M) ratio on methane production using vinasse as substrate. This motivated the study of the effect of the F/M ratio on methane yield (Y_{CH4}) through a BMP test with vinasse under mesophilic conditions. In the study a factorial design 2^3 with a central point was used, and the BMP was modeled. Y_{CH4} results were significantly higher (mean 275 $NmL.gSCODr^{-1}$) for higher F/M ratios (0.6). The effects of M and pH were not significant at the levels evaluated. The correlation model between Y_{CH4} and [F] had an unacceptable adjustment. A Central Composite Rotational Design (CCRD) will be performed with other levels of [F] and [M] ensuring F/M ratios greater than 0.6.

Keywords: anaerobic digestion; vinasse; biochemical methane potential; substrate-to-inoculum ratio

INTRODUCTION

Sugarcane vinasse is the main wastewater from ethanol production in Brazil (FUESS; GARCIA, 2014). Anaerobic digestion has been highlighted as a potential alternative for the management of vinasse (MORAES; ZAIAT; BONOMI, 2015; PARSAEE; KIANMI; KARIMI, 2019). In this scenario, in the last decade in Brazil there has been an increase in the number of studies that evaluated the potential of methane, hydrogen and energy from residues of the sugar and alcohol industry (DE AQUINO; FUESS; PIRES, 2017; FUESS *et al.*, 2017; JÚNIOR. *et al.*, 2016; MORAES *et al.*, 2014; SANTOS *et al.*, 2019). However, further research needs to be done to study the food-to-microorganism (F/M) ratio to optimize methane production using vinasse as substrate. The F/M ratio is a key parameter of biochemical methane potential (BMP) tests (HOLLIGER *et al.*, 2016). Field, Alvarez and Lettinga (1988) recommended F/M ratio of 1 for wastewaters but warned that the optimal ratio depends on the compositional characteristics of the food and the activity of microorganism. Therefore, in order to adequately estimate BMP assay results, it is important to optimize the F/M ratio for the substrate and inoculum to be used in advance. In this sense, the objective of this research was to carry out a study of different conditions of food, microorganism, and pH that favor the production of methane using vinasse.

MATERIAL AND METHODS

Sugarcane vinasse and inoculum

Vinasse samples, from mixed source (must of broth + molasses), were collected from an ethanol and sugar plant (annexed ethanol production, at Pradópolis, São Paulo). The sampling was performed at the beginning of the 2017/2018 sugarcane harvest season (May 2017). The inoculum was obtained in June 2018 (Pereiras, São Paulo) from a full-scale mesophilic upflow anaerobic sludge blanket reactor (UASB) applied to the anaerobic digestion of poultry slaughterhouse wastewaters.

Experimental design and statistical analysis

The effects of microorganism concentration [M] (X1), food concentration [F] (X2) and pH (X3) on the methane yield (Y_{CH4}) response variable were investigated by complete factorial experimental design. The method used was factorial design 2^3 with three repetitions in the central point, totaling 11 trials. A linear model with first-order interactions was fitted to the data to quantify the main effects of each factor and interactions on the dependent variables. A One-way Analysis of Variance (ANOVA) with post-hoc Tukey Honestly Significant Difference (HSD) was performed to determine which means are significantly different from others with a 95% confidence level. The quality of the fit was tested using ANOVA. The non-significant effects ($p \geq 0.05$) were eliminated and the model parameters were recalculated. The statistical analysis was performed on the Action Stat® 3.5.152.34.

Biochemical methane potential (BMP) and specific methanogenic activity (SMA) assays

The BMP assay was performed in batch according to Holliger *et al.* (2016). It was run in the Automatic Methane Potential Test System II (AMPTS II, Bioprocess Control) in 500 mL flasks, incubated at 35 °C, continuously shaken (150 rpm) and 250 mL reaction volume. External nutrient supplementation was not provided. The pH, total and soluble chemical oxygen demand (TCOD, SCOD) of the treatments were evaluated. For modeling the accumulated CH_4 production over time and obtain parameters (Y_{CH4} and specific rate constant (k_0)) that would serve as a response in the statistical analysis, the Roediger model (Equation 1) (JIMÉNEZ; BORJA; MARTÍN, 2004) was used. SMA was also evaluated according to Field, Alvarez and Lettinga (1988). The regression was developed with Solver supplement in the Microsoft Excel® 2016 software using the Nonlinear Generalized Reduced Gradient (GRG) method.

$$Y(t) = Y_{max.}(1 - e^{-k_0 t}) \qquad \text{(Eq. 1)}$$

The SMA assay of the inoculum was run in OxiTop® Control equipment (OxiTop-C, WTW) in triplicate and by the experimental procedure reported by Simões (2017). The reaction volume was 100 mL in 330 mL flasks, incubated at 30 °C and continuously shaken (200 rpm) in orbital shaker incubator (430-RD, Ethiktechnology). A solution of acetic, propionic and butyric acid (33.3: 33.3: 33.3%w/w of COD), neutralized with NaOH pellets, was used as a substrate to obtain a reaction concentration of COD = 3 $g.L^{-1}$. Inoculum concentration used was 4 $g.L^{-1}$ of volatile suspended solids (VSS), and macro and micronutrient solutions composition were defined according to Martins *et al.* (2015).

Analytical methods

pH, total volatile solids (TVS) and volatile suspense (VSS), TCOD, SCOD, BOD, total Kjeldahl nitrogen (TKN) and sulfate (SO_4^{2-}) were obtained according to the Standard Methods (APHA, AWWA, WEF, 2005). Total carbohydrates (TCH), alkalinity and volatile fatty acid (VFA) were determined according to Dubois *et al.* (1956), Ripley *et al.* (1986) and Cavalcanti and van Haandel (2001), respectively. For TCH and SCOD determination the samples were centrifuged (3.500 rpm, 15 min) and filtered on 0.45 µm polyvinylenedifloride's (PVDF) membranes. For alkalinity and VFA the samples were centrifuged (1.500 rpm, 3 min). Elemental analysis (C, H, N, S) was attained using element analyzer (Flash EA-1112, Thermo Scientific) with BBOT ($C_{26}H_{26}N_2O_2S$) as standard and with vinasse samples lyophilized. This analysis was carried out at the Multi-user Experimental Center in UFABC.

RESULTS AND DISCUSSION

The pH (5.96 ± 0.02), TVS (18.69 ± 0.31 $g.L^{-1}$), TCOD (24.90 ± 0.87 $g.L^{-1}$), BOD (11.45 $g.L^{-1}$) and SO_4^{2-} (1.45 $g.L^{-1}$) of vinasse were significantly different from reported for CETESB (1982), however, TKN (0.59 $g.L^{-1}$) was within the interval. SCOD and TCH was 21.88±0.40 $g.L^{-1}$ and 7.51±0.5 $g.L^{-1}$, respectively. Fuess *et al.* (2017) also worked with vinasse from must mixed collected at the same plant and reported 4.5 pH, 28.3 $g.L^{-1}$ TCOD, 22.9 $g.L^{-1}$ SCDO, 0.77 $g.L^{-1}$ TKN, 1.81 $g.L^{-1}$ of SO_4^{2-} and 6.9 $g.L^{-1}$ TCH. The differences in composition found between this research and by the references cited can be attributed to variations in composition commonly observed in sugarcane vinasse (CETESB, 1982; COSTA *et al.*, 1986; FUESS *et al.*, 2017; MORAES *et al.*, 2015). The result of the elemental analysis (% w/w dry base) was 32.99 ± 1.01 (C), 5.75 ± 0.09 (H), 1.63 ± 0.09 (N) and 1.82 ± 0.02 (S). The C, N, SCOD and SO_4^{2-} contents guarantees C/N ratio (20.24) and SCOD/SO_4^{2-} ratio (15.09) favorable for anaerobic process. According to Kayhanian (2010) and Lens *et al.* (1998), respectively, anaerobic treatment always occurs successfully for C/N ratios ranging from 20 to 35 and COD/sulfate ratios above 10.

The collected sludge was classified as granular according to its physical appearance. The characterization results were 7.19 ± 0.01 pH, 38.90 ± 2.8 $g.L^{-1}$ VSS, 2.8 ± 0.06 $g_{CaCO3}.L^{-1}$ alkalinity and 0.22 ± 0.01 $g_{CH3COOH}.L^{-1}$ VFA. According to Holliger *et al.* (2016) an anaerobic inoculum of quality has: pH > 7.0 and < 8.5, VFA < 1 $g_{CH3COOH}.L^{-1}$ and alkalinity > 3 $g_{CaCO3}.L^{-1}$. These criteria were verified in the inoculum and, therefore, it was considered of good quality for the research. Another indicator of quality inoculum is its SMA with different standard substrates such as propionate, butyrate, acetate, etc., to evaluate the capacity to degrade the substrate by the microbial consortium (HOLLIGER *et al.*, 2016; AQUINO *et al.*, 2007). SMA test results indicated a sludge with an activity of 0.58 ± 0.01 gCH_4-$COD.gSSV^{-1}.d^{-1}$. According to Angelidaki *et al.* (2009) quality granular sludge should have a minimum SMA on acetate of 0.3 gCH_4-$COD.gSSV^{-1}.d^{-1}$. The SMA result confirm the quality of sludge and corresponds to the results of De Zeeuw (1984) (0.5 to 2) and Field, Alvarez and Lettinga (1988) (0.5 to 1.5) who worked with granular sludge under conditions like this SMA test.

For treatments with higher F/M ratio (D, H, C and G) a higher Y_{CH4} and SMA and a lower k_0 was achieved compared to those with lower F/M ratio (A, B, E and F) (Table 1). The behavior of the system was interpreted as follows: As the amount of food became more available, the activity of methanogenic archaea (SMA) increased, as a result superior methane production (Y_{CH4}) was achieved, but with a lower consumption rate (k_0) of the substrate, and vice versa. These results corresponded to those of Díaz (2013), Simões (2017) and Caillet *et al.* (2019) when they increased to F/M ratio from 0.6 to 1.2, 0.06 to 0.5 and 0.5 to 2, respectively. Differences in Y_{CH4} among treatments C, D, G and H were not significant (p> 0.05) for levels of factors [M] and pH. This was also verified in ANOVA ($p \geq 0.05$) (Table 2) made to check the significance of the factors on Y_{CH4}. The good fit quality (R^2 > 90%) of experimental data from treatments C, D, G and H to Roediger model can be seen in Table 1.

Table 1. Design matrix for experimental factors and corresponding response at different factor levels.

Experiment	[M]	[F]	pH	F/M	$^{**}Y_{CH4}$	k_0	SMA	R^2
A	14.3 (-1)	1.7 (-1)	6.60 (-1)	0.1	105.26^{a}	13.57	0.044	61.6
B	19.0 (1)	1.7 (-1)	6.60 (-1)	0.09	136.49^{a}	12.15	0.047	84.7
C	14.3 (-1)	10.0 (1)	6.60 (-1)	0.7	247.35^{b}	0.84	0.211	99.6
D	19.0 (1)	10.0 (1)	6.60 (-1)	0.5	299.73^{b}	0.63	0.222	96.5
E	14.3 (-1)	1.7 (-1)	7.40 (1)	0.1	150.10^{a}	3.11	0.049	93.4
F	19.0 (1)	1.7 (-1)	7.40 (1)	0.09	153.74^{a}	12.50	0.054	76.8
G	14.3 (-1)	10.0 (1)	7.40 (1)	0.7	254.17^{b}	0.98	0.248	99.1
H	19.0 (1)	10.0 (1)	7.40 (1)	0.5	297.42^{b}	0.71	0.231	98.7
I-J-K*	16.5 (0)	6.6 (0)	7.00 (0)	0.4	277.72^{b} ± 0,02	0.93 ± 0,02	0.173 ± 0,002	97.8 ± 0,01

Note: [M] ($gVSS.L^{-1}$), [F] ($gSCOD.L^{-1}$), Y_{CH4} ($NmL.gSCODr^{-1}$) (SCODr: SCOD removed), k_0 (d^{-1}), SMA (gCH_4-$COD.gSSV^{-1}.d^{-1}$), R^2 (%), *experiments of central point (n = 3), **mean values followed by equal letters do not differ from each other (Tukey, $p \leq 0.05$)

Table 2. ANOVA for experimental response at different factor levels (*p-value ≤ 0.05)

Response	Factors	SS	GL	MS	F-value	p-value
Y_{CH4}	[M] (X1)	2129.16	1	2129.16	0.74	0.44
	[F] (X2)	38235.63	1	38235.63	13.32	0.02*
	pH (X3)	554.27	1	554.27	0.19	0.68
	X1X2	461.32	1	461.32	0.16	0.71
	X1X3	168.58	1	168.58	0.06	0.82

	X2X3	414.53	1	414.53	0.14	0.72
	Residual errors	11481.06	4	2870.27		

Note: SS - sum of square; GL - degrees of freedom; MS - mean square

According to the p-value results from Table 2, it can be stated that only the linear term of the variable [F] was significant. Therefore, only this was considered for regression reevaluation.

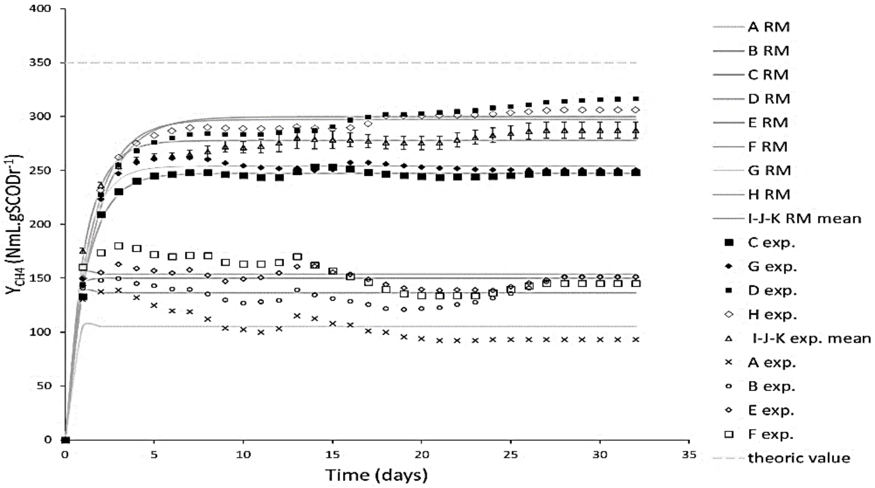

Figure 1. Experimental and regression curves of the BMP test (A exp. until K exp.: experimental curves; I-J-K exp. mean: mean experimental curve of the central point; A RM. until K RM.: regression curves; I-J-K RM mean: mean regression curve of the central point; RM: Roediger model)

The Y_{CH4} curves of the BMP test are presented in Figure 1. Experimental data from the higher Y_{CH4} treatments (C, D, G and H) showed a good fit to the model. In these treatments (F/M mean = 0.6) an average of 275 NmL.gSCODr^{-1} was reached, corresponding to 78% to the theoretical value (350 NmL.gSCODr^{-1}) (FIELD; ALVAREZ; LETTINGA, 1988). Díaz (2013) worked with vinasse from annexed ethanol production and reported 332 and 327 NmL.gSCODr^{-1} for experiments with F/M ratio of 0.6 and 1.2 gTCOD.gVSS^{-1}, respectively. Santos *et al.* (2019) reported a Y_{CH4} = 334 NmL.gSCODr^{-1} for F/M ratio to 0.5 gTCOD.gTVS^{-1} and with vinasse from annexed ethanol production. Y_{CH4} levels below the theoretical value could be explained by the low content of biodegradable organic matter in the vinasse to this research (BOD/TCOD = 0.46) in relation to Díaz (2013) and Santos *et al.* (2019) (BOD/TCOD = 0.7 and BOD/TCOD = 0.54, respectively) (FUESS; GARCIA, 2014). In addition, it can be attributed to the relatively low SCOD/sulfate ratio (15.09) most likely favored the electron flow deviation from methanogenesis to sulfidogenesis, impacting SCOD removal and methane production. Kiyuna, Fuess and Zaiat (2017) achieved approximately 35% lower methane production for the SCOD/sulfate ratio of 7.5 compared to the 12.0 ratio. Although the Y_{CH4} achieved were lower than those reported in the literature, the highest values corresponded to the highest F/M ratio used, as reported by Díaz (2013) and Simões (2017).

The results of the ANOVA test for the lack of adjustment of the reevaluated model presented a significant lack-of-fit (p-value = 0.001) (p-value $\leq$ 0.05) and R^2 = 0.715. Only about 71% of data variability is explained by the adjusted regression model, suggesting an unacceptable adjustment.

In order to find the correlation between the [F] and [M] that maximize Y_{CH4} from the collected vinasse and sludge, a Central Composite Rotational Design (CCRD) will be developed with levels of [F] and [M] that guarantee F/M ratio greater than 0.6.

Conclusion

According to vinasse compositional characteristics and sludge activity, Y_{CH4} results were significantly higher (average of 275 NmL.gSCODr^{-1}) for higher F/M ratios, as reported in the literature. The effects of [M] and pH on this result were not statistically significant at the levels evaluated (14.3-

19 gVSS.L^{-1} and 6.6-7.4). The model found to correlate Y_{CH4} with [F] had an unacceptable fit and consequently, a CCRD will be performed with other levels of [F] and [M] ensuring F/M ratios greater than 0.6.

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REFERENCES

ANGELIDAKI, I.; ALVES, M.; BOLZONELLA, D.; BORZACCONI, L.; CAMPOS, J. L.; GUWY, A. J.; KALYUZHNYI, S.; JENICEK, P.; VAN LIER, J. B. Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays. Water Science and Technology, [s.l.], v. 59, n. 5, p. 927-934, mar. 2009. DOI: http://dx.doi.org/10.2166/wst.2009.040.

APHA; AWWA; WEF. Standard Methods for the Examination of Water and Wastewater. 21st. ed. Washington DC, American Public Health Association, 2005, 1368 p.

AQUINO, S. F. D.; CHERNICHARO, C. A. D. L.; FORESTI, E.; SANTOS, M. D. L. F. D.; MONTEGGIA, L. O. Metodologias para determinação da Atividade Metanogênica Específica (AME) em Lodos Anaeróbios. Engenharia Sanitária e Ambiental, [s.l.], v. 12, n. 2, p. 192-201, abr. 2007.

CAILLET, H.; LEBON, E.; AKINLABI, E.; MADYIRA, D.; ADELARD, L. Influence of inoculum to substrate ratio on methane production in Biochemical Methane Potential (BMP) tests of sugarcane distillery wastewater. Procedia Manufacturing, [s.l.], v. 35, p. 259–264, 2019. DOI: 10.1016/j.promfg.2019.05.037

CAVALCANTI, P. F. F., van HAANDEL, A. Comparação entre os métodos titulometricos Kapp e DiLallo para determinação da alcalinidade e AGV. *In*: Chernicharo, C. A. L. (coord.). Pós-tratamento de efluentes de reatores anaeróbios: aspectos metodológicos. Belo Horizonte: PROSAB. p. 25-34, 2001.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO (São Paulo). Utilização de restilo como fertilizante em solos cultivados como cana de açúcar: relatório final. São Paulo: CETESB, 1982. 262 p.

COSTA, F. J. C. B.; ROCHA, B. B. M.; VIANA, C. E.; TOLEDO, A. C. Utilization of vinasse effluents from an anaerobic reactor. Water Science and Technology, [s.l.], v. 18, n. 12, p. 135-141, dez. 1986. DOI: https://doi.org/10.2166/wst.1986.0169

DE AQUINO, S.; FUESS, L. T.; PIRES, E. C. Media arrangement impacts cell growth in anaerobic fixed-bed reactors treating sugarcane vinasse: Structured vs. randomic biomass immobilization. Bioresource Technology, [s.l.], v. 235, p. 219-228, jul. 2017. DOI: https://doi.org/10.1016/j.biortech.2017.03.120

DE ZEEUW, W. J. Acclimatization of anaerobic sludge for UASB-reactor start-up. 168 f. Thesis (Ph D.), Landbouwhogeschool Wageningen, Wageningen, Netherlands, 1984. Available in: https://library.wur.nl/WebQuery/wurpubs/fulltext/166630. Access in: 5 set. 2019

DÍAZ, A. C. Tratamiento de vinazas en un filtro anaerobio empacado de flujo ascendente. 100 f. Dissertação (Mestrado) - Master en Ingeniería Ambiental, Centro de Estudios de Ingeniería de Procesos (CIPRO), Instituto Superior Politécnico “José Antonio Echeverría” (ISPJAE), La Habana, 2013.

DUBOIS, M.; GILLES, K. A.; HAMILTON, J. K.; REBERS, P. T.; SMITH, F. Colorimetric Method for Determination of Sugars and Related Substances. Analytical Chemistry, [s.l.], v. 28, n. 3, p. 350-356, mar. 1956. DOI: http://dx.doi.org/10.1021/ac60111a017.

FIELD, J.; ALVAREZ, R. S.; LETTINGA, G. Ensayos Anaerobios. *In*: FERNANDEZ-POLANCO, F.; GARICA, P. A.; HERNANDO, S. 4º Seminario de Depuración Anaerobia de Aguas Residuales: Actas del 4º Seminario D.A.A.R. Valladolid: Secretariado de Publicaciones Universidad de Valladolid, 1988. p. 52-80.

FUESS, L. T.; GARCIA, M. L. Implications of stillage land disposal: A critical review on the impacts of fertigation. Journal of Environmental Management, [s.l.], v. 145, p. 210-229, dez. 2014. DOI: http://dx.doi.org/10.1016/j.jenvman.2014.07.003.

FUESS, L. T.; KIYUNA, L. S. M.; JÚNIOR, A. D. N. F.; PERSINOTI, G. F.; SQUINA, F. M.; GARCIA, M. L.; ZAIAT, M. Thermophilic two-phase anaerobic digestion using an innovative fixed-bed reactor for enhanced organic matter removal and bioenergy recovery from sugarcane vinasse. Applied Energy, [s.l.], v. 189, p. 480-491, mar. 2017. DOI: https://doi.org/10.1016/j.apenergy.2016.12.071

HOLLIGER, C.; ALVES, M.; ANDRADE, D.; ANGELIDAKI, I.; ASTALS, S.; BAIER, U.; BOUGRIER, C.; BUFFIÈRE, P.; CARBALLA, M.; DE WILDE, V.; EBERTSEDER, F.; FERNÁNDEZ, B.; FICARA, E.; FOTIDIS, I.; FRIGON, J.-C.; DE LACLOS, H. F.; GHASIMI, D. S. M.; HACK, G.; HARTEL, M.; HEERENKLAGE, J.; HORVATH, I. S.; JENICEK, P.; KOCH, K.; KRAUTWALD, J.; LIZASOAIN, J.; LIU, J.; MOSBERGER, L.; NISTOR, M.; OECHSNER, H.; OLIVEIRA, J. V.; PATERSON, M.; PAUSS, A.; POMMIER, S.; PORQUEDDU, I.; RAPOSO, F.; RIBEIRO, T.; RÜSCH PFUND, F.; STRÖMBERG, S.; TORRIJOS, M.; VAN EEKERT, M.; VAN LIER, J.; WEDWITSCHKA, H.; WIERINCK, I. Towards a standardization of biomethane potential tests. Water Science and Technology, [s.l.], v. 74, n. 11, p. 2515-2522, set. 2016. DOI: https://doi.org/10.2166/wst.2016.336

JIMÉNEZ, A. M.; BORJA, R.; MARTÍN, A. A comparative kinetic evaluation of the anaerobic digestion of untreated molasses and molasses previously fermented with *Penicillium decumbens* in batch reactors. Biochemical Engineering Journal, [s.l.], v. 18, n. 2, p.121-132, maio 2004. DOI: https://doi.org/10.1016/S1369-703X(03)00198-0

JÚNIOR, A. D. N. F.; KOYAMA, M. H.; DE ARAÚJO JÚNIOR, M. M.; ZAIAT, M. Thermophilic anaerobic digestion of raw sugarcane vinasse. Renewable Energy, [s.l.], v. 89, p. 245-252, abr. 2016. DOI: https://doi.org/10.1016/j.renene.2015.11.064

KIYUNA, L. S. M.; FUESS, L. T.; ZAIAT, M. Unraveling the influence of the COD/sulfate ratio on organic matter removal and methane production from the biodigestion of sugarcane vinasse. Bioresource Technology, [s.l.], v. 232, p. 103-112, maio 2017. DOI: https://doi.org/10.1016/j.biortech.2017.02.028

LENS, P. N. L.; VISSER, A.; JANSSEN, A. J. H.; POL, L. H.; LETTINGA, G. Biotechnological Treatment of Sulfate-Rich Wastewaters. Critical Reviews in Environmental Science and Technology, [s.l.], v. 28, n. 1, p. 41-88, jan. 1998. DOI: http://dx.doi.org/10.1080/10643389891254160.

MARTINS, T. H.; NERY, V.; POZZI, E.; ALVES, I.; DAMANOVIC, M. H. R. Z.; PIRES, E. C.; FORESTI, E. Rapid Specific Methanogenic Activity Tests Using a Manometric System. *In*: 14 World Congress on Anaerobic Digestion, 2015, Viña del Mar. Proceedings, 2015. Available in: https://www.researchgate.net/publication/309904235_Rapid_Specific_Methanogenic_Activity_Tests_Using_a_Manometric_System. Access in: 9 set. 2019.

MORAES, B. S.; JUNQUEIRA, T. L.; PAVANELLO, L. G.; CAVALETT, O.; MANTELATTO, P. E.; BONOMI, A.; ZAIAT, M., 2014. Anaerobic digestion of vinasse from sugarcane biorefineries in Brazil from energy, environmental, and economic perspectives: Profit or expense? Applied Energy, [s.l.], v. 113, p. 825-835, jan. 2014. DOI: https://doi.org/10.1016/j.apenergy.2013.07.018

MORAES, B. S.; ZAIAT, M.; BONOMI, A. Anaerobic digestion of vinasse from sugarcane ethanol production in Brazil: Challenges and perspectives. Renewable and Sustainable Energy Reviews, [s.l.], v. 44, p. 888-903, abr. 2015. DOI: http://dx.doi.org/10.1016/j.rser.2015.01.023

PARSAEE, M.; KIANI, M. K. D.; KARIMI, K. A review of biogas production from sugarcane vinasse. Biomass and Bioenergy, [s.l.], v. 122, p. 117-125, mar. 2019. DOI: https://doi.org/10.1016/j.biombioe.2019.01.034

KAYHANIAN, M. Ammonia Inhibition in High-Solids Biogasification: An Overview and Practical Solutions. Environmental Technology, [s.l.], v. 20, n. 4, p. 355-365, nov. 2010. DOI: https://doi.org/10.1080/09593332008616828

RIPLEY, L. E.; BOYLE, W. C.; CONVERSE, J. C. Improved Alkalimetric Monitoring for Anaerobic Digestion of High-Strength Wastes. Water Environment Federation, [s.l.], v. 58, n. 5, p.406-411, maio 1986.

SANTOS, P. S; ZAIAT, M.; OLLER DO NASCIMENTO CA, FUESS L. T. Does sugarcane vinasse composition variability affect the bioenergy yield in anaerobic systems? A dual kinetic-energetic assessment, Journal of Cleaner Production (Journal Pre-proof), [s.l.], v. 240, dez. 2019. DOI: https://doi.org/10.1016/j.jclepro.2019.118005

SIMÕES, A. L. G. Estudo da aclimatação de lodos anaeróbios como estratégia de inoculação para partida de biometanizadores alimentados com fração orgânica dos resíduos sólidos urbanos. 2017. 316 f. Dissertação (Mestrado) - Curso de Pós-graduação em Engenharia Hidráulica e Saneamento e Área de Concentração em Hidráulica e Saneamento, Escola de Engenharia de São Carlos da Universidade de São Paulo, São Carlos, 2017.

A MIXED INTEGER LINEAR PROGRAMMING STRATEGY FOR DISTRIBUITION NETWORK RECONFIGURATION PROBLEM IN AMPL

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ABSTRACT

This paper presents a modeling for the distribution network reconfiguration (DNR) problem associated with a classical optimization technique using the AMPL modeling language. The problem with DNR is to open or close toggle switches, seeking optimal network reconfiguration. The optimization problem is established considering the minimization of the objective function (activity reduction) and is subject to load flow restrictions, voltage limits, network radiality and connectivity. A radiality constraint is composed of a set of equations that considers the network topology and the discrete (binary) values of the switches. Limiting the problem characteristics, which has binary variables, is considered a Mixed Integer Nonlinear Programming (MINLP) problem. For a solution of the problem, an algorithm was developed in AMPL using the KNITRO solver. The good performance of the model, best performance strategy and efficience of the solver KNITRO is illustrated with case of study of 33 buses.

Keywords: Distribution Network Reconfiguration, Classical Optimization Techniques, AMPL, KNITRO, Simulation and optimization.

Introduction

The incentive for technological advancement, together with the high dependence and high consumption of electricity, makes the concern about the operation of the power distribution systems in an efficient, reliable and economical way, ensuring the basic parameters of the power quality is increasing. Distribution networks traditionally operate in radial topology, with disconnect switches installed at strategic points of the network. Opening and closing these switches modifies the network topology and, depending on the configuration, ohmic losses resulting from the Joule effect may decrease or increase (SILVA; BELATI; SILVA JUNIOR, 2016). This procedure is known as Distribution Network Reconfiguration (DNR). The search for DNR with the lowest possible ohmic loss is an optimization problem that aims to find the best distribution network topology by opening and closing switches that interconnect the buses subject to network operating restrictions (MERLIN, 1975).

In relation to classical optimization techniques, this discontinuity implies difficulty or even impossibility of convergence, being necessary to add some heuristics to circumvent it. DNR, seeking to minimize losses and increase power quality, appears as a low cost implementation alternative when compared to other commonly used alternatives (GEREZ et al., 2019). However, DNR is a highly complex combinatorial problem, non-convex, nonlinear, multimodal and has continuous and discrete variables making it a difficult task, regardless of the technique used. Due to these characteristics, computational techniques have been widely used to solve the problem and can be divided basically into two groups: exact and approximate techniques. The first group deals with techniques that always seek the optimal global optimization problems, as presented in (ABUR, 1996; GLAMOCANIN, 1990; MERLIN, 1975). These papers discuss the application of these techniques to small and medium size DNR problems, and their use to large problems is questioned.

The second group deals with techniques that do not ensure the global optimum, as found in the papers (CARRENO; ROMERO; PADILHA-FELTRIN, 2008; CHANG; KUO, 1994; CHIANG; JEAN-JUMEAU, 1990a, 1990b; MORI; OGITA, 2000; NARA et al., 1992; ZHANG; FU; ZHANG, 2007; ZHU, 2002). Mentioned techniques always find good quality local solutions that improve system performance compared to the initial operating point. Within this latter group there is still a specific niche of techniques that are specifically based on the observation and modeling of natural phenomena (ABDELAZIZ et al., 2009; ADEYEMI AMON, 2015; JIN; ZHAO; SUN, 2005; NAVEEN; SATHISH KUMAR; RAJALAKSHMI, 2015; NGUYEN; TRUONG, 2015; SU; CHANG; CHIOU, 2005), called bioinspired metaheuristics that have been widely used, but have the disadvantage that the solution is not conservative. Each group of techniques has particularities that influence the search process and the computational time, and it is not clear the indication of a specific alternative to solve the DNR problem.

Material and Methods

The methodology of development of the work is based on the consolidation of the theoretical foundations through the accomplishment of a deep bibliographical revision, development of computational models, implementation, computational simulation and analysis of the results.

a. Distribution Network Reconfiguration

DNR is the most attractive technique for reducing losses, as it allows the reuse of existing equipment without the need for major investments. DNR consists of opening and closing keys that connect the network nodes. This causes the system topology to be modified, shifting the power flows from overloaded lines to less requested ones, which decreases ohmic losses due to the Joule effect. Considering that in DNR a key can only assume two states, open or closed, in a system with n keys, there are 2n possibilities of reconfiguration. Systems with many keys inevitably result in an enormous amount of possible combinations for their reconfiguration and, consequently, require the use of scientific computing to solve the problem. The DNR problem has binary variables (open "0" or closed "1") and continuous variables associated with load flow variables (MONTICELLI, 1983). Another necessary restriction is the radiality (SHIRMOHAMMADI; HONG, 1989). Seeking a methodology that presents greater assertiveness and conservative solution, the present work aims to analyze the use of a classical optimization technique to solve the DNR problem using algorithms dedicated to this class of problem.

b. AMPL e KNITRO

Problem modeling, performed in AMPL programming environment (*A Mathematical Programming Language*) (FOURER; GAY; KERNIGHAN, 1990), use KNITRO solver (BYRD; NOCEDAL; WALTZ, 2006) which uses the Branch and Bound (B&B) algorithm to solve mixed integer nonlinear programming (MINLP) problems such as DNR. Developed in the late twentieth century, the AMPL programming language meets the need for writing complex optimization models without requiring the operator to have deep knowledge of logical programming as in the FORTRAN, C and PASCAL programming languages. The programming environment provides more user-friendly code writing for professionals in many fields. By interconnecting with various types of solvers, algorithms for equation solving, modeling becomes more productive by eliminating the need for more code implementation and saves resolution time, as these solvers are designed to make maximum use of them. Computational capabilities that deliver high efficiency even for extremely complex models. The B&B technique was developed in the 60's (LAND; DOIG, 1960) for application in discrete combinatorial optimization problems, being widely used in integer linear programming (ILP). The DNR problem is a MINLP problem, so the B&B technique will be associated with the MINLP problem. One of the advantages of B&B is to explore a search space through a tree search until the optimal solution is obtained. The performance of the B&B algorithm is related to the search strategy used. In (MORRISON et al., 2016) several strategies are presented, such as Depth-First Search (DFS), amplitude or width search (BA), best bound search (BBS), first best search (BPM) and cyclic first best search (CFBS). Another key point in a B&B algorithm is the definition of the branching strategy, which determines how sub problems will be divided. There are several strategies, such as binary branching (BB) (MORRISON et al., 2016), amplitude branching (AB) (MORRISON et al., 2016), pseudo cost branching (PCB) (BENICHOU et al., 1971), most fractional branching (MFB) (ACHTERBERG; KOCH; MARTIN, 2005) and the branch *Strong Branching* (SB) (APPLEGATE et al., 1995).

All mentioned strategies can be adjusted in the KNITRO solver through their parameterization. Regardless of the search and branch strategy, the B&B algorithm finds the same solution, but with a different number of iterations. In some cases a particular strategy can lead to too many iterations. Modeling the DNR problem for solution by the exact technique was performed in the AMPL environment, together with the KNITRO solver.

Results and Discussion

The simulations were performed using an Intel ® Core ™ i5 CPU @ 1.8 GHz computer with 8 GB RAM and Windows 10 Home Operating System - 64 bits. The tests were performed on the 33 node and 37 line system. The voltage at the substation was set at 1.0 pu. The node voltages were limited between 0.93 to 1.05 pu. The 33 node and 37 line system is described in (BARAN; WU, 1989). The initial topology of this case considers switches 33 - 34 - 35 - 36 - 37 as open, with active losses of 202.68 kW. Fig. 1 shows the 33 node system.

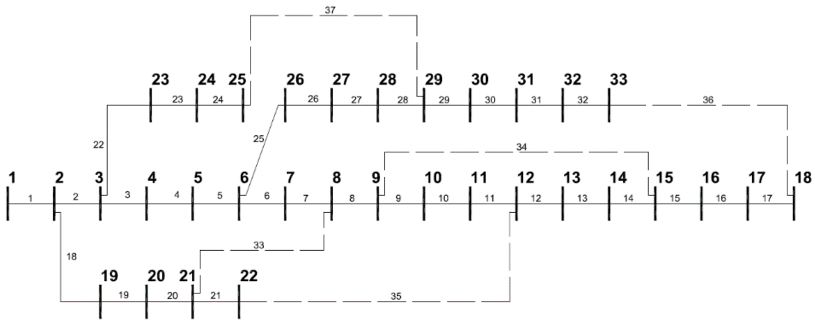

Figure 1. 33-node, 37-line system (GEREZ et al., 2019)

The choice of search and branch strategies was defined through a pre-analysis of the parameters available in the solver. Based on the parameters available in the Knitro solver, pre-simulations were performed to identify which parameters would be most effective for the tests. The parameters 'mip_selectrule' and 'mip_branchrule' were tested. The 'mip_selectrule' parameter specifies the MIP selection rule for choosing the next node in the branch and linked tree, and has 4 options: Automatic, DFS, BBS and Combo (DFS and BFS). The 'mip_branchrule' parameter specifies which branch rule is used for the MIP branch and linked procedure and has 4 options: Automatic, MFB, PCB, and SB strategies. Table I shows the results obtained with Knitro solver parameters. Although all tests converged, the values with (*) were lower than the others that converged to 139.55kW, a value found in the literature, with the best results being the parameters: Automatic and SB. Thus, this parameterization was used for the rest of the simulations.

Table 1. Pre Simulation

Pre Simulation (number of nodes)				
mip_select rule	**mip_branchrule**			
	Automatic	***MFB***	***PCB***	***SB***
Automatic	613	1057	613	249
DFS	679	911	679	1301
BBS	613	1057	613	249
Combo	403*	987	403*	431

Table 2 shows the details of the problem characteristics, iterative process, computational time and the results found.

Table 2. Final Statistics for MIP KNITRO

mip_selectrule	**Final Statistics for MIP KNITRO**			
	Automatic x Automatic	***Automatic x MFB***	***Automatic x PCB***	***Automatic x SB***
Final Objective	139,551 kW	139,551 kW	139,551 kW	139,551 kW
Nodes Processed	613	1057	613	249
Subproblems Processed	604	1285	604	730
Total program time (secs)	7,668	22,424	6,910	5,094

The proposed algorithm found the best known solution with the KNITRO Automatic and SB solver strategy, having exploited 249 nodes at the end of the process, 730 subproblems processed, spending 5,094 s in processing time. In the tested system, the solution found is in agreement with those presented in the specialized literature, showing that the methodology can be used with these parameters. The change in strategy showed a big advantage in computing expenses, from 22,424s in the Automatic version and MFB to 5,094s in the Automatic and SB version. The great advantage of the methodology is that it presents conservative solutions, which does not occur when approximate techniques are employed.

Conclusion

This paper presents a strategy for the Branch and Bound algorithm to solve mixed integer nonlinear programming problems in DNR. The proposed algorithm was implemented in AMPL and the commercial KNITRO solver was used to solve MINLP problems.

The algorithm was applied to the distribution technique reconfiguration problem with classical technique, in a 33 buses test system shown in the specialized literature. The proposed algorithm found the best known solution for the system tested, with a large reduction in the number of P MINLP problems solved, with the configuration of B&B Strong Branching strategy available in the KNITRO solver. The results show the efficiency of the algorithm which adds a contribution in time gain and computational memory with the use of the AMPL language together with the KNITRO solver.

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References

ABDELAZIZ, A. Y. et al. Distribution Systems Reconfiguration using a modified particle swarm optimization algorithm. **Electric Power Systems Research**, v. 79, n. 11, p. 1521–1530, 2009.

ABUR, A. A modified linear programming method for distribution system reconfiguration. **International Journal Electr. Power Energy Systems**, v. 18, n. 7, p. 469–474, 1996.

ACHTERBERG, T.; KOCH, T.; MARTIN, A. Branching rules revisited. **Operations Research Letters**, v. 33, n. 1, p. 42–54, 2005.

ADEYEMI AMON, D. A Modified Bat Algorithm for Power Loss Reduction in Electrical Distribution System. **TELKOMNIKA Indonesian Journal of Electrical Engineering**, v. 14, n. 1, 2015.

APPLEGATE, D. et al. **Finding Cuts in the TSP (A Preliminary Report)**. [s.l: s.n.].

BARAN, M. E.; WU, F. F. Network reconfiguration in distribution systems for loss reduction and load balancing. **IEEE Transactions on Power Delivery**, v. 4, n. 2, p. 1401–1407, 1989.

BENICHOU, M. et al. Experiments in mixed-integer linear programming. **Mathematical Programming**, v. 1, n. 1, p. 76–94, 1971.

BYRD, R. H.; NOCEDAL, J.; WALTZ, R. A. Knitro: An Integrated Package for Nonlinear Optimization. p. 35–59, 2006.

CARRENO, E. M.; ROMERO, R.; PADILHA-FELTRIN, A. An efficient codification to solve distribution network reconfiguration for loss reduction problem. **IEEE Transactions on Power Systems**, v. 23, n. 4, p. 1542–1551, 2008.

CHANG, H.-C.; KUO, C.-C. Network reconfiguration in distribution systems using simulated annealing. **Electric Power Systems Research**, v. 29, n. 3, p. 227–238, 1994.

CHIANG, H.-D.; JEAN-JUMEAU, R. Optimal network reconfigurations in distribution systems. II. Solution algorithms and numerical results. **IEEE Transactions on Power Delivery**, v. 5, n. 3, p. 1568–1574, 1990a.

CHIANG, H. D.; JEAN-JUMEAU, R. Optimal network reconfigurations in distribution systems--I: A new formulation and a solution methodology. **IEEE Transactions on Power Delivery**, v. 5, n. 4, p. 1902–1909, 1990b.

FOURER, R.; GAY, D. M.; KERNIGHAN, B. W. A Modeling Language for Mathematical Programming. **Management Science**, v. 36, n. 5, p. 519–554, 1990.

GEREZ, C. et al. Distribution Network Reconfiguration Using Selective Firefly Algorithm and a Load Flow Analysis Criterion for Reducing the Search Space. **IEEE Access**, v. 7, p. 67874–67888, 2019.

GLAMOCANIN, V. **Optimal loss reduction of distributed networksIEEE Transactions on Power Systems**, 1990.

ISAC SILVA, L.; ANTONIO BELATI, E.; CHAVES SILVA JUNIOR, I. Heuristic Algorithm for Electrical Distribution Systems Reconfiguration Based on Firefly Movement Equation. **IEEE Latin**

America Transactions, v. 14, n. 2, 2016.

JIN, X.; ZHAO, J.; SUN, Y. Distribution network reconfiguration for load balancing using binary particle swarm optimization. **International Conference on Power System Technology**, 2005.

LAND, A. H.; DOIG, A. G. An Automatic Method of Solving Discrete Programming Problems. **Econometrica**, v. 28, n. 3, p. 497–520, 1960.

MANTOVANI, J. R. S.; CASARI, F.; ROMERO, R. A. Reconfiguração de Sistemas de Distribuição Radiais Utilizando o Critério de Queda de Tensão. **SBA Controle & Automação**, v. 11, n. 03, p. 150–159, 2000.

MARTÍN, J. A.; GIL, A. J. A new heuristic approach for distribution systems loss reduction. **Electric Power Systems Research**, v. 78, n. 11, p. 1953–1958, 2008.

MERLIN, A.; BACK, H. **Search for a Minimal-Loss Operating Spanning Tree Configuration in an Urban Power Distribution System**Procedings 5th Power System Computation Conference (PSCC), , 1975.

MONTICELLI, A. J. **Alcir Jose Monticelli**, 1983.

MORI, H.; OGITA, Y. A Parallel Tabu Search Based Method for Reconfigurations of Distribution Systems. **IEEE Power Engineering Society Summer Meeting**, v. 1, p. 73–78, 2000.

MORRISON, D. R. et al. Branch-and-bound algorithms: A survey of recent advances in searching, branching, and pruning. **Discrete Optimization**, v. 19, p. 79–102, 2016.

NARA, K. et al. Implementation of Genetic Algorithm for Distribution Systems Loss Minimum Re-Configuration. **IEEE Transactions on Power Systems**, v. 7, n. 3, p. 1044–1051, 1992.

NAVEEN, S.; SATHISH KUMAR, K.; RAJALAKSHMI, K. Distribution system reconfiguration for loss minimization using modified bacterial foraging optimization algorithm. **International Journal of Electrical Power & Energy Systems**, v. 69, p. 90–97, 2015.

NGUYEN, T. T.; TRUONG, A. V. Distribution network reconfiguration for power loss minimization and voltage profile improvement using cuckoo search algorithm. **International Journal of Electrical Power and Energy Systems**, v. 68, p. 233–242, 2015.

OLIVEIRA, M. B. C. D. **Reconfiguração de Alimentadores em Sistemas de Distribuição Usando a Metaheurística GRASP**. Dissertação de Mestrado—[s.l.] Faculdade de Engenharia de Ilha Solteira - FEIS, Universidade Estadual Paulista - UNESP, Ilha Solteira - SP, 2011.

PRIETO, L. P. V; BELATI, E. A. B.; VITTORI, K. **Reconfiguração de Sistemas de Distribuição de Energia utilizando PSO Modificado**. The XI Latin-American Congress Electricity Generation And Transmission - Clagtee 2014. **Anais**...2014

SHIRMOHAMMADI, D.; HONG, H. W. **Reconfiguration of electric distribution networks for resistive line losses reductionIEEE Transactions on Power Delivery**, 1989.

SU, C. T.; CHANG, C. F.; CHIOU, J. P. Distribution network reconfiguration for loss reduction by ant colony search algorithm. **Electric Power Systems Research**, v. 75, n. 2–3, p. 190–199, 2005.

ZHANG, D.; FU, Z.; ZHANG, L. An improved TS algorithm for loss-minimum reconfiguration in large-scale distribution systems. **Electric Power Systems Research**, v. 77, n. 5–6, p. 685–694, 2007.

ZHU, J. Z. Optimal reconfiguration of electrical distribution network using the refined genetic algorithm. **Electric Power Systems Research**, v. 62, n. 1, p. 37–42, 2002.

EVALUATION OF GENERATED BIOGAS PRODUCTION DURING THE SPECIFIC METHANOGENIC ACTIVITY OF DIFFERENT ANAEROBIC INOCULA

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ABSTRACT

This study presents an evaluation of the specific methanogenic activity performed with two distinct inocula: Dacar (anaerobic reactor sludge from the Dacar's farm) and GOP (sludge from the anaerobic reactor at Ouro Preto farm). The final product obtained, biogas, besides being considered an alternative source of energy is also a solution for the treatment of livestock residues and environmental pollution generated by this activity. In this study, the analysis of total and volatile solids of the inocula was carried out. Then, according to the set standards the amount of substrate for each sludge was defined. For the reaction of the specific methanogenic activity, the equipment automatic methane potential test system (AMPTS) II was used, being programmed to maintain the temperature at 35ºC and the bottles under constant agitation. The results showed that in few hours there was a maximum CH_4 production rate for Dacar inoculum was 7,23 NmLCH4.day^{-1}. For the GOP inocula the maximum methane production rate was 11,92 NmLCH4.day^{-1}. The results concluded that the microorganisms present in Dacar sludge have lower methanogenic activity and consequently lower methane gas production when compared to GOP inoculum.

Keywords: anaerobic sludge, agroindustrial waste, methane, biogas.

Introduction

The current energy scenario of the country allows the growth of clean technologies, such as the bigger use of biomass (ANEEL, 2002). According to the International Energy Agency (1998), a.k.a. ANEEL (2002), it is estimated that by 2020 the global energy matrix will be made up of 11% biomass. This is one of the strategies used to promote a decentralized market while at the same time intensifying the need for more rational use of energy (EPE, 2016). Among the biomass, stand out the sludge, also known as inoculum, that comes from the treatment of agro-industry, such as swine, poultry and cattle

The inoculum have such microbiological diversity that, upon contact with any organic substrate, produces a series of reactions whose main product is biogas (CH_4 + CO_2, among other gases). One way to evaluate the viability of the maximum biochemical activity of converting organic substrates to biogas using inoculum is by Specific Methanogenic Activity (SMA) test. In general, SMA is defined as the maximum capacity of methane production by anaerobic inoculum microorganisms under specific laboratory conditions (SIMÕES, 2017). SMA is expressed in $gDQO_{CH_4}$/gSVT.day, with the specific maximum rate of CH_4 gas formation.

The procedures for determining SMA are diverse in the literature. And, due to this factor, one of the difficulties in performing the tests is the lack of international standardization, which makes it difficult to compare the results obtained (AQUINO et al., 2007).

In this work, two inocula from different origins were analyzed according to their SMA. The first (Dacar) is a granular inoculum from a UASB reactor used to treat wastewater from a poultry slaughterhouse. The second one, GOP, is a less dense inoculum, originating from a UASB reactor used to treat swine manure raised for slaughter.

Material and Methods

Inoculum samples were collected directly at the place of origin (Dacar poultry, in Tietê, SP and Ouro Preto farm, in Ibiúna, SP), stored in plastic drums, and stored in a freezer at 4ºC when arriving at the laboratory at the Federal University of São Paulo. ABC campus SBC.

For SMA, the procedures were established by AQUINO et al. (2007). First, the food (substrate) / inoculum (microorganisms) ratio of 0.25 g COD / gSVT and the inoculum concentration of 10 g SVT / L were determined. The substrate concentration from the parameters determined above was calculated at 2.5 g COD / L. It was also considering the theoretical COD of acetic acid (substrate) which is 106.67 g / L.

Subsequently, the substrate solution and the nutrient stock solution (macronutrients and micronutrients) were prepared, as established by SIMÕES (2017).

In order to obtain the SVT content of the inoculum, the solids series was performed according to the procedures of the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

With this information, it was possible to make the experimental design with the amount of inoculum, substrate and nutrient solution to be added in each reactor flask. To complete the total of 300 mL of each, distilled water was added. For both inocula samples were made in triplicate.

Thus, the reactors were prepared with the amounts of inoculum, nutrient solution and water previously determined. Then, each reactor was coupled to the AMPTS II (Bioprocess Control) equipment. Afterwards, N2 gas was injected into each sample for two minutes. Gas circulation was performed to ensure the anaerobic environment necessary for SMA to occur. Then, the equipment water bath was set at 35ºC and the stirring system was turned on.

Prior to substrate addition, the pH was adjusted to approximately 7.0 by addition of sodium hydroxide (NaOH) solution. Finally, the substrate was added to all reactor flasks, the measurement time was followed until the eighth day of the experiment, when CH_4 production began to stabilize.

At the end of the trial, the AMPTS II system provided an Excel spreadsheet with the collected data. To obtain the accumulated methane production curve per day for each inoculum, the triplicate averages were calculated, excluding the values obtained by the reactors used as blank (AQUINO et al., 2007).

On this curve, a second degree polynomial curve was projected, from which the derivative was calculated to obtain the maximum slope.

Results and Discussion

With the results of the series of solids it was possible to determine the total volatile solids concentrations to calculate the amount, in mL, of each inoculum that was added in each reactor. The fixed solids and volatile solids content can be observed in Figure 1.

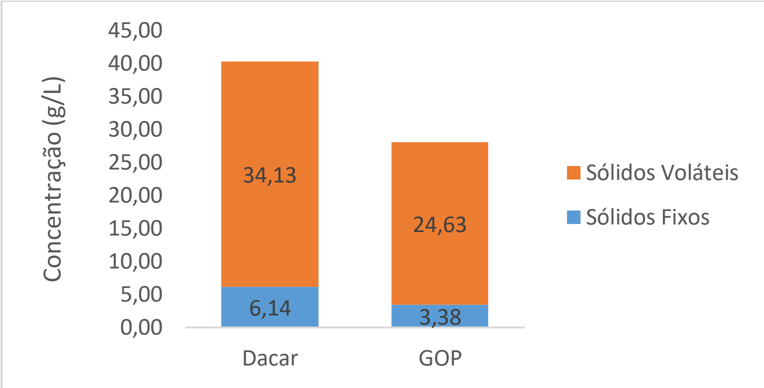

Figure 1. Dacar and GOP inoculum solids series.

The Dacar inoculum had a volatile solids content of 34.13 g / L, about 38.6% more than the GOP inoculum. This difference is mainly due to the granular characteristic of the first sludge, which has a higher density. From the parameters established in the methodology, it was possible to obtain the experimental design of the SMA assays, as observed in Table 1.

Table 1. Experimental design for the SMA assay.

	Amostra	**Inóculo (mL)**	**Substrato (mL)**	**Nutrientes (µL)**	**Água destilada (mL)**
1	Dacar Branco (1)				
2	Dacar Branco (2)		-		212,11
3	Dacar Branco (3)	87,89			
4	Dacar Subst. (1)				
5	Dacar Subst. (2)		7,03		205,08
6	Dacar Subst. (3)			3	
7	GOP Branco (1)				
8	GOP Branco (2)		-		151,40
9	GOP Branco (3)	148,60			
10	GOP Subst. (1)				
11	GOP Subst.(2)		7,03		144,37
12	GOP Subst.(3)				

The physicochemical parameters of pH and total alkalinity were evaluated before and after SMA and the means for the triplicates of each reactor flask can be observed in Table 2.

Table 2. pH and total alkalinity values before and after SMA for both inocula.

Sample	Average initial pH inicial	Average final pH	Average total initial alkalinity ($mgCaCO_3/L$)	Average total final alkalinity ($mgCaCO_3/L$)
Dacar (Branco)	7,86 ± 0,07	7,58 ± 0,12	1210 ± 57,85	2073 ± 64,70
CV (%)	0,85	1,62	2,97	3,12
Dacar + ácido acético	6,22 + 0,03	7,14 ± 0,02	1173 ± 67,98	1950 ± 84,85
CV (%)	0,45	0,30	3,49	4,35
GOP (Branco)	7,97 ± 0,08	8,27 ± 0,10	1723 ± 134,67	6675 ± 246,37
CV (%)	1,04	1,15	3,21	3,69
GOP + ácido acético	6,13 ± 0,09	8,00 ± 0,06	1538 ± 129,72	6225 ± 176,78
CV (%)	1,50	0,71	2,87	2,84

Generally, although some pH values are outside the range considered ideal for the development of methanogenic archaeas (between 6.8 to 7.4), the system alkalinity fulfilled its buffering role, preventing the acidification of the medium.

The specific methanogenic activity obtained in the tests can be observed in Figures 2 and 3, which show the projection of the second degree polynomial function over the function that represents the accumulated volume of gas over time.

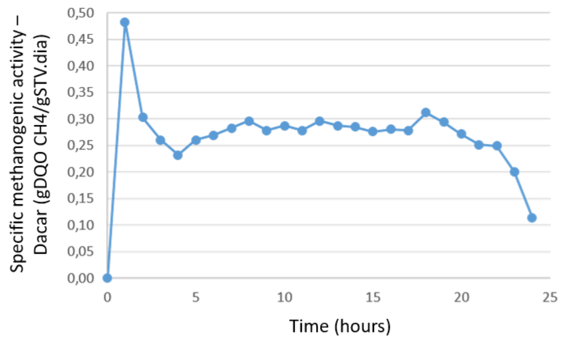

Figure 2. Accumulated methane volume - Dacar inoculum assay.

The Dacar inoculum maximum CH_4 production rate was 7.23 $NmLCH_4.day^{-1}$. As the inoculum concentration for each reactor flask was set at 10 gSVT / L, and considering that each sample contained 300 mL altogether, the amount of STV present in each sample was 3g. Also, taking into consideration the stoichiometric calculations of methane oxidation, according to AQUINO et al. (2007), it is possible to express the maximum gas production rate in $gDQOCH_4.gSTVinóculo^{-1}.day^{-1}$. Therefore, Dacar inoculum AME was 0.48 $gDQOCH_4.gSTVinocular^{-1}.day^{-1}$.

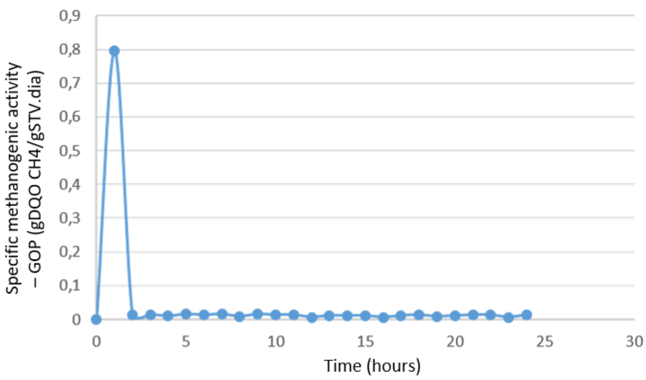

Figure 3. Accumulated methane volume - GOP inoculum assay.

The AME assay using the GOP inoculum showed a maximum methane production rate of 11.92 NmLCH4.day^{-1}. Using the same parameters as described for obtaining the Dacar inoculum assay SMA, the GOP sludge assay SMA was 0.80 gDQOCH4.gSTVinocular^{-1}.day^{-1}. Thus, GOP inoculum was higher in methane production than Dacar inoculum.

ANGELIDAKI et al. (2009) point out in their work that, for inoculants to be considered active, those that are non-granular, or those with low granulation, as is the case with the GOP inoculum, must have AME at least 0.1 acetic acid. gDOQCH4.gSTV^{-1}.day^{-1}, result achieving in this work

The result with the Dacar inoculum approached what was found when performing SMA with granular sludge from a UASB reactor that treats domestic sewage: 0.19 gDOQCH4.gSTV^{-1}.day^{-1} (SIMÕES, 2017).

Conclusion

For the pre-established conditions, the results of inoculum SMA concluded that the microorganisms present in Dacar sludge have lower methanogenic activity and consequently lower methane gas production when compared to GOP inoculum. It is noteworthy that comparisons with the literature are complex, since there is no standardization for this essay, and the conditions that each author establishes can influence the data comparison.

Acknowledgment

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References

ANEEL. Agência Nacional De Energia Elétrica (Brasil). **Atlas de energia elétrica do Brasil.** Brasília, 2002. 153 p.

APHA, AWWA;WEF. **Standard Methods for the Examination of Water and Wastewater.** 21ª Edição. Washington: American Public Health Association, 2005. 1368 p.

AQUINO, S. F. CHERNICHARO, C. A. L., FORESTI, E., SANTOS, M. L. F., MONTEGGIA, L. O. Metodologias para determinação da Atividade Metanogênica Específica (AME) em Lodos Anaeróbios. **Engenhari Sanitária e Ambiental**, v 12, n 2, p 192-201, 2007.

EPE. Empresa de Pesquisa Energética. **Energia Renovável Hidráulica, Biomassa, Eólica, Solar, Oceânica.** Rio de Janeiro, 2016. 452 p.

SIMÕES, A. L. G. Estudo da aclimatação de lodos anaeróbios como estratégia de inoculação para partida de biometanizadores alimentados com fração orgânica dos resíduos sólidos urbanos. **Dissertação (Mestrado)**. Programa de Pós-graduação em energia Hidráulica e Saneamento e Área de Concentração em Hidráulica e Saneamento. Escola de Engenharia de São Carlos da Universidade de São Paulo. 2017. 316 p.

BIOSIM: THE ANAEROBIC DIGESTION SIMULATOR

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ABSTRACT

Biogas is a very promising renewable energy source and its use has increased in recent years. However, biogas laboratory research is time consuming and requires skilled labor and expensive equipment. BioSim is an anaerobic digestion computer simulator using artificial intelligence and is designed to help biogas researchers achieve fast and accurate results from anaerobic digestion of substrates and inoculums combinations with minimal configuration. As first results with a set of twelve samples, BioSim obtained an R^2 = 0.9915 and MAPE = 1.6%, which can be considered excellent for a work in progress project, showing that BioSim development deserves more effort. Moreover, these results also show that the artificial intelligence technique used in BioSim, Agent-Based Modeling and Simulation, can make interesting contributions to laboratory-scale anaerobic digestion simulation.

Keywords: Biogas; Agent-Based Modeling; Computational Simulation; Virtual Digester

1. Introduction

Biogas and biomethane production are a very common option for biomass energy recovery. Firstly, biomethane is a promising substitute for fossil fuels, and can be used both for transportation and in combined heat and power plants. Secondly, biogas can be produced by the anaerobic digestion of manure, agricultural residues and municipal solid waste, and it is an alternative to the treatment for these wastes (BIERNACKI et al., 2013). Biogas is composed mainly of methane (50~60% by vol.) and carbon dioxide (40~45%), with small traces of other gases (BEYLOT et al., 2012). Biomethane is a purified biogas, with a higher concentration of methane (above 94%) and can substitute natural gas for all purposes (BLEY, 2015). In Brazil, biomethane is inserted in the gas distribution network and it is used in residential cooking, water heating and as vehicle fuel.

According to EPE (2018), the biomass energy potential in Brazil will increase from 250 million TOE (tons of oil equivalent) in 2018 to 520 million TOE by 2050, and 60% of this increment will come from biogas. Brazil is making a significant effort to increase the biogas production due to the large availability of agricultural and livestock waste.

In order to increase the biogas production, it is very common to mix different substrates, or to add an inoculum to the original organic waste. There are plenty of works on this subject (ACHINAS et al., 2017; KOCH et al., 2017; GUVEN et al., 2018; HOBBS et al., 2018), with studies on different mixtures and proportions between substrates and/or inoculums. However, laboratorial researches require highly technological equipment, skilled labor, and time-consuming experiments, usually with a high cost, which can make the research unfeasible.

In order to predict the biogas yield and its composition, several models were developed. Anaerobic Digestion Model 1 (ADM1) is a well-known mathematical model (BATSTONE et al., 2002), and it has been used, with minor adjustments, by many researchers (CHEN et al., 2016; SENDJAJA et al., 2015; SATPATHY et al., 2013). There are mathematical models based on multivariate regression (LAUWERS et al., 2013) and other non-linear mathematical methods (GODIN et al., 2015; GARCÍA-GEN et al., 2014). Some artificial intelligence techniques have been used to create computational models, like artificial neural networks (JAIN et al., 2015) and genetic algorithms (KRAUSE et al., 2015).

The aim the present study was to develop a laboratory scale anaerobic digestion computer simulator that can be used with an wide range of substrates and inoculums, but keeping the configuration simple, obtaining a satisfactory prediction of both biogas yield and its composition from a reduced set of configuration parameters.

2. Material and Methods

BioSim, the anaerobic digestion simulator, uses an artificial intelligence technique called Agent Based Modeling and Simulation, and consists of four modules:

1) the database of substrates and inoculums, with both physical and chemical properties;
2) the simulation module, where the experiment parameters are configurated;
3) the virtual digester, where the biochemical reactions of the anaerobic digestion are simulated;
4) the data output module, which provides information about the biogas production process.

The development of BioSim was divided into seven steps, as shown in Figure 1. The first step was to find the prediction models that could be used to implement the rules of the simulator. An extensive literature review was performed in order to find both mathematical and statistical models of biogas production forecasting that are simple and yet versatile. BioSim intend to be used with a wide range of organic matter, so it was important that the model implemented in the virtual digester could be applied to a large variety of biomasses.

After choosing the model, the next step was to define the parameters used in the substrates and inoculums database, as well as the parameters used to configure the simulations. The main papers used to define such parameters were the works of Angelidaki et al. (2009) and Raposo et al. (2011). Both works propose protocols to ensure the reproducibility of laboratorial essays of biogas / biomethane production.

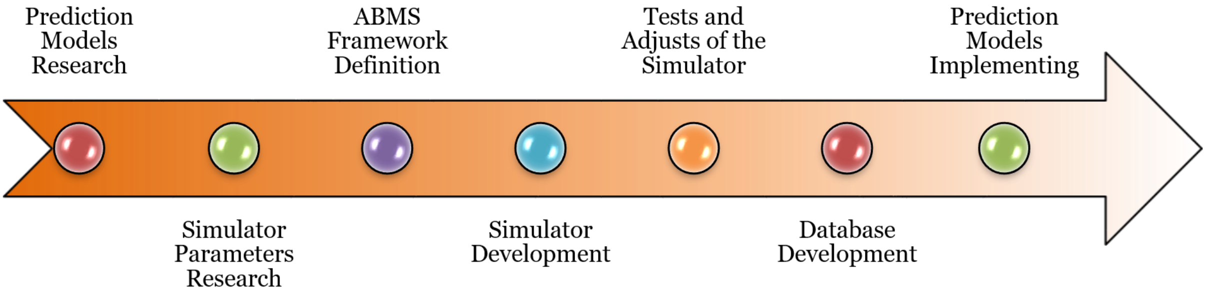

Figure 2. The seven methodology steps.

The third step was to define the ABMS framework most suitable for the task (biochemical reaction modeling and simulation). There are several ABMS frameworks, most of them available under a free license. However, biochemical processes simulated in BioSim have two important characteristics: the large number of agents interacting and the need of tridimensional representation, in order to allow both temporal and spatial analysis of the anaerobic biodigestion. At the end of the research, the MASON framework (LUKE, 2015), developed by the Department of Computing Science of the George Mason University was selected.

With the ABMS framework defined, the next step was the development of the simulator. The virtual simulator is a fixed-size three-dimensional matrix with a continuous space, where all interactions between simulator agents take place. The agents "live" and interact each other inside an environment that simulates a real biodigester, where variables such temperature and stirring speed can be controlled.

After creating of the biodigester environment, the next step was the implementation of the agents present in the simulator. At first, substrate agents – the computational representation of the organic matter to be decomposed – were implemented. Substrate agents come from de substrate database and their behavior depend on the characteristics registered in that database. Inoculum agents were then developed, and their behavior is far more complex than substrate agents, because inoculum agents are responsible for the decomposition of the organic matter (substrate agents), and they can grow, multiply and die inside the virtual biodigester. Finally, the biogas agents (methane and carbon dioxide) were implemented in the simulator.

The interaction between agents are determined by the rules implemented in the simulator. These rules depend on four specifications:

(i) the characteristics of the agents registered in the database;
(ii) the configuration parameters of the simulation;

(iii) the biochemical reactions of the anaerobic digestion;
(iv) the mathematical model implemented in the virtual digester.

Each rule implemented in BioSim uses the basic principles of anaerobic digestion and follows the production forecast provided by the mathematical model used, according to the simulation parameters and the characteristics of the agents retrieved from the database. Furthermore, the results of BioSim are subject to variations due to the stochastic nature of the ABMS.

The last two steps are database development and implementation of the prediction models. These two steps are intended to be in continuous development, with more substrates and inoculum added to the database as more researchers start using BioSim, and new mathematical or statistical models are incorporated into the simulator.

3. Results and Discussion

Presently, BioSim is a work in progress, and new results will be available soon. Meanwhile, a comparison with a statistical model was performed to validate the rules implemented in the simulator so far.

The results of BioSim were compared with the forecasting model published in the work of Schievano et al. (2009). The database was created with the data from the twelve samples available in Schievano work. After the database creation the simulations were processed with the same parameters used by Schievano, and then the biogas production predictions were compared.

Figure 3 shows the correlation graph of BioSim biogas production forecasts and the forecasts obtained from the Schievano model. The correlation coefficient R^2 = 0.9915 shows the excellent performance of BioSim, whose prediction values were very close to the prediction values of the statistical model.

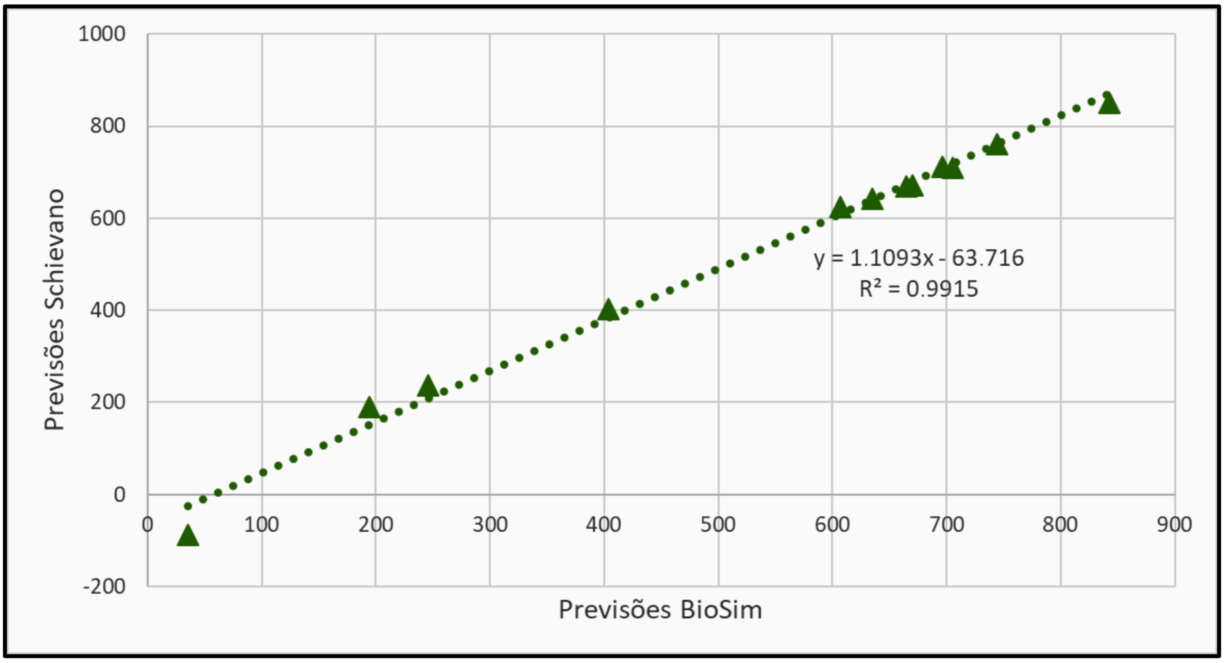

Figure 3. BioSim predictions vs. Schievano model predictions.

It is important to note that BioSim produces very similar predictions using a totally different approach. The prediction values of BioSim are the result of applying the interaction rules between agents, and their final values emerge from these interactions, and the simulator predicts also the daily production (kinetics of the process), not only the final yield. Figure 4 shows the daily production of methane, carbon dioxide and total biogas, estimated by BioSim, during the sixty days of the simulation, for one of the Schievano samples (vegetable wastes). The BioSim data output module allows daily tracking of each of the simulation agents, generating a rich supply of information about the reactions that occur inside the virtual digester.

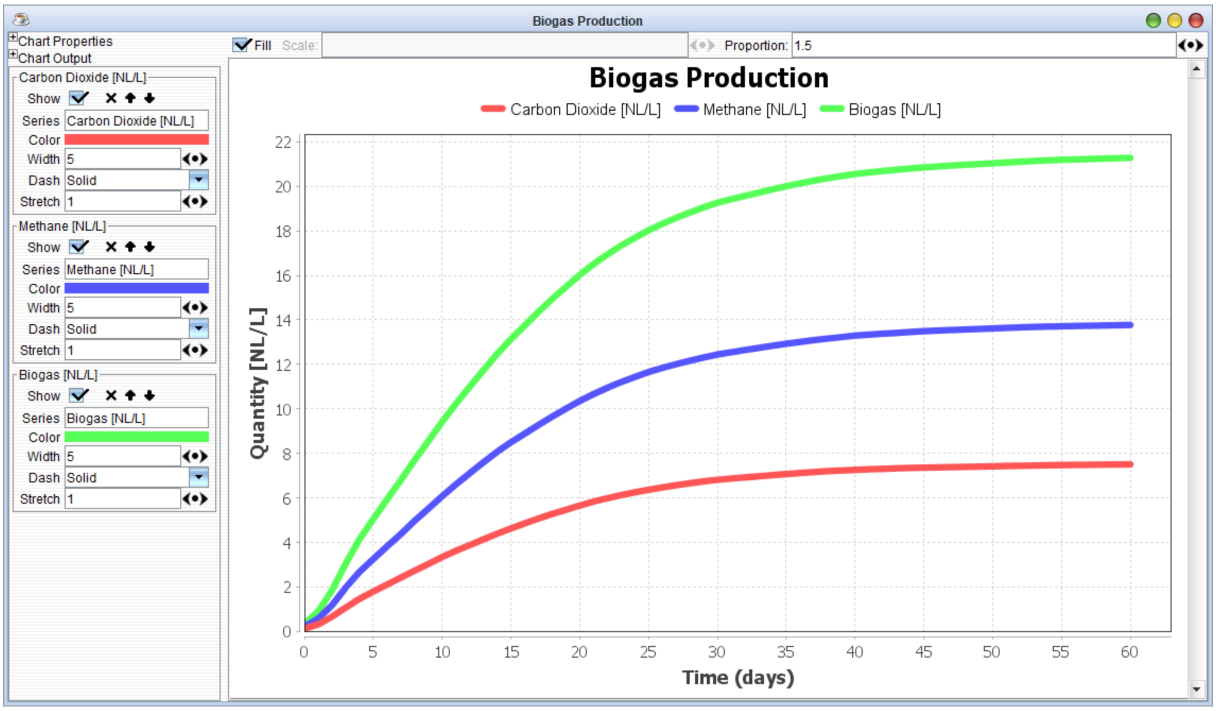

Figure 4. BioSim daily predictions for methane, carbon dioxide and biogas.

Besides de R^2, three other indices were analyzed, as shown in Table 1. A MAPE = 1.6% shows that the predictions of BioSim differ by 1.6% of the Schievano model predictions, on average. This is an excellent result, confirming that BioSim has a similar accuracy to the models from literature. The AAD = 8.3 means that there was an average difference of 8.3 NL/kg TS in BioSim forecasts, and ABE = -0.4% indicates that BioSim has a slight tendency to underestimate the value of biogas production, when compared to the Schievano model.

Table 3 . Performance indices from BioSim predictions.

Index	MAPE	AAD	ABE
Valor	1.6%	8.3 [NL/Kg TS]	-0.4%

MAPE: Mean Absolute Percentage Error
AAD: Absolute Average Deviation
ABE: Average Bias Error

4. Conclusion

BioSim is a work in progress, and new prediction models and more substrates and inoculums will be added to the simulator database. However, the preliminary results seem to be very promising. The main advantages of using BioSim are:

(i) the ability to analyze the agent behavior during anaerobic digestion;

(ii) the usability of the simulator, which can make predictions with a minimum of input parameters.

Due to these two characteristics BioSim can contribute to the laboratorial research on biogas production from anaerobic digestion, saving time, lowering the costs of the research and enabling increasing the number of laboratorial experiments.

5. Acknowledgment

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6. References

ACHINAS, S. et al. A Technological Overview of Biogas Production from Biowaste. **Engineering**, v. 3, n. 3, p. 299–307. Elsevier LTD on behalf of Chinese Academy of Engineering and Higher Education Press Limited Company, 2017. DOI: 10.1016/J.ENG.2017.03.002.
ANGELIDAKI, I. et al. Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays. **Water Science and Technology**, v. 59, n. 5, p. 927–934. 2009. DOI: 10.2166/wst.2009.040.
BATSTONE D.J. et al. The IWA Anaerobic Digestion Model No 1 (ADM1). **Water Science and Technology,** Vol 45, Issue 10, Pages 65-73. IWA Publishing, 2002.
BEYLOT A. et al. Life Cycle Assessment of landfill biogas management: Sensitivity to diffuse and combustion air emissions. **Waste Management** 33, 401–411. Elsevier Ltd, 2012.
BLEY Jr., C. Biogas: the invisible energy. 2nd ed. São Paulo: Atol Studio, 2015.
BIERNACKI, P. et al. Application of Anaerobic Digestion Model No. 1 for describing an existing biogas power plant. **Biomass and Bioenergy** 59: 441-447. Elsevier Ltd., 2013.
CHEN, X., CHEN, Z., WANG, X., HUO C., HU Z., XIAO B., HU M. Application of ADM1 for modeling of biogas production from anaerobic digestion of Hydrilla verticillata. **Bioresource Technology** 211:101-107. Elsevier, 2016.
EPE – Energy research company. Brazilian Energy Resources Potential by 2050. Technical Note PR 04/18. Sept. 2018. Rio de Janeiro: EPE, 2018.
GARCIA-GEN, et al. Optimization of substrate blends in anaerobic co-digestion using adaptive linear programming. **Bioresource Technology**, vol. 173, pp. 159-167, Dec. 2014.
GODIN, B. et al. Biochemical methane potential prediction of plant biomasses: Comparing chemical composition versus near infrared methods and linear versus non-linear models. **Bioresource Technology**, vol. 175, pp. 382-390, Feb. 2015.
GUVEN, H. et al. Co-digestion performance of organic fraction of municipal solid waste with leachate: Preliminary studies. **Waste Management**, v. 71, p. 775–784. Elsevier Ltd, 2018. DOI: 10.1016/j.wasman.2017.04.039.
HOBBS, S. R. et al. Enhancing anaerobic digestion of food waste through biochemical methane potential assays at different substrate: inoculum ratios. **Waste Management**, v. 71, p. 612–617. Elsevier Ltd, 2018. DOI: 10.1016/j.wasman.2017.06.029.
JAIN, V. et al. Predictive modeling of an industrial UASB reactor using NARX neural network. **International Renewable Energy Congress** (IREC), pp. 1-6, 2015.
KOCH, K. et al. E. The role of inoculum's origin on the methane yield of different substrates in biochemical methane potential (BMP) tests. **Bioresource Technology**, v. 243, p. 457–463. Elsevier Ltd, 2017. DOI: 10.1016/j.biortech.2017.06.142.
KRAUSE, D. et al. Online monitoring of bioprocesses via multivariate sensor prediction within swarm intelligence decision making. **Chemometrics and Intelligent Laboratory Systems**, vol. 145, pp. 48-59, Jul. 2015.
LAUWERS, J. et al. Mathematical modelling of anaerobic digestion of biomass and waste: Power and limitations. **Progress in Energy and Combustion Science**, vol. 39, Issue 4, pp. 383-402, Aug. 2013.
LUKE, S. Multiagent Simulation And the MASON Library. Manual version 19. George Mason University, 2015. Available in https://cs.gmu.edu/~eclab/projects/mason/. Accessed in Aug 20, 2019.
RAPOSO, F. et al. Biochemical methane potential (BMP) of solid organic substrates: Evaluation of anaerobic biodegradability using data from an international interlaboratory study. **Journal of Chemical Technology and Biotechnology**, v. 86, n. 8, p. 1088–1098. 2011. DOI: 10.1002/jctb.2622.
SATPATHY P. et al. Application of Anaerobic Digestion Model 1 (ADM1) for Prediction of Biogas Production. **International Journal of Scientific & Engineering Research**, Vol 4, Issue 12, Dec 2013.
SCHIEVANO, A. et al. Bioresource Technology Prediction of biogas potentials using quick laboratory analyses: Upgrading previous models for application to heterogeneous organic matrices. **Bioresource Technology**, v. 100, n. 23, p. 5777–5782. Elsevier Ltd, 2009. DOI: 10.1016/j.biortech.2009.05.075.
SENDJAJA, A. et al. Regression based state space adaptive model of two-phase anaerobic reactor. **Chemosphere**, vol. 140, pp. 159-166, 2015.

EVOLUTIONARY SOCIO-BIO INSPIRED TECHNIQUE - ESBIT

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ABSTRACT

This paper presents the new Evolutionary Socio-Bio Inspired Technique to solve large and complex problems of optimization and decision support. This technique is inspired in the impact of social arrangement on biological evolution and in the gradual increase of complexity and differentiation of species along time. It has been successfully implemented and applied to the problem of long term energetic planning of hydro-thermal power systems presented in the paper.

Keywords: Evolutionary computation, Artificial intelligence, Decision support system, Power generation planning, Optimization.

Introduction

Artificial intelligence techniques such as genetic algorithms (GA) and particles swarms optimization have found its practical application in many engineering areas in which decision support, selection, adjusts or optimization is needed. It has been mainly used to solve problems with no traditional techniques available or in which those techniques are subjected to restrictions and therefore, simplifications are applied to the model [1-10].

This is the case of the hydrothermal operation planning problem, once the long term energetic planning of hydrothermal power systems is a non-linear, non-convex, complex problem of large dimensions which is interconnected in time and space with non-separable objective function [11-17].

The problem consists in the optimization of total operational costs of an electrical power grid of multiple hydroelectric plants and its thermal energy complementation. Minimal costs is obtained with the scheduling of monthly energy dispatch of each hydroelectric power plant during the planning period, taking into consideration the forecasted behavior of rivers' inflows and energy consumption expectations. The complexity of this problem resides in the fact that whenever power plants are installed in the same river or in cascade, the availability of water in one plant depends on the operation of the plants upstream [16-18].

Modeling of GA with real numbers to solve this problem was first proposed in 1998 [16, 17] and has been successfully used since them [19-22].

In spite of the improvements introduced with additional specialized operators [23], the complexity and dimensions of the problem is still a major difficulty when dealing with real numbers of double representation (64 bits). This difficult is frequently translated in very long and time consuming simulations until an acceptable solution is found.

Therefore, this paper introduces a new evolutionary metaheuristic with dynamically increasing complexity, which is inspired in social behavior of individuals, inside colonies and among different colonies impacting species evolution. This new technique provides socio-bio inspired mechanisms to accelerate problem solving while avoiding early manifestation of dominant individual in a local minimum. Finally, a case study with realistic data from the Brazilian power system is presented to illustrate the good performance of this proposed technique in the optimization of large scale problems.

Material and Methods

In the Socio-Bio Inspired Technique, individual, characterized by its DNA, represents one complete solution of the problem, providing values to all variables necessary to evaluate it. Once all individuals are subject to the objective function, it is possible to rank them (each set of value for the variables) by its adaptation to the objective function. In the case study, an individual has a DNA with three chromosomes of 24 genes each, corresponding to three power plants and a planning period of two years. Each gene has the characteristic of the planned normalized volume of water stored in the power plant reservoir in a corresponding month, similar to the GA model presented in [16, 17].

In the proposed Evolutionary Socio-Bio Inspired Technique (ESBIT), multiple colonies are created, depending on the availability of computational resources. As an example, up to 250 non-synchronous colonies (independent logical threads) were used in tests of ESBIT in the computer cluster of Federal University of ABC (type SGI H2106-G7 of 64 Cores/ 4 sockets equipped with AMD processor Opteron Sixteen-Core 6376, 2.3 GHz with 6 MB cache, 6.4 GT/s and 256 GB of RAM, DDR3 1600 MHz).

Each of the colonies is home of three coexisting generations (populations) which includes individuals classified as infants, young adults and senior adults. In the growing and maturing process from infant to senior adults, population size is reduced and only the individuals better adapted survive. The longer the individual survives, the greater are their chances to have their genes passed to the next generation of infants. Thus, coexistence of generations preserves the strongest while allows a large degree of diversity which can be tuned according to the problem. Within ESBIT a preferable reproduction strategy is also dedicated to the reproduction of senior adults, both among themselves and with young adults.

During the generation's cycles of the ESBIT, individuals may be selected to depart from its colony and eventually arrive in another one that accepts an immigrant individual. This implementation allows good flexibility in the case of asynchronously computed parallel colonies. The probability of migration regulates the movement of the population and allows the control of the diversity while it avoids premature stagnation of one colony [24, 25].

Once the convergence criterion is reached, the evolution criterion is checked. In the context of the problem solution, evolution is reached when sufficient precision is obtained in the calculated solution. Different from the approach from [16, 17], where the genes are represented by real numbers with extremely high precision, in ESBIT the gene represents the normalized value of the variable with a positive integer. The end of the scale of the positive integers limits the precision of the solution and its granularity. If the precision after reaching the convergence criteria is not adequate, it can be improved by increasing the complexity of the system i.e. reducing the size of the discrete steps of possible solutions (in powers of 10 for simplification). The gene value is therefore:

$$gene\ value = \ [0, a] \mid a \ \in \{10^1, 10^2, \dots 10^n\}$$

where: n is an integer number that defines the precision required for the problem and the evolution criterion for the conclusion of the calculation as illustrated in Figure 1.

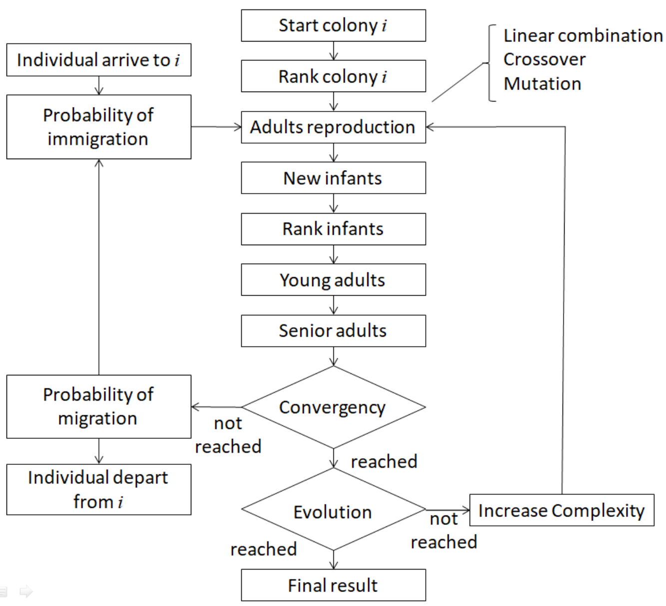


Figure 1. Algorithm implemented for each colony of ESBIT.

Traditional techniques of reproduction from the genetic algorithms have been used in the ESBIT implemented, namely: linear combination, crossover and mutation. However, besides the possibility to increase the complexity in controlled steps, the evolution (complexity increase) is also used to affect the reproduction mix of techniques and to adjust the mutations' scope and intensity, different from other previous reported techniques [26, 27].

Depending on the evolution stage, adaptation requires more emphasis on a greater search scope while in other stage it may require more refinement and local search.

Case Study

The case study was selected to check the applicability and efficacy of the ESBIT in a problem of considerable scale. A part of the Brazilian electric system composed by three power plants with reservoirs along Parnaíba River was selected for optimization of their operation scheduled.

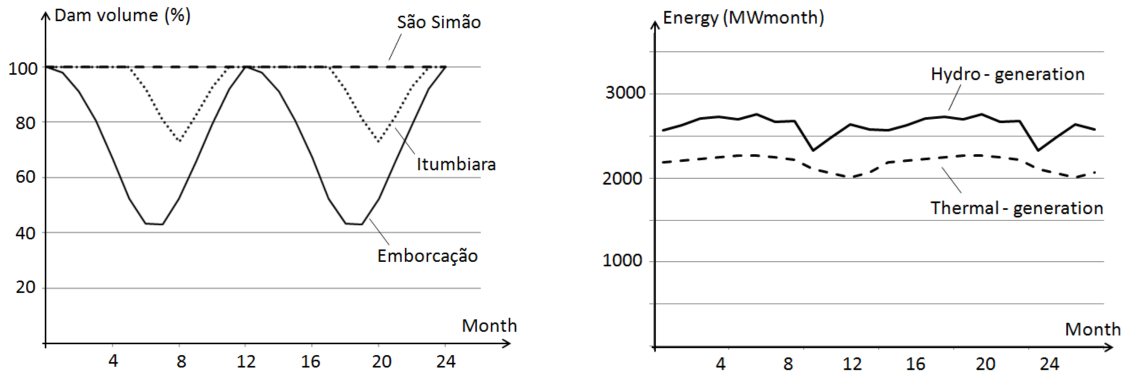
Optimal operation of a Hydrothermal- Power System (HPS), with individualized representations to Hydropower Plants (HPP) and deterministic inflows, can be formulated as the minimization of the complementary thermal energy cost along the planning horizon [1,T] as a function of the reservoirs operation, which is given by:

$$\min_{x} C_o = \min_{x} \left[\sum_{t=1}^{T} C_{ce}(t,x) \right]$$

where, x is a vector of values of reservoirs volumes of all HPP at every time step, and represents the HPP operation that is aimed to be optimized. Operation cost at stage t, $C_{ce}(t,x)$, is defined by the cost of non-hydraulic complementary energy, $E(t,x)$, necessary to accommodate the demand. This energy can be evaluated as the difference between consumption, $D(t)$, and all hydraulic generation, $H(t,x)$, including therefore, if necessary, the cost of load shortages or energy import.

Results and Discussion

ESBIT was implemented in Java 8 language and its JAR file was used to simulate the case study described in the previous section on a Intel Core i5 2410M with 8Mb RAM. Figure 2 presents the results from the optimization with the reservoir volumes of the three power plants along the two years of the planning horizon. The perfect repetition of the behavior in both years is good indication that the solution obtained is acceptable once the cycle is repeated. It is also valuable to note in Figure 2 that the three reservoirs reached 100% in the 12th month as expected (end of the wet season).



a) volume of each power plant reservoir in the same cascade of Brazilian power system. Emborcação is the uppermost power plant followed by Itumbiara and São Simão power plants downstream.

b) Optimized production of energy by the three hydropower plants and the complementary thermal generation to meet the consumption.

Figure 2. Quasi-optimal solution with the monthly scheduled

When compared with other heuristics presented in [23], which made use of the same set of parameters to solve this problem, it is possible to confirm that the numerical result obtained is in the same range of the other solutions, as presented in Table 1, indicating that the solution is valuable as well. Information in parenthesis is related to the initialization of the populations for the technique presented in [23]: Random, linear at 100% and the outputs of a previous simulation with Non Linear Programming were used as inputs for the Genetic Algorithms.

Table 1. Cost Indexes

ESBIT	GA (random)	GA (100%)	GA (NLP)
21,727,089.11	22,094,935.74	21,727,512.96	21,727,519.07

Regarding the performance of the ESBIT, it is impressive to note that the combination of the social environment in the genetic development with the evolving process accelerate the achievement of acceptable solutions in this complex problem. Figure 3 shows actual data from the simulation where it is possible to observe that in 10% of the simulation time the solution was already in the range of 90% accuracy. It is also noticeable in the same figure the quality steps with each increase in complexity, visually observed in the plateaus created in the curve.

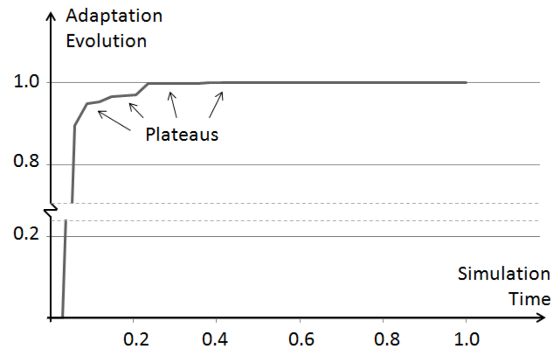


Figure 3. Relative evolution of the adaptation variable during the simulation time. The arrows indicate plateaus of evolution stagnation before or after steps of complexity increase.

Conclusion

This paper presented a new Evolutionary Socio-Bio Inspired Technique (ESBIT) in which social environment is taking into consideration during the specie gradual evolution. ESBIT takes advantages of periods of higher or lower communication among the societies to allow specialized development without missing the diversity. The ESBIT possibility to increase complexity gradually is also a greater accelerator of the solving process.

A case study of relatively high complexity was presented and the solution obtained with the ESBIT showed good qualitative and quantitative performance for the problem of the optimal operation of a Hydrothermal Power System. This indicates the applicability of ESBIT to solve optimization of problems with single objective function with high complexity.

Besides multiple other applications of the techniques, there are plenty of opportunities to assess and improve the performance of the ESBIT by fine tuning the migration strategies or the mix of reproduction techniques and the scope and intensity of the mutations or even the pace of the complexity increase.

Acknowledgment

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References

[1] L. N. Castro, “Fundamentals of natural computing: an overview,” Physics of Life Reviews, vol. 4, pp. 1-36, Dec., 2006.
[2] I Fister Jr., X.-S. Yang, I. Fister, J. Brest and D. Fister, “A Brief Review of Nature-Inspired Algorithms for Optimization,” *ELEKTROTEHNISKI VESTNIK*, vol. *80*, no. *3*, pp. *1-7*, Jun., 2013.
[3] J. S. Huang. Enhancement of Hydroelectric Generation Scheduling Using Ant Colony System Based Optimization Approach. *IEEE Transactions on Energy Conversion.*. vol.16, no.3, pp. 296-301. Sept. 2001.
[4] C. Zoumas, *et al*. A genetic algorithm solution approach to the hydrothermal coordination problem. *IEEE Trans. Power Systems*, vol. 19, no.2, pp. 1356–1364. 2004.
[5] P. T. Leite, A. A. F. M Carneiro and A. C. P. L. F. Carvalho. Energetic operation planning using genetic algorithms. *IEEE Transaction on Power Systems*, vol.1, no.1, pp.173–179, February, 2002.
[6] R. S. Parpinelli and H. S. Lopes, “New inspirations in swarm intelligence: a survey,” *Int. J. Bio-Inspired Computation*, vol. *3,* no. *1*, pp. *1-16*, 2011.
[7] R. A. L Rabêlo, R. A. S Fernandes and I. N Silva. “Operational planning of hydrothermal systems based on a Fuzzy-PSO Approach”. *In: IEEE Congress on Evolutionary Computation (CEC 2012)*, 2012, Brisbane. Operational Planning of Hydrothermal Systems Based on a Fuzzy-PSO Approach.
[8] C. Peng, H. Sun, J. Guo and G. Liu, “Dynamic economic dispatch for wind-thermal power system using a novel bi-population chaotic differential evolution algorithm,” *Electrical Power and Energy Systems*, vol. 42, pp. 119-126, May, 2012.
[9] F. Antunes, T. R. Alencar, P. T. L. Asano, K. Vittori, R. A. L. Rabêlo, and D. L. Toufen. Techniques of the Optimization Based in Artificial Intelligence Applied to Hydrothermal Power Systems Operation Planning. *IEEE Latin America Transactions*. Vol. 12, pp. 1615-1624. 2014.
[10] S. Behera, S. Sahoo and B. B. Pati, “A review on optimization algorithms and application to wind energy integration to grid,” *Renewable and Sustainable Energy Reviews*, vol. 48, pp. 214-227, Apr., 2015.
[11] M. V. F. Pereira. “Optimal Scheduling of Hydrothermal Systems – An overview”. *In: IFAC Symposium on Planning and operation of Electric energy Systems* – Preprints, 1985. Rio de Janeiro, pp. 1-9.
[12] M. V. F. Pereira. “Optimal Stochastic Operations Scheduling of Large Hydroelectric Systems,” *International Journal of Electric Power and Energy Systems*, vol. 11, no. 3, pp. 161-169, 1989.
[13] S. Soares and A. A. F. M. Carneiro, “Optimal Operation of Reservoirs for Electric Generation,” *IEEE Trans. on Power Delivery*, vol. 6, no.3, pp.1101-1107. 1991.
[14] L. A. M. Fortunato, A. Neto, L. A. L. Barreto and C. Ferreira. “Operation Planning Studies of the Brazilian Generation System”. *IFAC Symposium on Planning and Operation of Electric Energy Systems*, pp. 193–200. 1985.
[15] M. S. Zambelli, S. F. Soares, S. F, S. A. Martins, L. Azevedo and A. de Tavares. Long-Term Generation Scheduling of Hydro Plants. In: Saeid Eslamian. (Org.). Handbook of Engineering Hydrology. 1ed.: CRC Press, pp. 411-432. 2014.
[16] P. T Leite, A. A. F. M. Carneiro and A. C. P. L. F Carvalho. “A Genetic algorithm approach to optimize the operation planning of hydrothermal system scheduling”. In:*: Simpósio Brasileiro de Redes Neurais - Vth Brazilian Symposium on Neural Networks*, Belo Horizonte - Brazil. California: Printing House, 1998. vol. 1. pp. 253-258.
[17] A. A. F. M. Carneiro, P. T Leite and A. C. P. L. F Carvalho. “Genetic algorithms applied to hydrothermal system scheduling”. *In: International Conference on Power System Technology* -

POWERCON'98, 1998, Beijing. Power System Technology. IEEE Power Engineering Society (IEEE PES). vol. 1. pp. 547-551.

[18] W. C. Conceição, A. M. Marcato, P. A. M. S. David, J. A. Passos Filho, T. Ramos, R. Brandi, B. Silva and I. C. Silva Junior, "Hydrothermal systems operation planning using a discretization of energy interchange between subsystems," *Electric Power Systems Research* (Print), v. 132, p. 67-77, 2016.

[19] A. L. M. Marcato et al., "Global parallel genetic algorithm approach applied to long term generation expansion planning". In: *2007 42nd International Universities Power Engineering Conference*, Brighton, 2007.

[20] T. R Alencar and P. T. Leite, "Development of a computational tool for application in the operation of hydrothermal power systems". In: *Transmission and Distribution Conference and Exposition and Exposition. Smart Solutions for a Changing World, IEEE PES*, 2010 New Orleans, Louisiana.

[21] R. A. L. Rabêlo, F. A. S. Borges, R. A. S. Fernandes, A. A. F. M. Carneiro and R. T. V. Braga, "An Application of Genetic Fuzzy Systems to the Operation Planning of Hydrothermal Systems". In: *Rosario Carbone. (Org.). Energy Storage in the Emerging Era of Smart Grids: INTECH*, 2011, pp. 69-88.

[22] P. C. B. Rampazzo, A. Yamakami and F. O. De França, "Evolutionary approaches for the multi-objective reservoir operation problem," *Journal of Control, Automation and Electrical Systems*. vol. 26, pp. 297-306. 2015.

[23] T. R. Alencar, J. Gramulia Junior, R. F. Otobe Junior and P. T. L. Asano. "Decision Support System Based on GeneticAlgorithms for Optimizing the Operation Planning of Hydrothermal Power Systems". *In: 5 International Youth Conference on Energy (IYCE)*, 2015, Pisa, Italy.

[24] W.-Y. Lin, T.-P. Hong and S.-M. Liu. (2004). "On adapting migration parameters for multi-population genetic algorithms." Presented at *2004 IEEE International Conference on Systems, Man and Cybernetics*. [PDF]. Available: http://ieeexplore.ieee.org.

[25] T. Park and K. R. Ryu, "A Dual-Population Genetic Algorithm for Adaptive Diversity Control," *IEEE Trans. on Evolutionary Computation*, vol. *14,* no. *6,* pp. *865-884,* Dec., 2010.

[26] A. E. Eiben, R. Hinterding, and Z. Michalewicz, "Parameter Control in Evolutionary Algorithms," *IEEE Trans. on Evolutionary Computation*, vol. *3,* no. *2,* pp. *124-141,* Jul., 1999.

[27] G. Karafotias, M. Hoogendoorn, and A. E. Eiben, "Parameter Control in Evolutionary Algorithms: Trends and Challenges," *IEEE Trans. on Evolutionary Computation*, vol. *19,* no. *2,* pp. *167-187,* Apr., 2015.

[28] I. G. Hidalgo, S. Soares Filho, D. G. Fontane, J. E. G. Lopes, M. A. Cicogna and D. Silva Filho. Analysis of the Level-Release Polynomial from a Hydroelectric Plant. *Journal of Systemics, Cybernetics and Informatics*, vol. 10, pp. 62, 2012.

[29] M. A. Cicogna, et al. "Multireservoir Simulation Using Multipurpose Constraints and Object-Oriented Software Design". World Environmental & Water Resources Congress 2009, EWRI/ASCE, Kansas City, Missouri, EUA, 2009.

EVALUATION OF PLACES WITH POTENTIAL FOR VIRTUAL POWER PLANT IMPLEMENTATION, FOR PROVISION OF ANCILLARY SERVICES

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ABSTRACT

This paper presents an analysis of locations in the state of São Paulo with favorable profile to the implantation of a virtual power plant, aiming to provide ancillary services. The potential of these regions was evaluated according to criteria related to the distance between their photovoltaic plants and substations, individual generation capacity and possibility of clustering. The tool used in the study was QGIS 3.4.5, geoprocessing software, which analyzed the distribution of photovoltaic power plants in the region, the location of the distribution lines of 88 kV, 138 kV and 230 kV in its power grid and the arrangement of the substations, aiming at the choice of sites with a favorable profile for the implantation of the virtual power plant.

Keywords: virtual power plant; photovoltaic power generation; ancillary services.

1. Introduction

Although centralized generation is the main model of electric power generation in Brazil (SOUZA et al., 2018), the expansion of distributed generation (GD) in its energy matrix has been motivating discussions on the subject and bringing new insights on the power management model in the grid.

The presence of distributed generation, which is often seen as a complicating factor in network management, begins to be seen as a possible auxiliary agent. However, there are still several technical and economic factors that hinder the participation of intermittent generation technologies in the energy market, especially regarding ancillary services.

There are several proposals and studies that propose to overcome these technical difficulties, such as the use of storage and development of energy management methodologies that consider these conditions in their management.

In a search in the specialized literature, it is possible to find energy management proposals, such as the one presented by Yousaf et al. (2017) which uses a control method called Intelligent Autocontrol System (IAS) to implement power sharing among all distributed management units. The method consists of the use of a logical algorithm, which characterizes a control coordination center that performs the active sharing of energy between the distributed generation units.

Galvão et al. (2017) presents the development of a monitoring and automation system for hybrid power microgeneration plants, proposing a flexible monitoring system that utilizes easily accessible equipment in the market, making it more viable for small generation units, with possible expansion to larger structures generation.

Makohin (2015) highlights the ability of generating units to provide ancillary services to energy utilities, optimize their operation and control of demand through a virtual power plant.

In this paper, the virtual power plant (VPP) is presented as a tool that enable a better management and use of distributed generation sources with geographic proximity, which allows the grouping of multiple energy generating sources, being possible to obtain a higher generation capacity and a better management about the elements of its network.

The objective of this work is to develop an evaluation in the state of São Paulo of regions that may present a favorable profile for the implementation of a VPP, aiming at providing ancillary services to distribution and transmission system operators

2. Material and Methods

The profile analysis of the regions evaluated in the state of São Paulo was performed using the QGIS geoprocessing tool, version 3.4.5, which is a software utilized for cartographic use that allows the visualization, editing and analysis of georeferenced data (QGIS, 2019). Figure 1 shows the flow of the evaluation process.

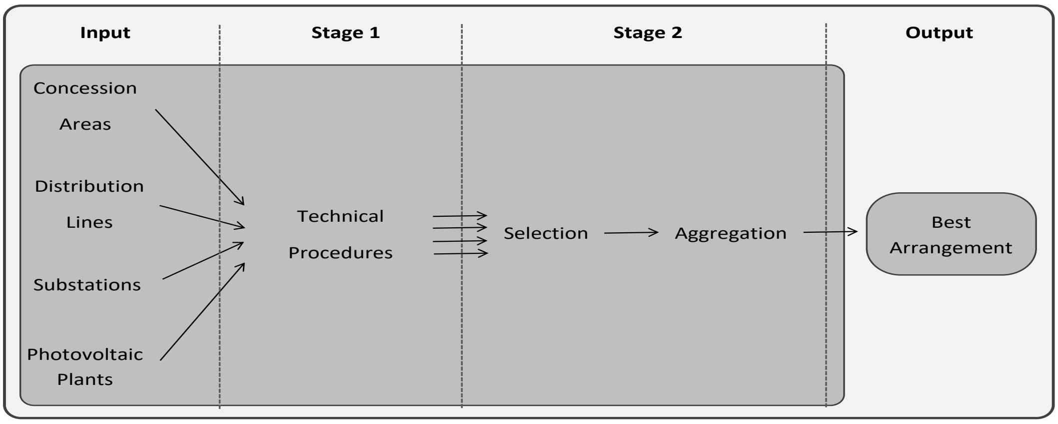

Figure 1. Flow of the evaluation process

Input – Database

The main database used in the analysis was obtained from the website of the State System Foundation of Data Analysis (SEADE), which is an agency of the Department of Planning and Management of the São Paulo State Government (SEADE, 2019).

The files (.shp) were imported into QGIS and it was arranged in layer format, enabling the visualization and processing of the data, as explained in stages 1 and 2. Thus, the input data formed the layers "Concession Areas", "Distribution lines", "Substations" and "Photovoltaic plants", with coordinate system SRC, datum e EPSG: SCG/SIRGAS 2000/4674 reported according to the metadata file available on SEADE website.

For the “Concession Areas” layer, the available data were already directed to the state of São Paulo, as well as the list of municipalities in the state added to this layer. However, in the others, the information covered the whole country.

Stage 1 - Technical procedures

At this stage, tools available in QGIS 3.4.5 were used to process the data obtained, aiming to adjust, filter and structure the data in order to generate numerical and visual information that could assist in the identification and evaluation of regions with potential for implementation of the VPP.

Data Adjustment

For the “Concession Areas” and “Photovoltaic Plants” layers some adjustments were made due to divergences between the data of the SEADE and other sites. ‘However, during the development of the work it was observed that the changes did not impact the results obtained.

For the “Concession Areas” layer, the concession area for distributor Energisa Sul Sudeste was updated, based on information obtained from the website of São Paulo State Sanitation and

Energy Regulatory Agency (ARSESP, 2019). In the layer “Photovoltaic Plants” some small plants were inserted that were not in the data informed by SEADE. However, due to the low generation capacity of these plants, their presence had no influence on the analysis.

Selection and filtering

The procedure of selection and filtering data was focused on the layers referring to distribution lines and the substations.

Because the data for the two layers were obtained with distribution throughout Brazil, it was necessary to use the “Intersection” tool to restrict the data to the limits of the state of São Paulo. As a result, two new temporary layers were created and saved as a file.

Due to the direction of this work for distributed generation, the focused lines and substations were those found within the distribution boundaries. Based on this definition, the data concerning the transmission lines were filtered to delimit the information available in the attribute table, selecting only the transmission lines, whose value in the column named “Voltage” was 230, 138 and 88.

After delimiting the transmission lines at the mentioned voltages, a visual scan was performed on the map, observing which substations have connection with any of the selected lines and excluding the substations outside this condition.

Data processing

At this stage, tools were used to generate new data by processing existing data. For better visualization of information regarding the concession areas, a tool was used to select all fields with information that is repeated in a given column of the attribute table, resulting in data groups with a certain characteristic in common.

Another tool that was very helpful in visualizing the data was the setting of the "Symbology" in the "Layer Properties" option. Through this option it was possible to represent the graphs information in a graduate way, being possible to relate the variation of values with color variation or symbol size, making explicit the visual identification of the plants with the highest generation capacity.

For the concession areas, the configuration of symbology was categorized, with the area referring to each distributor symbolized by its respective color. Transmission lines (TLs) and substations used simple symbology, changing only the type of line for TLs.

To obtain the distance data, initially the “Substations” and “Photovoltaic Plants” layers were exported with a projected coordinate system, to ensure that the calculation was performed with values in meters. In sequence, the “Distance matrix” tool was used, in which the field "Input" was filled with the substations layer and the field "Target" with the photovoltaic plants layer, resulting in a matrix with the shortest distances between substations and photovoltaic plants.

Stage 2 – Sites Selection

In this phase, the distance relations between plant and substation and the power generated by each plant were observed, resulting in the indication of regions with more favorable characteristics for the VPP implementation. The selection, based on the distance matrix, of areas with the desired profile, considered two aspects related to the practical implementation of the plant.

The first criterion is related to the distances between the power plants and each substation. This parameter must be considered, as the need to connect the plant to the substation or to reinforce the transmission lines, if the connection does not exist, can result in high investment values in case of long distances. For this reason, the distance limit defined in this work was 10 km.

Another parameter evaluated was the generation capacity of the plants, since the objective of the VPP is to provide ancillary services in transmission, requiring a higher value of reactive power generated. The minimum value of generated power defined for each plant was S = 20000 kVA, however this criterion may vary according to the characteristics of the service demanded.

Output – Definition of best arrangements

In order to define the best arrangements, besides the previously mentioned criteria, the possibility of grouping nearby plants was considered. So that the total power available at the VPP was the sum of individual generation capacities.

3. Results and Discussion

After data processing and filtering according to the established criteria, the distance matrix presented in Table 1 was obtained.

Table 1. Matrix of distances between substations and selected photovoltaic plants

Substation	Photovoltaic Plant	Distance (km)
Ilha Solteira	Ilha Solteira I	9.45
	Ilha Solteira II	
	Ilha Solteira III	
	Ilha Solteira IV	
	Ilha Solteira V	
	Ilha Solteira VI	
Taubaté	Taubaté	7.78
	Taubaté II	
	Taubaté III	

Based on the matrix of distances and generation capacity of the plants, two groupings of plants with the proper profile for providing ancillary services through a VPP were found. The generation capacity of each plant group is presented in Table 2.

Table 2. Grouping of selected photovoltaic plants

Photovoltaic Plant	Capacity (MW)	Total Capacity (MW)
Ilha Solteira I	28.93	148.64
Ilha Solteira II	28.93	
Ilha Solteira III	24.94	
Ilha Solteira IV	28.93	
Ilha Solteira V	28.93	
Ilha Solteira VI	7.98	
Taubaté	29.95	89.85
Taubaté II	29.95	
Taubaté III	29.95	

It can be observed that the total value of each plant presents a satisfactory potential for the ancillary service rendering in the transmission.

Figure 2 shows the selected substations and photovoltaic plants, represented according to the legend below the map.

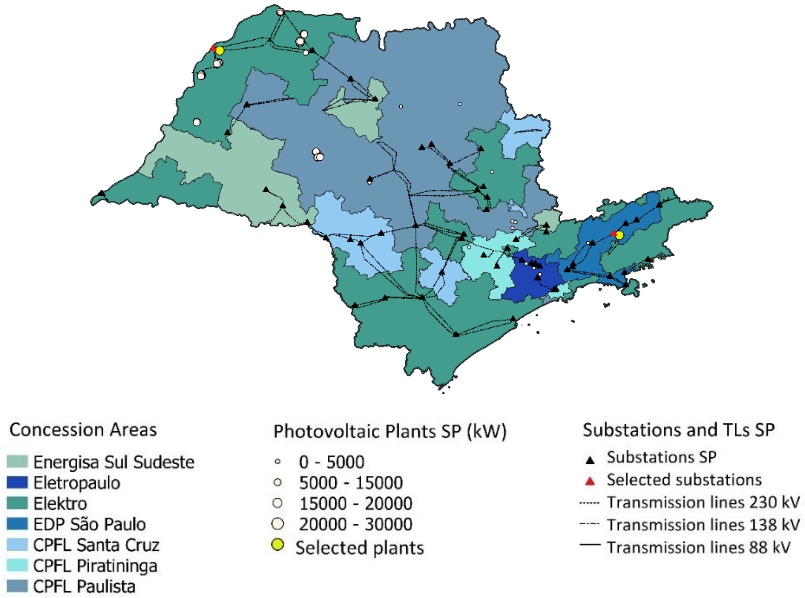

Figura 2. Selected photovoltaic plants

4. Conclusion

The methodology used presented as a result the indication of two regions, in which the presence of photovoltaic plants that have a combined generation capacity of 148.64 MW (Ilha Solteira) and 89.85 MW (Taubaté) was observed.

The regions indicated by the assessment are concession areas of the energy distributors Elektro and EDP. The Ilha Solteira plant group is in the Elektro concession area and the Taubaté plant group in the area of the distributor EDP São Paulo. Through this identification, the concessionaires may propose to the photovoltaic plants a contract for the management of their ancillary services, enabling the participation of the concessionaire and the plants in the ancillary services market.

Identifying potential sources for providing ancillary services can result in several advantages for power utilities and distributed generation units, as some characteristics of photovoltaic plants limit their individual participation in this market. However, the development of monitoring and control strategies through the use of a VPP enables the grouping of multiple power sources, which individually could not provide these services.

For energy utilities, participation in this market comes through the management of services using VPPs, thus having access to the compensation that is defined annually by ANEEL. In accordance with ANEEL Homologating Resolution No. 2,498 of December 18, 2018, the Ancillary Services Fee was set at R $ 7.19 / Mvar-h for 2019 (ANEEL, 2018).

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References

ANEEL. AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). Nota Técnica nº 44/2015-SEL/ANEEL. Assunto: Análise das contribuições da Audiência Pública nº 55/2015, que subsidia a aprovação do Edital e Anexos do Leilão nº 09/2015 — “2º LER” de 2015, contratação de energia de reserva proveniente de novos empreendimentos de geração a partir das Fontes Solar Fotovoltaica e Eólica, com início de suprimento em 1º de novembro de 2018, October 9, 2015.

ANEEL. AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). Resolução Homologatória Nº 697, de 16 de novembro de 2015 - Estabelece os procedimentos para prestação de serviços ancilares e adequação de instalações de centrais geradoras motivada por alteração na configuração do sistema elétrico.

ANEEL. AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). Resolução Homologatória Nº 2.498, de 18 de dezembro de 2018 - Estabelece os valores das Tarifas de Energia de Otimização – TEO e TEO Itaipu, da Tarifa de Serviços Ancilares – TSA e dos limites mínimo e máximo do Preço de Liquidação de Diferenças – PLD para o ano de 2019.

ARSESP. Agência Reguladora de Saneamento e Energia do Estado de São Paulo. Available from: <http://www.arsesp.sp.gov.br/SitePages/home.aspx> Accessed May 2019.

GALVÃO, R. R. A.; PINHEIRO, B. C.; FRAGA, R.; FRANÇA, T. J. L.; TORRES, L. G. G.; **Monitoramento e Automação de Plantas Híbridas em Sistemas de Microgeração Distribuída.** XIII Simpósio Brasileiro de Automação Inteligente, Porto Alegre, outubro 2017.

MAKOHIN, D. G.; **Concepção de Usinas Virtuais de Energia no Cenário Brasileiro: Controle e Gerenciamento da Demanda.** Projeto de Conclusão de Curso, Universidade Federal de Santa Catarina, agosto 2015.

MALHEIRO, C. T.; LUCENA, J. S.; DANTAS, L.S.; CAPOVILLA, C. E,; SGUAREZI, A. J. e CASELLA, I. R. S.; **Avaliação de Locais com Potencial para a Implantação de GD Fotovoltaica sob a Perspectiva do Desenvolvimento Sustentável.**

QGIS. QGIS Official Website, Available from: < www.qgis.org > Accessed May 2019.

RIBEIRO, A. E. D.; AROUCA, M. C.; COELHO, D. M.; **Electric energy generation from small-scale solar and wind power in Brazil: The influence of location, área and shape.** Renewable Energy 85, 2016, p. 554- 563.

SEADE. Fundação Sistema Estadual de Análise de Dados. GeoSeade Download, Available from: <http://portalgeo.seade.gov.br/download-de-dados/> Accessed May 2019.

SOUZA, K. J. F. N. C.; MANITO, A. R. A.; MELENDEZ, T. A. F.; MOCELIN, A.; ZILLES, Z.; PINHO, J. T.; **Geração Distribuída Com Armazenamento Conectada à Rede Elétrica.** VII Congresso Brasileiro de Energia Solar, Gramado, April 17-20, 2018.

YOUSAF, W.; ASGHAR, E.; MENG, H.; SONGYUAN, Y.; FANG, F.; **Intelligent Control Method of Distributed Generation for Power Sharing in Virtual Power Plant.** IEEE International Conference on Unmanned Systems (ICUS), p. 576- 581, outubro 2017.

ENVIRONMENT, SOCIETY AND ENERGY PLANNING

BIOGAS FROM FOOD WASTE: POSSIBILITIES AND CHALLENGES OF SMALL ANAEROBIC REACTORS

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ABSTRACT

Two major problems today are: access to energy from sustainable sources and waste treatment. The use of anaerobic digestion has been proposed as a response to these two problems. A considerable part of the municipal solid waste is organic, which includes the food waste, especially the food remainder of meal consumption or leftovers, which are the remains left on the plate, and that possess a good potential of methane production. These dietary residues of consumption when mixed with municipal solid waste, hinder their separation, besides contaminating recyclables, therefore a possible solution for their energy recovery through anaerobic digestion are small family or community reactors, near the generation point before being mixed with other residues. It is proposed the use of Social Technology asa theoretical reference of operation and construction for biodigester. The solid series analysis of food residues of a restaurant in São Vicente/SP was performed and the biochemical methane potential was experimentally determined. The results show high moisture content of 62,3% and a high rate of volatile solids VS = 95% of total solids (TS) and a specific production of methane of 415 NmL/gVS, demonstrating the viability of using this biomass for biodigestion, the results are similar to those found in literature.

Keywords: Biogas, anaerobic digestion, consumption food residues, minigeration, social technology.

Introduction

In Brazil, about 78 million tons of municipal solid waste (MSW) (ABRELPE, 2016) are generated per year. It is believed that in Latin America (FAO,2011) about 30 Kg of food per capita a year are discarded, in the last evaluation (IBGE, 2018) brazilian population is estimated in 208.5 million. Considering the data presented, it can be estimated that about 6,260,000 tons of food per year are discarded, which would represent 8% of the MSW in Brazil.

Several Brazilian municipalities are discussing and implementing legislations on MSW management. In São Vicente, due to this new legislation, restaurants may be framed as medium and large waste producers. This would make them responsible for the management of their own waste. Similarly to the hardening of the legislation that occurred in Europe in the years 90, this happens now in Brazil, and in the same way that anaerobic digestion has proved to be a solution in the European countries, it is believed that it can also be in the case of Brazil.

This paper aims to analyze the possibility of biogas generation using food waste (FW) as substrate in small reactors in urban or semi-urban environments.

This objective is unfolded in the following specific objectives:

To characterize the food residues of consumption through the determination of total solids (TS), volatile (VS) and biochemical potential of methane (BPM);

a) Evaluate the possibility of using FW in small reactors operated by Non-specialized people.

Material and Methods

There are two methodological aspects in this work: the first is related to the characterization of the FW for energy recovery by anaerobic digestion and the second related to the use of digesters using FW by non-specialized people.

A sample of food waste (leftovers from dishes) was collected in a popular restaurant in the center of São Vicente/SP (FWSV), for three consecutive days, totaling 1768g, this establishment is of the type of a single price per person that can “eat-all-you-can ", and customers are basically the local population and workers of services in the region, the owner estimates an average of 30 Kg of FW per day.

The fresh sample was chopped and homogenized manually and 300g of the sample was removed to perform the analysis of solids, which was dried in a drying oven at 105 °C until constant weight, as directed by the EPA 2540G/1997.

The Standard Methods EPA 2540G/1997 were used to establish total solids, volatile solids and fixed solids.

The rest of the sample was dried at 104°C until constant weight, crushed and vacuum packed for the BMP tests.

For the determination of moist content of the monocrystalline cellulose, used as a testimony test and of the dried FW sample a Shimadzu MOC63U Moisture analyzer was used with 2 g samples placed in an aluminum crucible. It was automatically measured according to the manual of this instrument. The repeatability error for 2g is 0.15%. (SHIMADZU, 2019).

	Monocrystalline Cellulose (work base)	FW (Work base)
humidity (%)	5,62±0,01	1,14±0,01

VDI 4630/2006 was used as a methodological framework for the experimental analysis of the potential of methane formation.

The equipment used for the analysis of biochemical methane potential (BMP) was the Automatic methane potential Test System (AMPTS II), a triplicate of the inoculum and FWSV sample, a triplicate of inoculum and microcrystalline cellulose and a Inoculum (white test).

The test was carried out in full compliance with the criteria established by VDI 4630/2006, at a mesophilic temperature (35 °c). Reactors of 500 mL of total volume were used, however the workload was 300 mL. After filling the reactors with these samples, all the remaining volume was inert flushing nitrogen for 2 minutes.

For pH measurements at the end of the digestion process a phmeter DIGIMED model DM 22 was used.

Using the criteria of VDI4630/2006, the reactors with FW, Monocrystalline cellulose and inoculum were filled in triplicate and the respective quantities were presented in table 1.

Table 1. Quantities of substrate, inoculum and microcrystalline cellulose disposed in the reactors

Reactor	Substrate(g)	Inoculum (g)	Substrate
1	3,723	146,952	FW
2	3,723	146,946	
3	3,723	146,956	
4	3,787	146,949	Monocrystalline cellulose
5	3,786	146,954	
6	3,787	146,956	
7	0	146,923	none (only inoculum)
8	0	146,944	
9	0	146,957	

As a methodology for evaluating biodigesters operated by non-specialized citizens, the concept of Social technology was adopted, which is defined as "reproducible products, techniques and/or methodologies developed in the interaction with the community and which represent effective solutions for social transformation "(DAGNINO, 2011, p. 1).

Results and Discussion

Following the proposed methodology, the results of the solids series for the FWSV sample were obtained before the digestion presented in table 2. Table 3 presents the results of humidity of the samples “in natura”.

Table 2. Moisture Content Analyzer Shimadzu MOC63u

	Monocrystalline Cellulose(work base)	FW (Work base)
humidity (%)	5,62±0,01	1,14±0,01

Table 3. Result of the initial solids series

Substance	Total Solids gTS/g (in natura	Volatile Solids gVS/g (dry base)	Volatile Solids gVS/g (in natura)
FWSV	0,377 ± 0,003	0,951±0,001	0,359 ± 0,003
Microcrystalline Cellulose	0,9880 ±0,001	0,9770 ± 0,001	0,965 ± 0,001
Inoculum	0,065 ± 0,001	0,853 ± 0,004	0,056 ± 0,001

At the end of the digestion, using the criteria presented, the data from table 4 were obtained.

Table 4. Final Result (digestate) of THE PBM analysis

Digestate	Total Solids gTS/g (Work Base)	Volatile Solids gVS/g (Dry Base)	gVS/g sample	Ph
FWSV	0,037±0,001	0,169±0,01	6±1 .10^{-3}	7,67±0,11
White	0,029±0,002	0,145±0,01	5 ± 1. 10^{-3}	7,88±0,02

The normalized daily methane production is provided by the AMTPS II system, these data were plotted in Figure 1

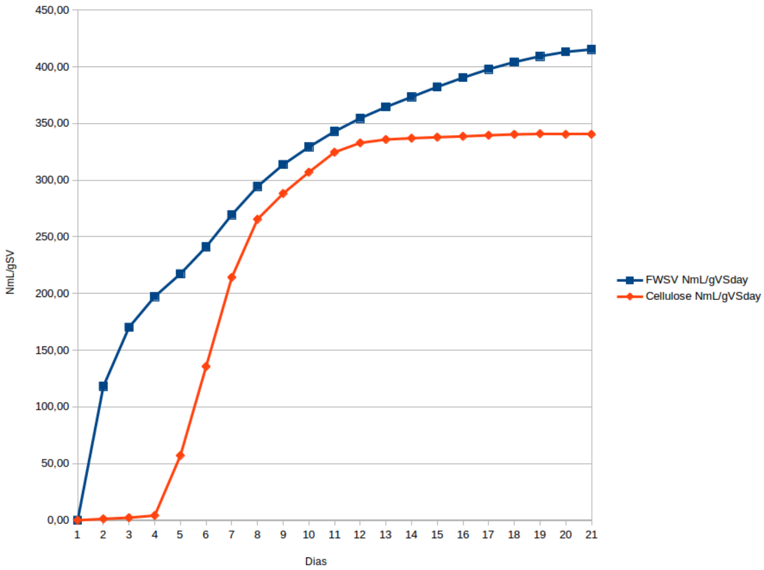

Figure 1 - Acumulated Yield biomethane from FWSV

The BPM is very coherent with the literature in general, and shows the rapid conversion of FWSV into biogas, a very desirable feature because it allows the construction of reactors with smaller hydraulic retention time (HRT) and consequently of smaller dimensions. On the other hand, this rapid conversion may generate instability in the reactors operated exclusively with this biomass, in this analysis we used a substrate/inoculum ratio of less than 0.5 (base on VS), and therefore we did not observe instability

The specific yield of biomethane is approximately 415 NmL/gVS, this value is expected by the literature and confirms the great energy potential of FW.

According to Lou, Nair and Ho (2012) There are about 30 million small digesters scattered around the world, we can assume that the vast majority of these digesters operate with low feeding rate, the most popular are Chinese and Indian type.

A theoretical estimation of a daily production of 50 mL/gVS and an average production of 30 Kg daily FW (a preliminary and informal estimate of FW production), would generate an average of 0.8 m^3 per day of biogas, following the estimation of Lou, Nair and Ho (2012 , p. 4), this would be possible to feed a stove mouth for 180 min. The resultas of production obtained in present work has reached a 415 NmL/gVS, which is much more than the value reported by Lou, Nair and Ho(2012).

Conclusion

As verified in the results and discussions, the FW presents potential to be a diffuse source of biogas. The management, feeding and operation of a small biodigester using this substrate can be done domestically, communitarian or in popular ventures such as restaurants, meaning a significant economy to the community, family or enterprise, whereas it is also a highly effective way to process and reduce solid organic residue. It is also necessary to take into consideration the reduction of environmental damage, the reduction of the expense of transport and storage of these residues, finally it seems that the biodigester in this context is an important part in a circular economy model.

In order to be viable this decentralized model of energy production and waste treatment it is necessary a simple, robust and inexpensive reactor technology. A central focus is that it can be incorporated into the everyday life of people, homes, establishment and cities, it is therefore essential that the small biodigesters of FW are recognized as true objects of Social technology.

References

ABRELPE, Panorama of solid waste in Brazil: 2016, São Paulo, 2016

DAGNINO, R. **Social Technology:** Conceptual basis, revist @ of the Movement Observatory

By the Social technology of Latin America, v. 1, N. 1, 2011

FAO. **Global food losses and food waste – Extent, causes and prevention** . Rome, 2011.

Shimadzu, **MOC63u – Moisture Analyzer**, 2019 available at:

http://www.shimadzu.com.br/analitica/produtos/balance/analisador-umidade/moc63u.shtml.

Accessed on: 14 May 2019.

IBGE, **ESTIMATES of THE RESIDENT POPULATION IN Brazil AND units of THE FEDERATION WITH REFERENCE DATE ON July 1, 2018,** brasilía, 2018.

LOU X. F., NAIR J., HO G. **Field performance of small scale anaerobic digesters treating food waste.** Energy for Sustainable Development 16 (2012) 509–514, 2012.

OH J. et al. **Biogas production from food waste via anaerobic digestion with wood chips**, Energy & Environment 0(0) 1–8, 2018.

LITERATURE REVIEW: ECONOMIC AND ENVIRONMENTAL IMPACTS ASSOCIATED WITH OIL EXPLORATION IN PRE-SALT

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ABSTRACT

The literature on "economic and environmental impacts associated with pre-salt oil exploration" is pertinent, because the subject influences in several areas of knowledge: economic, social, environmental, etc. The paper aims to review the studies that address issues related to economic and environmental impacts associated with oil exploration in certain locations. The strategy was to use bibliometric review and systematic review of international reference in bases like the magazine Energy Policy and Resources Policy, 13 papers were selected. The topics approached in the research were: Energy Economics, Public Policy, Economy/ oil and gas, Energy and Environment. All papers found are case studies, presenting quantitative, qualitative approaches, or both. The data-bases were from secondary sources. Only two papers were made on multiple case analyzes.

Keywords: Literature; Economic impacts; environmental; pre-salt.

Introduction

Brazil has become a potentially relevant actor as an oil producer and exporter, expectation was created in the generation of economic surplus associated with oil development and extraction for social investments capable of rescuing the serious social asymmetries that affect the Brazilian people(SAUER; RODRIGUES, 2016).

Pre-salt production in February totaled 1.826 million boe / d, an increase of 3.6% compared to the same month in 2018 and a decrease of 0.6% over the previous month. 1.450 million barrels of oil per day and 59.8 million cubic meters of natural gas were produced daily through 88 wells. Pre-salt's share of total national production in February was 57.4% (ANP, 2018).

These activities trigger changes in nearby locations exploitation and neighboring regions, positive and negative impacts. For example, those related to industrial activities and those arising from the receipt of financial compensation (MONIÉ; et. al, 2012). Related to industrial activities are the increase in expectations of job opportunities, since offsets are the Royalties, financial compensation owed to the Union by companies that produce oil and natural gas in the Brazilian territory: a remuneration to society for the exploitation of these nonrenewable resources (ANP, 2018).

The literature on "economic and environmental impacts associated with oil" is growing and it is the specific case of the pre-salt it becomes relevant because, officially, the first fields were discovered in 2006 and the activities were only initiated in 2008. An Art of state update for this issue is pertinent to contribute to the current studies and futures on the impacts involved in this economic activity model.

The work aims to conduct a review of studies that address issues related to economic and environmental impacts associated with oil exploration in some places and pre-salt.

Material and Methods

To achieve the goal, it was used bibliometric and systematic review. Such approaches allow to analyze specific points of content from an updated timeline. Bibliometric and systematic analysis are meta-scientific methods, effective ways to evaluation of scientific literature in a specific knowledge area. This assessment was performed using a systematic review of information in scientific publication sources, data indexing data-bases, scientific journals, generating important indicators of production, synthesizing ideas, methods, results as well as the impact of production (WITTER, 2005).

The use of these methods is to identify trends and growth of knowledge on the issue in question and to identify the most productive journals in a particular topic (MEDEIROS et al. 2011).

The bases used were the Energy Policy magazine, Resource Police and the International Conference on Ocean, Offshore and Arctic Engineering to complement was also used the base of theses and dissertations in Brazil, "BDTD". Keywords used in research consult in results.

Results and Discussion

Scientific works were collected in “Energy Policy” has high level energy content. It was searched for papers that addressed economic and environmental impacts caused by oil and gas exploration in various places and in pre salt. The following search form was obtained:

Table 1 - Bibliometric research form on economic impacts of petroleum / pre-salt / Energy Policy

Factors	Description	Papers
Journal Areas	Economy, Energy	
Search String	“impact of pre sal”	133
Filter	Title, abstract and keywords	
Inclusion Factor	Full text available	
Final Inclusion Factor	Previous reading: theme identification by author	4

SOURCE: Self elaboration, 2019

At first, 133 works were selected that passed search filters and presented in the summary title and / or keywords the expressions that had the word "impact", but often called the other approaches, for example the proper use of diesel. From the screening with the inclusion factors the final collection of papers totaled 4, of the journal “Energy Policy”, impact factor 4.039: (INACIO, O.; SANTOS, B.; RATHMANN, R, 2009; ANTOLÍN, M. J. P.; CENDRERO, J. M. R, 2013; PAZ, M. J., 2014; SILVESTRE, H. C. GOMES, R. C. LAMBA, J. R, 2018). These papers were cited, respectively: 27, 14, 17, 1, times.

The matters addressed in these works are: impacts of energy resource exploitation, such as biodiesel, employability, income, health, education. Also, importance of the regulatory framework and the performance of state-owned companies in oil exploration and the implementation of public policies regarding the “regional energy policy”. Only one paper seeks alternatives in the energy industry based on natural resources, performance analysis of the Brazilian oil sector and, in particular, its industrialization trajectory (INACIO. et al 2009; ANTOLÍN; CENDRERO, 2013; PAZ, 2014; SILVESTRE et al, 2018).

Second, 3296 papers were selected that passed search filters and presented in the summary title and / or keywords the expressions that had the word “energy ”, “recovery”, “gas”, but often called the other approaches. For example efficient ways to use fuels in automobiles. From the screening with the inclusion factors the final collection of works totaled 6:

Table 2 - Bibliometric research form on economic impacts of petroleum / pre-salt / Energy Policy 2

Factors	Description	Papers
Journal Areas	Economy, Energy	
Search String	"The regional economic impact of oil"	3296
Filter	Title, abstract and keywords	
Inclusion Factor	Full text available	
Final Inclusion Factor	Previous reading: theme identification by author	6

SOURCE: Self elaboration, 2019

It was necessary to change the keywords throughout the search to get more focused data for the chosen theme. In the journal "Energy Policy" it were chosen: (AYDIN, L, 2012; VANDYCK, T.; REGEMORTER, D. V.,2014; LI, Y.; SHI, X.; S;2017; OLADOSU, G. A.; et al, 2018; NEWELL, R. G; RAIMI, D,2018; LEE, J., 2015). These papers were cited, respectively: 7,34, 7, 11, 5, 34 times.

The matters addressed in these works are: economic impact of certain regions (in loco survey), incentives by oil draft law, for to attract foreign oil companies, analysis of macroeconomic and distributive effects of tax increase, about the oil of a particular region.

Analysis of the potential impact of energy tax removal in the economy of a region, microeconomics is also evaluated too. The relationship of oil price elasticity and its effects on GDP of oil importing countries and net fiscal impacts on municipalities affected by oil exploration added state and municipal policies. Other matter connected is the growth analyzes of the oil industries, directly or indirectly.

Some papers explain on economic impact, focus on shale oil, which not yet as explored as oil, because of high cost and there are oil reserves more advantageous. The studies are macroeconomic and microeconomic. The analyzes are related to the post and during the oil exploration, positive and negative aspects of activity in the affected regions (AYDIN, 2012; VANDYCK; REGEMORTER, 2014; LI et al, 2017; OLADOSU et al, 2018; NEWELL; RAIMI, 2018; LEE, 2015).

In the third stage the "environment" is considered. Was difficult to find papers focusing pre-salt reserves. Therefore, the base diversification was chosen as follows: periodicals "Resources Policy", impact factor 2.695; "Impact Assessment and Project Appraisal" impact factor 1.213 and Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering.

It were chosen: (SEABRA, A. A.et al, 2015; VILARDO, C.; ROVERE, E. L. L,2018; GONÇALVES, M. M., et al, 2014) These works were cited, respectively: 7, 0, 0, times.

After analysis of the works of the found in third stage, forms of administration of oil royalties have been identified and impact on the environment in regions close, political issues, public policies, legislation and regulations related to the studied reality, emphasizing the environment.

It was identified that when oil royalties are inefficiently managed, the economy of the area, which is dependent which relies heavily on its oil exports, often there is inefficiency economic, mismanagement and corruption (Seabra, et al 2015).

Another relevant aspect was it the royalties management in Brazil so far (Campos basin - Rio de Janeiro) despite the fact that economic incentives to region, municipalities have not always resulted in social development. Oil and gas revenues created social unrest in the producing regions, mainly due to excessive of freedom by lack of on income administration at municipal level (Seabra, et al 2015).

In summary, the main topics dealt with are: Energy Economics, Public Policy, Energy economy, Oil and gas and energy and environmental. All the papers found are case-studies, present quantitative or qualitative approaches, or both. The databases were from secondary sources. Only two articles were made multiple case analyzes: “Management of pre-salt oil royalties: Wealth or poverty for Brazilian coastal zones as a result?” e “Multi-project environmental impact assessment: insights from offshore oil and gas development in Brazil”.

From the perspective of scientific, it is important although some works not be that recognized, to be considered representative, because represents with precision of details the case pre-salt, these are the theses and dissertations respectively: (TROJBICZ, B., 2014; REIS, C. M., 2016; GOMES, F. L., 2015; JULIANI, L. I. ,2014; RODRIGUES, L. A., 2016) e (TAFFAREL, C.C., 2014; MEERHOLZ, A. L., 2016; BRITTO, C. M., 2014; MODESTO, L. A. M. S., 2016; PRADO, F. A. B.,2016; COSTA, L. A. D., 2016; PINTO A.G.V., 2016). These works were being reported topics associated with Public policies/ pre-salt, Geopolitics of oil, State regulation after the discovery of the pre-salt, the impact on the domestic economy after the discovery of the pre-salt too, sustainability and economic Law.

Conclusion

The aims of the work on the review of studies that address issues related to economic impacts was better addressed than the environmental issues associated with oil exploration in some locations and pre-salt.

These targeted surveys was possible to notice that the Brazilian coast presented other developments vectors, during the expansion process by pre-salt, including tourism, ports, renewable energy deployment, and aquaculture as well as industrial equipment and logistics facilities involved in oil production. These activities can be strengthened and society's base could be diversified through efficient management of oil revenues (Seabra, et al 2015).

However, governance quality and corruption control should be significantly improved in Brazil, so that the country benefits economically and socially from its oil revenues by responsibly managing the resource.

Suggested for future work searches across other data sources, such as Web of Science to reach a larger database and enables a more detailed analysis, including cases related to pre-salt exploration and other forms of fossil fuels.

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References

ANP. <Anuários Estatísticos Disponível em: http://www.anp.gov.br/?id=661>. Acesso em: 17 jan. 2018.

ANTOLÍN, M. J. P.; CENDRERO, J. M. R. How important are national companies for oil and gas sector performance? Lessons from the Bolivia and Brazil case studies. **Energy Policy**. v.61, p. 707–716, may/2013.

AYDIN, L. The economic impact of petroleum royalty reform on Turkey’s upstream oiland gas industry. **Energy Policy**. v.43, p. 166–172, jan. 2012.

BRITTO, C. M. **Sustentabilidade e Intradisciplinaridade: elementos para uma abordagem sociológica, a partir do Pensamento Sistêmico Multimodal, para um estudo preliminar do Pontal do Pré-Sal.** Dissertação (Mestrado em Sociologia). -UFPR - Universidade Federal do Paraná, Curitiba 2014.

COSTA, L. A. D. **A indústria do petróleo: disputas por territórios cada vez mais profundos**. Dissertação (Mestrado em Desenvolvimento territorial na américa latina e caribe) - UNESP-Universidade Estadual Paulista Júlio de Mesquita Filho, São Paulo, 2016.

GONÇALVES, M. M.; MOROOKA, C. K.; GUILHERME, I. R. Selection of an offshore petroleum production system by Evaluating an environmental impact index. In Proceedings of the ASME 2014 33rd **International Conference on Ocean, Offshore and Arctic Engineering OMAE 2014.** California, Jun. 2014.

GOMES, F. L. **Regulação estatal e o pré-sal: por uma proposta de modelagem institucional voltada à promoção do direito fundamental ao desenvolvimento econômico mediante a otimização dos contratos de partilha de produçã**o. Tese (Doutorado em Direito) – UFPE -Universidade Federal de Pernambuco, Recife, 2015.

INACIO, O.; SANTOS, B.; RATHMANN, R. Identification and analysis of local and regional impacts from the introduction of biodiesel production in the state of Piauí. **Energy Policy**. v.37, p. 4011–4020, may/2009.

JULIANI, L. I. (2014). **Fatores de impulso na economia brasileira: O Caso do Pré-Sal e a Indústria do Petróleo.** Tese (Doutorado em Energia) - UFABC - Universidade Federal do ABC, Santo André, 2014.

LEE, J. The regional economic impact of oil and gas extraction in Texas. **Energy Policy**. v. 87, p.60–71, sept. 2015

LI, Y.; SHI, X.; S. Economic, social and environmental impacts of fuel subsidies: A revisit of Malaysia. **Energy Policy**. v. 110, p. 51-61, aug. 2017.

MEDEIROS, M. L. et al., Administração e políticas em educação: uma revisão sistemática da produção do EnANPAD e do EnAPG de 1997 a 2009. **Revista de Ciências da Administração**, v. 13, n. 13, 2011. 61-87.

MEERHOLZ, A. L. **O modelo regulatório do pré-sal e a neutralização da doença holandesa. Dissertação (Mestrado em Direito).** – UFPR - Universidade Federal do Paraná, Curitiba, 2016.

MODESTO, L. A. M. S. **Contratação direta da Petrobras no pré-sal: análise constitucional das implicações para a livre concorrência e para o desenvolvimento econômico do setor.** Dissertação (Mestrado em Direito) – UFRN - Universidade Federal do Rio Grande do Norte, Natal, 2016.

MONIÉ, F. (Org.). **Geografia e geopolítica do petróleo**. Rio de Janeiro: Mauad X, 2012.

NEWELL, R. G; RAIMI, D. The fiscal impacts of increased U.S. oil and gas development on local governments. **Energy Policy**. v.117, p.14–24, marc. 2018.

OLADOSU, G. A.; LEIBY, P. N.; BOWMAN, D. C.; MARTÍNEZ, R. U.; JOHNSON, M. M. Impacts of oil price shocks on the United States economy: A meta-analysis of the oil price elasticity of GDP for net oil-importing economies. **Energy Policy**. v.115, p. 523–544, feb. 2018.

PINTO A.G.V. **Direito econômico do petróleo: as consequências da descoberta do pré-sal.** Dissertação (Mestrado em Direito) - PUC - Pontifícia Universidade Católica do Paraná, Curitiba, 2016

PAZ, M. J. Oil and development in Brazil: Between an extractive and an industrialization strategy. **Energy Policy**. v. 73, p. 501–511, July/2014.

PRADO, F. A. B. **Alterações legislativas dos royalties do pré-sal: Efeitos sobre os Princípios Constitucionais e as Políticas Públicas**. Dissertação (Mestrado em Direito) PUC - Pontifícia Universidade Católica do Paraná, Curitiba, 2016.

REIS, C. M. **Por uma nova geopolítica para o petróleo brasileiro: o caso do pré-sal.** Tese (Doutorado em Geografia) – UERJ - Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2016.

RODRIGUES, L. A. **Cenários Econômico-Financeiros da Produção em Campos do Pré-Sal sob Distintos Regimes Regulatórios.** Tese (Doutorado em Energia) – USP – Universidade de São Paulo, São Paulo, 2016.

SAUER I. L.; RODRIGUES L. A. Pré-sal e Petrobras além dos discursos e mitos: disputas, riscos e desafios. **Estudos avançados**. São Paulo, v.30 n.88 Set./Dez. 2016.

SEABRA, A. A.; KHOSROVYAN, A.; VALLS, T. A. D. POLETTE, M. Management of pre-salt oil royalties: Wealth or poverty for Brazilian coastal zones as a result? **Resources Policy**. v.45. p.1–8. marc. 2015

SILVESTRE, H. C. GOMES, R. C. LAMBA, J. R. Implementation of Brazil's energy policy through the national oil company: From institutional chaos to strategic order. **Energy Policy**. v. 119, p. 87–96, April 2018.

TAFFAREL, C.C. **O novo marco regulatório do pré-sal e a autonomia local: uma abordagem a partir da efetivação da subsidiariedade administrativa.** Dissertação (Mestrado em Direito) - UNISC - Universidade de Santa Cruz do Sul, Santa Cruz do Sul, 2014.

TROJBICZ, B. **Formação de agenda e formulação de uma política pública no Brasil: o caso do Fundo Social do Pré-Sal.** Tese (Doutorado em Administração Pública e Governo) - FGV - Fundação Getúlio Vargas, São Paulo, 2014.

VANDYCK, T.; REGEMORTER, D. V. Distributional and regional economic impact of energy taxes in Belgium. **Energy Policy**. v. 72, p. 190-203, may. 2014.

VILARDO, C.; ROVERE, E. L. L. Multi-project environmental impact assessment: insights from o ff shore oil and gas development in Brazil. In. Impact ssessment and project appraisal. Disponível em: <https://doi.org/10.1080/14615517.2018.1475615> Acesso em May, 2018

WITTER, G. P. **Metaciência e Psicologia**. Campinas: Alínea, 2005.

ECONOMIC ORDER OF THERMALETRICS OF SIN USING GENETIC ALGORITHM

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ABSTRACT

This work aims to use an artificial intelligence technique, by genetic algorithm (AG), for cost optimization in the economic dispatch of thermoelectric plants. For this, two case studies were performed, in which the Artificial Intelligence method by Genetic Algorithms proved to be very effective and promising to optimize the thermoelectric dispatch.

Keywords: Genetic Algorithms, optimization, thermoelectric dispatch.

INTRODUCTION

The economic dispatch and operation planning problem can be modeled as an optimization problem, where the total demand between the generating units is allocated so that the production cost is minimized satisfying the system operating conditions and constraints. This study results in the output powers of each generating unit.

In a system like SIN, classical optimization techniques may present some difficulty due to the complexity of the objective function and its constraints. However, other methodologies involving Artificial Intelligence techniques have been studied and used to solve different optimization problems in which we can mention the works ofMiranda et al. (1998), Zoumas et al. (2004), Leite e Carneiro (2006) [2-4].

MATERIAL AND METHODS

The basic formulation for the operative optimization problem in SIN generation planning is the definition of which thermoelectric generation units and what amounts of energy each of these generators should produce in order to meet the demand at minimal costs. Assuming that each generator offers a single price for all its available capacity, the operation planning problem of a thermoelectric system can be represented mathematically as follows [1]:

$$\sum_{i=1}^{NT} G_i + D_{ef} = D \tag{1}$$

Composed by:

$$z = Minimizar \sum_{i=1}^{NT} p_i\, G_i + c_{def} D_{ef} \tag{2}$$

$$G_i^{min} \leq G_i \leq G_i^{max} \tag{3}$$

Where z is the total cost of operation, NT number of thermoelectric units, p_i is the price offered by your thermoelectric unit, G_i is the dispatch of your first thermoelectric unit, c_def is the system cost, D_ef is the system power deficit , D is a load met in the system, G_min is the minimum generation of its thermoelectric unit and G_i ^ max is the maximum generation of its thermoelectric unit.

Problem (1) is solved by linear programming techniques, so that the spot price will be obtained by a dual variable (Lagrange Multiplier). The first restriction of the problem refers to the sum of the dispatch of all generating units being equal to the demand minus the energy deficit in the system, therefore, it is observed that there is a variable associated with the energy deficit, this variable must exist due to The possibility of adverse situations may make it impossible to meet demand, ie the available thermal generation capacity is less than the demand. Next, the second restriction states that the order must be such that there is no breach of the minimum or maximum limit of each of the generating units. Thus, the dual variable is associated with the demand fulfillment constraint, that is, the spot price will be equal to the price offered by the marginal source of the system, i.e., by the source price that would be dispatched to meet an infinitesimal increase in demand.

In order to search for the optimal solution, metaheuristic techniques will be employed, considered a subfield of the stochastic optimization area. Within the metaheuristics, the genetic algorithm (GA) is a method based on evolutionary computation with biological inspiration in Darwin's theory. The technique is based on the characterization of the problem by a set of variables to which a set of variables are assigned. of values to optimize: (xa, xb, .., xn) ← (x1, x2, ..., xn). The modeling of GAs can be defined by a set of variables representing the individual (candidate solution), being coded following the biological inspiration of the chromosome, so that each variable is coded in one gene, with the set of genes making up a chromosome. From the selection of the best generated individuals (most fit and adherent to the objective function), intermediate populations are defined from the crossing and mutation operators, such operations are responsible for exploring the search space for solutions in the objective function region. Figure 1 describes the technique.

```
1.  Start;
2.  Generate the initial population;
3.  Evaluate each individual in population;
4.  Repeat until N generations:
    4.1. Repeat until the number of offspring equals the desired amount (crossing rate
         (%));
        4.1.1.  Select two individuals according to selection method;
        4.1.2.  Perform the crossing operation in the selected individuals;
        4.1.3.  Perform the mutation operation on the descendants generated from the
                previous crossing;
        4.1.4.  Evaluate the descendants;
    4.2. Replace the individuals of the population with the new individuals generated in
         the reproduction stage;
5.  The best individual in the population is the solution of the problem;
6.  End.
```

Figura 1. AG Script

RESULTS AND DISCUSSION

Considering a hypothetical configuration where 3 thermal generating units are connected to an ideal bus that meets a load without transmission losses, as shown in Fig. 2. Generators are subject to operating restrictions which are their maximum and minimum limits.

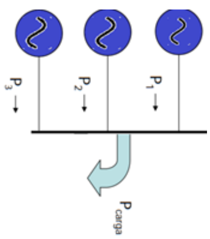

Figure 2. Representation of 3 generation units connected to a bus

Data from the three generating units (1, 2 and 3) are shown in Table 1, along with their cost function as a function of their power, fuel cost and maximum output power constraints and minimum output power. The idea of this first case study is to determine the optimal operating dispatch to meet a demand load of 850MW.

Table 1: Operating data of the three generating plants

	Coust Function x Production (MBtu/h)	Fuel Coust (R$/MBtu)	Maximum Coust (MW)	Minimum Power (MW)
1	$510 + 7{,}2P_1 + 0{,}0014P_1^2$	1,1	600	150
2	$310 + 7{,}85P_2 + 0{,}00194P_2^2$	1,0	400	100
3	$78 + 7{,}97P_3 + 0{,}0048P_3^2$	1,0	200	50

Table 2: Results calculated from lagrange method and by ag for case study 1

	Lagrange		**Algoritmo Genético**	
Usina	**Potência (MW)**	**Custo (R$/h)**	**Potência (MW)**	**Custo (R$/h)**
1	393,2	R$3.916,64	342,03	3452,61
2	334,6	R$3.153,81	307,9	2910,93
3	122,2	R$1.075,26	200,0	1734,48
	Custo Total (R$/h)	R$8.145,70	Custo Total (R$/h)	R$8.098,02

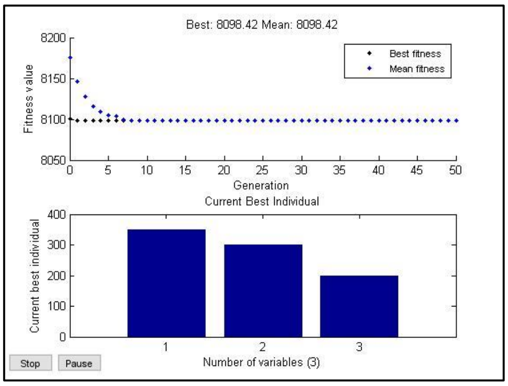

Figure 3. Convergence presented by AG and the output powers found for each generator.

For the first case study exposed, the Lagrange method was used to optimize this dispatch and its results compared with the GA technique, as shown in Table 2. The GA was applied using Matlab®, adopted by If an 80% crossover rate between individuals, elitism and mutation of generations being performed 5 times with a population of 24 individuals, the same number used by Leite and Carneiro (2006), the stopping criterion for 50 was applied. generations, more than enough solution, as can be seen in Fig. 3. The results shown in Table 2 refer to the averages of the powers found in the dispatch of each generator.

For case study 2, it was considered that the thermal generating units are connected to an ideal bus that meets a load without transmission losses. In this case neither the system energy deficit nor the corresponding transmission costs were considered.

The study included the use of 36 thermoelectric plants of various types of fuels. Table III below shows the operation data of these thermoelectric plants in the southeast / midwest subsystem. These data were extracted from CCEE, used by NEWAVE software, a computational solution used by the sector for system optimization [5]. The power represents the installed capacity of each plant in MW, the maximum available power was calculated through the capacity factor, forced unavailability and programmed unavailability of each plant, data that were also collected by CCEE.

For simulation purposes the generation must meet a demand of 4150MW, values considerably close to the ONS thermal dispatch standard.

Table 3: Operating data of the thermoelectric power plants of the southeast-central subsystem

NUM	NAME	FUEL	Cost (R$/MWh)	Power (MW)	Máx. Power (MW)	Min. Power (MW)
1	ANGRA 1	Nuclear	31,17	640	511,91	142,28
2	ANGRA 2	Nuclear	20,12	1350	1226,49	1080,00
3	BAIXADA FLU	Gás	88,32	530	460,37	0,00
4	CARIOBA	Óleo	937,00	36	36,00	0,00
5	CCBS_L1	Gás	306,74	157	143,28	62,87
6	CCBS_L13	Gás	300,71	59	53,84	23,53
7	CUIABA G CC	Gás	511,77	529	359,41	0,00
8	DAIA	Diesel	883,20	44	28,76	0,00
9	ATLAN_CSA	Resíduos	176,98	255	224,50	12,45
10	ATLANTICO	Resíduos	176,98	235	206,89	201,50
11	EBOLT_L1	Gás	282,71	321	243,03	12,45
12	EBOLT_L13	Gás	306,66	65	49,21	2,53
13	F.GASPARIAN	Gás	548,04	572	451,35	0,00
14	GOIANIA II	Diesel	920,49	140	62,12	0,00
15	IBIRITERMO	Gás	346,37	226	191,63	0,00
16	IGARAPE	Óleo	689,98	131	78,20	0,00
17	JUIZ DE FORA	Gás	283,74	87	79,50	0,00
18	LINHARES	GNL	189,33	204	194,46	150,00
19	NORTEFLU-1	Gás	60,60	400	400,00	399,99
20	NORTEFLU-2	Gás	71,62	100	87,05	0,00
21	NORTEFLU-3	Gás	135,76	200	174,09	0,00
22	NORTEFLU-4	Gás	364,06	127	110,55	0,00
23	PALMEIRAS GO	Diesel	662,13	176	65,85	0,00
24	PIRAT.12 G	Gás	470,34	200	164,29	0,00
25	R.SILVEIRA	Gás	723,35	25	15,66	0,00
26	ST.CRUZ 34	Óleo	310,41	436	249,13	0,00
27	ST.CRUZ NOVA	GNL	126,93	500	447,30	32,40
28	T LAGOAS_L1	Gás	187,08	134	127,81	0,00
29	T LAGOAS_L13	Gás	302,22	216	206,02	0,00
30	T.NORTE 2	Óleo	910,86	340	297,43	0,00
31	TERMOMACAE	Gás	512,29	929	823,80	0,00
32	TERMORIO_L1	Gás	222,50	770	660,25	46,25
33	TERMORIO_L13	Gás	305,16	266	228,09	15,95
34	UTE BRASILIA	Diesel	1047,38	10	7,37	0,00
35	VIANA	Óleo	460,17	175	156,79	0,00
36	XAVANTES	Diesel	1268,12	54	53,14	0,00

Analyzing the results obtained, it can be observed that the GA obtained a lower total cost than the Lagrange method. Which makes the genetic algorithm validated, with an approximate error of 0.5% in relation to the theoretical method. Another finding is that the Lagrange method often finds a solution that does not meet individual generator constraints. When this happens, the analytical way to solve this problem is to force its result to fit the constraints, which does not always bring the optimal solution to the system.

For the second, more complex case study, the results can be found in Table 3 and Fig. 4. GA was run 5 times with a population of 24 individuals on a stopping criterion for 8000 generations. It had an 80% crossover rate between individuals, elitism and mutation of generations.

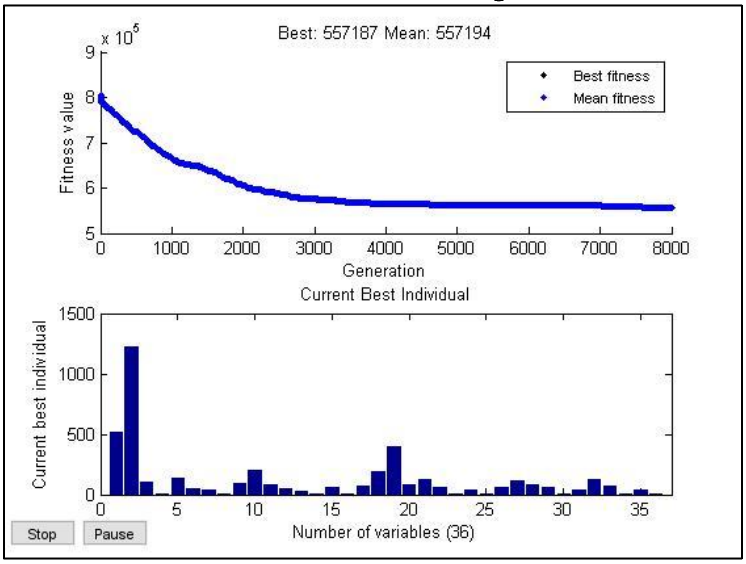

Figure 4. Convergence presented by GA and output powers found in case study 2

Analyzing the results, it was observed that the total cost was R $ 557,187 per hour. The largest shipments were from Angra I and II nuclear plants due to their low cost. The results also show that the plants with higher costs, those that use oil and diesel, had little participation in the dispatch, contributing practically insignificant.

This result demonstrates that the cost of energy production would be approximately 135R $ / MWh. At the last energy auction held in December 2017, electricity was contracted at an average price of approximately 190R $ / MWh.

CONCLUSIONS

Based on this work, the method of Artificial Intelligence by Genetic Algorithms proved to be effective and promising to optimize thermoelectric dispatch.

As is known, the Brazilian SIN is hydrothermal, that is, its dispatch occurs simultaneously between the thermoelectric and hydroelectric plants, which, in turn, do not have fuel cost, therefore, are more modest, but the decision to use or not to use it. reservoir is more complex because it also involves climate factors. However, for the initial level in GA studies, the work obtained a good result in the two case studies presented, due to their large number of plants and complexity of constraints, making the use of “brute force” unnecessary to solve them.

Another conclusion to be pointed refers to possible future works, in which the complexity can be increased, especially in the second case study described. To do this, simply implement the use of transmission lines and their respective power losses. Moreover, it is possible to consider the issue of load deficit and possibly use all generating units of the SIN.

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REFERENCES

[1] Oliveira, Armando Matos de; Souza, Reinaldo Castro, Melo, Albert C. Geber (2013). Estratégia Ótima de Oferta de Preços no Mercado de Curto Prazo em Sistemas com Predominância Hidrelétrica. Rio de Janeiro 225p. Tese de Doutorado – Departamento de Engenharia Elétrica, Pontifícia Universidade Católica do Rio de Janeiro.

[2] Miranda, V., Srinivasan, D. and Proenca, L. M. (1998). Evolutionary computation in power systems – example 2: Genetic algorithms in hydrothermal operation planning, Eletrical Power & energy Systems 20(2): 93–97.

[3] Zoumas, C., Bakirtzis, A., Theocharis, J. and Petridis, V. (2004). A genetic algorithm solution approach to the hydrothermal coordination problem, IEEE Trasaction on Power Systems 19(2): 1356–1364.

[4] Leite, P. T., Carneiro, A. A. F. M. (2006). Aplicação de Algoritmos Genéticos na determinação da operação ótima de sistemas hidrotérmicos de potência, Revista Controle & Automação 17(1): 81-88.

[5] LUKE, S. (2009). Essentials of Metaheuristics. Disponível em <http://cs.gmu.edu/~sean/book/ metaheuristics/>

[6] CCEE (2018) Biblioteca Virtual. Disponível em: < https://www.ccee.org.br/portal/faces/acesso_rapido_header_publico_nao_logado/biblioteca_virtual>

WASTE-DERIVED FUEL: AN ALTERNATIVE ENERGY RECOVERY

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ABSTRACT

Energy demand in Brazil grows every year and the main matrix has instabilities, which attests to the need for new power generation technologies. The generation of municipal solid waste in the country only increases, and the advances in its management is not significant yet. Non-generation, reduction and reuse of waste, as well as proper disposal are principles of the National Solid Waste Policy that guides the government and society in all its sectors, fosters discussions, and encourages the use of technologies. to recover energy from municipal solid waste since capturing the energy potential contained in urban waste is a key way of reducing greenhouse gases (GEE in portuguese) and contributing to the environment. From this assumption the study will bring as an alternative the Waste Derived Fuel (WDF – CDR in portuguese), the possibility of economic and energy use of urban solid waste in order to contribute to the reduction of environmental liabilities arising from the accumulation of waste in landfills.

Keywords: municipal solid waste, renewable sources, trash.

Introduction

Brazil has an electrical matrix composed mainly of energy from hydroelectric plants (65.2% - EPE, 2018), although it is more sustainable than the energy matrix, this predominance demonstrates a weakness in the energy supply, since it is subject to direct influences of the climate change. Using other sources of energy can complement each other in a clean and sustainable manner, bringing advantages especially in periods with lower energy production from hydroelectric plants, as is the case in drought times. (Gomes *et al*, 2019).

Brazil's main energy sources are fossil fuels and their derivatives (67,1 – EPE,2018). Biomass attracts remarkable attention to address the possible depletion and high cost of fossil fuels as it is a renewable and low cost source that can contribute to the electrical matrix (He *et al*, 2018).

Inadequate disposal of municipal solid waste is a Brazilian reality, dumps and controlled landfills are still present in all regions of the country and received in 2017 (ABRELPE, 2018) more than 80 thousand tons of waste per day, with an index over 40 %. The release of these wastes without any control in the environment has been a source of greenhouse gas emissions in the atmosphere, soil and water contamination and vectors of various pathologies.

According to ABRELPE (2018), Brazil has a coverage of 91.24% of collection services, 196,050 tons per day in 2017 of solid waste were collected. 3 million tons of household waste collected were received in 991 sorting units and 246,400 tons were received in 68 composting units. A small portion of the waste is sent to environmentally sound disposal, 1.65% of the total household and public waste collected in the country is recovered, or 5.4% of the potentially recoverable total mass of dry recyclables, which makes up a index of 7,4 kg / kghab / year of recovered waste (SNIS,2019).

The mass collected from recyclable waste through selective collection in Brazil was only 13,7 kg/hab./year, equivalent to 1.5 million tons in 2017. Therefore, for every 10 kg of waste that is made available for collection, only about 400 grams are collected selectively. The practice of selective collect in the country, although presenting some advances, is still at a very low level (SNIS, 2019). Of the possible recycling materials found in municipal solid waste, paper, glass, plastics and metal stand out. Of these, plastic presents greater difficulty of recycling due to the low added value.

Non-generation, reduction and reuse of waste, as well as proper disposal are principles of the National Solid Waste Policy that guide the public power and society in all its sectors. The classic hierarchy of urban solid waste management makes reuse and recycling rather than energy recovery preferable (Figure 1).

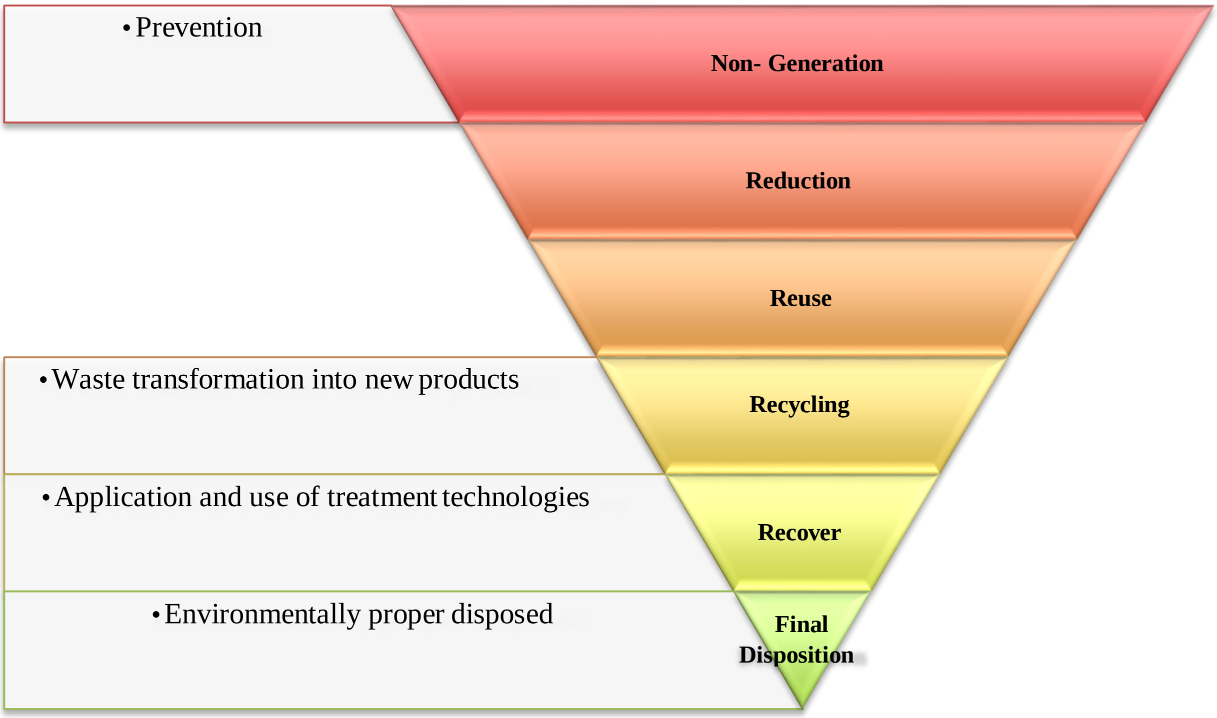

Figure 1. Urban solid waste management hierarchy according to PNRS (adapted from PNRS, the authors)

PNRS encourages the use of technologies to recover energy from municipal solid waste. Since capturing the energy potential contained in these wastes is a fundamental way of reducing greenhouse gases (GHG – GEE in portuguese) and contributing to the environment based on this assumption, the study will provide, as an alternative to fuel derived from waste, a possibility of economic use. and energy from solid waste, feasibility of CDR production and utilization.

Definition and Uses of CDR

RDF (refuse-derived fuel): Obtained from a basic processing of a non-specific waste to increase its energy content and therefore refers to the segregated MSW fuel fraction after removal, where applicable, of recycled or reused quality products from organic matter. and incombustible products (metals, glass etc.). ASTM E 856 the standard defines RDF. The ideal composition of RDF is its high content in plastics, paper / board, polymeric textile packaging, wood and other organic materials (Brás *et al*, 2017).

SRF (solid recovered fuel): is prepared solid fuel (after processing, homogenization and upgrading to a quality that can be traded between producers and users) from high calorific fractions of non-hazardous waste to be used for energy recovery in incineration or co-incineration plants (L. Del Zotto *et al*, 2015). For characterization and processing for fuel production is supported by CEN/TC 343 e a CEN EN 15359 establishes definitions, characteristics, sampling methods, parameters of interest and analytical methods, classification and requirements for the SRF quality management system.

It can be applied in conjunction with Co-combustion or co-gasification in energy conversion systems and is used as a primary or complementary fuel to reduce costs without significantly compromising the energy content of the other fuel.

In Brazil there is still no market for this technology, in São Paulo CDR (in portuguese) is incipiently produced from household, industrial and mixed waste, the State Environment Secretariat issued, on May 31, the resolution nº 38/2017, laying down guidelines and conditions for the licensing and operation of the energy recovery activity from the use of Urban Solid Waste Derived Fuel (CDRU - in portuguese) in cement industry clinker kilns (SAMPAIO, 2014). Establishes Lower Calorific Power:> 3583 kcal / kg on dry basis, Chlorine Content: <1.0%. Mercury content: <0.5 mg / kg. Emission limit of material from CDRU burning limited to 50 mg/Nm3 a 11% de O_2. The limits in SMA38 are more tolerant than those set by the directive IED (2010/75/EU), Hydrochloric acid, volatile metals (Hg, Cd, Tl) and dioxins / furans are identical.

Worldwide, mechanical biological treatment (TMB) is the waste processing technology to transform it into widespread and better consolidated CDR, highlighting the United States, Japan and Europe.

Possibility of economical use of solid waste

National Solid Waste Policy law 12.305/10 promotes improvements in waste management and from management plans, whether state or municipal, when implemented favor the recycling system and selective collection implementation, according to data from ABRELPE (2018) 70% of Brazilian municipalities have selective collection initiatives in their management plans. Proper management favors the obtaining of CDR because of the waste that is sent for sorting, only waste considered as waste is used in the process.

Of the total amount of municipal solid waste, the paper / board, wood, textile and plastic fractions account for about 80% of the energy generated (D. Glushkov *et al*,2018). According to ProteGEEr Considering that the CDR is a secondary resource with limitations on ashes, chlorine and sulfides, the price in the Brazilian market would be R$ 100,00/t.

Methods

The present paper is characterized by being a study of bibliographical survey on the subject. The research was conducted on the main public data platforms considered reliable, were used as reference sources: National Sanitation Information System (SNIS) of the Ministry of Cities, Studies of the National Solid Waste Plan (PNRS) of the Ministry of the Environment, Panoramas of Solid Waste in Brazil of the Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE), National Energy Balance of the Energy Research Company (EPE),American Society for Testing and Materials (ASTM), European Committee for Standardization e Manual on waste statistics (Eurostat).

There were exclusion criteria, articles and data prior to the year 2014. In this context, there were few articles which hindered a better explanation, perhaps because the subject is currently gaining strength in the energy scenario.

Partial Conclusion

It can be concluded that:

Demand for energy grows every year and our main matrix tends to run out which attests to the need for new power generation technologies.

The generation of municipal solid waste in Brazil only increases, and the advances in its management is not yet significant.

The use of CDR promotes energy recovery, reduces environmental liabilities arising from landfill accumulation contributing to the environment.

It is necessary to develop a trade to support this technology and that the dissemination of reliable results collaborates.

Acknowledgment

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References

ABRELPE, Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. Panorama dos resíduos sólidos no Brasil - 2017. São Paulo, Brasil: ABRELPE, 2018.

ASTM, American Society for Testing and Materials. E 856: Standard definitions of terms and abbreviations relating to physical and chemical characteristics of refuse-derived fuel. West Conshohocken, United States of America: ASTM, 1983 (2004).

Brás, I., Silva, M. E., Lobo, G., Cordeiro, A., Faria, M., & de Lemos, L. T. (2017). **Refuse Derived Fuel from Municipal Solid Waste rejected fractions- a Case Study**. *Energy Procedia, 120, 349–356.* doi:10.1016/j.egypro.2017.07.227

BRASIL. Lei nº 12.305, de 2 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei nº 9.605, de 12 de fevereiro de 1998; e dá outras providências. Diário Oficial da União, Poder Executivo, Brasília, Página 3, Seção 1, 03 de agosto de 2010.

CEN, European Committee for Standardization. EN 15359: Solid recovered fuels - Specifications and classes. Brussel, Belgium: CEN, 2011.

Del Zotto, L., Tallini, A., Di Simone, G., Molinari, G., & Cedola, L. (2015). **Energy Enhancement of Solid Recovered Fuel within Systems of Conventional Thermal Power Generation.** *Energy Procedia, 81, 319–338.*

EPE Empresa de Pesquisa Energética - **Matriz Energética e Elétrica Mundial e do Brasil**. Disponível em <http://epe.gov.br/pt/abcdenergia/matriz-energetica-e-eletrica>; acesso em:11/09/2019.
Eurostat - Manual on waste statistics - A handbook for data collection on waste generation and treatment European Union, 2013

Gomes, S, M., Faulstich de Paiva, J. M., Aparecida da Silva Moris, V., & Nunes, A. O. (2019). **Proposal of a methodology to use offshore wind energy on the southeast coast of Brazil. Energy**. doi:10.1016/j.energy.2019.07.057

SAMPAIO, R.P. **Estudo de caso dos possíveis efeitos deletérios causados pelo combustível dericado de resíduo (CDR) em caldeiras voltadas a produção de energia elétrica queimando principalmente bagaço de cana.** Dissertação apresentada ao programa de pós-graduação em engenharia mecânica – Escola de Engenharia de São Carlos da Universidade de São Paulo, USP, 2015.

Sistema Nacional de Informações sobre Saneamento SNIS: **Diagnóstico do Manejo de Resíduos Sólidos Urbanos** – 2017. – Brasil. Ministério do Desenvolvimento Regional. Secretaria Nacional de Saneamento - SNS - Brasília: MDR.SNS, 2019.

PROGRESS OF INSTALLED PHOTOVOLTAIC GENERATION CAPACITY IN NATIONAL TERRITORY

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ABSTRACT

This paper shows the analysis of the progress and spatial distribution of installed photovoltaic capacity in the Brazilian states. The QGIS software is used to map this distribution of power generation capacity in the Brazilian territory. The study shows the need to implement a policy of increasing and better distribution of installed capacity.

Keywords: energy capacity, photovoltaics, qgis.

Introduction

The theme of sustainability has been highlighted in recent years due to climate change observed on the planet, promoting the use of clean energy such as solar energy that has been gaining prominence as a substitute in the planet's energy matrices, as a renewable and clean energy source. In Brazil, photovoltaic systems connected to the grid began in the late 1990s (PINHO, 2014). The installed capacity was insignificant until 2012, when the Normative Resolution 482/2012 of the National Electric Energy Agency (ANEEL - Agência Nacional de Energia Elétrica) was published, which regulated the general conditions for access to distributed microgeneration and mini-generation (NÓBREGA et al, 2018). Since then there has been a large increase in installed capacity, however yet far below other renewable sources such as wind (BEN, 2018). The presented work makes a research of the installed photovoltaic capacity in the country, evaluating its development between 2012 and 2017 and also how it is the distribution in the national territory.

Material and Methods

The data used in the research were obtained from the National Energy Balance (BEN) reports of the years of study, with information on the installed capacity for photovoltaic generation by federation unit (states). For presentation and comparison of the distribution of installed capacity in the national territory maps were made showing the installed capacity by state, each one representing a federation unit. For the elaboration of the maps the program QGIS version 3.4 - Madeira was used, based on the information obtained in the National Energy Balance (BEN), and using a base map of the national territory with the political-administrative divisions by state, obtained in the website of the Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística), in shapefile format.

Results and Discussion

The values of total installed capacity in each year were tabulated (Table 1). In 2012, the installed capacity was 2 MW, reaching 24 MW in 2016. Between 2016 and 2017, the installed capacity shows a significant increase reaching 935 MW.

Table 1. Installed capacity each year in MW

Installed photovoltaic capacity						
Ano	2012	2013	2014	2015	2016	2017
Cap.	2	5	15	21	24	935

It can be seen that in 2013 the installed capacity was 5 MW. With the information of values by state, the map (Figure 1) shows the distribution among the federation units. The only Brazilian states with the most significant values were: Bahia, Ceará and São Paulo. The state of Bahia led this year with 3 MW of installed capacity.

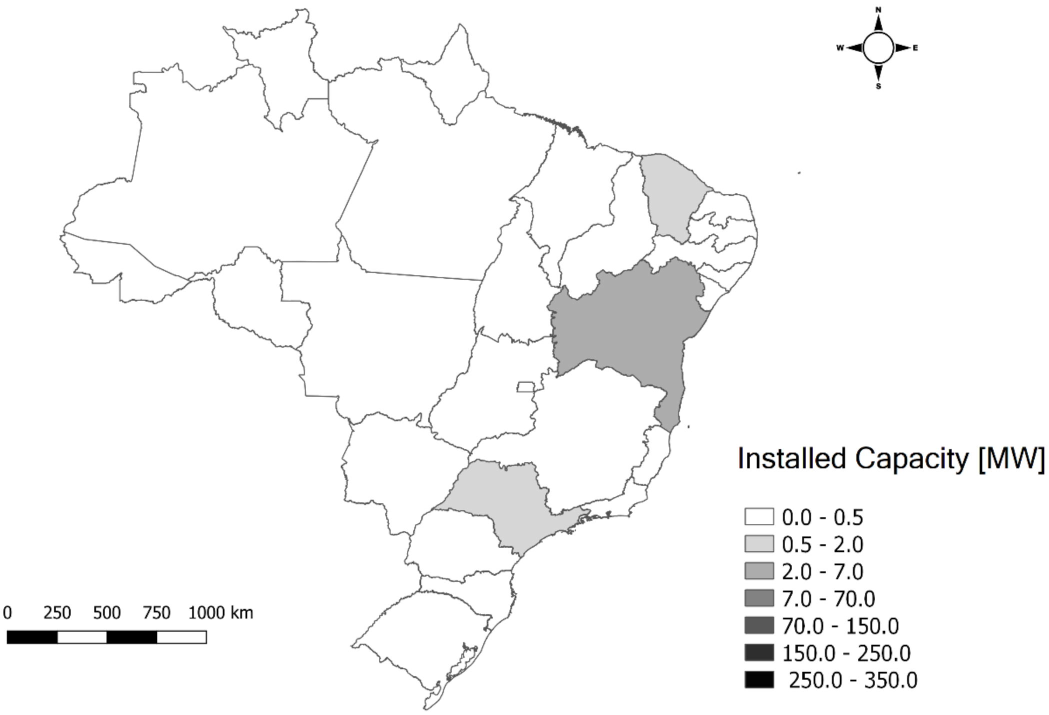

Figure 1. Map of installed capacity distribution in 2013

In 2017, there is a significant increase in installed capacity values (Figure 02). More states have significant values. In the leadership appears again the state of Bahia, but now with 319 MW. The increase in capacity observed in 2017 is significant, showing a photovoltaic capacity installed in the whole territory reaching 935 MW. The maps show large concentration of installed capacity in a few states, which in addition to providing a little economic use of the potential for receiving solar radiation. Concentration also ends up not promoting social and economic development in many regions, with possible economic gains and job creation.

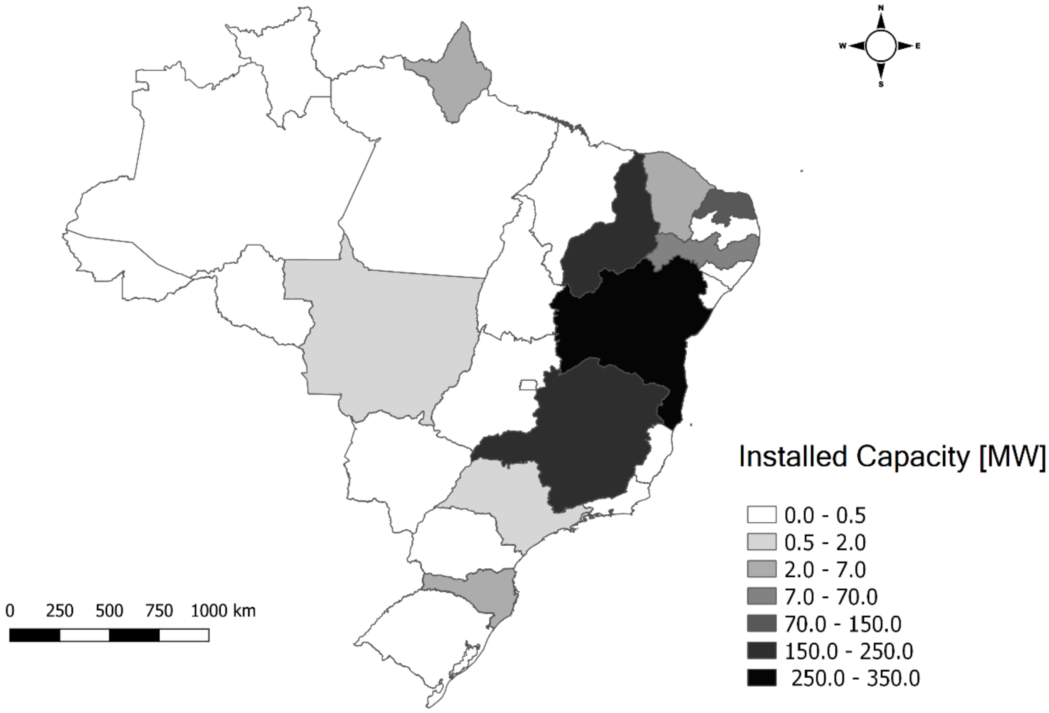

Figure 2. Map of installed capacity distribution in 2017

Conclusion

Photovoltaic energy is an important renewable source of electricity and should be further explored in the coming years, as can be seen from the increase in installed capacity in recent years. The installed capacity distribution data show that in many states there is no significant installed power for photovoltaic power exploration. The analysis indicate to the need for an incentive policy in the installation of photovoltaic modules in states with less expressive values, in order to promote regional development and make better use of the full potential of solar energy in the national territory.

Acknowledgment

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References

EPE, Empresa de Pesquisa Energética (Brasil). BEN – Balanço Energético Nacional 2018: Ano base 2017. Ministério de minas e energia. Rio de Janeiro: EPE, 2018, 292 p.

______. BEN – Balanço Energético Nacional 2017: Ano base 2016. Ministério de minas e energia. Rio de Janeiro: EPE, 2017, 292 p.

______. BEN – Balanço Energético Nacional 2014: Ano base 2013. Ministério de minas e energia. Rio de Janeiro: EPE, 2014, 288 p.

IBGE, Instituto Brasileiro de Geografia e Estatística. Mapa: Brasil - Unidades da Federação 2018. Disponível em: https://portaldemapas.ibge.gov.br/portal.php#mapa222184. Acesso em: 01 abr. 2019.

PINHO, João Tavares e GALDINO, Marco Antônio (Orgs.). Manual de Engenharia Para Sistemas Fotovoltaicos. Rio de Janeiro: Grupo de Trabalho de Energia Solar, GTES– CEPEL – DTE – CRESESB, Edição revisada e atualizada, Março 2014, 530 p.

NÓBREGA, Baldoino Sonildo et al.Desempenho de um sistema solar fotovoltaico com diferentes inclinações e orientações azimutais em cidades da Paraíba. Revista Principia n. 43, Fevereiro 2018.

MALHEIRO, C. T. et al. Avaliação de locais com potencial para a implantação de GD fotovoltaica sob a perspectiva do desenvolvimento sustentável. Santo André, s.d. UFABC. Disponível em: http://eventos.ufabc.edu.br/siimsps/files/id110.pdf. Acesso em: 29 abr. 2019.

VELAYOS, Javier G. et al. Metodología para la localización óptima de instalaciones de energia solar fotovoltaica em la Isla de Tenerife, España. Congreso nacional de medio ambiente – Conama 2018. Nov. 2018.

SOLID FRACTION SEPARATION IN BIOGAS PRODUCTION FROM DAIRY CATLE MANURE

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ABSTRACT

This work aimed to evaluate the biogas production during the anaerobic digestion of manure from dairy cattle with and without solids separation. The anaerobic digestion was performed in 8 continuous digesters, filled with waste without separating the solid fraction (WSSF) and separating the solid fraction (SSF) in a sieve of 1.0 mm mesh. The period for the evaluation of the digestion process was 5 weeks, after stabilization of the digester, which took approximately 30 days. The methane production (CH_4) were higher for the digesters with solid fraction separation in relation to the added volatile solids content. The biogas production in the digesters without solid fraction separation were higher when compared to the digesters with solid fraction separation, but the average methane content (67%) was higher in digesters with solid separation. The higher methane yields have been observed for lowered solids concentration in manure, and the hydraulic retention times can be reduced, which reduces the volume of the digester and costs of implementation and maintenance due to decreased risks of clogging. If there is area limitation and mechanization or maintenance of the digesters is not desirable, the separation of solids is more advantageous, but the separated waste must have a proper disposal destination for treatment. If the interest is energetic and there is no area limitation, the non-separation of solids provides greater gains, but the digester will need more maintenance.

Keywords: Biogas, Anaerobic Digestion, Dairy Cattle Manure, Solid Separation

Introduction

Brazil is a large cattle producer that, in 2012, had a herd of over 218 million heads. According to IBGE (2016), the dairy cattle accounted for about 10.9% of the total herd, totaling approximately 24 million heads. The increased demand for animal products causes intensive livestock breeding, producing a large volume of waste in small areas, causing problems for both treatment and disposal, as well as for the environment. The possibility of biogas recovery with the manure treatment, stands out in the dairy cattle production system due to the production of large amounts of manure.

In practice, biogas recovery is possible with the use of anaerobic digesters and, according to Barbosa & Langer (2011), the anaerobic digester represents an excellent alternative for the treatment of the manure generated, as producers are responsible for allocating an appropriate treatment to these. Batch-type digesters are loaded once, kept in fermentation for a convenient period, and the material is discharged after the effective biogas production period ends (BONTURI & VAN DIJK, 2012). Continuous type digesters are fed daily.

The manure collected to feed the digester may contain fractions which may be considered non-biodegradable or slowly biodegradable, from parts not degraded by the animal feed, such as fibers or debris from the washing process and sand, for example. These fractions can affect the anaerobic digestion process and the separation of this fraction can contribute to the process to become more efficient (higher biogas production per kg of solid), faster (hydraulic retention time reduced) and more economical because it requires smaller reactors for the same number of animals

In this way, the objective was to evaluate the biogas production in continuous digesters with and without the separation of solids of the substrate (dairy cattle manure), evaluating the potential of methane production and reductions of the volatile solids to obtain biogas production parameters.

Material and Methods

The experiments were conducted at the Faculty of Agricultural and Veterinary Sciences (FCAV) of the Universidade Estadual Paulista (UNESP) - Jaboticabal - SP. The manure used was from dutch dairy cattle with an average body weight of 640 kg. . The installation was the type *Tie stall* (where animals remain side by side in individual stalls) facility on the concrete floor.

Eight digesters were used with a useful fermentation capacity of 60 liters of substrate each, whose scheme of the model is shown in Figure 1.

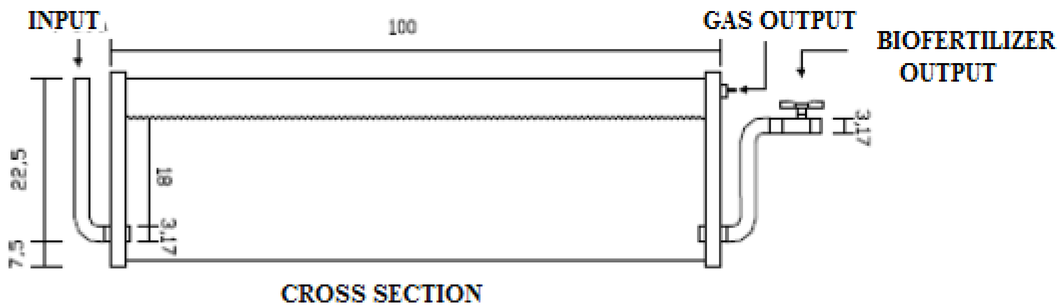


Figure 1 - Cross section of tubular biodigesters used in the experiment (measures in cm and non-scaled drawing)

To prepare the charges, the manure was collected manually by scraping the concreted floor with a hoe. Manure from dairy cattle fed with a diet composed of 60% concentrate and 40% forage was studied. In each supply, the mixture (manure + water) was prepared to have a total solids content close to 3%.

Initially, the continuous digesters were charged with 60 kg of substrates that were manually homogenized with the aid of paddles and then fed into the digesters.

The samples were placed in continuous digesters and maintained for a 30 day hydraulic retention time (HRT). The loads were performed daily, a period of 5 weeks was agreed to analyze the process.

For the anaerobic digestion test, continuous digesters were used with the following treatments for the manure, with 4 replications:

- without solid fraction separation (WSSF); and
- with solid fraction separation (SSF)

In the treatment described as the solid fraction separation treatment (SSF) the mixture was sieved in a 1.0 mm mesh sieve and thus the liquid that passed through the sieve was used to supply the digesters. Daily, the digesters were supplied with 250 grams of cattle manure and diluted in 1.65 liters of water.

Manure characterization analyzes were performed at the Anaerobic Biomass and Digestion Laboratory, belonging to the Rural Engineering Department of Unesp / Jaboticabal (SP). The contents of TS (total solids) and VS (volatile solids) were determined according to the methodology described by APHA (2005).

Biogas yields were calculated based on gasometer displacements, measured with a scale. The number obtained in the reading was multiplied by the internal cross-sectional area of the gasometers, equal to 0.04909 m^3. After each reading, the gasometers were zeroed using the biogas discharge register. The correction of biogas volume for the conditions of 1 atm and 20 ºC was based on the work of Caetano(1985).

The biogas and methane production potentials were calculated using the total biogas production data of each digester and the amount of waste, TS and VS added in the digester and the reduced VS during the process. Values were expressed in m^3 of biogas and methane per kg of manure, TS added, VS added and VS reduced.

The analysis of the quality of the biogas produced were made weekly to determine the contents of methane (CH_4) and carbon dioxide (CO_2), using a gas chromatograph Finnigan GC-2001.

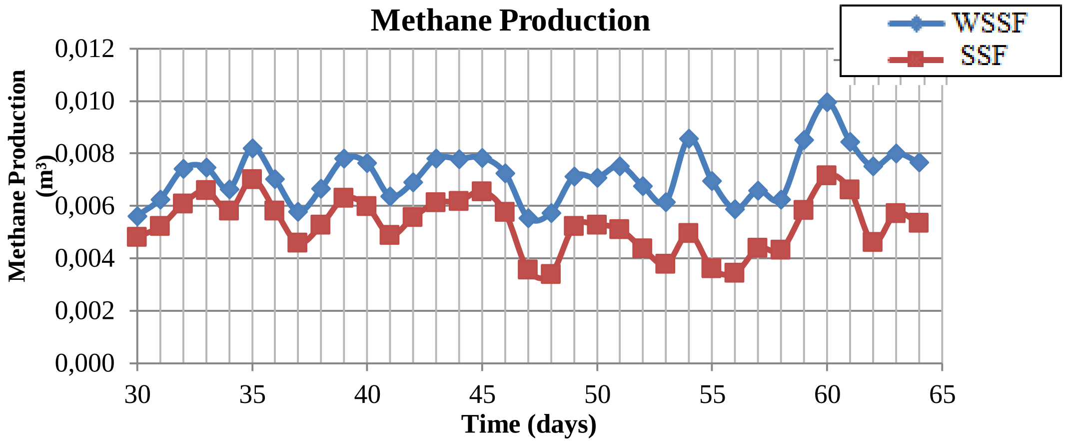
For the anaerobic digestion experiment, a general linear model with 4 repetitions was used. The assumptions for variance analysis were verified and the averages compared by Tukey test at 5% probability level in the SAS (Statistical Analysis System) program.

Results and Discussion

The volatile solids contents (VS) represented 77.8% and 74.3% of the total solids contents (TS), that is, the amount of VS present in the TS for the without solid fraction separation digester (WSSF) and with solid separation (SSF), respectively. These values were close to those found by Amaral et al. (2004) who worked with dairy cattle manure, in continuous digesters and different hydraulic retention times (HRT), for HRT 30 days (81%) and HRT 20 days (79%).

During the digestion process, larger reductions in TS (74%) and VS (73%) levels occurred in the solid separation treatment (SSF) while in the non solids treatment (WSSF) values were obtained. 40% and 38%, respectively for TS and VS. These differences indicate that solids separation may be particularly important for rural properties that have small areas for manure application, solids separation allows the removal of an organic compound with higher total solids content and the net fraction obtained during separation it undergoes large reductions in total solids contents during the anaerobic digestion process. The reduction of VS in solid fraction separation digesters (SSF) were close to the values found by Miranda et al. (2006), who worked with cattle manure in batch digesters, and had a volatile solids reduction of 76%.

The time for the digesters to start in both treatments was similar and the methane production start was around 25 days, when both treatments showed stability in the daily methane production, with the digesters supplied with manure without solids separation (WSSF) always presenting higher productions. For a better analysis of the results, it was decided to present and discuss separately the results obtained when the digesters presented production stability. Thus, data obtained at 5 weeks, ie 30 days after the initial supply of the digesters were used separately (Figure 2).



WSSF- without solid fraction separation ; SSF - with solid fraction separation;

Figure 2 - Methane production (m³), during the 5-week period of the selected experiment, in continuous digesters, 30-day HRT, and operated with dairy cattle manure obtained from without solid fraction separation (WSSF) and with solid fraction separation (SSF)

The average weekly biogas production from without solid fraction separation (WSSF) and with solid fraction separation (SSF) digesters were 0.07984 and 0.0557 m³, respectively. Galbiatti (2013) obtained values close to those of solid fraction separation digesters (SSF), with a weekly average of 0.0465 and 0.0557 m³ of biogas from manure cattle without sugarcane and with sugarcane, respectively.

When evaluating the production of methane, the separation of the solid fraction led to a 26% reduction in methane production, but the average contents of methane in the biogas were 63% for digesters without separation of solid fraction (WSSF) and 67 % for digesters with solid fraction separation (SSF). Xavier (2005), working with dairy cattle manure and co-digestion of sugarcane juice in continuous digesters, obtained an average of 62% of biogas methane for digesters supplied with dairy cattle manure only, being close to that found in digesters without solid fraction separation (WSSF) (63%). The methane contents found by Amaral et al. (2004), who worked with dairy cattle manure submitted to different hydraulic retention times and continuous digester types, were lower and ranged from 60 to 54% of biogas methane.

Table 1 shows the values of methane production potentials, expressed in m³ per kg manure, per kg total solids (TS) added, per kg volatile solids (VS) added.

Table 1- Methane production potentials, expressed in m³ of methane per kg of manure, per kg of TS and VS added

	METHANE PRODUCTION		
	m^3 kg^{-1} Manure	**m^3 kg^{-1} TS in**	**m^3 kg^{-1} VS in**
WSSF[1]	0,0287 a	0,1631 b	0,2101 b
SSF[2]	0,0212 b	0,1785 a	0,2407 a
Values of P	<0,0001	<0,0005	<0,0001
Values F	171,70	13,79	30,71
CV(%)	3,26	3,43	3,46

P - probability; F- significance; CV - coefficient of variation;

For the production of methane per kg of manure, the difference of methane per kg of manure production potential drops to 26% because the obtained biogas from digesters with solid fraction separation (SSF) showed a higher methane content in their composition. The with solid fraction separation digesters (SSF) presented higher production potentials in terms of the volume of biogas and methane produced per kg of total and volatile solids added indicating better efficiency for manure treatment.

Orrico Jr. et al. (2010) found values of 0.110 to 0.350 m³ of methane per kg of TS added and 0.130 to 0.410 m³ of methane per kg of VS added. Potentials found were higher for animal manure fed with 60% concentrate content of 40% forage.

The digesters without solid fraction separation(WSSF) and with solid fraction separation(SSF) showed statistically significant differences for both methane production potentials, including methane production in m³ per kg of TS added.

Conclusion

The separation of the solid fraction increased the reduction of total and volatile solids during the anaerobic digestion process. This aspect and the separation of solids themselves become particularly interesting in rural properties that have limited areas for waste disposal, as, although there is a reduction in biogas production, most waste can be transported in solid form to other locations. The separation of the solid fraction reduced methane production by 26%, consequently improving biogas quality. And the solid separation digesters showed better efficiency in the production of biogas and methane per kg of total and volatile solids added, which indicates a better efficiency for manure treatment.

References

AMERICAN PUBLIC HEALTH ASSOCIATION (APHA). Standard methods for the examination of water and wastewater.**2540-SOLIDS**.25th ed. Washington, DC, 2005.

AMARAL, C. C., AMARAL, L. A., LUCAS JUNIOR, J. Biodigestão anaeróbia de dejetos de bovinos leiteiros submetidos a diferentes tempos de retenção hidráulica. *Ciência Rural*, v.34, n.6, p.1897-1902, nov/dez., 2004.

BARBOSA, G.; LANGER, M. Uso de biodigestores em propriedades rurais: uma alternativa à sustentabilidade ambiental. *Unoesc & Ciência*, Joaçaba, v.2, n. 1, p. 87-96, jan./jun., 2011.

BONTURI, G. de L.; VAN DIJK, M. Instalação de biodigestores em pequenas propriedades rurais: análise de vantagens socioambientais. *Revista Ciências do Ambiente On-Line*, v.8, n.2, p.88-95, 2012.

CAETANO, L. **Proposição de um sistema modificado para quantificação de biogás**. Botucatu: Universidade Estadual Paulista, 1985. 75f. Dissertação (Mestrado em Energia na Agricultura) Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, 1985.

GALBIATTI, J.A.; CARAMELO, A.D.; SILVA, F.G.; GERARDI, E.A.B.; CHICONATO, D.A. Estudo qualiquantitativo do biogás produzido por substratos em biodigestores tipo batelada. **Revista Brasileira de**

Engenharia Agrícola e Ambiental, Campina Grande, v.14, n.4, 2010.

MIRANDA, A. P.; AMARAL, L. A.; LUCAS JUNIOR, J. **Influência da temperatura na biodigestão anaeróbia de dejetos de bovinos e suínos**. In: X Encontro Latino Americano de Iniciação Científica e VI Encontro Latino Americano de Pós-Graduação – Universidade do Vale do Paraíba. p. 2829 – 2831. 2006.

ORRICO JÚNIOR M, O. P.; ORRICO A. C. A.; LUCAS JÚNIOR, J. Influência da relação volumoso: concentrado e do tempo de retenção hidráulica sob a biodigestão anaeróbia de dejetos de bovinos. *Revista Engenharia Agrícola*, Jaboticabal, v.30, p.386-394. 2010.

XAVIER, C. A. N. **Biodigestão anaeróbia de dejetos em sistema de produção de leite: obtenção de parâmetros e dimensionamento**. 2005. 90f. . Dissertação (Mestrado em Zootecnia- Área de Concentração em Produção Animal) – Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista, Jaboticabal, 2005.

TRANSMISSION LINES: A DIRECT CORRELATION BETWEEN AMPACITY AND WIND POWER PRODUCTION

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ABSTRACT

The electricity generation by wind power plants has increased significantly in Brazil in the last years. However, what has been observed is that the infrastructure needed to take this energy from the areas where it's generated to the consumption places has not kept up with the same pace of growth. Consequently, the transmission system has become a bottleneck for the electricity sector expansion and the construction of new transmission lines involves huge amounts of investments. The transmission line rating establishes maximum allowable current given the conductor temperature, concept also known as ampacity. These ratings for overhead conductors are determined according to technical norms, which consider a predetermined set of environmental conditions, such as wind speed and solar radiation, to determine the conductor thermal capacity and consequently the static line rating. An alternative to promote better use of the existing grid is to use dynamic limits based on the current environmental conditions, thereby enabling one to maximize the line utilization based georeferenced meteorological information. This paper presents a review of the issue and identifies the transmission facilities interconnecting particular regions that can most benefit from this approach.

Keywords: Ampacity, Wind Farms, Environmental Conditions, Dynamic Line Rating, Overhead Conductor.

Introduction

The current capacity of overhead power transmission lines (LTs) is determined based on the temperature and minimum distance between the conductor cable and the ground. As the cable exchanges heat with the surrounding environment, its temperature is influenced by surrounding environmental conditions. To determine current capacity, standards use a deterministic methodology to represent meteorological data such as ambient temperature, solar radiation, and wind using critical statistical criteria. The critical conditions assumed in these criteria have low probability of occurrence (NASCIMENTO, 2009). Given this, the conductor temperature is much of the time below the thermal design limits, leaving an idle portion that can be better exploited in the operation of the network.

In general, the main elements involved in the thermal balance of an overhead conductor are: heating due to solar radiation; heating due to current intensity (Joule effect); and cooling by the surface convection and radiation phenomena of the conductor. The solution for steady-state cable ampacity due to these effects is given by:

$$I = \sqrt{\frac{P_r + P_c - P_s}{R_{ac}(T_c)}}$$

where the terms P_r (W/m) and P_c (W/m) are respectively radiation and convection cooling. I is the current at maximum temperature that the cable can safely reach (or ampacity). The term Ps (W/m) represents the solar radiation heating, R_{ac} (ohm/m) is the conductor resistance in alternating current and Tc is the conductor temperature (PORTELA, 2014).

This parameter makes it possible to relate the intensity of the electric current to the conductor temperature, enabling applications that take into account the real environment and line operating conditions. However, in practice, the transmission line designs end up following NBR-5422 recommendations and calculating the ampacity based on constant wind speed values (ABNT, 1985).

Studies and experiments have been carried out in several countries, including Brazil, with the application of real-time monitoring devices of the environment and conductor for dynamic calculation of current capacity (KARIMI, 2018), (CHEN, 2012) and (FERNANDEZ, 2016). In these approaches, for each weather condition there is a current that raises the conductor to the limit temperature, allowing knowing the variations of the network loading conditions, and making room for a better use of it. The use of real-time weather data to determine the flow capacity of the transmission lines is particularly advantageous in areas of high wind power production, in which transmission loads and transmission ampacity are positively correlated to wind speed. There are studies that point to substantial gains of transmission ampacity in periods of high wind speeds. Applications of monitoring systems show that cases with gains greater than 50% of load limit (RANIGA, 2000), in certain periods, without exceeding safety limits are common.

This study uses geoprocessing tools and information from transmission electric grid to identifies segments of the National Interconnected System (SIN) of Brazil, especially in the Northeast region that are more apt to the benefits of this approach.

Methods

The method applied in this paper correlates the potential of wind generation with the increased ampacity of the transmission lines installed in areas with average wind speeds above the limits (0,61m/s) established by NBR-5422 in force. For this, were used georeferenced data from wind power plants, transmission grid and wind speed data (ANEEL, 2019). This information was compiled and analyzed using GIS software (QGIS and ArcGIS).

Since in Brazil the northeast region has the highest potential for wind generation (AMARANTE, 2001), this area, despite the distribution of wind projects installed in several states, the highlight in terms of power and number of wind power plants, both in terms of existing and contracted plants (until 2018), are in the states of Ceará, Rio Grande do Norte and Bahia. For this reason, the projects present in these three states were selected. Distances between the transmission lines and areas with average wind speed greater than 6 m/s were calculated. Finally, were selected the lines near or within areas with high winds.

Results and Discussion

The projects and study sites that resulted from the analysis are shown in Figure 1.

The Table 1 presents the LTs located in the areas characterized by winds with annual averages greater than 6 m/s. Therefore, these projects may have their current capacities subject to increase by applying the dynamic ampacity calculation. The projects selection resulted in approximately 2,700 km of transmission lines under wind conditions favorable to the application of the approach proposed in this study. This highlights potential gains in the use of the grid by wind farms in the indicated locations. In addition to the leadership in terms of exploited wind potential, the Northeast region shows a lack of transmission infrastructure, leaving significant areas with no possibility of power plants connection. Thus, the area becomes a good target for the approach of this study.

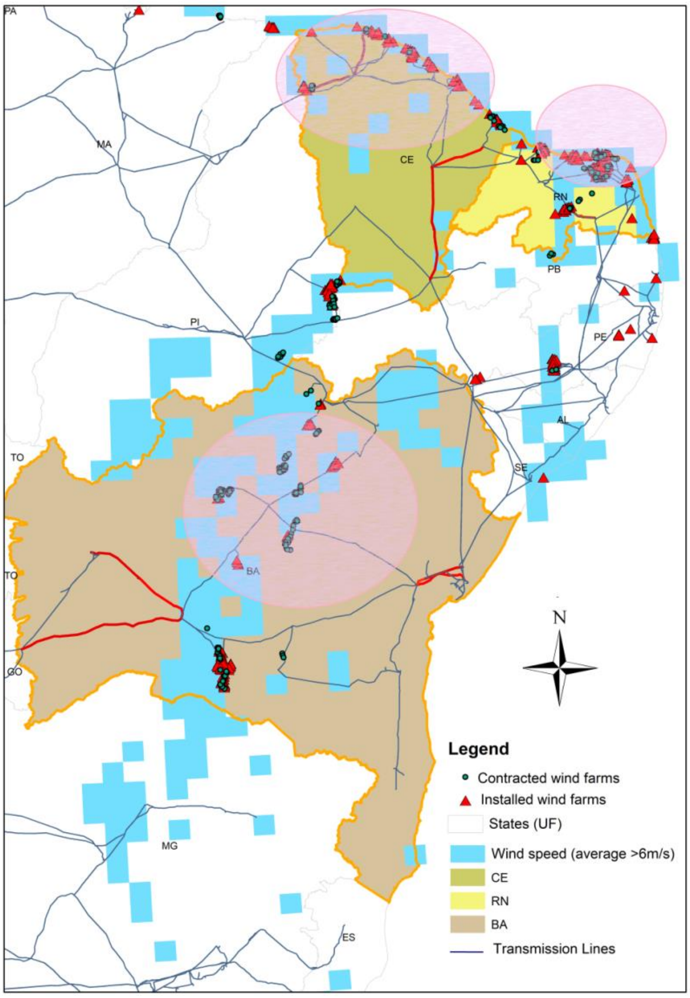

Figure 1. Representation of wind potential and power transmission grid in Northeast Brazil

Table 1. Transmission lines selected for potential application of dynamic monitoring systems for ampacity calculation

State	Transmission Lines in areas with average wind speed > 6 m/s
Bahia	LT 230 kV Bom Jesus da Lapa I - Brotas de Macaúbas C1
	LT 230 kV Bom Jesus da Lapa II - Igaporã II C1
	LT 230 kV Campo Formoso - Irecê C1
	LT 230 kV Itagibá - Brumado II C1
	LT 500 kV Bom Jesus da Lapa II - Igaporã III C1
	LT 500 kV Luiz Gonzaga - Sobradinho C1 e C2
Ceará	LT 230 kV Acaraú II - Itarema V C1
	LT 230 kV Aquiraz II - Banabuiú C3
	LT 230 kV Fortaleza II - Pici II C1
	LT 230 kV Pecém II - Trairí C1
Rio Grande do Norte	LT 230 kV Açu II - Alegria C1
	LT 230 kV Açu II - Lagoa Nova II C1
	LT 230 kV Ceará Mirim II - João Câmara II, C1 e C2
	LT 230 kV Ceará-Mirim II - Extremoz II C1 e C2
	LT 230 kV Ceará-Mirim II - Touros C1
	LT 230 kV Extremoz II - Natal III C1
	LT 230 kV Galinhos - Miassaba 3 C1
	LT 230 kV João Câmara II - União dos Ventos C1
	LT 500 kV Açu III - João Camara III C1
	LT 500 kV Campina Grande III - Ceará Mirim II C1
	LT 500 kV João Câmara III - Ceará Mirim II C1 e C2

The selected projects are appointed as candidates for the installation of monitoring systems, in order to obtain experimental data that validate and justify the application as an alternative to grid expansion.

Conclusion

The growing importance of wind power brings new challenges and the need for improvement in the technical requirements of network access and use. The current capacity of the lines, despite being influenced by atmospheric conditions around the conductor, is still calculated based on conservative limits. Thermal models show that increasing the wind speed on the conductor has an effect of the more effective convection process and, consequently, a reduction in the conductor temperature. This results in increased ampacity, i.e. the maximum allowable current value increase. The use of devices for dynamically calculating the ampacity of transmission lines installed in high wind locations may promote gains in the use of SIN and delay the need of grid expansion. The crossing of information from the SIN, wind farms and wind characteristics in the Northeast of Brazil allowed the selection of 17 of transmission lines considered candidates for monitoring and dynamic calculation of ampacity.

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References

ABNT. NBR 5422: “Projeto de linhas aéreas de transmissão de energia elétrica”. Rio de Janeiro: ABNT, 1985.

AMARANTE, O. A. C. et al. Atlas do potencial eólico brasileiro. Brasília: Camargo Schuber & CEPEL, 2001.

ANEEL. Sigel. Disponible in: https://sigel.aneel.gov.br/portal/home/. Acesso em: 2019 July 15.

CHEN, L. et al. Thermal Grading around Overhead Transmission Line under Various Environments and its Influence to Load Capacity. Beijing – China: IEEE, 2012.

FERNANDEZ, E. et al. Review of dynamics line rating systems for wind power integration. Bilbao: Renewable and Sustainable Energy Reviews, 2016.

KARIMI, S.; MUSILEK, P.; KNIGHT, A. M. Dynamic thermal rating of transmission lines: A review. Renewable and Sustainable Energy Reviews, Calgary, n. 91, p. 600-612, Aug. 2018.

NASCIMENTO, C. A. M. D. Cálculo da Ampacidade de Linhas Aéreas de Energia Considerando a Influência da Camada Limite da Atmosfera – Doctoral thesis. Belo Horizonte: Universidade Federal de Minas Gerais, 2009.

PORTELA, T. M. Avaliação teórica e experimental da transferência de calor em cabos de linhas aéreas com foco na análise da ampacidade. Belo Horizonte: UFMG, 2014.

RANIGA, J. K.; RAYUDU, R. K. Dynamic Rating of Transmission Lines - A New Zealand Experience. Wellington: IEEE, 2000.

EFFECTS OF DISTRIBUTED GENERATION IMPLEMENTATION AND RETROFIT ACTIONS IN A FEDERAL UNIVERSITY

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ABSTRACT

Observing the large amount spent by public higher education institutions on the cost of electricity, ANEEL launches Call no. 001/2016 - Priority Energy Efficiency and Strategic R&D Project: “Energy Efficiency and Mini Generation in Public Higher Education Institutions” to open space for further research and minimize the impacts of high electricity demand on these institutions. In this context, this paper seeks to analyze, through a case study, how the implementation of a photovoltaic solar generation plant and the retrofit of part of the lighting system may benefit the institution. However, the results show that the implementation of photovoltaic plants on the SA and SBC campuses could represent an annual savings of R$ 458,632.01 that would no longer be spent on the payment of the electricity bill. Already the retrofit in the lighting system generates a reduction of R$ 28,835.14 monthly expenses with electricity. Therefore, it is possible to notice that the actions developed under Call nº. 001/2016, brings relevant financial benefits to the institution, and also provides the enrichment of research in the area of energy efficiency.

Keywords: Energy efficiency; photovoltaic plant; retrofit of the lighting system; distributed generation; consumption of electricity in a public university.

Introduction

At a time of economic, social and environmental development, where the increase in electricity demand has intensified, due to the increasing modernization of the productive and population sectors, awareness about the impacts caused by the generation of electricity has been the subject of debate among legislators, generators and consumers, making it necessary to discuss measures that can positively intervene in the growing demand for energy resources.

In Brazil, the consumption of electricity has been growing since the 1950s, driven by the industrialization of the post World War II period, with a sharp increase in consumption since the 1970s, having increased by approximately 1300%, from 39,659 GWh in 1970 to 526,118 GWh in 2017, as observed in Figure 1. (EPE, 2018)

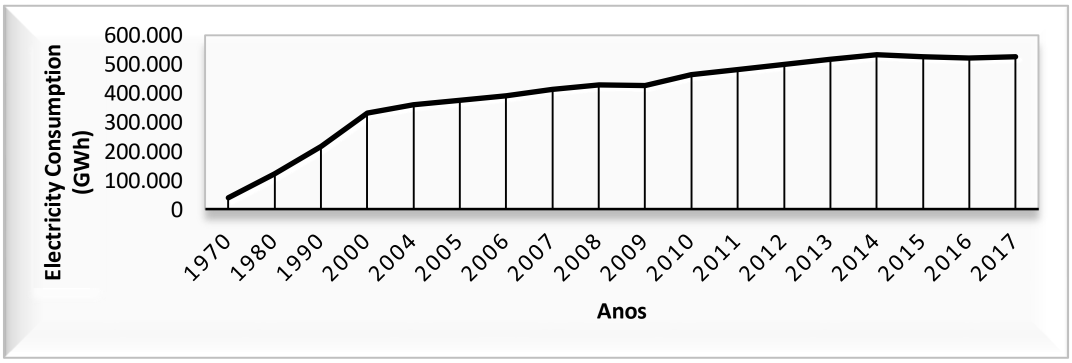

Figure 1. Electricity consumption in Brazil between 1970 and 2017. (EPE 2018)

Regarding federal universities, Benedito et.al (2018) mentions that data from the National Electric Energy Agency (ANEEL) show that the payment of electric energy expenses at the 63 Brazilian federal universities constitutes one of the expenses that generate the largest expenditure for these. In 2015, R$ 430 million was spent for this purpose, which represents approximately 9% of the total expenses for the year.

According to data from the Federal University of ABC Budget Bulletin 2018/2019, launched by the Dean of Planning and Institutional Development, R$ 4,438,779.26 was spent on electricity, which represents 68.60% of operating expenses of the institution. The same amount represents 8.97% of the amount equivalent to R$ 49,477,807.00 for university funding.

The importance of this study arises from the similarity that exists in the consumption pattern of UFABC with the other federal universities, and the similar financial limitation for electricity payments. Thus, understanding how projects in this category impact the operation of public higher education institutions, showing the feasibility and benefits that are provided, would help in future decision making.

However, in the context of Call No. 2016/01 - Priority Project for Energy Efficiency and Strategic R&D: “Energy Efficiency and Mini generation in Public Higher Education Institutions” by ANEEL is intended through a case study, defined by Yin (2005), as a strategy for research that has as a procedure the observation and data collection in the environment where the study will be carried out, followed by analysis and interpretation of the data, to infer what will be the impact of the implementation of the photovoltaic solar plant and the replacement of the fluorescent tubes with LED lamps electricity consumption, and how will this impact on the amount spent on the payment of electricity to the distributor.

Material and Methods

The current budget crisis has led public higher education institutions to take steps to reduce expenditures and control waste in order to maintain essential services. The Federal University of ABC, through the scarcity of resources, began to run campaigns on its conscious use of electricity. Such campaigns involve moderate use of the air conditioning system, shutdown computers and lighting after use.

However, although valid, these are palliative measures that depend on the awareness and collaboration of the entire academic community, in order to have a significant result and an effective reduction in electricity expenses. However, concrete measures such as those carried out by the priority energy efficiency project, established by the partnership between distributor Enel and UFABC, can and have been showing effective results in terms of energy savings.

The project mentioned includes the installation of a 663.1 kWp solar photovoltaic plant, composed of 9 subsystems distributed between the Campuses of Santo André and São Bernardo do Campo, as shown in Figure 2. The project also has the replacement of 12,136 fluorescent lamps (consequently the withdrawal of 6,068 2x16W electronic ballasts) on the Santo André campus by LED lamps.

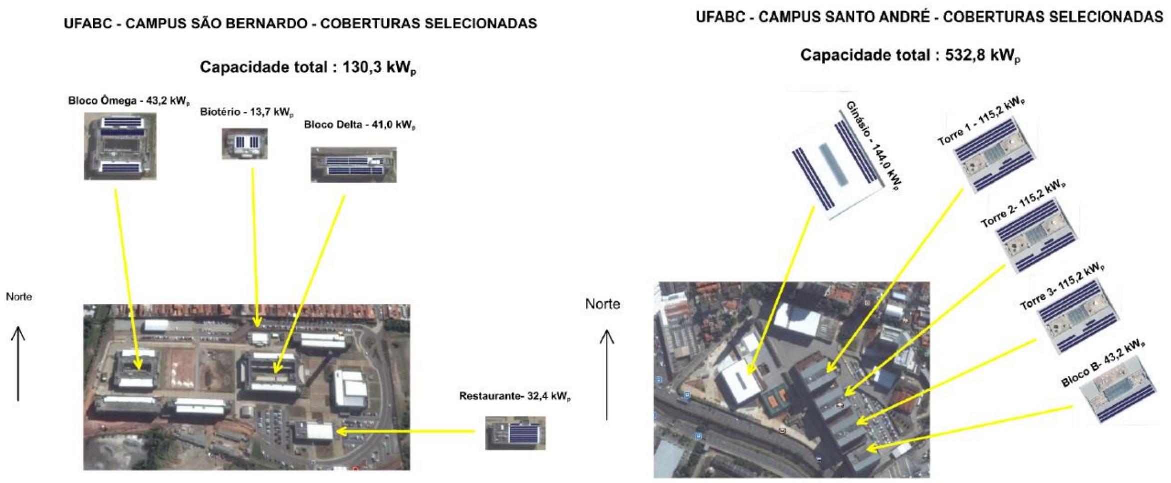

Figure 2. Subsystems of the São Bernardo do Campo and Santo André campuses. (Source: UFABC, 2018)

To analyze the impact of photovoltaic generation on the institution's consumption, the arrangements shown in Figure 2 were considered, with the campus of SA being a 532.8kWp installed capacity plant and in SBC a 130.3kWp installed capacity plant. Due to the placement of the modules on top of buildings and without large surrounding structures, the Shading Factor (SF) was considered 1.

To calculate the total alternating current electric energy delivered by the system ($E_{c.a.i}$), considering the photovoltaic arrays of SA and SBC campuses separately, Equation 1, presented by Lorenzo (2002) and also used by Benedito et. al (2018). Where, P_{FV}^{0} is the nominal array power, PR is the performance ratio or overall performance rate, $H_{t,\beta}$ is the array plane irradiation, G_0 is the reference irradiance (1000 W/m^2) and SF the shading factor.

$$E_{c.a.i} = P_{FV}^{0} * PR * \frac{H_{t,\beta}}{G_0} * SF \tag{1}$$

Dividing the irradiation in the arrangement plane by the reference irradiance, we have the Full Sun Hours (FSH), so we have Equation 2.

$$E_{c.a.i} = P_{FV}^{0} * PR * FSH * SF \tag{2}$$

Therefore, obtaining FSH data from the Brazilian Solar Energy Atlas (2017) (LABREN) as shown in Table 1, already knowing the nominal power of the arrangements, adopting the performance ratio as 0.8 and the shading factor as 1, is possible to obtain the electrical energy generated by the system.

Table 1. Sum of full sun hours accumulated in a year.

Campus	Santo André	SBC
ANNUAL FSH (h)	1,579.35	1,541.56

The retrofit of part of the institution's lighting system, as described above, is replaced by the fluorescent lamp assembly and electronic ballasts shown in Figure 3, with LED lamps such as the one shown in Figure 4. The ballasts used are designed to operate at together with two tubular fluorescent lamps, the retrofit resulted in the removal of 6,068 electronic ballasts. Detailed quantities and equipment specifications are shown in Table 2.

Figure 3. Replaced equipment on the retrofit, lamp on the left and ballast on the right.

Figure 4. New equipment placed.

Table 2. Equipment specifications, power and daily operating hours.

Equipment	Amount	Power Consumed (W)	Hours of operation per day (h)
Fluorescent lamps	12,136	16	18
Electronic ballasts	6,068	2	18
Led lamps	12,136	9	18

The daily power consumption (P_{day}) of the equipment was obtained by multiplying the amount in use (A) by the power consumed (Pcons), multiplied by the operating hours per day (H_{day}), as shown in Equation 3.

$$P_{day} = A * P_{cons} * H_{day} \quad (3)$$

The monthly consumption was obtained by multiplying the P_{day} by 30 days of the month, and the power consumed by the replaced equipment (fluorescent lamp + reactor) was added to find the savings related to the replacement by the LED.

Results and Discussion

Table 3 shows the total values of alternating current electricity calculated from Equation 2, where it can be observed that on campus SA, would be saved about 673.18 MWh per year, ie, the consumption of this amount of energy from the distributor would be avoided. In financial terms, considering the tariff of R$ 0.55/kWh would save about R$ 370,251.12 that would be spent on the payment of the energy bill. On campus SBC would be saved 160.69MWh per year, representing about $ 88,380.89.

Added to the saved values, we obtained a total of R$ 458,632.01, which would represent a 10.33% reduction in the amount spent on electricity in 2018.

Table 3. Total values of electricity generated in each system.

Campus	Santo André	São Bernardo do Campo
$\boldsymbol{E_{c.a.i}}$ **(kWh)**	673,183.85	160,692.53

Table 4 shows the consumption values (in kWh) calculated by Equation 1 multiplied by 30, referring to the number of days of the month for the old case, with fluorescent lamps and with electronic ballasts and for situation after retrofit, ie , with the LED lamps already in operation. Also shown is the monthly savings that technology replacement has provided, reaching a real savings of 52427.52 kWh/month, representing a 47.05% reduction over initial consumption. In financial terms, considering the tariff charged by the distributor per kWh equal to R$ 0.55 cents, the reduction in the amount spent on electricity expenses may be equivalent to R$ 28,835.14 per month.

Table 4. Calculated values of consumption and savings obtained with the retrofit.

Equipment	**Monthly Consumption (kWh/month)**	**Monthly Consumption with Fluorescent+Reactor (kWh/month)**	**Monthly Cost Fluorescent + Reactor**	R$ 61,274.66
Fluorescent lamps	104,855.04	111,408.48	**Monthly cost LED**	R$ 32,439.53
Electronic ballasts	6,553.44		**Economy (kWh/month)**	52,427.52
Led lamps	58,980.96	---	**Savings (in%)**	- 47.05

Conclusion

The present work investigated through concrete data, which would be the benefits and the possible contributions of the implementation of a photovoltaic solar plant and the retrofit of part of the lighting system in a public institution of higher education (UFABC). The results show that the savings achieved due to the on-site generation of electricity, that is, the amount that would no longer be consumed from the grid, would reach 10.33% of the amount spent in 2018. Another relevant figure appears when we look at the retrofit of the lighting system, given that the economy represents a 47.05% reduction in consumption prior to the retrofit, however a considerable financial savings would be generated for the institution, corresponding to about R$ 847 thousand per year. Thus, the similarity that exists in the consumption pattern of public higher education institutions, makes this work as a model and incentive for new projects and future decision-making processes.

Acknowledgment

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References

ANEEL. Agência Nacional de Energia Elétrica. Chamada nº. 001/2016 - Projeto Prioritário de Eficiência Energética e Estratégico de P&D: “Eficiência Energética e Minigeração em Instituições Públicas de Educação Superior”.

Benedito, R. S., Asano, P. T.L., Torin, L. R., 2018. Limites de Inserção da Geração Solar Fotovoltaica em Universidades Federais. VII Congresso Brasileiro de Energia Solar – Gramado, 17 a 20 de abril de 2018.

EPE. Empresa de Pesquisa Energética (Brasil). Balanço Energético Nacional: Séries Históricas Completas. Rio de Janeiro. 2018b. Disponível em: <http://epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/BEN-Series-Historicas-Completas> Acesso em: 13 mar 2019.

LABREN. Laboratório de Modelagem e Estudos de Recursos Renováveis de Energia / CCST Centro de Ciência do Sistema Terrestre / INPE Instituto Nacional de Pesquisas Espaciais – Brasil.

Lorenzo, E., 2002. La energía que producen los sistemas fotovoltaicos conectados a la red: el mito del 1300 y “el cascabel del gato”, Revista Era Solar, n.107, p. 22-28.

UFABC. Universidade Federal do ABC, 2018. Boletim do Orçamento 2018/2019. Disponível em http://propladi.ufabc.edu.br/images/boletim_orcamento/boletim_orcamento_2018_2019.pdf>. Acesso em: <28 ago 2019>.

UFABC. Universidade Federal do ABC, 2018. Folder: Usina Fotovoltaica da UFABC.

YIN, R. K., 2005. Estudo de casos: Planejamentos e métodos. 3ed. Porto Alegre: Bookman.

COMPUTER MODELING AND SIMULATION FOR FEASIBILITY ANALYSIS OF A HYBRID ON GRID RENEWABLE ENERGY SYSTEM USING HOMER PRO

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ABSTRACT

Renewable energy generation has attracted a lot of attention in recent years. Among the most used sources in this context, Photovoltaic Solar and wind have presented the highest growth in recent years. Considering the new topologies and possibilities that arise with the evolution of technology, the Hybrid Renewable Energy System has been widely explored, being an excellent alternative in the new ways of generating energy in the future. Similarly, the traditional concept of centralized power systems has been replaced by distributed power generation levels. Thus, this work proposed to perform a technical and economic feasibility analysis in order to examine the possibility of an HRES composed by wind and solar sources, connected to the electricity grid. For the development of the study, it was used a methodology based on computational modeling and simulation in HOMER Pro.

Keywords: Distributed generation, Energy optimization, Hybrid System, Solar energy, Wind energy.

Introduction

The evolution of technology has enabled new concepts regarding power generation, which has imposed major transformations in electrical systems. Among these possibilities, the generation of energy through renewable sources is certainly the one that has attracted the most attention in recent years, being the object of research of the academic community and the industrial sector. Decreased prices for power generation from renewable sources associated with increased energy conversion efficiency, which has driven its growth every year (ADEFARATI; BANSAL, 2016). Among the renewable sources, photovoltaic (PV) and wind are the fastest growing. According to data obtained from the International Renewable Energy Agency (IRENA, 2019), the total power installed worldwide from these sources is already over 1 TW. In fact, renewable generation is more sustainable, less harming nature and contributing to lower carbon emissions and global warming. (AL GARNI; AWASTHI; RAMLI, 2018).

Against this backdrop, new approaches to power generation become possible and necessary. One is the combination of more than one generation source through a Hybrid Renewable Energy System (HRES) (KHARE; NEMA; BAREDAR, 2016). The literature has widely discussed HRES, its advantages and challenges. Another major change observed concerns the generation mode, as the traditional concept of centralized power systems has been replaced by distributed generation (DG) which has gained an important role in the future of power systems (MEHIGAN et al., 2018). In this sense, Brazil allows the framing of this type of generation as prescribed by resolution 482/2012 (ANEEL, 2012), subsequently revised by resolution 687/2015 (ANEEL, 2015).

Thus, the present work aims to conduct a study through computer modeling and simulation for analysis of technical and economic feasibility of a HRES composed by PV and wind generation, connected to the power grid. For the study case, the Hybrid Optimization Model for Electric Renewable

(HOMER) software developed by the National Renewable Energy Laboratory's (NREL) was used (HOMER ENERGY, 2019).

Material and Methods

The conception of the present study started from the demand presented by the consumer to the research group, demonstrating the need to reduce expenses related to the consumption of electricity. This consumer has a set of 50 buildings distributed in the different cities of the state of São Paulo, Brazil, and registered under the same National Register of Legal Entities (CNPJ). Based on the dialogues with the consumer engineering department, an initial project was proposed, which considered an HRES for installation at its main unit in Suzano. Such headquarters has an available area that could be used to implement a generation system equivalent to 2,302.30 m^2.

As per standard, it is possible that a facility containing DG may share the energy produced with other facilities in different locations, but with the same ownership and concession area of the energy company in the form of credits, since in Brazil the monetization for the energy delivered electricity is not provided for by law (ANEEL, 2012; ANEEL, 2015). In this way, it would be possible to install a generation system at the institution's headquarters that was robust enough to generate what was necessary to meet all the energy demand of the 50 buildings.

It was proper to use HOMER Pro software, as it is a widely used tool for sizing power generation systems. This software is capable of accurately performing optimization procedures from hourly simulations of the energy flow occurring at the load and other system components. Another advantage is that the software can estimate the initial installation cost and operating cost considering the project life, presenting all the necessary indicators for a correct economic analysis (AL GARNI et al., 2018).

The first stage was the survey of the annual demand for electricity[1], which was a total consumption of 297,236 MWh. As the software works with hourly power demand (kW) and energy bills are detailed by monthly consumption (kWh), it was necessary to perform the conversion using mathematical methods along with understanding the hourly consumption profile of the facilities. From the data properly parameterized in the model, it was obtained the load profile (which is not presented in this version of the article).

Then, it was performed a market analysis in order to relate the price, power ratio of available solar modules, inverters and wind turbines, as well as the other variables that influence the software analysis procedure. From the survey, the information was inserted into the model, configuring each generation unit. The software has a library that assists in this procedure, where from it you can get the models of the components to be used in the project (HOMER ENERGY, 2019).

The irradiation profiles, temperature and wind speed required to calculate the generation potential are loaded by the software itself, which integrates with NASA's database. Regarding irradiation (in the horizontal plane) and temperature, the average monthly value of a 22-year measurement period was considered. As for wind speed, it is considered the average monthly value over a 10-year measurement period considering a height of 50 meters.

To establish project costs, several procedures are required. Regarding the economic variables included in the software, the current interest rate and inflation provided by (BANCO CENTRAL DO BRASIL, 2019). From these inputs the software itself calculates the actual interest rate. It is equally important to consider operating and maintenance (O&M) expenses. Following the guidelines of (ENBAR; WENG; KLISE, 2016) and (KOST et al., 2018), PV system-related expenses cost the system R $ 40.30 kW / yr whereas, in relation to the wind system, this expense was set at 1% of the value of the chosen turbine, therefore 6,000.00 R $ / yr.

[1] The calculation period was from March 2018 to March 2019 for the sum of the consumption of all facilities.

Finally, in relation to the electricity grid, the energy purchase tariff considered was R $ 0.88 / kWh. It is appropriate to justify that the chosen tariff value considers all the costs inherent to the energy bill as taxes and public lighting costs, being also considered an increase of 20%, overestimating the tariff. This was necessary as the cost of availability was disregarded at this stage of the project, as suggested in (NURUNNABI; ROY, 2016). The price of energy sold to the grid was considered the same purchase price, R $ 0.88 / kWh[2].

From the steps described above, it was possible to obtain the model to perform tests as shown in Figure 1, representing an HRES composed by a solar generation, a wind and the electric grid.

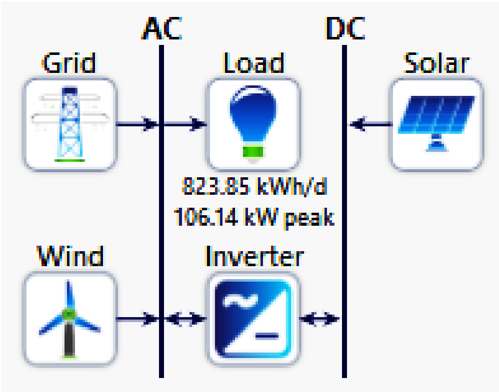

Figure 1. Diagram of the proposed hybrid system.

Results and Discussion

After the construction of the model, the results were simulated. The software performs optimizations from its algorithms to size the most appropriate proportion of each source's generation, peak power, topologies and all other indicators for system analysis. Thus, the optimal options considered by the software are described in Figure 2. For better understanding, System 1 will be named the first option presented (Composed by Grid and Solar Generation), marked in green while System 2, the second option presented (Composed by Grid, Solar and Wind Generation), marked in red.

Architecture					Cost				System	
Solar (kW)	Wind	Grid (kW)	Inverter (kW)	Dispatch	NPC (R$)	COE (R$)	Operating cost (R$/yr)	Initial capital (R$)	Ren Frac (%)	Total Fuel (L/yr)
201		999,999	82.4	CC	R$3.74M	R$0.469	R$161,253	R$567,023	55.6	0
199	1	999,999	81.3	CC	R$4.38M	R$0.548	R$163,626	R$1.16M	56.6	0
		999,999		CC	R$5.21M	R$0.880	R$264,622	R$0.00	0	0
	1	999,999		CC	R$5.80M	R$0.979	R$263,906	R$600,000	2.54	0

Figure 2. HOMER optimization results.

It can be observed that, contrary to the project applicant's desire, the best alternative pointed out by the software does not consider the use of wind generation[3]. The initial investment of the project corresponding to System 1 is R $ 567,023.00 and System 2 to R $ 1,160,000.00. Through Table 1, it is possible to observe the comparative related to the financial indicators that guide the economic analysis of the two systems.

[2] Legislation in Brazil does not allow the monetization of energy sales, but considering the energy sold equal to that purchased, it is believed to approach the scenario of offsetting credits currently in force in the country.
[3] The software performs the sorting of optimized alternatives considering Net Present Cost (NPC) and Cost Of Energy (COE).

Table 1. Comparison of Financial Indicators

	System 1	System 2
Metric	**Value**	**Value**
Present worth (R$)	R$1,469,449	R$829,019
Annual worth (R$/yr)	R$74,588	R$42,080
Return on investment (%)	14.3	4.7
Internal rate of return (%)	18.3	7.2
Simple payback (yr)	5.29	11.07
Discounted payback (yr)	5.63	12.57

The economic analysis performed was based on consolidated guidelines in the area, considering the reports (ENBAR; WENG; KLISE, 2016) and (KOST et al., 2018). Therefore, four criteria for project acceptance were employed:

- NPC > 0;
- Internal Rate of Return (IRR) > Real Market Rate;
- Discounted Payback < Desired Payback by the investor;
- COE < Energy tariff paid to the utility,

Looking at Figure 2 and Table 1, it will be clear that both projects meet all four criteria described above, so they are economically viable and advantageous when analyzed over the long term. However, System 1 clearly presents itself as the best option, both for the analysis of the indicators and the order suggested by the software.

Finally, comparisons were made about the energy produced by the two systems during the 1-year period. Thus Figure 3 (a) presents the results for System 1 and Figure 3 (b) for System 2. Also, through Table 2, a comparison between the two systems was presented. Both the systems presented approximate results, although System 1 presented more advantages over the lifetime project.

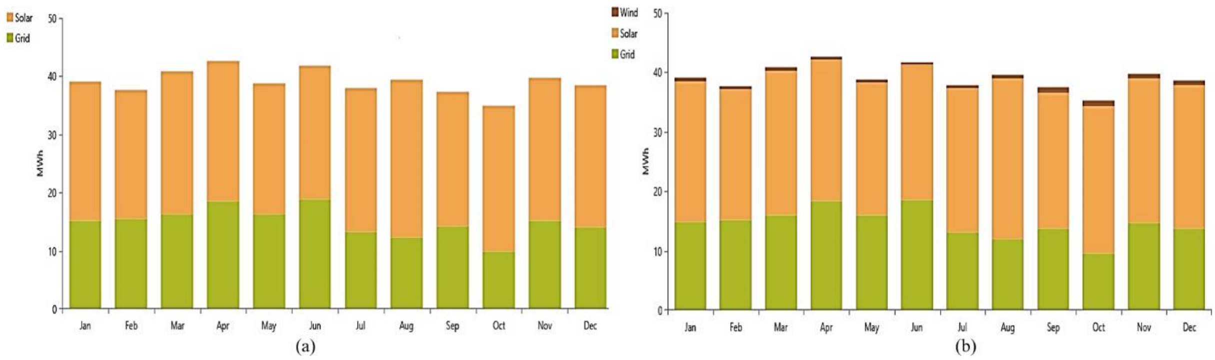

Figure 3. (a) System 1 Monthly Energy. (b) System 2 Monthly Energy

Table 2. Total Energy Production of Systems in 1 year

	System 1	System 2
Description	**Value**	**Value**
Solar Energy (kWh/yr)	288.624	285.607
Wind Energy (kWh/yr)	0	7.632
Grid Purchases (kWh/yr)	180.054	176.194
Grid Sales(kWh/yr)	104.489	105.560

Conclusion

Taking into account the project objective´s, it was considered successfully modeled and simulated a generation system using HOMER. A system capable of meeting the demand of consumer buildings in the region of São Paulo, Brazil. Thus, it was possible to perform the technical and economic analysis of the proposed system following the guidelines consolidated in the literature.

It is pertinent to point out that the software chosen for the system modeling presented several instabilities at various stages of the project, which raised severe doubts about the utility and reliability to the designers. Notes were made to the developer company that did not comment on it until the writing of this paper was completed.

Finally, the analysis of the results concluded that the most advantageous solution is not a hybrid system, but a system containing only solar PV generation, although both systems were economically and technically viable. It has been found that the area required for the installation of either system is compatible with the available area from consumer. Finally, it is proper to highlight the partial results shown in this paper, where new details, modeling, and simulations will be performed in the next stages to better approximate the results with reality.

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References

ADEFARATI, T.; BANSAL, R. C. Integration of renewable distributed generators into the distribution system: a review. **IET Renewable Power Generation**, [s. l.], v. 10, n. 7, p. 873–884, 2016. Disponível em: https://digital-library.theiet.org/content/journals/10.1049/iet-rpg.2015.0378. Acesso em: 22 ago. 2019.

AL GARNI, Hassan Z.; AWASTHI, Anjali; RAMLI, Makbul A. M. Optimal design and analysis of grid-connected photovoltaic under different tracking systems using HOMER. **Energy Conversion and Management**, [s. l.], v. 155, n. July 2017, p. 42–57, 2018. Disponível em: https://doi.org/10.1016/j.enconman.2017.10.090. Acesso em: 15 ago. 2019.

ANEEL. **Resolução Normativa nº 482/2012**. Brasília, Brazil. Disponível em: http://www2.aneel.gov.br/cedoc/ren2012482.pdf. Acesso em: 08 set. 2019.

ANEEL. **Resolução Normativa nº 687/2015**. Brasília, Brazil: Agência Nacional de Energia Elétrica, 2015. Disponível em: http://www2.aneel.gov.br/cedoc/ren2015687.pdf. Acesso em: 08 set. 2019.

BANCO CENTRAL DO BRASIL. **Valores presentes de inflação e taxa de juros**. 2019. [s. l.]Disponível em: https://www.bcb.gov.br/. Acesso em: 11 set. 2019.

ENBAR, Nadav; WENG, Dean; KLISE, Geoffrey Taylor. **Budgeting for Solar PV Plant Operations & Maintenance: Practices and Pricing**. Albuquerque, NM, and Livermore, CA (United States). Disponível em: http://www.osti.gov/servlets/purl/1237001/. Acesso em: 05 set. 2019.

HOMER ENERGY. **HOMER Pro 3.13 User Manual**. 2019. [s. l.]Disponível em: https://www.homerenergy.com/products/pro/docs/latest/index.html. Acesso em: 06 set. 2019.

IRENA. **Statistics Time Series**. 2019. [s. l.] Disponível em: https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Statistics-Time-Series. Acesso em: 03 ago. 2019.

KHARE, Vikas; NEMA, Savita; BAREDAR, Prashant. Solar-wind hybrid renewable energy system: A review. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 58, p. 23–33, 2016. Disponível em: https://www.sciencedirect.com/science/article/pii/S1364032115016068#!. Acesso em: 06 ago. 2019.

KOST, Christoph et al. **Study: Levelized Cost of Electricity- Renewable Energy Technologies**. Freiburg, Germany. Disponível em: https://www.ise.fraunhofer.de/en/publications/studies/cost-of-

electricity. Acesso em: 10 ago. 2019

MEHIGAN, L. et al. A review of the role of distributed generation (DG) in future electricity systems. **Energy**, [s. l.], v. 163, p. 822–836, 2018. Disponível em: https://www.sciencedirect.com/science/article/pii/S0360544218315366#bib13. Acesso em: 10 ago. 2019.

NURUNNABI, Md; ROY, N. K. Grid connected hybrid power system design using HOMER. **Proceedings of 2015 3rd International Conference on Advances in Electrical Engineering, ICAEE 2015**, Dhaka, Bangladesh , p. 18–21, 2016.

CLIMATE REANALYSIS DATA VALIDATION AND ADJUSTMENT FOR WIND RESOURCES CHARACTERIZATION IN THE STATE OF SÃO PAULO

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ABSTRACT

Wind energy as well as other renewable sources has become a supported choice to complement the energy supply in Brazil. In order to carry out the most appropriate energy planning from this source there is the need to characterize the wind potential of a region to identify the best locations for wind turbines installation. In this context, this work aims to improve the wind resource characterization for power generation through the use and validation of climate reanalysis data from the European Center for Medium-Range Weather Forecasts (ECMWF) ERA-Interim model. For this, a case study will be conducted for the state of Sao Paulo, Brazil. Validation metrics were calculated and it was stated that this dataset tends to overestimate the wind speed. Adjustments were made to increase the data reliability.

Keywords: Wind energy, Climate reanalysis, ECMWF, Energy planning

Introduction

The Brazilian electric sector has shown new characteristics of energy production and distribution. Following global trends, policies have been created to encourage the electric matrix diversification through the insertion of more renewable sources. As a consequence, it is possible to move towards sustainable development. In this context due to recent law incentives, wind power has become an economically advantageous way of energy generation and is aligned with the principles of sustainability (CARDOSO DE LIMA et al., 2018).

Thus, in order to carry out the most appropriate energy planning for this source it is necessary to characterize the wind potential of a region in order to identify the best locations for wind turbines installation. As measurement with meteorological masts can be expensive and take a long time, it is important to have alternatives for such characterization. Reanalysis models can be considered an option due to their quality and public availability free of charge. These data can be used to characterize and provide an overview of a region's wind resources (MOTTA et al, 2016), but validation is required to ensure that resources are described correctly.

In this context, this paper aims to apply a methodology for reanalysis wind data validation in order to provide a more reliable dataset. After validation, data can be used in tools that seek to guide investments in wind projects. There is also the possibility of using the data to characterize regions where the wind power has not been implemented yet.

The methodology was applied to a case study for São Paulo state, located in the southwest region of Brazil. It was decided to explore this region due to its high amount of energy consumption and generation. It consumes 26% of the country energy and generates more than 15% of the whole country energy generation (EPE, 2017; SÃO PAULO, 2017).

Material and Methods

Data produced by the ERA-Interim reanalysis model (DEE et al., 2011) were used in this paper. These data are available for a global grid with different spatial resolutions. In view of this, it was decided to use date with the highest resolution available: 0.125º, which corresponds to approximately 13 km, the downloaded dataset covers the São Paulo state area. The selected data were analyzed in monthly time resolution. The wind speed was obtained at a height of 10 m above the ground and the study comprised the period from 1979 to 2015.

Validation of such data implies the need to make comparisons with observed data. Thus, six meteorological measurement stations were selected. All of them provide information on wind speed and direction in the state of São Paulo, and are from the National Institute of Meteorology (*Instituto Nacional de Meteorologia*, INMET). The sensors used by this center measure wind speed and direction data at 10 m above ground level and their measurement is available on the institute website database.

The evaluation of variables produced by reanalysis climate models is an important step to identify the model's ability to reproduce the atmospheric behavior of a region and determine its degree of uncertainty (SILVA; VALVERDE, 2017).

The statistical indices and their respective equations (1 to 3) used for the comparison between the model data and the observed ones are presented below:

- Bias:

$$Bias = \frac{1}{N}\sum_{t=1}^{n}(U_{ERA}^{t} - U_{obs}^{t}) \quad (1)$$

- Mean Absolute Error (MAE):

$$MAE = \frac{1}{N}\sum_{t=1}^{n} | U_{ERA}^{t} - U_{obs}^{t}| \quad (2)$$

- Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(U_{ERA}^{t} - U_{obs}^{t})^2} \quad (3)$$

where U_{obs}^{t} is the observed wind speed at time t, U_{ERA}^{t} is the wind speed obtained by the ERA-Interim reanalysis model at time t and N is the number of records (MARIANO; CAVALCANTI; BESERRA, 2017). These errors are calculated in order to gauge the accuracy of reanalysis data to simulate real conditions (HALLAK; PEREIRA FILHO, 2011).

In addition, the consistency of the ECMWF dataset against the observed data needs to be assessed. Thus, Pearson's correlation coefficient r between the variables should be analyzed. The coefficient value can vary between -1 and 1, and the closer to 1, the better the correlation result (PEREZ, 2015).

It was also calculated the coefficient of determination (R^2) that consists on the adjustment degree of a statistical model when considering the total dispersion of the data around their average. Its value is numerically equal to the square of the correlation coefficient (SILVA, 2016).

In addition to the correlation analysis, it is also necessary to determine a significant result in relation to the sample and, for this, a Student T test is applied. For the sample with 444 monthly values, assuming a significance of 95% ($\alpha = 0.05$), the result of t_c and r_c were, respectively, 1.9659 and 0.093 (GONZÁLES-APARICIO et al, 2017).

In order to adjust or correct the data extracted from ERA-Interim, two methods were applied and are briefly described below. The first method aims at reducing systematic errors, considering the mean and standard deviation of simulated and observed data. This method is represented by equation (4):

$$U_{corr}^{t} = \left(U_{ERA}^{t} - \overline{U}_{ERA}\right)\frac{\sigma_{obs}}{\sigma_{ERA}} + \overline{U}_{obs} \quad (4)$$

where U_{corr}^{t} is the wind speed corrected at time t, U_{ERA}^{t} is the wind speed from ERA-Interim model, $\overline{U}_{ERA}$ is the average wind speed model, σ_{obs} is the standard deviation of observed data, σ_{ERA} is the standard deviation of the reanalysis data, and, finally, $\overline{U}_{obs}$ is the average wind speed of the observed data (MARIANO; CAVALCANTI; BESERRA, 2017).

The second method is a way of adjusting a variable according to the shape and scale parameters obtained from the Weibull distribution. Equation (5) presents such method:

$$U_{corr}^{t} = A^{*}\left(\frac{U_{ERA}^{t}}{A}\right)^{k/k^{*}} \quad (4)$$

where wind speed is corrected according to the shape and scale factors of the observed data, which are respectively represented by A* and k*. Factors A and k refer to the model data series (BETT; THORNTON; CLARK, 2017) and are needed to determine its Weibull distribution curve (KAOGA et al., 2014).

Results and Discussion

Wind resource characterization

The map in Figure 1 below presents the wind resource characterization for São Paulo state. For each state municipality it was attributed the annual average wind speed of ERA-Interim reanalysis data. Annual averages were calculated from monthly values over the period 1979 to 2015. The figure also indicates the location of INMET weather stations in the state of São Paulo. The INMET data represent one of the most complete sources because it has a long data series, with more than 30 years of records. Note that the most intense winds occur in the coastal region of the state, but it is also possible to identify a more intense nucleus in the midwest region. Average annual speeds, however, do not exceed 4.5 m/s.

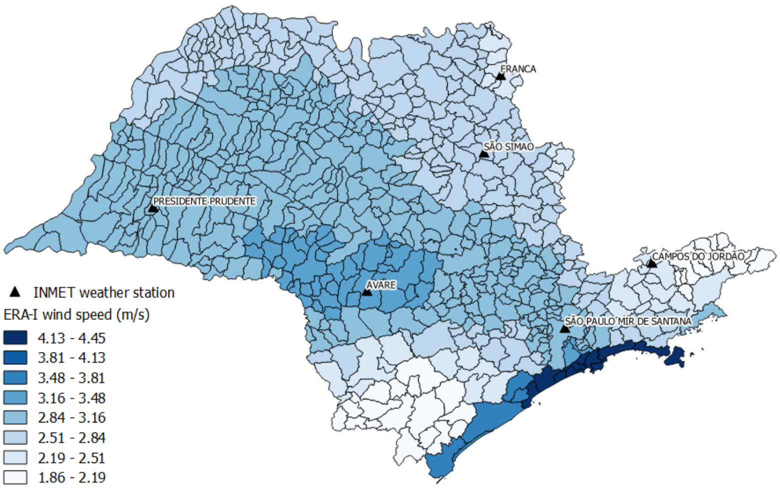

Figure 1. Location of INMET weather stations with observed wind speed data in the state of São Paulo. The municipalities are classified according to the wind speed at 10 meters height calculated from the annual average data of the ERA-Interim model for the period between 1979 and 2015.

Monthly data validation and correlation analysis

As a remark, the model data is made available to a fixed coordinate grid (with latitude and longitude resolution of 0.125º), so that they are not always in the exact positions of the weather stations. Thus, ERA-Interim data were extracted from the closest possible coordinates of the stations.

Table 1 below shows the results of the statistical errors calculation. By analyzing these results it is possible to state that ERA-Interim tends to overestimate the wind speed in all selected locations.

In addition to the errors, it was calculated the correlation and determination coefficients between the observed and simulated. It is possible to observe that the calculated coefficients are low for most points. In other words, it means that the observed data and those from ERA-Interim are poorly related.

Table 1 below summarizes the statistical errors and correlation (Pearson's r) and determination coefficients (R^2). In order to gauge the significance of these values the T test was applied showing that the correlations are significant for all locations except Campos do Jordão, whose coefficients r and R^2 are almost zero.

Table 1. Calculation of statiscal errors and correlation coefficients for each of the selected locations for validation of ERA-Interim reanalysis during the period from 1979 to 2015.

INMET station	Average ERA-I (m/s)	Average INMET (m/s)	Bias	MAE	RMSE	Pearson's r	R^2	T Test
Avaré	3.21	2.03	1.20	1.24	1.40	0.391	0.153	Significant
Campos do Jordão	2.18	0.98	1.20	1.27	1.35	-0.003	0.000	Not significant
Franca	2.48	1.96	0.52	0.53	0.59	0.654	0.427	Significant
Presidente Prudente	3.02	2.44	0.57	0.61	0.75	0.463	0.214	Significant
São Paulo Mir. Santana	2.93	2.56	0.37	0.46	0.59	0.466	0.217	Significant
São Simão	2.59	0.67	1.92	1.92	1.95	0.496	0.246	Significant

Monthly data adjustment

After calculating errors and correlations between the observed and reanalysis data, it was carried out the data adjustments by using two methods. Thus, new simulated data series were calculated, but now taking into account corrections based on the observed values. The graphs shown in Figure 2a and 2b are examples of the new calculated wind speed series. For Franca weather station, the adjustments provided a new data series much closer to the observed data. Therefore, adjusted wind speed from ERA-Interim could be used to represent the wind resource of this location. However, as expected due to high error values and low correlations, the adjusted data series of Campos do Jordão do not represent the real wind speed. For other weather stations, the adjusted data are closer to those observed.

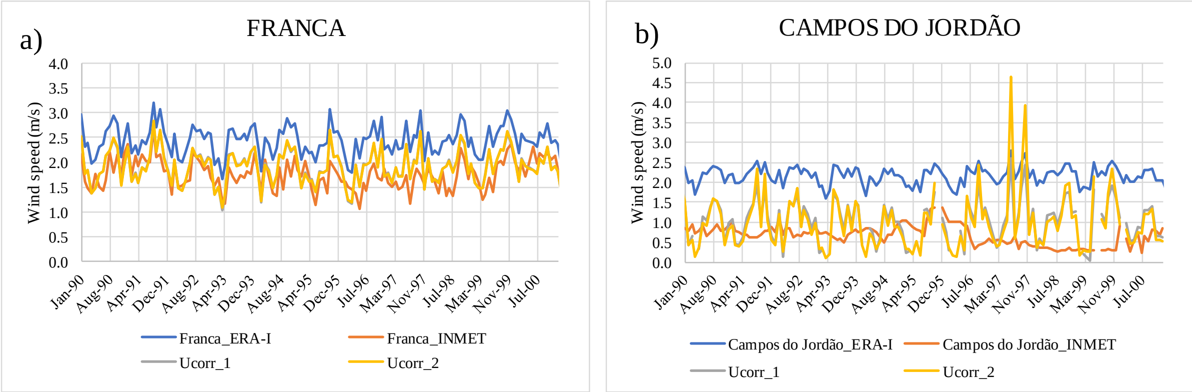

Figure 2. ERA-Interim wind speed series with and without adjustments compared to the observed wind speeds at two of the weather stations: a) Franca and b) Campos do Jordão. The blue lines present the data obtained directly from ERA-Interim, the orange ones are the observed data and the gray and yellow are the ones adjusted from methods 1 and 2, respectively.

In order to verify if the adjustments actually decreased the errors of the reanalysis data in relation to the observed ones, the statistical indices were recalculated as presented in Table 2. By comparing the values of Table 1, it is noted that the post adjustment error values were reduced, indicating the effectiveness of the adjustments applied.

Table 2. Errors and statistical indices calculated between observed and ERA-Interim data after adjustment by method 1 and 2.

		Adjustment method 1				**Adjustment method 2**			
INMET station	**Average INMET (m/s)**	**Average (m/s)**	**Bias**	**MAE**	**RMSE**	**Average (m/s)**	**Bias**	**MAE**	**RMSE**
Avaré	2.03	2.06	0.03	0.66	0.85	2.06	0.03	0.68	0.89
Campos do Jordão	0.98	1.08	0.09	0.59	0.76	1.02	0.05	0.71	0.93
Franca	1.96	1.96	0.00	0.24	0.30	1.96	0.00	0.25	0.30
Presidente Prudente	2.44	2.44	0.00	0.41	0.51	2.44	0.00	0.42	0.52
São Paulo Mir. Santana	2.56	2.55	0.00	0.40	0.51	2.55	0.00	0.40	0.52
São Simão	0.67	0.69	0.01	0.25	0.34	0.68	0.01	0.27	0.39

Conclusion

From the analysis performed, it is possible to conclude that the data provided by the ERA-Interim reanalysis model is able to provide information to characterize the average wind speed of the state of São Paulo. However, after comparison with the observed data, through the verification of errors and correlations, it has become evident the need to apply adjustments and corrections.

The bias indicated that the reanalysis tends to overestimate the wind speed. Thus, if the data are used directly in applications related to energy planning, it may result in subcontracting energy to meet demand.

After adjustments, the new comparisons made with the observed data showed a significant decrease in errors, especially when using method 1, which is mainly used to reduce systematic model errors.

Acknowledgment

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References

BETT, P. E.; THORNTON, H. E.; CLARK, R. T. **Using the Twentieth Century Reanalysis to assess climate variability for the European wind industry**. Theoretical and Applied Climatology, v. 127, n. 1-2, p. 61-80, 2017.

CARDOSO DE LIMA, G. S. et al. **Sustainable development enhanced in the decision process of electricity generation expansion planning**. Renewable energy, v. 123, p. 563-577, 2018.

DEE, D. P. et al. **The ERA-Interim reanalysis: configuration and performance of the data assimilation system**. Quarterly Journal of the Royal Meteorological Society, v. 137, n. 656, p. 553–597, 2011.

EMPRESA DE PESQUISA ENERGÉTICA (EPE). **Anuário Estatístico de Energia Elétrica 2017**. Ministério de Minas e Energia, Brasília, Brazil, 2017.

GONZÁLEZ-APARICIO, I. et al. **Simulating European wind power generation applying statistical downscaling to reanalysis data**. Applied Energy, v. 199, p. 155-168, 2017.

HALLAK, R.; PEREIRA FILHO, A. J. **Metodologia para análise de desempenho de simulações de sistemas convectivos na região metropolitana de São Paulo com o modelo ARPS: sensibilidade a variações com os esquemas de advecção e assimilação de dados**. Revista Brasileira de Meteorologia, v. 26, n. 4, p. 591-608, 2011.

KAOGA, D. K. et al. **Comparison of five numerical methods for estimating Weibull parameters for wind energy applications in the district of Kousseri, Cameroon**. Asian Journal of Natural & Applied Sciences, v. 3, p. 72-87, 2014.

MARIANO, E. B.; CAVALCANTI, E. P.; BESERRA, E. A. **Análise comparativa da velocidade do vento simulado pelo BRAMS com dados observados e de reanálises**. Revista Brasileira de Meteorologia, v. 32, n. 2, p. 269-276, 2017.

MOTTA, J. G. et al. **Metodologia para caracterização de vento no estado de São Paulo para a implantação de geradores eólicos sob a perspectiva do desenvolvimento sustentável**. In: X Congresso Brasileiro de Planejamento Energético – CBPE. Gramado, Brazil, 2016.

PÉREZ, J. M. et al. **CariCOOS: Real-time data validation of high-resolution wind forecast**. In: OCEANS'15 MTS/IEEE Washington. IEEE, p. 1-7, 2015.

SECRETARIA DE ENERGIA DO GOVERNO DO ESTADO DE SÃO PAULO (São Paulo). **Atlas Eólico do Estado de São Paulo**. São Paulo, 2012.

SILVA, M. C. O. **Cenário futuro da disponibilidade hídrica na Bacia Do Alto Tietê: subsídio à gestão dos recursos hídricos**. Dissertação de Mestrado. Programa de Pós-Graduação em Ciência e Tecnologia Ambiental. Universidade Federal do ABC. Santo André, 2016.

SILVA, M. C. O.; VALVERDE, M.C. **Cenário futuro da disponibilidade hídrica na Bacia do Alto Tietê.** Revista Brasileira de Ciências Ambientais, n.43, p. 114-130, 2017.

PROJECT OF A PHOTOVOLTAIC SYSTEM IN PARAISÓPOLIS FAVELA, SUBSIDIZED BY THE ENEL COMPANY

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ABSTRACT

Overcoming energy poverty is a very important step to achieving a healthier society. Government-assisted electricity distributors could easily universalize access to modern forms of energy to the low-income population through distributed generation. The installation of photovoltaic generators, after an initial investment, produces clean and low cost energy, bringing more security to the electrical installations of low income communities, as well as reducing the damage to the distribution company and society as a whole by theft and default. This paper presents a case study of the Paraisópolis favela, located in the city of São Paulo, where is designed a grid-connected photovoltaic system for each irregular house and is estimated the initial investment to expand this system to all irregular houses in the community.For this, the power of the photovoltaic generators for all houses with irregular connection of the community was calculated and the initial value of the investment was predicted. It was noticed that the proposal is interesting for the electricity distribution company Enel, since the amount of energy loss due to theft or default would be reduced.

Keywords: slum, energy poverty, distributed generation, renewable energy, low-income.

Introduction

Reducing poverty in all its forms is improving the quality of life of the population as a whole. Energy poverty is defined by the World Energy Assessment (WEA) (2000) as the "inability to choose energy services (in terms of reliability, quality, safety and environmental protection) under economic conditions that support the economic and social development of families and individuals". It is a consensus in the literature that energy poverty does not allow the economic and social development of people, and thus does not allow them to achieve an adequate level of quality of life (UFRJ, 2005). Overcoming energy poverty is a very important step towards achieving a healthier society. Government-assisted electricity distributors could easily universalize access to modern forms of energy to the low-income population through distributed generation.

The UFRJ (2005) report suggests that this initiative should be taken by energy companies, which have the capital to invest in and that would pay off with the regularization of the facilities. This initiative in partnership with the government in the form of subsidies or regulation would be even more effective.

The technology of photovoltaic modules, which has high potential for deployment in the Brazilian territory, is already advanced worldwide. There is a lot of capital invested and the technological rush to increase cell efficiency is fierce, as shown by Yergin (2014).

Unable to afford the costs of maintaining their access to electricity, low-income households end up defaulting or resorting to "gatos" - the type of facility that causes theft of electricity unsafe by users with inadequate labor and materials (FOURNIER, 2014).

Power thefts fall into the category of Non-Technical or Commercial Losses and constitute losses to the electricity distributors (ANEEL, 2018). The installation of photovoltaic generators, after an initial investment, produces clean and low cost energy, bringing more security to the electrical installations of low-income communities, as well as reducing the damage to the distribution company and society as a whole by theft and default. The initial investment would be made by the energy distribution company of São Paulo, Enel Distribuição São Paulo, which suffers from the theft of energy and would benefit from the reduction of its loss through Non-Technical Losses.

Paraisópolis is the largest favela in São Paulo with 64,397 inhabitants, domiciled in 19,361 households (IBGE, 2010). The community is located in the south of São Paulo, totaling an area of 1,084,000 square meters. It is located in the Morumbi district (Vila Andrade district), southwest of the city of São Paulo, surrounded by high and medium standard residential areas to the north and south, with Morumbi Avenue to the east and Giovanni Gronchi Avenue to the west as shown in Figure 1.

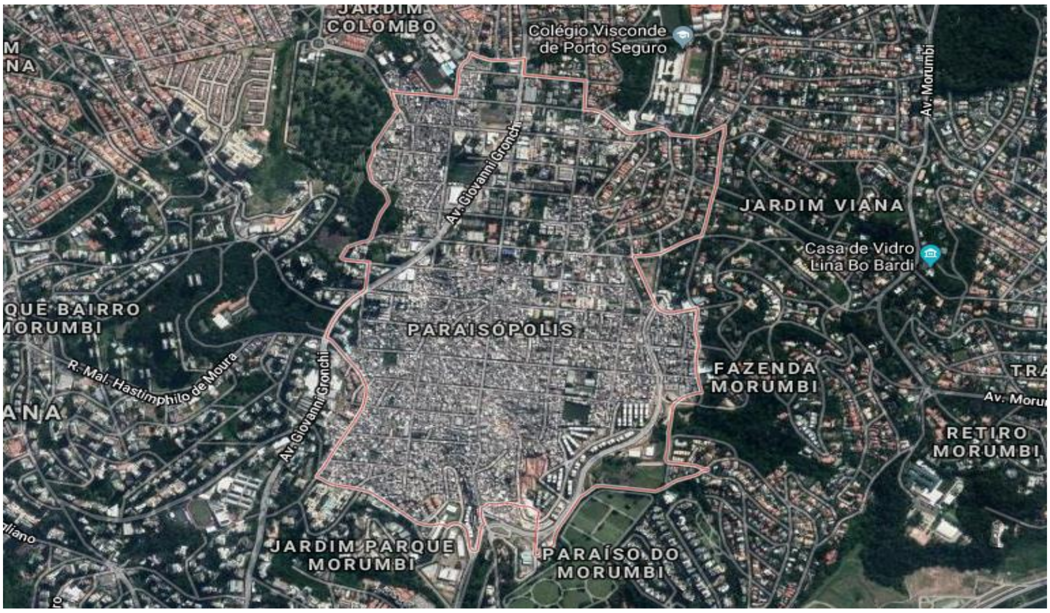

Figura 1. Favela de Paraisópolis – Imagem de Satélite.

This paper presents a case study of the Paraisópolis favela, located in the city of São Paulo, where is designed a grid-connected photovoltaic system for each delinquent residence and is estimated the initial investment of a project that covers all delinquent residences in the community.

Material and Methods

From the bibliographic survey in the IBGE (2010) databases, the resident population, the number of households in Paraisópolis and the percentage of households not regularly connected to the network are obtained. The average consumption adopted by a family living in this region is 400kWh per month, as estimated by Francisco (2006). The potential of solar energy in the region where the favela is located is also determined (with latitude and longitude data being 23.613102; 46.725235), with the Radiasol 2 software, through the annual irradiation incident (HSP -Full Sun Hours) on the plan of each arrangement of the region considering the average annual hours. The overall performance ratio (PR) is 80% and the installation is at an azimuthal angle of 10° over the roofs of existing residences. With this data, it is possible to know the power of the photovoltaic generator (P_{FV}), through Equation 1, and then dimension the amount of photovoltaic generators needed to supply this demand.

$$P_{FV} = \frac{L}{HSP * PR} \tag{1}$$

In this dimensioning was adopted the Network Connected System, so that it is possible to fit the installation in the Electric Power Compensation System (brazilian program of incentive). Moreover, it was considered the installation of individual generation system by residence.

With the known of the photovoltaic generator power (P_{FV}), the photovoltaic module chosen was WEG's 335W GCL model, with the specifications shown in Table 1.

Table 1. Photovoltaic Solar Power Generator's Specifications – 4.02kWp. GCL-P6/74H-335W Model

Maximum Power	335Wp
Tolerance	0% a +5%
Open circuit voltage (Voc)	46.4V
Peak voltage (Vmpp)	38
Short circuit current (Isc)	9.41A
Peak current (Impp)	8.82A
Cell types	Polycrystalline Silicon
Panel dimensions	1956 X 992 X 35 mm
Weight	22.2kg

Dividing the power value of the array by the power of each photovoltaic module gives the number of photovoltaic modules required. As well as dividing the value of the array power by the inverter power, the number of inverters required is obtained. A 4kW single-phase 220V inverter with the following technical specifications, described in Table 2, was used.

Table 2. 4kW single-phase 220V inverter's specifications. SIW300H M030 Model

Maximum input voltage	1000Vcc
MPP Voltage Range	210Vcc a 800Vcc
Minimum input voltage	80Vcc
Maximum input current	12A/12A
Rated output power	4000W
Output Voltage (Range)	180Vca a 270Vca
Output current	17.4A
Maximum efficiency	98%
Operating temperature	-40˚C a +55˚C
Output frequency	60Hz
Dimensions (mm)	(645 x 431 x 204)
Weight	21.5kg
IP65	

The supplier of photovoltaic modules and inverters also estimates the amount of materials required for the installation of the assembly as well as the total value of the materials including the modules and the inverter. With the total number of homes that will benefit, the value of the investment can be estimated.

Results and Discussion

The results obtained for sizing a photovoltaic generator for a single residence are listed in Table 3.

Table 3. Project for one residence

P_{FV}	3,94kW
Number of modules	12
Number of inverters	1
Occupied zone	23,28m²
Investment value	R$ 14.500,00

The results obtained for the design that covers all delinquent homes in the Paraisópolis favela are listed in Table 4.

Table 4. Project for all irregular houses

Number of houses	2517
Number of modules	30204
Number of inverters	2517
Occupied zone	58596m²
Installed power	10,1MW
Investment value (R$)	40.473.460,00
Investmente amount per installed power	R$4000,00/kW

As noted, the value of the investment is high, however it is fully supported by Enel's budget. This statement is based on current legislation that allows part of the damage that the energy distribution company has with Non-Technical Losses to be passed on to other consumers. Currently ANEEL allows Enel to pass on its Non-Technical Losses to other consumers, if it does not exceed a percentage value stipulated by the agency which is called Regulatory Non-Technical Loss. According to ANEEL's Loss Base (2018), Enel, in 2017, still under the name of Eletropaulo, had a Non-Technical Loss of 8.33%, totaling 2,008,188 MWh, while the Non-Regulatory Loss was 8.48%. That is, the amount of loss that Enel had with theft or default could be passed on in its entirety to the other regular consumers. Thus, this amount that Enel had reimbursed by other consumers could be invested in this project.

Conclusion

The proposal of photovoltaic solar energy generation in the Paraisópolis favela, targeting homes with irregular access to the distribution network is viable. Enel may invest the amount of loss saved to you due to Non-Technical Losses, and as a benefit to reduce your losses from theft of electricity or default with the Paraisópolis community.

Another benefit that the energy distribution company has with the implementation of such a project is to value the company's image, as it is a social improvement. The government can also assist this initiative in the form of subsidies and regulations aimed at improving the quality of life of the needy population.

The project comprises 2517 houses with an installed capacity of 10.1MW. The investment amount is R$ 4000.00 / kW, totaling the amount of 40.5 million reais.

An obstacle that hinders the implementation of the project is the case that some dwellings are not legalized (LIPU, 2013). Another difficulty is the fact that some homes do not have a roof structure that allows this type of installation.

It should be noted that this text does not cover all aspects that sentence the viability of the project. For this reason, energy poverty in large urban centers needs to be more widely debated.

References

ANEEL – Agência Nacional de Energia Elétrica. *Perdas de Energia*. Disponível em: <http://www.aneel.gov.br/metodologia-distribuicao/-/asset_publisher/e2INtBH4EC4e/content/perdas/654800?inheritRedirect=false> . Acessado em 20 de novembro de 2018.

FOURNIER, A. C. P. Luz na Favela: *A complexidade no processo de regularização da energia elétrica na favela Bougival, em Santo André – SP*. 138 p. Tese – Universidade Federal do ABC (UFABC). Santo André. 2014.

FRANCISCO, E.R. *Relação entre o consumo de energia elétrica, a renda e a caracterização econômica de famílias de baixa renda no município de São Paulo.* 349 p. Dissertação – Fundação Getúlio Vargas (FGV). São Paulo. 2006.

IBGE. *Censo Demográfico 2010*. Disponível em <https://censo2010.ibge.gov.br/> Acessado em 20 de novembro de 2018.

LIPU, M.S.H.; JAMAL, T.; MIAH, M.A.R. Barriers to Energy Access in the Urban Poor Areas of Dhaka, Bangladesh: *Analysis of Present Situation and Recommendations - International Journal of Energy Economics and Policy* - Vol. 3, No. 4, pg.395-411. 2013.

UFRJ. *Pobreza Energética: Complexo do Caju.* Instituto de Economia – Universidade Federal do Rio de Janeiro. Rio de Janeiro. 2005.

WEA. *Energy and the challenge of sustainability*. UNDP. World Energy Assessment – Overview. Nova York. 2000. Disponível em: <http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> . Acessado em 04 de setembro de 2016.

YERGIN, D. A Busca: *Energia, segurança e a reconstrução do mundo moderno*: tradução Ana Beatriz Rodrigues. – 1. Ed. – Rio de Janeiro: Intrínseca, 2014.

SUSTAINABLE WATER TRANSFER EVALUATION BETWEEN RIVERS AND BASINS IN CONTRIBUTION TO ENERGY PLANNING

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ABSTRACT

According to the National Water Agency, despite the abundance of water in Brazil, there is an imbalance between the water supply in a region and the demand for water in that region. Much of our energy comes from hydroelectric generation. The management of Brazilian reservoirs faces conflicts involving the generation of electricity and the multiple uses of water. Industrialization and economic development have intensified the use of water resources, and contributed to increased water pollution. Water transfer between rivers and basins is an interesting strategy for resolving the multiple use conflict and the imbalance between supply and demand of water. The project intends to evaluate the environmental impacts that can be caused by this transfer using the IQA, to find the ideal amount of water to be transferred, to study the real gain of this transfer and the feasibility of water depollution. Through bibliographic research and study of the information contained in the ENERG.IA platform, we intend to identify the mathematical modeling that accounts for the impact of water transfer between basins and develop the Sustainability Module using Java programming.

Keywords: Water transfer, hydroeletric generation, water quality

Introduction

In order to keep up with the accelerated growth of the Brazilian economy, Increased and Advanced Power Hydrothermal System Operation Planning (POSHP) is required, so that the energy demand can be met. The purpose of POSHP is to determine a generation strategy for each hydroelectric power plant that meets demand within a reliable limit and replaces, where possible, thermoelectric generation - high-cost and more polluting – by hydroelectric, of pratically null cost [3].

In Brazil, where the energy is largely from hydroelectric generation, the potential energy from water stored in reservoirs is used; having proper management of this water it is possible to meet the demand and rationally replace the use of thermal units. [4].

According to the National Water Agency (ANA), Brazil is divided into 12 hydrographic regions: Amazon, Tocantins-Araguaia, Northwest Atlantic, Parnaiba, Northeast Atlantic, San Francisco, East Atlantic, Southeast Atlantic, Paraná, Paraguay, Uruguay and South Atlantic [1]. Four of these regions (Paraná, Southeast Atlantic, South Atlantic and Uruguay) house more than half of the country's population in an area that represents only 17% of the Brazilian territory [5]. So, despite the abundance of water in Brazil, there is an imbalance between the water supply in a region and the demand for water in that region. The Tocantins-Araguaia Region has the largest volume of per capita water stored, while the Paraná Region has the largest number of inabitants, and consequently a higher demand for water [5].

Figure 1. Representation of hydrographic regions. Source: ANA, 2018.

In addition to the imbalance between water supply and demand in the various river basins, the management of Brazilian reservoirs faces conflicts involving power generation and multiple water uses such as irrigation, navigation, flood control and public supply[3] [8].

Industrialization and economic development have intensified the use of water resources in the most varied sectors - industrial, electrical, sanitation, irrigation - contributing to the increase of water pollution, especially in rivers near major urban centers. [8].

Water transfer between rivers and basins is an interesting strategy for resolving multiple water use conflicts, it can help meet the public supply demand and provide a better use of the productivity of hydroelectric power plants. Such water transfer causes environmental impacts in both the donor and recipient basins, so the overall benefits of the transfer must overcome its impacts. Every ecosystem is capable of withstanding natural or human-made changes and returning to or near their original condition as long as their physical and biotic means are maintained. [5].

According to ANA, the Water Quality Index (IQA) is used in Brazil to evaluate the quality of water for public supply after conventional treatment. Used in Brazil since 1975, a low IQA value indicates poor water quality, although it can be used for other purposes such as navigation and power generation. The IQA is calculated based on nine parameters: water temperature, dissolved oxygen, total residue, biochemical oxygen demand, pH, thermotolerant coliforms, total nitrogen, turbidity and total phosphorus. [2].

The Energ.IA platform contains relevant information about hydroelectric plants, their reservoirs, their characteristics, monthly flow history, among other interesting data for this study. Energ.IA is a platform for artificial intelligence and optimization tools developed by LabBITS (Technology and Bioinspired Solutions Laboratory) that is applied to solve energy planning and power system problems. [7].

The project aims to evaluate the environmental impacts that can be caused by water transfer between rivers and basins using the IQA, to find an optimal point of transfer between points of the National Interconnected System from the management of Brazilian reservoirs, and to study the real gain. transfer and the feasibility of cleansing the waters of the basins participating in the process. Water treatment actions are as important to society as the production of electricity. The search for conciliating forms for the multipurpose of water is fundamental for the development of society. [6].

Material and Methods

According to the available literature, it is possible to see how important it is to study the use of water from Brazilian reservoirs for power generation, public supply, irrigation and navigation. It is also realized that water transfer between rivers and basins, if properly planned, can benefit all sectors involved, without harming energy demand. Therefore, this research proposes to study the water transfer points of the National Interconnected System, making a sustainable analysis and indicating alternatives to the environmental problems faced.

To this end, the bibliographic research methodologies and study of flow information, hydroelectric plants and water transfer contained in the ENERG.IA platform are being applied. Along with other LabBITS researchers, a constantly updated database was developed with files from the Electric Energy Trading Chamber (CCEE) database. This database allows access to real and update information, as well as storage space used in this study that will allow the development of the Java language Sustainability module as part of the platform.

Results and Discussion

After bibliographic research and analysis of water transfer points of the National Interconnected System it was decided that the sustainable analysis of these points and the identification of environmental impacts in the basins or rivers involved in the process will be based on the Water Quality Index.

The IQA is calculated based on nine parameters and their respective weights determined according to their importance for the overall conformation of water quality. The IQA values of several Brazilian rivers are available from ANA, as well as the values of the parameters: dissolved oxygen, total phosphorus, turbidity and biochemical oxygen demand.

It is also intended to determine the optimal amount to be transferred (bearing in mind that the overall benefits should overcome the impacts caused to the basins and rivers), to identify the viability obtained with the transfer that can be used for water pollution and to make an analysis of contribution of the transfer to society.

Conclusion

The planning of hydrothermal systems in Brazil is important due to the immensity of the territory and the imbalance between water supply and demand in the various Brazilian Hydrographic Regions. The conflict over the various uses of water makes this planning more necessary. And it can also hinder better use of hydroelectric plants in power generation by limiting the amount of water transferred to these plants due to the poor quality of this water, also used for public supply. Thus, this study becomes important because it identifies the water transfer points in the National Interconnected System and develops a module in Java programming that makes a sustainable analysis of this transfer, also indicating the viability obtained to be used in water depollution

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References

[1] Agência Nacional de Águas - ANA. **Divisões Hidrográficas: As 12 Regiões Hidrográficas Brasileiras.** Disponível em: <http://www3.ana.gov.br/>. Acesso em 12 setembro 2019.

[2] Agência Nacional de Águas - ANA. **Indicadores de Qualidade – Índice de Qualidade das Águas (IQA).** Disponível em: <http://pnqa.ana.gov.br/indicadores-indice-aguas.aspx#_ftn1>. Acesso em 14 setembro 2019.

[3] ALENCAR, T. R. **Otimização da Potência de bombeamento aplicado ao planejamento do sistema hidrotérmico de potência via colônia de formigas.** Tese de doutorado. Pós-graduação em Energia, Universidade Federal do ABC. Santo André, São Paulo, Brasil. 2017.

[4] KELLNER, E.; GRAMULIA JUNIOR, J.; LEITE, P. T.; MORETTI, R. S.; BENASSI, R. F. **Contribuição da Usina Hidrelétrica de Henry Borden Para o Planejamento Energético Brasileiro**. Sinergia, vol. 11, n. 1, p. 96-112, jan./jun., São Paulo, 2010.

[5] GRAMULIA JUNIOR, J. **Uma abordagem baseada em algoritmo genético para gerenciamento e controle de transferência não natural de água entre rios em contribuição ao planejamento da operação de sistemas hidrotérmicos**. Tese de doutorado. Pós-graduação em Energia, Universidade Federal do ABC. Santo André, São Paulo, Brasil. 2014.

[6] KELLNER, E.; GRAMULIA JUNIOR, J.; LEITE, P. T.; MORETTI, R. S.; BENASSI, R. F. **Contribuição da Usina Hidrelétrica de Henry Borden Para o Planejamento Energético Brasileiro**. Sinergia, vol. 11, n. 1, p. 96-112, jan./jun., São Paulo, 2010.

[7]Laboratório de Tecnologias e Soluções Bioinspiradas – LabBITS. **Plataforma Energ.IA.** Disponível em < https://energ.ia.abc.br/> Acesso em 13 setembro 2019.

[8] RISSO, S. S. O. **Análise de desempenho de reservatório de uso múltiplo: estudo de caso na sub-bacia Billings.** Dissertação de mestrado. Pós-graduação em Energia, Universidade Federal do ABC. Santo André, São Paulo, Brasil. 2017.

ANALYSIS OF THE EMERGENT DIAGRAM OF URBAN SOLID WASTE TREATMENT IN SANTO ANDRÉ - SP

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ABSTRACT

This article deals with the treatment of municipal solid waste (MSW) generated in the municipality of Santo André. The municipality has 71,6109 population, and has the PIB of R $ 36,249.85, in addition to allocating about 800 tons per day pf waste to the Santo André Municipal Landfill, which on average represents 0.89 kg per person of waste per day, less than the national average, which is at 1 kg per person today. Even though the municipality of Santo André has been a national reference in the requirement for more than 20 years and having 100% of the city served. This article presents an analysis of the emergency flow for the presentation of data on urban waste in the municipality of Santo André, this analysis can be applied to assess the global and national level and presents a flow of analysis where there is an exchange of energy used to carry out a process and the problems that are evaluated and thus this analysis intends to help the municipality in this evaluation.

Keywords:, pnrs, selective collection, energy use

Introduction

The municipality of Santo André, located in the ABC Paulista of the metropolitan region of São Paulo, is one of the most reputed to have a selective collect in the municipality for more than twenty years and gains national prominence by example being given to other municipalities, the readiness in not only to establish a selective collection as well as to destine the waste properly.

According to the Regional Plan for the Integrated Management of Solid Waste in the ABC (2016), Santo André receives daily 800 tons per day of waste collected in the community and has a gravimetric composition. It is verified that the municipalities of Santo André generate the largest amount of organic waste (52%), followed by paper and paper (14%) and plastics (12%), since the (2%) in the complete composition and in the gravimetric composition of the dry ones in (6%), which may represent a greater representativeness in the recycling of this material, and therefore has a smaller scale collection.

In 2015, the Semasa (Environmental Sanitation Authority) created a new Recyclable Waste Sorting Plant in which the two cooperatives work together in the same plant in two warehouses of 1,055 m² each, the cooperatives are: Coopcicla and the Clean City. From these collected residues it is possible to compose the gravimetry in which the gravimetric field of dry residues received by the cooperatives.

In this sense, the emergency study presents an energy flow that presents environmental practices, improves the packaging process and has a greater positive impact on global sustainability (BARROS et al., 2009).

The objective of this article is to present the analysis of the treatment of urban solid waste of Santo André through the diagram of emergy, this diagram is an analysis is from the area of economics and deals with the symbols often found in literature is exposed with. In addition to addressing the problems presented, this article will discuss how the treatment of MSW can be improved, as well as, in the future, to realize the energetic use of waste, besides applying the guidelines of the National Solid Waste Policy 12,305 / 2010 as the main target for improving waste treatment.

Material and Methods

In order to carry out the analysis of the emergent diagram on the treatment of MSW in the municipality of Santo André, the methodology of this work was Creation of a diagram of the emergy flow on the collection and destination of the MSW destination in Santo André;

The emergence accounting allows to construct a systems diagram in order to simulate the behavior of all the resources involved in the scheme of study (ALCANTARA et al, 2018). The symbols are divided into the diagram in:

- Energy sources - What is the energy source needed to produce the products?
- Source of Materials - Which product origin?
- Producers - What does the producer need to produce the final product?
- Materials - What materials are needed to produce the product?
- Consumer - Who consumes this product? Who is responsible for this product?

The emergy analysis is divided by figures representing objectives through symbols in which they have interactions with the system and represents the energy. This diagram uses the methodology of Odum (1996). A emergia é a energia disponível de um determinado tipo, previamente requerida, direta ou indiretamente, para obter um bem ou um serviço.

Results and Discussion

The emergence diagram as shown in figure 1, a flow of RSU systems is created, the two-axis representation of both the landfill and the landfill are connected vertically to make their participation and responsibility clearer in the diagram.

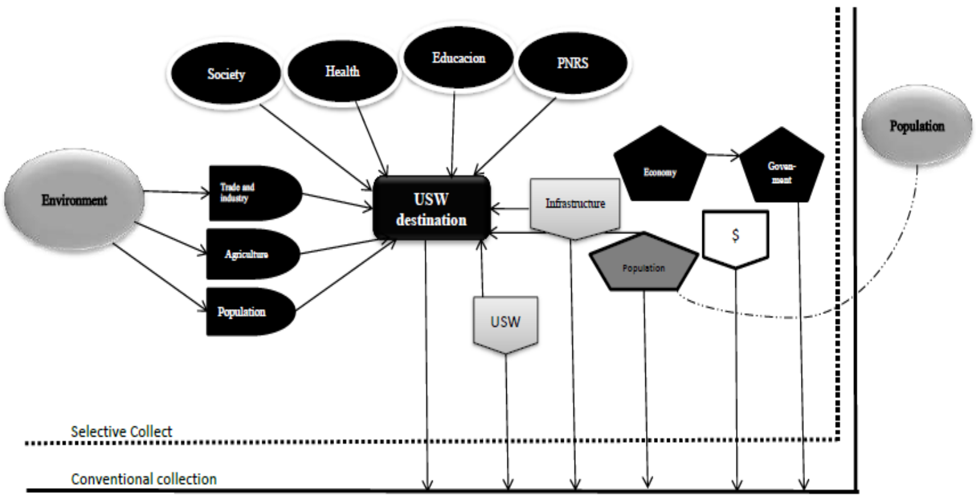

Figure 1. Emergent diagram of the municipal management of Santo André

Source: elaborated by the author

The diagram presented in Figure 1, contextualized the situation of MSW management of waste collected by the municipality of Santo André:

- Environment: The environment in Santo André is very favorable, it has an effective environmental education. In addition to the analysis presented, the area of the environment involves the areas of industry, agriculture that are most responsible for the creation of packaging that could be eco-efficient and agriculture / livestock for the content of packaging, being food. The environment is involved by being in direct contact with these three areas, which affect the environment directly and indirectly.

- USW destination: For the municipality of Santo André that has municipal landfill in addition to selective collection more than twenty years in the municipality has 100% selective collection throughout the city being very positive in this requirement. Waste disposal directly involves health areas, education in which waste directly impacts. In the National Policy of Solid Waste 12.305 / 2010, which states that the only corrective destination for the shipment of municipal waste is the Sanitary Landfill.

- Infrastructure: The infrastructure for the best destination of the waste, is essential for the municipality being involved the economy and government, besides all the planning involved. In the case of Santo André, yes, there is infrastructure in the municipality. In which it is only worrying that the landfill has been depleted within two years. It is important to point out that the municipal landfill of Santo André is considered a reference, since the IQR (Waste Quality Index) measures the conditions of all existing Sanitary Landfills in the Metropolitan Region of São Paulo.

- Population: Population is responsible for generation as well as decision-making power after waste, after consumption. That is why it is outside the matrix of emergy, being the main actor of change for the improvement of waste treatment.

The emergence diagram presented a positive factor of the national situation in relation to the destination of the waste, since the municipality of Santo André sends the waste correctly to Landfill considered by PNRS 12,305 / 2010 as suitable destinations, in addition to investing each time more in the selective collection being one of the main concerns by the municipal managers.

Another research with primary data done directly with the municipality of Santo André, it was possible to establish that the municipality is favorable to the technology of organic digestion and that Semasa had a pioneer initiative with the implementation of these cooperatives, because, in addition to the amount collected with In sales of recyclables, cooperatives receive an additional amount related to the amount that would be spent to land the waste in the municipal landfill, that is, for each (one) ton of separate recyclable waste, the cooperatives receive an additional amount of R$ 45 (Brazilian reais). The requirements set by Semasa for the additional payment is to have a maximum of 35% rejects in the separation of recyclables and a monthly sale of at least 200 tons of recyclables (SEMASA, 2019).

CONCLUSION

The emergy analysis showed that all sectors, from generation and change instruments linked to the destination of waste, are in accordance with two forms of selective collection and selection and how energy interactions are applied in accordance with PNRS 12.305 / 2010.

The city is a pioneer in the requirement of the selective collection initiative from the 1980s, and this can contribute to the improvement of the treatment and destination of MSW through the education provided by SEMASA.

The municipality of Santo André has always invested in environmental education, in addition to improving the percentage of recyclables recycling constantly directly helps the cooperatives of the municipality and the treatment of this waste has been increasingly improved in recent times.

A survey with primary data conducted with SEMASA servers in 2019, shows that the municipality is favorable in the future to realize the energy use through biodigestion and it is necessary to see its economic and technical viability, through academic research besides placing the cooperatives as indispensable actors. to treat recyclables and technologies to treat tailings.

It is noteworthy that the measures used so far are used as an appropriate destination for the shipment of MSW and that in some years, long-term landfills will also be unviable. For this reason, it is suggested for the municipality of Santo André to invest in energy-efficient technologies to extend the useful life of the city's municipal landfill.

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References

ALCANTARA, K. D. S.; ANTONIO, G. C.; TONELI, J. T. C. L. ; GONCALVES-DIAS, S. L. F. . DIAGRAMA EMERGÉTICO DO DESTINO FINAL DOS RESÍDUOS SÓLIDOS URBANOS NO BRASIL. In: 1º ENCONTRO REGIONAL SUDESTE DA ANPPAS, 2018, SAO PAULO. 2018. v. I.

BRASIL, lei nº 12.305, de 2 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei no 9.605, de 12 de fevereiro de 1998; e dá outras providências.

BARROS I, BLAZY JM, RODRIGUES GS et al. Emergy evaluation and economic performance of banana cropping systems in Guadeloupe (French West Indies) agriculture. Agriculture, Ecosystems & Environment 129:437-449, 2009.

SEMASA – Saneamento Ambiental de Santo André. Disponível em: http://www.semasa.sp.gov.br. Acesso em 15 de setembro de 2019. Santo André, 2019

IBGE – Instituto Brasileiro de Geografia e Estatística. Plano cidades, 2013. Rio de Janeiro, 2013.

____________. PLANO REGIONAL DE GESTÃO INTEGRADA DE RESÍDUOS SÓLIDOS DO GRANDE ABC. Disponível em http://arquivos.ambiente.sp.gov.br/cpla/2017/05/santo-andre.pdf. Acesso em 10 de setembro de 2019.

ODUM, H.T."Environmental Accounting. Emergy and Environmental Decision Making". John Wiley & Sons, INC, (1996).

INTERNATIONAL SYSTEMATIC REVIEW OF THE STATE OF URBAN SOLID WASTE MANAGEMENT AIMING ENERGY USE

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ABSTRACT

Brazil has experienced a few obstacles and significant advances in the experiences of urban solid waste management (MSW), especially in dealing with waste treatment in the last twenty years. Thus, in order to carry out a systematic review aiming at this history of treatment of MSW carried out in the international aspect, a survey of articles was conducted over a period of 10 years, involving three dimensions of search and treatment of articles, namely: Municipal Management of Waste, waste treatment technique and environmental management. For these three areas, three article filters were selected, resulting in a total of 1280 articles, 410265, 310 and 29 articles. From all the reading made it was possible to understand the international scenarios can help how the Brazilian scenario can improve in the waste treatment aspect, aiming at its energy use and immediate solutions to the problems that still involve the municipal management in the country.

Keywords: municipal management, waste treatment, environmental management.

Introduction

In Brazil, Law No. 12.305 / 2010, characterized as the National Solid Waste Policy, is an important milestone in the advancement of environmental policies, as it regulates changes in urban solid waste management (MSW) and establishes the correct destination of waste as one of the main goals, the improvement of management and the management accomplished so far in the country.

Currently, Brazilian municipalities still have modest results compared to the goals set by the policy, and many of them cannot even elaborate a Municipal Waste Plan and, in the worst case, still have open dumps / dumps (about 18% of Brazilian municipalities). Based on this, the federal government launched the “Dump Zero” program on April 30, 2019, which brings a significant action plan that addresses improvements and promotes incentives for the energy use of MSWs.

Therefore, in order to understand how the international scenario has changed after the 10 years of national waste policy, a systematic review was performed as a form of research that uses the literature Sampaio and Mancini (2007) as a source of data. With the systematic review performed, it is possible to present articles that registered significant advances in the waste management sector aimed at energy use. Thus, with the result of this research it will be possible to identify which are the most explored areas in the scientific community, and which sectors need further studies to improve the discussion and approach on the theme analyzed.

In order to evaluate the international scenario, after the implementation of the Brazilian National Solid Waste Policy 12.305 / 2010, the objective of this paper is to present the management of urban solid waste through the systematic review of the international parameter in the period of ten years, in which presents municipal management, treatment technician and environmental management of waste, focusing on energy use.

Material and Methods

To build the systematic review, we used the free desktop Publish or Perish software that analyzes academic citations using information from Google's academic search engine (http://scholar.google. com (La Serena, 2012).

For the division of the search for national articles to be performed, were divided into three dimensions of search, which are: Municipal Management of Urban Solid Waste (GMRSU), Urban Solid Waste Treatment (TRSU) and Environmental Management (GA). For each dimension was created an analytical category that must characterize the articles according to each purpose. From this, we selected 29 international articles that portray waste management, divided by the dimensions mentioned above. This division is based on categories that link the area of waste, according to each theme created.

Results and Discussion

To understand how waste management is an international reality, a systematic review was carried out in 2010-2018 based on national articles, it was possible to identify several barriers that persist today.

Thus, it was necessary to perform three stages of filter searches in order to find articles that present the situation is happening in recent years, for the search filter were divided the articles, as shown in Figure 1.

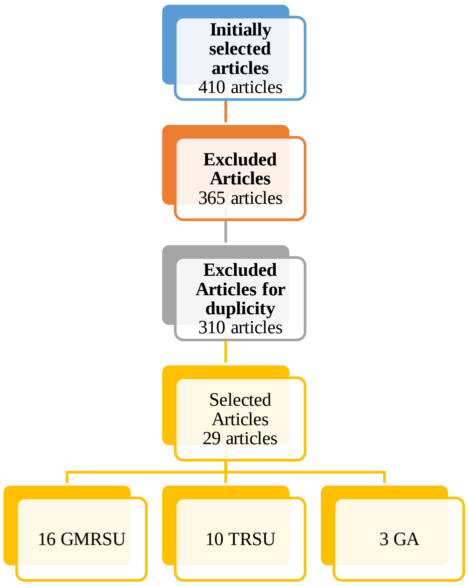

Figure 1. Filter used to search national articles

Source: elaborated by the author

The search words were municipal Waste solid; treatment Decision Making waste management; Energy utilization of municipal solid waste; Sociotechnical transition of energy use. Based on the key words, it was possible to map the international scenario regarding municipal waste management and energy use in the international scenario, as shown in graph 5, 10 articles of solid waste treatment, 16 municipal management articles from waste and 3 environmental management articles as shown in table 1.

Of the filtered articles, the municipal waste management area presents in several articles the transition areas of municipalities for energy use (SMITH AND STIRLING (2010); COUTARD AND

RUTHERFORD (2010); NG QUIN ET AL (2014) this must be accomplished by multiple stakeholder forces, usually facilitated by a government department who develop a shared vision to achieve sustainability goals (SHMELEV (2010); CERO ET AL (2015). According to Liu et al (2015), the incineration regulations and the related policy laws on the effectiveness of environmental programs and where inefficiencies reside, as well as providing lessons for countries wishing to initiate or revise their environmental regulations can assist developing countries.

Table 1. International Article Search Filter

ANALYTICAL DIMENSIONS AND CATEGORIES OF ARTICLES	**ARTICLES**				
Municipal Management of Urban Solid Waste					
Management case study (MSW collection, separation, recycling and disposal)	ZHANG ET AL (2010)	LEBERSORGER E BEIGL (2011)	DESA ET AL (2011)	BELIEN ET AL (2012)	ZAMAN (2016)
Application and policy reviews	-	SENG ET AL (2011)	-	-	-
Municipal plan for integrated urban solid waste management		-	FERRI ET AL (2015)	-	-
Socio-technical transition to improve waste management by municipalities	SMITH E STIRLING (2010)	COUTARD E RUTHERFORD (2010)	NG QUIN ET AL (2014)	TING TANG (2015)	PELESAREI ET AL (2017)
Municipal waste management for environmental management	SAKAWI (2011)	SONG E WANG (2013)	GREENE E TONJES (2014)	HERVA ET AL (2014)	YAY (2015)
URBAN SOLID WASTE TREATMENT					
Destination given to municipal solid waste	GAIDAJIS ET AL (2010)	-	-	-	-
Extended life of recyclable waste (Recycling, Composting, Selective Collection)	SMITH ET AL (2010)	JHA ET AL., (2010)	-	-	-
Gravimetric caracterization of MSW	ALLEGRINI ET AL (2014)	-	-	-	-
Estimated useful life of waste landfills		-	-	-	-
Technologies for the treatment of municipal solid waste	OEHMEN E REBENTICH (2010)	PONSÁ E SHÁNCHEZ (2011)	HOSSAIN ET AL (2014)	ARAFAT ET AL (2015)	LIU ET (2015)
ENVIRONMENTAL MANAGEMENT					
Environmental preservation	SHMELEV (2010)	CESARO ET AL (2015)	-	-	-
Impact of improper disposal of municipal solid waste on the environment	LAURIDSEN E JØRGENSEN, (2010)	-	-	-	-

Source: elaborated by the author

The waste treatment dimension articles present relevant discussions of how solid waste treatment has been changing over time. According to Arafaft et al (2015), the use of the gasification process for the energy use of MSW has an overall electricity production efficiency using a gas turbine, which is around 40. As for anaerobic digestion, electrical efficiencies can reach up to 39% (BRAUN, 2007). Song and Wang (2013) advocate waste management practices as the priority to achieve mitigation of environmental impacts and nature conservation is a priority (CERO ET AL (2015).

Conclusion

This research allowed a mapping of the international discussions in which presented larger studies of municipal waste management (16 articles), urban solid waste treatment technique (10 articles) and environmental management (3), it is worth mentioning that this research is part of the results. the elaboration of the author's thesis on energy.

The international scenario highlights first world and developing countries that are increasingly changing and seeing the need for energy use as an opportunity for change in the ten-year search period, with Europe as a reference model in technologies, including biodigestion, waste incineration, and it is a priority to send less and less waste to landfills. What should be carefully analyzed, when compared, is the budget of the countries implemented legislation, in addition to the management of waste treatment, in many articles was treated waste generation as a priority of the problem and not just direct treatment and disposal Final. It is noteworthy that before any deployment of energy use of waste it is essential that the waste passes the priorities set out in PNRS 12.302 / 2010 in article 9 being instructed to: no generation, second reduction, then reuse, later recycling, before of MSW undergo any kind of physical and chemical treatment. In addition to the insertion of cooperatives as a basic and essential source of support for waste treatment and the increase of recycling rate in Brazil.

Finally, it is worth reinforcing that for improvements in the management and treatment sector of MSW in Brazil, it is essential to disseminate research in universities that make reality in the country feasible, considering budgets, legislation, and treatment for current waste, besides being The implementation of Environmental Education as a tool for change is becoming increasingly necessary, so that the valorization of waste is increasingly improved.

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References

ALLEGRINI, Elisa; MARESCA, Alberto; OLSSON, Mikael Emil; HOLTZE, Maria Sommer; BOLDRIN, Alessio; ASTRUP, Thomas, Fruergaard. Quantification of the resource recovery potential of municipal solid waste incineration bottom ashes, Waste Management, Volume 34, Issue 9, 2014.

ARAFAT, Hassan A; JIJAKLI, Kenan; AHSANB, Amimul. Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. Journal of Cleaner Production, Volume 105, 15 October Pages 233-240, 2015.

BELIËN, J.; BOECK L De.; ACKERE, J. Van. Municipal solid waste collection and management problems: a literature review. Transportation Science.;48(1):78– 102. 2012.

BRASIL, lei nº 12.305, de 2 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei no 9.605, de 12 de fevereiro de 1998; e dá outras providências.

BRASIL. Ministério do Meio Ambiente. Agenda Nacional de Qualidade Ambiental Urbana: Programa Nacional Lixão Zero [recurso eletrônico] / Ministério do Meio Ambiente, Secretaria de Qualidade Ambiental, Departamento de Qualidade Ambiental e Gestão de Resíduos, Coordenação-Geral de Qualidade Ambiental e Gestão de Resíduos. – Brasília, DF: MMA, 2019.

Braun, R. Anaerobic digestion – A multi faceted process for energy, environmental management and rural development. In: Improvement of crop plants for industrial end users. Ranalli, P. (Publisher), Springer., 2007.

CESARO, A.; BELGIORNO, V.; GUIDA, M. Compost from organic solid waste: Quality assessment and European regulations for its sustainable use. Resources, Conservation & Recycling, 94, 72-79. (2015).

COUTARD, O., RUTHERFORD, J. Energy transition and city-region planning: understanding the spatial politics of systemic change, Technology Analysis & Strategic Management, 22(6), pp. 711–727, 2010.

COUTARD, O., RUTHERFORD, J. Energy transition and city-region planning: understanding the spatial politics of systemic change, Technology Analysis & Strategic Management, 22(6), pp. 711–727, 2010.

DESA, Samajwadi; KADIR, Abdul, Nor Ba'yah; YUSOOFF, Fatimah. Study on the Knowledge, Attitudes, Awareness Status and Behaviour Concerning Solid Waste Management, Procedia - Social and Behavioral Sciences, 2011.

FERRI, Giovane Lopes; CHAVES, Lorena Diniz; RIBEIRO, Glaydston Mattos. Reverse logistics network for municipal solid waste management: The inclusion of waste pickers as a Brazilian legal requirement. Waste Management, Volume 40, June 2015, Pages 173-191, 2015.

GAIDAJIS G.; ANGELAKOGLOU K.; and AKTSOGLOU, D. “E-waste: environmental problems and current management,”. Journal of Engineering Science and Technology Review, vol. 3, no. 1, pp. 193– 199, 2010.

GREENE, Krista L; TONJES, David J. Quantitative assessments of municipal waste management systems: Using different indicators to compare and rank programs in New York State. Waste Management, Volume 34, Issue 4, April Pages 825-836, 2014

HERVA, Marta; NETO, Belmira; ROCA, Enrique. Environmental assessment of the integrated municipal solid waste management system in Porto (Portugal). Journal of Cleaner Production, Volume 70, 1 May 2014, Pages 183-193, 2014.

HOSSAIN, H.M; HOSSAIN, Zakir, Quazi Hasna; MONIR, Md. Minhaj Uddin; AHMED Md. Tofayal. Municipal solid waste (MSW) as a source of renewable energy in Bangladesh: Revisited. Renewable and Sustainable Energy Reviews, 2014, vol. 39, issue C, 35-41, 2014.

Inf. tecnol., La Serena, v. 23, n. 4, p. 1-2, 2012 . Disponible en <https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0718-

JHA, A.K..; SINGH S. K., SINGH J.P.; GUPTA P.K. “Sustainable municipal solid waste management in low income group of cities: a review,”. Journal of Tropical Ecology, Vol. 52(1), pp. 123-131, 2011.

LAURIDSEN, Erik Hagelskjær; JØRGENSEN, Ulrik. Sustainable transition of electronic products through waste policy. Research Policy Volume 39, Issue 4, Pages 486-494, 2010.

LEBERSORGER, S.; BEIGL, P. Municipal solid waste generation in municipalities: Quantifying impacts of household structure, commercial waste and domestic fuel. Waste Management, Volume 31, Issues 9–10, September– October, Pages 1907-1915, 2011.

NG QIN, Wendy, Pei; LAM, Hon Loong, VARBANOV, Petar; KLEMEŠ, Sabev, Jiří Jaromír. Waste-to-Energy (WTE) network synthesis for Municipal Solid Waste (MSW). Energy Conversion and Management, Volume 85, Pages 866-874, 2014.

OEHMEN, J., and REBENTICH, E. Waste in Lean Product Development. Cambridge:Massachusetts Institute of Technology's Lean Advancement Initiative, 2010

PELESARAEI, N; A., BAYAT, R., HOSSEINZADEH-BANDBAFHA, H., AFRASYABI, H., & CHAU, K.-w. Modeling of energy consumption and environmental life cycle assessment for incineration and landfill systems of municipal solid waste management – a case study in Tehran Metropolis of Iran. *Journal of Cleaner Production*, *148*, 427–440, 2017.

PONSÁ, Sergio; SÁNCHEZ, Teresa, Gea, Antoni. Anaerobic co-digestion of the organic fraction of municipal solid waste with several pure organic cosubstrates. Biosystems Engineering, Volume 108, Issue 4, April, Pages 352-360, 2011.

SAKAWI, Zaini. Municipal solid waste management in Malaysia: Solution for sustainable waste management, 2011.

SAMPAIO, R. F.; MANCINI, M. C. Systematic review studies: a guide for careful synthesis of the scientific evidence. Braz J Phys Ther, São Carlos, v. 11, n. 1, p. 83-89, 2007.

SHMELEV, Stanislav E. Dynamic sustainability assessment: The case of Russia in the period of transition (1985–2008). Ecological Economics Volume 70, Issue 11, 15 September 2011, Pages 2039-2049, 201

SMITH, A; VOSS, J-P; GRIN, J. "Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. Research Policy 39 435–448, 2010.

SMITH, Adrian; STIRLING, Andy. The Politics of Social-ecological Resilience and Sustainable Sociotechnical Transitions, ECOLOGY AND SOCIETY, 2010.

SONG, Q., WANG, Z., & Li, J. Environmental performance of municipal solid waste strategies based on LCA method: a case study of Macau. Journal of cleaner production, 57, 92-100. doi: 10.1016/j.jclepro.2013.04.042, (2013).

TAN, ST; HO, WS; HASHIM, H; LEE; Chew Tin; TAIB, Mohd Rozainee; HO, Chin Siong. Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia. Energy Conversion and Management 102: 111–120, 2015.

Wendy Ng PQ, Lam HL, Varbanov PS, Klemeš JJ. Waste-to-energy (WTE) network synthesis for municipal solid waste (MSW). Energy Convers Manage 85:866–874, (2014).

YAY, A. S. "Application of life cycle assessment (LCA) for municipal solid waste management: a case study of Sakarya,". Journal of Cleaner Production. vol.94, pp. 284-93, May 2015.

ZAMAN, Atiq Uz. Identification of key assessment indicators of the zero waste management systems. Ecological Indicators. Volume 36, January, Pages 682-693, 2014.

ZHANG, D.; TAN, S.; GERSBERG, R. Municipal solid waste management in China: Status, problems and challenges. Environ. Manag., 91,1623-1633, 2010.

SUSTAINABILITY ANALYSIS IN TRANSMISSION LINES ON THE BRAZILIAN STATE OF PARÁ

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ABSTRACT

The present work aims to verify, through a systemic perspective, the sustainability in the implantation of Transmission Lines in the State of Pará, characterized by being a poor Brazilian state, highly dependent on the mineral extraction activity for the development of the region and weakly connected to the National Interconnected System (NIS). As a first step, bibliographic research is performed in order to create a solid basis for the development of this work, containing data for general justification and procedures/criteria adopted in similar works. Subsequently, social, economic, and environmental indicators are chosen, which are processed through a geoprocessing tool and analyzed in order to relate direct and indirect impacts. The relationship of the transmission lines with the mining industry of Pará is treated with especial attention throughout the work. The mining industry is a high energy-consuming industry and is responsible for significant economic development in the region. The present work shows, through a systemic vision related to the social, economic, and environmental sphere, the implementation of Transmission Lines presents a good result focused on sustainability in the face of the proposed methodology.

Keywords: Transmission Lines, Sustainability, Systemic Perspective, Mining Industry, State of Pará

Introduction

Increasingly, electric power is being a critical and strategic input in general processes and activities in all sectors of the economy. The dependence on the quality of its supply accompanies its growing importance in several processes (GOMES; CHIPP; SCHILLING, 1993). In parallel there is the relationship between the availability of electricity as well-being and quality of life of the population.

The way in which electricity is produced, made available and consumed has direct impacts on the development of a region, whether human or economic social development, including the industrial sphere. One way of making energy available to a region is through transmission lines, so a sustainability analysis of this object is very important to assess the dimensions of the social, industrial and environmental impacts of this type of application in a given region.

With its electric matrix mainly composed of large hydroelectric plants, corresponding to 66.6% of the Brazilian electric matrix according to the National Energy Balance (EMPRESA DE PESQUISA ENERGÉTICA, 2018)Brazil follows the National Interconnected System for the distribution of the produced electricity, that is, an electricity transmission grid that seeks to electrically connect four large subsystems (South, Southeast / Midwest, Northeast and most of the North), seeking to optimize the hydrological regime of the basins. Today, the installed capacity in the SIN is 109,212MW in

161,526MW hydroelectric plants in total, including sources such as solar, wind, thermoelectric. (ONS, 2019).

Therefore, especially in Brazil, the decision regarding the construction of new transmission lines (TL) is directly related to the electrical planning of the region in question. Thus, the present work will analyze the sustainability regarding the implementation of Transmission Lines (TL) focusing on the industrial growth of the Brazilian state of Pará through the availability of electricity. As development is a multicriteria factor, sustainability analysis of this object is necessary in order to verify the impacts on the social, environmental and economic spheres of the region through a systemic view. One of the main focuses of analysis through the Geographic Information System (GIS) will be the verification of the industrial growth of the region, focusing on mining industries.

Methodology

The sustainability analysis will be based on environmental, economic, and social indicators organized and arranged in a sustainability matrix in a qualitative manner. In turn, a systemic view will be used regarding the technological object studied, understanding the interconnections and interdependencies between the problems encountered in relation to the implementation of transmission lines in the state of Pará.

A. Transmissions Lines

A transmission line design seeks to meet system planning requirements, ie to transmit a specific power under normal operation (long-term charging) and emergency (short-term charging) at a particular voltage level, while lower total cost, which is the investment cost plus the cost of losses, with low environmental and social impact, high reliability and availability, meeting minimum technical requirements from an electrical and mechanical point of view.

The main elements that make up the process of optimizing a transmission line are related to the project investment cost associated with the transmission function, ie, towers (geometry, spacing, heights), cables (type and number of conductors, span length, arrow), others the cost of project investment associated with environmental issues (lane, restrictions on route definition, environmental offsets, interference with the environment in general, as well as services and systems - telephony, radio, and humans - hazardous potentials - touch and step, audible noises).

The systematic approach in the implementation of transmission lines, considering environmental, social, technical, and economic factors made by the reference represent a source for the survey of indicators for the development of our project.

B. Economic, Social and Environmental Considered Aspects

Pará is the second largest state in Brazil, just below the Amazon, located in the northern region, the state has an area of 1,245,759.30km². The region was used for extraction purposes by the Portuguese from 1616, and later in the seventeenth century to produce coffee, rice, sugar cane, cocoa, tobacco and cattle, later in the nineteenth century there was another time of economic development. with rubber production (IDEFLOR-Bio; 2016). The Amazon rainforest covers about 45% of the state of Pará, with 21 protected areas (PA) being divided into sustainable use conservation units (49%), indigenous lands (31%) and full protection protected areas (20%) with 181 endangered species, 91 vertebrates, 37 invertebrates and 53 plant species. Integral protection areas and indigenous lands, concentrate a higher amount of these threatened species (IDEFLOR-Bio; 2016). The state has an estimated population of 8,513,497 people according to the IBGE in 2018, being the 9th state with the largest population and has an HDI of 0.646, sharing with Piauí state the third position of the worst states according to this indicator

(IBGE). The state has 11.4% of unemployment, below the 12.5% presented as a national average, but only 35.8% of the population over 14 have formal work, well below the 59.2% of the national average. The average household income has a value of R $: 873,00, below a minimum wage, while the national average is R $ 1,511.00 (IBGE).

C. Indicators

The sustainability pillars are interspersed in several instances, because of this, a new subdivision was made considering this factor. This new subdivision is called indicators, which are the basis of the sustainability analysis. Figure 1 a) shows those indicators and their relationship.

D. Systemic Model

A systemic model is a model which relate all the characteristics of a specific object of study instead of using a particular one characteristic to determine its sustainability. The advantages of using this model are the visualization and consideration of the interconnections. The interdependencies between the insertion consequences of the technological object in the environment in question, prioritizing integrated thinking. Figure 1 b) shows the schematic map of the systemic approach.

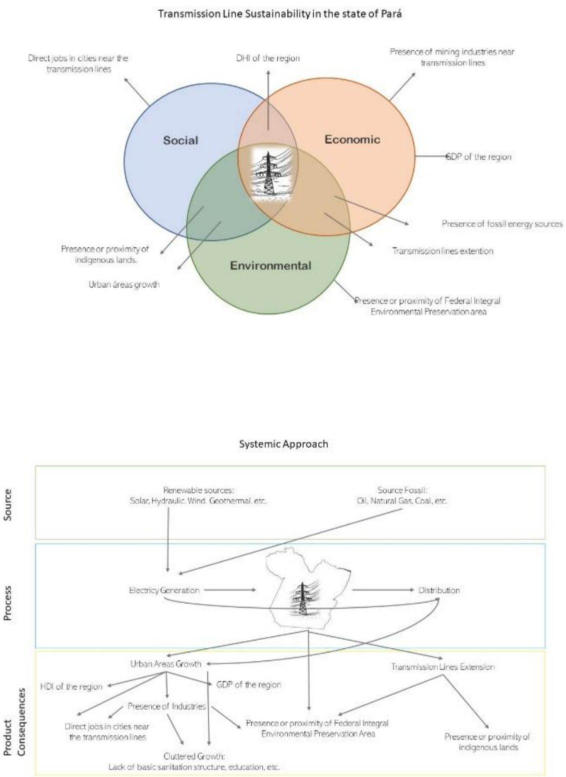

Figure 1. a) Sustainability Indicators and b) Systemic Approach used in this work

Results and Discussion

The analysis of this work followed two aspects, one focused on a visual analysis and a second focused on quantitative analysis, following the standard of sustainability indexes designated by EPE, related to the extension of transmission lines and proximity to environmental conservation units.

A. Visual Analysis

The first analysis proposed by layer intersection in QGIS software refers to the presence or proximity of transmission lines with indigenous reserves and Environmental Conservation Units, a topic that will also be addressed by quantitative analysis.

There are two types of environmental conservation units: integral protection units, consisting of ecological stations, biological reserves, national parks, natural monuments and wildlife refuge, and sustainable use units, composed of, among others, environmental protection areas and natural forests. For Integral Conservation Units, only the indirect use of natural resources is allowed and refers to this type of unit that this first analysis involves. (BRAZIL, 2010).

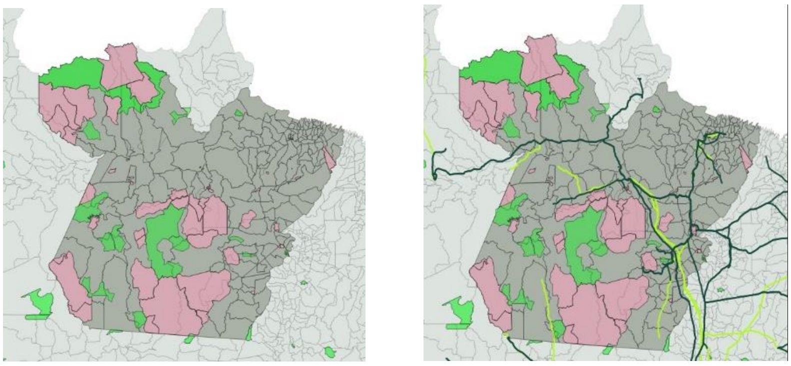

Figure 2. a) Environmental Conservation Units and b) Transmission Lines on the State of Pará: current-green lines and future-yellow lines.

B. Quantitative Analysis

Based on our QGIS analysis, we initially noticed a change between the values measured by the QGIS software with respect to the value tabulated by the original data source. Due to the unknown methodology of the original production, the data considered were the values redesigned by the QGIS environment. In addition to the direct data obtained from line extension, the data related to the "Direct Jobs" indicator were estimated. According to EPE (2010), it can be estimated that there are about three workers for each km of transmission line installed so that by the length obtained by the processing itself, this data can also be inferred. For defining the impact relative to both data, the sustainability classes presented by EPE (2010) were used as a reference, but for determining degrees of impact, these values were inverted. For the first measured indicator, we used Table 1.

Table 1. Sustainability levels for Transmission Lines extensions.

Classes	**Class Interval (km)**
Very High	$i>600$
High	$300<i\leq600$
Medium	$100<i\leq300$
Low	$50<i\leq100$
Very Low	$i\leq50$

Table 2 shows the results obtained after doing the quantitative analysis on the future transmissions lines on the Brazilian state of Pará until the year of 2022 by using the criteria of Table 1.

Table 1. Some Results of the Quantitative Analysis – until the year 2022.

Year	Transmission Line Name	Length (km)	Impact	Estimated Direct Jobs	Impact
-	LT 500 kV UHE São Manoel - Paranaíta C1	36	Very Low	109	Very Low
2019	LT 230 kV Xingu - Altamira, C1	60	Low	179	Very Low
2019	LT 800 kV CC Xingu - Terminal Rio	2552	Very High	7656	Very Low
2020	LT 230 kV Transamazônica - Tapajós, C1	183	Medium	550	Low
2020	LT 230 kV Altamira - Transamazônica, C2	187	Medium	562	Low
2021	LT 230 kV Vila do Conde - TomÚ-Aþu, C1	119	Medium	357	Very Low
2022	LT 230 kV Marituba - Utinga, C3 e C4 (CD)	10	Very Low	30	Very Low
2022	LT 500 kV Vila do Conde - Marituba, C1	57	Low	172	Very Low
2022	LT 230 kV Marituba - Castanhal, C1	67	Low	200	Very Low
2022	LT 230 kV Xinguara II - Santana do Araguaia, C1 e C2 (CD)	268	Medium	803	Low

Conclusion

This work showed that the application of the sustainability analysis in transmission lines on the state of Pará is very promising. Based on the concepts found in the literature, it was possible to define a number of indicators and a specific systemic model for transmission lines. In order to establish a way to ponder the Transmission Line sustainability, these indicators were used in visual and quantitative analysis. The results also demonstrated that the utilization of the QGIS software as a tool for processing geographic information is an excellent way to analyses the sustainability of a transmission line on the Brazilian state of Pará. It is also possible to conclude the direct and indirect impact of the transmission line implementations concern the social, economic, and environmental actors.

References

1. GOMES, Paulo; CHIPP, Hermes Jorge; SCHILLING, Marcus Theodor. Anais. In: ENCONTRO PARA DEBATES DE ASSUNTO DE OPERAÇÃO, 4º, 1993, Rio de Janeiro. Avaliação dos custos de interrupção no fornecimento de energia elétrica. Rio de Janeiro: Eletrobrás, 1993. p. 1 - 16.

2. MADURO-ABREU, Alexandre. Prospecção e hierarquização de inovações tecnológicas aplicadas a linhas de transmissão. Brasília, DF: Teixeira Gráfica e Editora, 2010.

3. EMPRESA DE PESQUISA ENERGÉTICA (Brasil). Ministério de Minas e Energia. Balanço Energético Nacional 2019. Rio de Janeiro: Ministério de Minas e Energia, 1 jan. 2018. Livro Digital.

4. IDEFLOR-Bio - Instituto de Desenvolvimento Florestal e da Biodiversidade do Estado do Pará. O Futuro da Fauna Ameaçada do Pará. Belém: Ideflor-bio, 2016.

5. IBGE - Instituto Brasileiro de Geografia e Estatistica, Pesquisa Nacional por Amostra de Domicílios Contínua. 2017.

6. OPERADOR NACIONAL DO SISTEMA ELÉTRICO (Brasil). ONS. Capacidade Instalada no SIN - 2018/2023. Brasilia. OPERADOR NACIONAL DO SISTEMA ELÉTRICO, 1 jan. 2018. Livro Digital.

WASTE BRIQUETTE AS AN ALTERNATIVE FOR THERMOELECTRIC INPUTS

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ABSTRACT

Energy generation and use are factors that contribute to the environmental problem, which has been growing over the years due to the excessive use of non-renewable sources. Brazil, although it has a large part of its energy matrix from renewable sources, has the reliability and efficiency in thermal power plants from fossil fuels that guarantee the supply of power generation in possible failures. Thus, this work aimed to present biomass insertion alternatives as input for thermoelectric plants. In this scenario, the production of solid fuels from the densification of residual biomass is an option for energy matrix diversification with efficiency gains. Considering that waste is generated in large quantities and often improperly disposed of, its energy use is an application that, at the same time as energy conversion, reduces the volumes destined for landfills. The densification of residual biomass, also known as briquetting, improves transport and storage efficiency while ensuring higher energy density and lower moisture content, while also improving combustion efficiency. With such advantages, biomass densification can be an option for minimizing the costs of generating thermal plants, which has one of the most significant investments at the price of its inputs, as well as reducing dependence on fossil fuels and helping to reduce emissions. Greenhouse gases, also reducing environmental and socioeconomic impacts.

Keywords: Thermoelectric, Inputs, Biomass, Briquettes.

1. Introduction

The environmental theme is the dominant issue among nations and world organizations, due to the concern about the risks inherent to life balance. Water pollution, deforestation, and climate change are examples of impacts that concerned authorities for their harmful effects on the environment [1]. In this sense, the problems associated with the generation and use of energy are among the most delicate aspects of the global environmental problem, given the excessive use of non-renewable sources that generate questions about the limit of energy supply and balance between economic and environmental sectors [2].

Brazil has a prominent place in the world for its broad representation of renewable sources in the domestic energy supply, with a share of over 80% in 2017, the base year of the last National Energy Balance (BEN, 2018). Hydroelectric dams make up the largest share of all renewable sources, around 65.2%, suggesting a strong reliance on water resources for the country's electricity supply [3]. The country also has a vast availability of natural resources favorable to energy applications that can diversify the energy matrix, ensuring the supply of energy that is a public good guaranteed by the National Constitution.

Renewable sources have been inserted in Brazil and, over the years, have gained more visibility and more significant opportunities to be installed in the country, to diversify the electrical matrix, and consequently, provide a better quality of life. This insertion of renewable sources was accompanied by government incentives, such as the creation of the Incentive Program for Alternative Sources of Electric Energy (Proinfa), caused by the constant droughts faced in recent years, which raised concerns about the supply of electricity, in view of that hydroelectric plants are the largest sources of electricity used in the country [4].

Fossil fuels still occupy a considerable portion of the country's electricity generation, mainly through thermoelectric plants, because they have high rates of generation efficiency and reliability [5]. In Brazil, in particular moments, when the electrical energy supply needs to be guaranteed, the use of thermoelectric plants occurs. The operation of thermoelectric plants represents high costs, which are felt mainly by the consumer through the tariffs charged. Typically, inputs for generation are distributed among biomass, natural gas, diesel oil, fuel oil, coal, other fossil fuels. Biomass as a thermoelectric input represents only 9% of the total, a percentage below what can still be exploited, given the broad availability of resources in the country [5]. An example of this potential is agroindustrial waste, which, according to the 2012 National Solid Waste Plan (PNRS), produced 290,838,411 tons of solid waste associated with agriculture [6]. The use of waste as inputs could also minimize environmental impacts by reusing resources that are usually incorrectly disposed of in landfills, degrading the soil and contaminating groundwater, while at the same time adding economic value to them, reducing the costs of generation and high tariff prices [7].

Among the existing thermochemical processes, direct combustion is unquestionably the most used for the energy conversion of such wastes, however certain disadvantages are observed. Among them, we can highlight the moisture, which is often high in residual biomass, resulting in less energy available in the combustion process [8]. The process of production of solid fuels by residual biomass densification, in turn, requires the use of low moisture biomass and, through the production of briquettes, have higher energy density, better quality and more excellent storage and transportation advantages because of their characteristics more uniform and standardized size when compared to bulk biomass [9 - 10].

Given the above, the present work aims to present alternatives for the insertion of residual biomass (or urban solid waste??) as input for thermoelectric plants, considering the production of solid fuels from the densification of residual biomass as an alternative to broaden their scope as sources for matrix diversification national electric.

2. Energy as a right

The modern man understands a way of living in which basic needs such as education and health, for example, need to be met, and their maintenance is essential and dependent on goods and services that are currently also considered fundamental rights, such as electricity [11].

Electricity is a common good, ensured by the Brazilian Federal Constitution, in which the interruption of its supply is prohibited. Thus, the search for ways to diversify Brazil's energy matrix is increasing, ensuring the generation necessary for the continuous energy consumption, as well as policies applied to storage methods that allow covering possible failures [12].

Thermoelectric plants in Brazil exist as a way of guaranteeing possible shortcomings in the National Interconnected System (SIN), which is responsible for the production and transmission of electricity in Brazil. This way, thermoelectric plants are considered a strategic source of electricity generation for the country [13].

3. Thermoelectric

Electricity generation in Brazil is based mainly on renewable sources from the most varied natural resources that the country has. Hydroelectricity is the most used form of energy production, which in turn, has been facing major problems due to the low inflow in its reservoirs. With the oscillations of precipitation in reservoir areas and intermittent renewable sources such as wind and solar, the public electricity sector in its planning, can not give up having thermal power plants as alternatives for diversification and guarantee of electricity production and supply [14]. However, thermoelectric plants have negative externalities that are still related to production inputs.

3.1 Non-renewable inputs and negative externalities

Thermoelectric plants make up 29% of the Brazilian electricity sector, and 20% of production uses fuel from non-renewable sources, namely: natural gas (9%), diesel oil (3%), fuel oil (3%), coal (3%), other fossil fuels (1%) and nuclear power plants (1%) [5].

Among the sources cited, natural gas is the fastest-growing input in use. From 2012 to 2015, it was the second-largest source present in the energy matrix, with the last percentage, in 2016, of 8.1% share [15]. Electricity generation through this resource raises questions about availability since there is a "competition" between consumer sectors, namely: residential, industrial, and transport. Thus, it is necessary to expand the gas supply to meet the demand, a factor that is estimated in the long term with the pre-salt exploration, requiring high investments in exploration and transport networks. As negative externalities, there are still large amounts of greenhouse gas (GHG) emissions, imports, which drive the economy through the high costs and needs of investments in pipelines [16].

Coal is undoubtedly the most polluting source among those mentioned above, both in its process of obtaining and converting it into electricity. Its burning generates high levels of GHG and damage currently considered irreparable. Diesel and fuel oils follow the same pollution line [5]. Thus, the environmental impacts associated with the use of non-renewable sources are certainly the most impacting externality, so much so that worldwide, there is a concern and the search for alternatives that may reduce its use [17].

Nuclear power plants, by contrast, are the only ones that do not emit GHG into the atmosphere. However, the use of this source raises questions about the risks to human health and the environment that potential accidents may generate. Thus it is necessary additional investments that are very high the ensure the use of the sophisticated security facilities. [18].

3.2 Renewable Inputs (Biomass)

In this scenario, the use of biomass-powered thermoelectric plants represents a viable option for the opportunities and availability of this resource in Brazil. Moreover, it has environmental and socioeconomic advantages as it is not a polluting source when compared to fossil fuels, and does not involve competition between sectors, allowing the use of waste that would typically be discarded. In this sense, there would be a possible reduction in fuel investment costs, since the biomass used in these processes is usually waste [19].

The amount of waste generated has been increasing, in general, by anthropogenic activities that gradually rise with population growth. Such waste comes from various activities: industrial, domestic, hospital, commercial, agricultural, service, and corroborate for possible significant changes in the environment, especially improper disposal, usually carried out in dumps [20].

Brazil is a country with an environmental policy that is constituted by various bodies and laws, for example, Law No. 9,605 of the National Solid Waste Policy (PNRS) of 12 February 1998, sanctioned on 2 August 2010 and the Ministry of Environment (MMA). That legitimizes participatory planning for sustainable development, and understand that the country has in its territory the largest forest area on the planet, with abundance of natural goods. Thus, it creates a view that environmental citizenship is legal, however, it is essential to emphasize that such a concept is a right that must be protected by the state and the community, in which environmental responsibilities require uniformity with society [21].

Specifically, in the energy sector, the use of solid waste as fuel is a direct alternative to conventional solid fuels. Although there are already many biomass inputs in Brazil, there is a need for their increasing insertion, given their environmental and socio-economic contributions. (Reference)

4. Waste briquetation

The energy conversion technologies to which biomass can be employed also need to be chosen in such a way that the process is efficient as it is intended to increase their use in place of fossil fuels. Direct combustion is the most used form for energy conversion of biomass; however, there are disadvantages in this process, such as the low efficiency observed when humidity is high. Another problem associated with the use of waste biomass is their low density, which entails high costs for their transportation and storage, often limiting their use only to where they are predicted.

The production of solid fuels from waste biomass is an alternative that, through the densification process, promotes the increase of its energy density. As a result of this process, there are briquettes, fuels with comparable quality to conventional firewood, material that comes from different wood species with different shapes and varying moisture content. The briquette is homogeneous in shape and with moisture close to 8%, which increases combustion efficiency [23].

The application of this technique has considerable advantages, such as [24-25]:

- Reduction of costs with inputs, transportation, etc,
- Minimization of impacts on forests for firewood, mainly native species,
- The final product (briquette) can be used in different types of boilers and ovens, for example in bakeries, pizzeria, etc,
- It has production in standardized format to reduce storage space; enabling better maintenance for the inventory system,
- It reduced moisture and thus reaches higher temperatures faster; producing less smoke, ashes, and soot,
- It guaranteed complete storage spaces, which makes margin for loss of storage voids impossible,
- Secure handling and less manpower,
- Finally, pollution rates lower than fossil fuels.

Thus, the application of the briquetting technique adds high efficiency to waste, which, compared to fossil fuels, ensures production efficiency in power generation in thermoelectric plants. The higher insertion of this resource as input from thermal power plants brings the possibility of substitution to fossil uses, having all the advantages listed that guarantee reduction of environmental impacts, reduction of costs for the reuse of waste, and minimization of losses.

5. Conclusions

Based on the above considerations, the use of the briquetting technique allows the production of more homogeneous solid fuels, which can be handled, transported, and stored more efficiently and at lower costs than bulk biomass. The most significant advantage of this process is to increase the possibility of covering these residues, which can be transported to generating plants. Another important vector is the non-emission of greenhouse gases by biomass since they have a closed carbon cycle. It is, therefore, a viable option to be used to minimize the costs of generating thermal plants, which has at the prices of their inputs, one of the most significant investments, in addition to reducing environmental impacts and risks to human health.

Due to the massive amounts of waste generated and incorrectly disposed of, the energy use of them as thermoelectric inputs would be of great importance, mainly if they are used after a compaction process that maximizes their energy density. There may be a higher insertion of biomass as input for thermoelectric plants, where waste briquettes are quality products with high levels of calorific value and low humidity levels, ensuring the efficiency of use in thermal cycles.

Thermal power plants are of great importance in Brazil for their efficiency and reliability for the process of generating and guaranteeing the supply of electricity. However, one of the concerns is with non-renewable inputs, which represent the majority used. Thus, a greater use of biomass, associated with the briquetting process, can confer numerous advantages, being a proven medium that needs to be further expanded.

References

1 VECCHIA, Rodnei. Combustíveis renováveis: propulsores na condução para uma nova civilização energética. In: VECCHIA, Rodnei. **O meio Ambiente e as Energias Renováveis:** Instrumentos de Liderança Visionária para a sociedade sustentável. São Paulo: Manole, 2010. Cap. 4. p.145-207

2 GINÂNI, T. P. **Estudo Preliminar da Produção de Briquetes Compostos a partir de Resíduos Vegetais**. 2013. 37 f. Monografia (Graduação em Ciência e Tecnologia) – Universidade Federal Rural do Semi-Árido, Angicos, 2013.

3 BRASIL. Ministério de Minas e Energia (MME). Empresa de Pesquisas Energéticas (EPE). **Balanço Energético Nacional**. 2018.

4 BRASIL. Ministério de Minas e Energia (MME). **Programa de Incentivo às Fontes Alternativas de Energia Elétrica (Proinfa).** Disponível em: <http://www.mme.gov.br/programas/proinfa/>. Acesso em: 02 abr. 2017.

5 TOLMASQUIM; Mauricio Tiomno. (coordenador). **Energia Termelétrica**: Gás Natural, Biomassa, Carvão, Nuclear. Empresa de Pesquisas Energéticas (EPE): Rio de Janeiro, 2016.

6 BRASIL. Ministério do Meio Ambiente (MMA). Plano Nacional de Resíduos Sólidos – PNRS. Brasília, 2012. Disponível em:< http://www.sinir.gov.br/documents/10180/12308/PNRS_Revisao_Decreto_280812.pdf/e183f0e7-5255-4544-b9fd-15fc779a3657>. Acesso em: 16 jul. 2016.

7 Agência Nacional de Energia Elétrica (Brasil) (ANEEL). Atlas de energia elétrica do Brasil. In: **Biomassa.** 2. ed.. Brasília, 2005.

8 FILIPPETTO, Daniele. **Briquetagem de resíduos vegetais:** viabilidade técnico-econômica e potencial de mercado. 2008. 74 f. Dissertação (Mestrado) - Curso de Planejamento de Sistemas Energéticos, Universidade Estadual de Campinas, Campinas, 2008.

9 MAIA, Bianca Goulart de Oliveira. **Valorização de Resíduos da Bananicultura e da Rizicultura na Produção de Briquetes.** 2013. 92 f. Dissertação (Mestrado) - Curso de Engenharia de Processos, Universidade da Região de Joinville, Joinville, 2013.

10. PAULA, Luana Elis de Ramos e et al. Produção e avaliação de briquetes de resíduoslignocelulósicos. **Revista Brasileira de Pesquisas Florestais,** Colombo, v. 31, n. 66, p.103-112, jun. 2011.

11. CALVACANTE, Hellen Priscilla Marinho. O acesso à energia elétrica no Brasil sob a ótica do desenvolvimento como liberdade. **Revista de Direito Econômico e Socioambiental,** Curitiba, v. 4, n. 2, p.58-86, dez. 2013.

12. ROSA, Taís Hemann da. Direito fundamental social de acesso à energia elétrica. In: Seminário Internacional de Ciências Sociais - Ciências Politicas, 3., 2014, São Borja. **Anais... .** 2014. Disponível em: <http://cursos.unipampa.edu.br/cursos/cienciapolitica/files/2014/06/ACESSO-À-ENERGIA-ELÉTRICA-evento-sb.pdf>. Acesso em: 2 abr. 2017.

7. 13. Operador Nacional do Sistema Elétrico (NOS). O que é o SIN - Sistema Interligado Nacional. Disponível em: <http://www.ons.org.br/conheca_sistema/o_que_e_sin.aspx>. Acesso em: 02 abr. 2017.

14. ROSA, Luiz Pinguelli. Geração hidrelétrica, termelétrica e nuclear. **Estudos Avançados,** São Paulo, v. 21, n. 59, p.1-0, abr. 2007.

15. BRASIL. Ministério de Minas e Energia (MME). Boletim Mensal de Energia. Dezembro. 2016. Disponível em: < http://www.mme.gov.br/documents/10584/3580498/01+-+Boletim+Mensal+de+Energia+(Dezembro+2016)+(PDF)/66fa4b91-f16e-4b9f-ae2a-edc3ad550fc8;jsessionid=41E8065CA95D1FABA7C8B26BB66878C9.srv154>. Acesso em: 24 ago. 2016

16. FARIA, Luiz Fernando Rocha de. **A integração dos mercados de gás natural e energia elétrica no Brasil.** 2010. 139 f. Dissertação (Mestrado) - Curso de Engenharia Elétrica, Universidade Federal de Minas Gerais, Belo Horizonte, 2010.

17. Agência Nacional de Energia Elétrica (Brasil) (ANEEL). Atlas de energia elétrica do Brasil**.** In: **Carvão Mineral**. 9. 2. ed.. Brasília, 2005.

18. HIRSCH, Helmut et al. Perigos dos reatores nucleares: Riscos na operação da tecnologia nuclear no século XXI. **Estudos Avançados.** v. 21, n. 59, p.253-257, 2007.

19. SANTOS, Fernando Alves dos. **Análise de Aplicação de Biomassa da Cana como Fonte de Energia Elétrica:** Usina de Açúcar, Etanol e Bioeletricidade. 2012. 127 f. Dissertação (Mestrado) - Curso de Enegenharia, Universidade de São Paulo, São Paulo, 2012.

20. HINRICHS, Roger A.; KLEINBACH, Merlin; REIS, Lineu Belico dos. Biomassa: Das plantas ao lixo. In: HINRICHS, Roger A.; KLEINBACH, Merlin; REIS, Lineu Belico dos. **Energia e Meio Ambiente.** 4. ed. São Paulo: Cengace Learning, 2011. Cap. 17. p. 623-652. Tradução técnica: Lineu Belico Reis, Flávio Maron Vichi, Leonardo Freire de Mello.

21. SANTAELLA, Sandra Tédde., *et al*. **Resíduos Sólidos e a Atual Política Ambiental Brasileira.** Fortaleza: UFC/LABOMAR/NAVE, 2014. p.231.

22. QUIRINO, Waldir Ferreira **Utilização energética de resíduos vegetais**. Laboratório de produtos florestais LPF/IBAMA. Módulo do Curso "Capacitação de agentes multiplicadores em valorização da madeira e dos resíduos vegetais", 2000.

23. FURTADO, Thielly Schmidt et al. Variáveis do processo de briquetagem e qualidade de briquetes de biomassa florestal. **Revista Brasileira de Pesquisa Florestal,** Colombo, v. 30, n. 62, p.101-106, jul. 2010.

24. **Empresa Brasileira de Pesquisa Agropecuária** (Embrapa). Ministério da Agricultura, Pecuária e Abastecimento. **Briquetagem e Peletização de Resíduos Agrícolas e Florestais.** 2012. Disponível em: <https://www.infoteca.cnptia.embrapa.br/bitstream/doc/932713/1/FOLDERBriquetagem22012.pdf>. Acesso em: 17 jul. 2016.

25. GONÇALVES, José Evaristo. **Avaliação Energética e ambiental de Briquetes Produzidos com Rejeitos de Resíduos Sólidos Urbanos e Madeira de Eucalyptus grandis.** 2010. 119 f. Tese (Doutorado) - Curso de Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, 2010.

NATURAL GAS DISTRIBUTED GENERATION: CURRENT SCENARIO AND CHARACTERIZATION OF COMMERCIAL AND RESIDENTIAL CUSTOMERS

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ABSTRACT

The natural gas on-grid micro and mini-generation market, which covers generation power up to 5MW, established by the *Agência Nacional de Energia Elétrica* (ANEEL) mainly with Normative Resolution 482/2012 has not developed actively in Brazil yet. Therefore in this paper, as part of a dissertation, reviews and studies the current scenario of these systems in an area restricted to the concession of the natural gas distributor of the State of São Paulo - COMGÁS, as well as evaluates the electric and thermal consumptions of the customers: hotels, hospitals, gyms/clubs and residential condominiums. This study was based on on-line available databases and databases provided by the responsible entities. The results achieved so far corroborate with the premise of this study that the natural gas micro and mini-generation in residential and commercial sector is still an unconsolidated and underdeveloped market, while the analysis of heat and electricity consumption shows great potential for this solution.

Keywords: cogeneration, natural gas, distributed generation, micro and mini-generation.

Introduction

Currently, the national cogeneration scenario is mostly composed of large systems, focusing on industrial use that has a consolidated business model and higher investment capacity. In the commercial and residential sectors, specifically those with heat demand, such as hotels, hospitals, gyms/clubs and residential condominiums, in addition to technical viability, new business models and public policies are essential to make the solution economically viable and to increase energy efficiency.

There are resolutions established by the *Agência Nacional de Energia Elétrica* (ANEEL), such as Normative Resolution 235/2006 with qualified cogeneration requirements, Normative Resolution 482/2012 that enables consumers to generate their own energy from renewable sources, cogeneration and to connect with the electrical distribution network (micro and mini distributed power generation), and the Normative Resolution 687/2015 that regulates the electricity compensation system and the general supply conditions (ANEEL, 2019). These regulating practices were very important in stimulating the implementation of distributed generation with economic benefits that attracted consumers and were effective, especially for renewable sources, such as solar and biomass. However, they still do not show results that consolidate natural gas cogeneration for small energy demands (power capacity up to 5MW). These incentives from the regulatory agency for distributed generation projects aim to ensure the supply of electricity, in quantity and quality compatible with the pace of economic growth (COGEN, 2018).

This paper is part of a dissertation that analyzes the dissemination of natural gas distributed on-grid micro and mini-generation and discusses possibilities and perspectives to be explored. Aiming at conducting an initial exploratory research of the current electricity and natural gas consumption of customers of the some categories of the commercial and residential sectors and the current scenario of natural gas micro generation in the study area defined as the concession area of *Companhia de Gás de São Paulo* (COMGÁS).

Figure 1 presents the COMGÁS concession area, which delimits the reviews and analysis in this study. The area represents about 26% of national GDP, covering 177 cities in the state of São Paulo that accounting for 30% of the country's energy consumption (COMGÁS, 2019).

Figure 1. COMGÁS concession area.

Source: COMGÁS, 2019.

Materials and Methods

To analyze the current scenario and the consumption of the customers, a data survey was carried out through bibliographic research and database provided by ANEEL and COMGÁS. The data searched can be characterized as follows:

- *Current scenario of natural gas distributed generation in the region covered by the study* - the research of the number of systems installed in the area to characterize the current scenario was done using ANEEL's database for distributed generation. It was filtered by generation type (hydroelectric, wind, photovoltaic and thermal generating plants), by UTE units (thermoelectric plants) natural gas source and municipalities of the State of São Paulo belonging to the area covered by the study.
- *Technologies currently used for on-grid natural gas micro and mini power generation in Brazil* - to characterize the systems used and equipment brands were analyzed data provided by COMGÁS (spreadsheet with the small generation units supplied by the concessionaire) and ANEEL’s online data (ANEEL, 2019) from distributed generation units.
- *Average monthly consumption of electricity and natural gas in the hotels, hospitals, gyms/clubs and residential condominiums costumers* - an analysis of data was available through a spreadsheet by COMGÁS (COMGÁS, 2019). Data about consumers' monthly natural gas consumption by segment and monthly electrical data filtered by *Classificação Nacional de Atividades Econômicas* (CNAE) and municipalities in the coverage area, provided by ANEEL through the *Sistema Eletrônico do Serviço de Informação ao Cidadão* (ANEEL, 2017).

Results and Discussion

Only three on-grid natural gas distributed generation systems were identified in the concession area of COMGÁS. The segment of each generating unit, the technologies used in these systems, as well as the power of the equipment are shown in table 1.

Table 1. Features of the technologies used in on-grid natural gas distributed generation systems in the delimited area.

Technology - Features			
	Customer[1]	**Installed Power (kW)[1]**	**Technology/Brand [2]**
Unit 1	gyms/clubs	25	Yanmar/ internal combustion
Unit 2	gyms/clubs	176	PowerLink/ internal combustion
Unit 3	Residential	10	Weichai/ internal combustion

Source: [1]ANEEL and [2]COMGÁS, 2019.

The number of installed systems is very small, and it is noteworthy that the two systems installed at the gyms/clubs come from R&D projects of the natural gas concessionaire itself, which shows an immaturity in the market. Besides, the three equipment are imported and represent the internationally most widespread technology.

The average monthly electricity and natural gas consumption, assumed as thermal demand, and the number of consuming units were surveyed, considering those customers with the highest thermal demand to justify the installation of a cogeneration, namely: hotels, hospitals, gyms/clubs and residential condominiums. Table 2 shows the results of this survey.

Based on data from the natural gas concessionaire and the agency responsible for regulating electricity in the COMGÁS concession area, it can be noticed that only a small part of electricity consumers also consume natural gas. It is important to emphasize that the number of consumers of natural gas analyzed for residential condominiums are those who consume gas for pool heating and collective hot water generation. Considering the lower heating value (LHV) of natural gas 9,721 kWh/m^3 (COMGÁS, 2014), the heat/electricity ratio for the segments ranges from 1.3 for gyms/clubs to 2.9 in residential condominiums, which show a suitable ratio for the use of internal combustion engines.

Table 2. Average monthly electrical and natural gas consumption of the some sub-sector

Average monthly consumptions				
sub sector	**Electric (kWh)[1]**	**Units[1]**	**Natural Gas (m^3)[2]**	**Units[2]**
Hotels	10.482	2.247	1.987	345
Hospitals	35.350	1.392	5.906	240
Gyms/ Clubs	12.809	983	1.693	354
Residential Condominiums	3.696	23.936	2.216	2.753

Source: [1]ANEEL, 2017 and [2]COMGÁS, 2019.

Conclusion

The results presented so far corroborate importance of the challenge of development and studies in the area of on-grid natural gas micro and mini distributed generation in the sub-sectors of hotels, gym/clubs, hospitals, ad residential condominiums for purposes of energy efficiency gains because it has not high dissemination yet. The costumers analyzed present a heat/electricity ratio suitable for the use of cogeneration technologies with internal combustion engines.

Acknowledgement

I would like to express my thanks to COMGÁS for providing the data that are indispensable for this study.

References

ANEEL. **Distributed generation**: Available in: <http://www.aneel.gov.br>. Accessed on: 10 set. 2019

ANEEL**. Distributed generation. Distributed generation consumer units with Generation Type: UTE.** 2019. Available in: <http://www2.aneel.gov.br/scg/gd/gd_fonte_detalhe.asp?Tipo=2>. Accessed on: 10 set. 2019.

ANEEL. **Electrical Data - State of Sao Paulo – spreadsheet extracted by the Citizen Information Service Electronic System - e-SIC.** Brazil. ANEEL, 2017.

COGEN. **Cogeneration: Energy Cogeneration Industry Association.** Available in: <http://www.cogen.com.br/>. Accessed on: 10 set. 2019.

COMGÁS. ***RIP*. General**. 2014. Available in: <https://www.comgas.com.br/wp-content/uploads/2017/05/RIP-2014_2-Generalidades-versao-marco-2014.pdf>. Accessed on: 21 set. 2019.

COMGÁS. **Where we operate.** 2019. Available in: <https://www.comgas.com.br/a-comgas/onde-atuamos/>. Accessed on: 20 set. 2019.

COMGÁS. **Average monthly natural gas consumption by segment - spreadsheet provided from the concessionaire's database.** São Paulo: COMGÁS, 2019.

ANALYSIS OF HYDRO- WIND ELECTRIC COMPLEMENTARITY IN BRAZIL

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ABSTRACT

In Brazil, the possibility of investing in renewable energy is great, since the country has a wide territorial extension and the climatic conditions favor. An example that has taken space in the energy matrix is wind energy. In addition, hydroelectric plants are the main electricity generators in Brazil, accounting for 65% of the energy potential. As for the two sources mentioned and other renewable sources, the climatic factor drastically interferes with generation, since there is a direct dependence. In the case of hydroelectric, it is necessary to precipitate and discharge the rivers to supply the reservoirs, and in the wind power, it is necessary to move the mass of air depending on pressure and temperature. In this article, a study of hydro-wind complementarity is carried out, analyzing wind and hydropower generation monthly in regions of Brazil. For 2018, it can be concluded that water and wind complementarity was possible, especially for the North and South. The National Interconnected System (SIN) allows the interconnection of the electric system, enabling the exchange of energy between regions. The complementarity and SIN, it is possible, thus, to obtain benefits of the diversity of the river regime and supplying the Brazilian internal energy need.

Keywords: wind energy, hydroelectric power, complementarity, energy analysis, climate conditions.

Introduction

In Brazil, although wind energy is still little explored, it has been shown to be effective in generating electricity. In 2017, wind power accounted for approximately 8% of Brazilian electricity (EPE, 2018).

Although it is considered a technology without greenhouse gas generation, low pollution and without many environmental impacts, most renewable sources depend on climatic conditions, causing the production to vary throughout the year and, consequently, bringing losses and market risks. Like wind power, water can also be considered seasonal (SILVA et al, 2015).

According to the authors Rampinelli and Junior, it is said that most of the tributaries with exploitable potential are in the North of the country, but due to environmental issues, it is not possible large water reservoirs, making them even more seasonal (RAMPINELLI & ROSA JUNIOR, 2012). To supply this reduction of energy produced, it is possible to implement, then, the complementary wind production, which unlike hydro energy, has its greatest potential in the period between June and November. The following graph (Figure 1) shows the ratio of winds and inflows from 2000 to 2008.

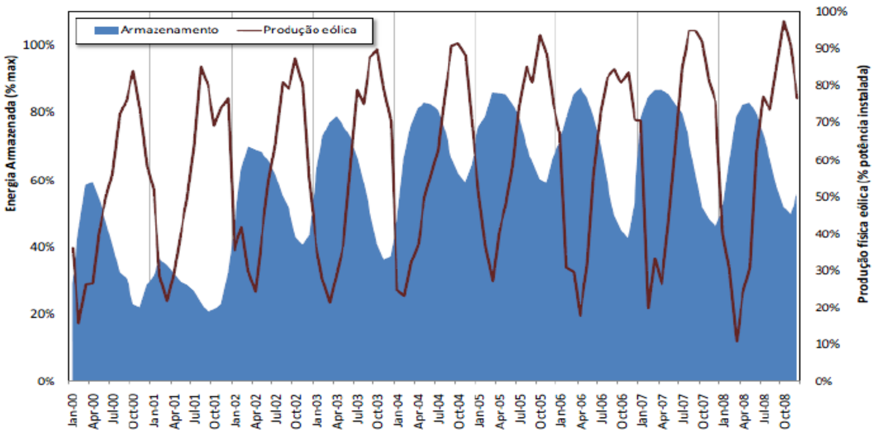

Figure 1: Complementarity chart of hydro and wind generation (RAMPINELLI & R. JUNIOR, 2012).

Given this approach, this study aims to analyze the hydro-wind complementarity in different regions of the country. To do this study, it was used current data from ONS- National Electric System Operator.

Material and Methods

The project aims to analyze three variables, namely, the potential of wind generation, the hydro potential for generation and the possibility of hydro and wind sources complementing each other in the generation of electricity in the Brazilian territory.

For the beginning of the project, the study area was delimited, which covered the entire Brazilian territory. The work steps consisted of:

1. Identify the location, regional boundaries and territorial extent;
2. Map wind and hydraulic potential indices in Brazilian regions;
3. Quantify electricity generation from wind power and hydroelectricity;
4. Evaluate the results obtained by comparing the mapping and graphing performed;
5. Use a comparative analysis with other published works.

Data will be based on ONS (National Electric System Operator) values over the 10-month and 10-day period beginning January 1 and ending November 10, 2018. For the graph it was used the weekly average. For these steps, we used the Microsoft Excel tool.

Results and Discussion

The CRESB and CPTEC present, from studies, climatological maps with data on rainfall and wind speed. The maps present interval data for every three months. It is possible to observe that the maps present great variations, proving influence of seasonality. (CRESB, 2001; CPTEC, 2018)

The topics presented below aim to observe the influence of climate on energy production from water and wind sources for the five regions of Brazil.

- **North**

The northern region is made up of seven states, namely: Amazonas, Acre, Roraima, Rondônia, Pará, Tocantins and Amapá. Figure 2 shows the wind power and hydroelectricity generation in the North.

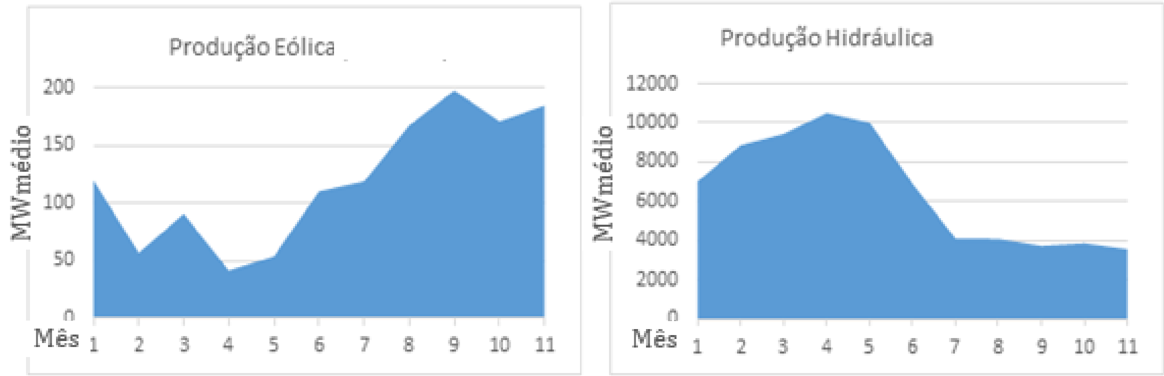

Figure 2: (a) wind power and (b) hydroelectricity in the North of Brazil (ONS, 2018)

The period of higher wind and hydraulic energy production contrasts, which shows the influence of seasonality, that is, during the rainier period, the amount of wind (air mass) is smaller, reducing wind production.

An important factor is the number of plants and the installed power. In this region it is noteworthy that there is much more hydropower and hydraulic potential than wind farms.

- **Northeast region**

The northeast region is composed of nine states, namely: Alagoas, Bahia, Ceará, Maranhão, Paraiba, Pernambuco, Piaui, Rio Grande do Norte and Sergipe.

The region is known in the energy environment as the area with the greatest wind potential, and its exploitation has been growing. Figure 3 shows the wind power and hydroelectricity generation in the Northeast of Brazil.

Among the points to be noted, the fact that hydraulic production had a very close distribution during the data collection period.

Another factor that should be highlighted is that wind energy production in the Northeast has surpassed hydro production, which is still the source responsible for 65% of the energy produced in Brazil.

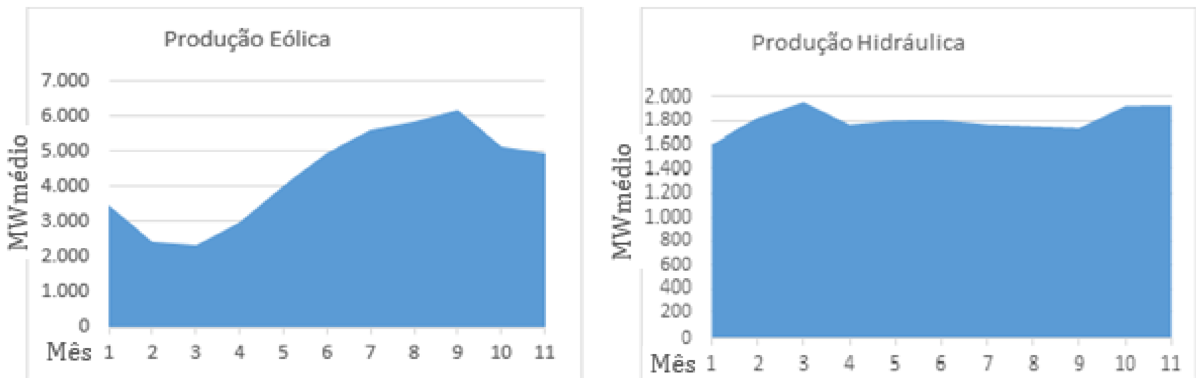

Figure 3: (a) wind power and (b) hydroelectricity in the Northeast of Brazil (ONS, 2018)

- **Southeast and Midwest region**

The Midwest region is made up of four states, namely: Goiás, Mato Grosso, Mato Grosso do Sul and the Federal District.

The Brazilian Midwest is the region that has been least installing and generating wind energy, so its potential is often added to the Southeast for calculation and analysis purposes. Figure 4 shows the hydroelectricity generation in the Southeast and Midwest of Brazil.

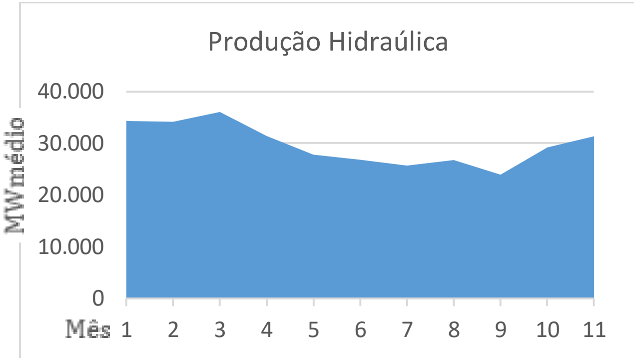

Figure 4: hydroelectricity in the Southeast and Midwest of Brazil (ONS, 2018)

In the Midwest and Southeast it is not possible to compare because there is no data on wind production. This is due to the lower wind potential compared to other regions, the low investment in technology and the fact that there is no link between parks and ONS.

- **South region**

The southern region is made up of three states: Paraná, Santa Catarina and Rio Grande do Sul. Figure 5 shows the wind power and hydroelectricity generation in the South of Brazil.

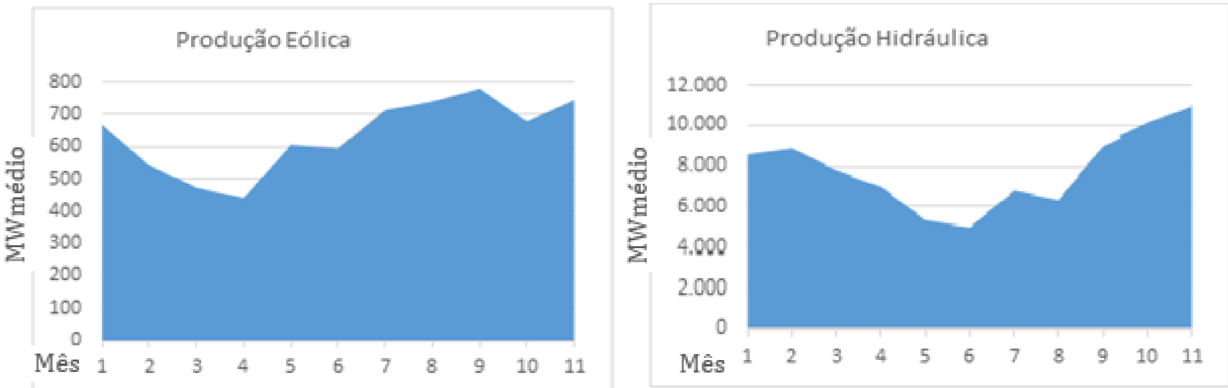

Figure 5: wind power and hydroelectricity in the South of Brazil (ONS, 2018)

For the southern region, it can be seen that there is a variation of production according to month and or season. The climate in southern Brazil has winter with temperatures between 13 and 18ºC and summer with temperatures above 30ºC. Rain is distributed throughout the year, being more intense in the months between June and September. Therefore, for hydro energy, it can be concluded that the period of greatest production occurs in the Brazilian summer and spring, that is, outside the rainy season.

For wind power, it mostly occurs in the dry season.

Relevant Works

To compare results and verify the reliability of the data obtained, we used other scientific articles already published. It should be considered that the data used are from different dates (period).

According to Rampinelli and Rosa Junior, commonly the seasonality of winds is inverse to the seasonality of the rainfall regime. In the North and Northeast, inverse seasonality occurs between water and wind sources, and thus there is the possibility of complementarity. However, for the southern region, there is a concomitance between the periods of higher wind and water production. The data analyzed were from 2000-2008 (8 years) (RAMPINELLI & ROSA JUNIOR, 2012).

In the article "Hydro Wind Complementarity: Challenges and Prospects for National Energy Planning", the author cites complementarity as a characteristic of the whole country, being clearer in the Northeast (SILVA et. al, 2015).

For the authors Marinho and Aquino, after analysis of the Northeast region, more specifically at the Sobradinho Hydroelectric Power Plant, it was concluded that, in a 74-year dataset, the affluent flow is higher in the inverse period. wind production, and thus there may be support for the reservoir in the dry season (MARINHO & AQUINO, 2007).

Finally, in the article Assessing Complementarity of Hydraulic and Wind Power Plants Related to Climate Change, for the Northeast there is a negative correlation between the two sources. For the South, there was a weakening in the positive correlation in the complementarity forecast (SCHERNER, 2018).

Conclusion

Complementarity is a concept used when there is an interdependence between two or more factors. In the present study, it was studied the possible complementarity between the energy produced from water and wind sources in the regions of Brazil.

After data collection and analysis of the results, it was concluded that for the Northern and Southern Region, although the amount of energy produced in the two sources is different, it is possible to observe a potential for complementarity, since the period of higher production between both occurs in distinct periods.

For the Northeast region, although three scientific articles point to the possibility of complementarity, the hydroelectric data showed a similar average rainfall distribution between the analysis period, and therefore, although with the well-marked wind period, it was not possible to observe seasonal complementarity. . As the Northeast is the region that has the largest wind energy generation and the smallest hydroelectric generation, wind generation becomes fundamental in the region's energy sector.

For the Midwest and Southeast, it is stated that the energy comes mainly from non-wind sources, and because it has a large industrial and commercial hub, such as São Paulo, the region still needs to be interconnected with other regions of the country to your supply.

There was divergence between the results of some scientific articles produced and published. This difference can be explained by the fact that different periods of time were chosen.

The National Interconnected System (SIN) is formed by companies from the South, Southeast, Midwest, Northeast and part of the North, and allows the interconnection of the electric system, enabling the exchange of energy between regions. With the complementarity and SIN, it is possible, thus, to obtain benefits of the diversity of the river regime and easly supplying the Brazilian internal energy need.

Thus, it can be stated that the insertion of wind generation in the system makes it more reliable as a whole, as it allows reservoirs to be kept full while wind is generating electricity.

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References

ANA- Agência Nacional das Águas. **Divisões Hidrográficas**. Available in: <http://www3.ana.gov.br/portal/ANA/panorama-das-aguas/divisoes-hidrograficas>

ANA- Agência Nacional das Águas. **Hidroeletricidade**. Available in: <http://www3.ana.gov.br/portal/ANA/usos-da-agua/hidroeletricidade>

CRESESB - CENTRO DE REFERÊNCIA PARA ENERGIA SOLAR E EÓLICA. **Atlas do Potencial Eólico Brasileiro**. Brasília, 2001.

CPTEC - CENTRO DE PREVISÃO DE TEMPO E ESTUDOS CLIMÁTICOS. **Monitoramento Brasil – Índice Pluviométrico**. Available in: <http://clima1.cptec.inpe.br/monitoramentobrasil/pt>

EPE - EMPRESA DE PESQUISA ENERGÉTICA. **Balanço Energético Nacional**. Brasil, 2017.

MARINHO, M. H. N.; AQUINO, R.R.B. **Complementariedade Sazonal Hidro-Eólica Para Oferta De Energia Elétrica**. XVII Simpósio Brasileiro De Recursos Hídricos- São Paulo- 2007.

ONS - OPERADOR NACIONAL DO SISTEMA ELÉTRICO. **Boletim Diário da Operação.** Available in: <http://sdro.ons.org.br/SDRO/DIARIO/index.htm>

ONS- OPERADOR NACIONAL DO SISTEMA ELÉTRICO. **Boletim Mensal de Geração Eólica.** Available in: <http://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/Boletim%20Mensal%20de%20Gera%C3%A7%C3%A3o%20E%C3%B3lica%202018-09.pdf>

RAMPINELLI G. A.; ROSA JUNIOR, C. G. **Análise da Geração Eólica na Matriz Brasileira de Energia Elétrica.** Revista Ciências Exatas e Naturais, Vol.14, n 2, Jul/Dez 2012.

Available in: <https://revistas.unicentro.br/index.php/RECEN/article/download/2298/2138>

SANTOS, M.C.S.R. **Manual de fundamentos cartográficos**. Secretaria da Ciência, Tecnologia e Desenvolvimento Econômico, São Paulo, s/ data.

SCHERNER N., MARANGON LIMA J. W., MARANGON LIMA L. M., QUEIROZ A.R. **Avaliação da Complementaridade das Usinas Hidráulicas e Eólicas frente às Mudanças Climáticas.** Brasil, 2018. Available in: <http://abeeolica.org.br/wp-content/uploads/2018/09/JOSe-WANDERLEY-MARAGONLIMA.pdf>

SILVA, S. S. F.; ALVES, A. C.; RAMALHOS, Â. M. C.; LACERDA, C. S.; SOUSA, C. M. **Complementaridade Hidro Eólica: Desafios E Perspectivas Para O Planejamento Energético Nacional.** Holos, Silva Et Al. 2015. Available in: <http://www2.ifrn.edu.br/ojs/index.php/HOLOS/article/view/2006/1211>

ENERGY RECOVERY FROM SPENT COFFEE GROUNDS

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ABSTRACT

Brazil consumes about 66% of all local coffee production according to ABIC (Brazilian Coffee Industry Association). All this consumption generates a large amount of waste along the whole production process. One of so many residues in this chain is the spent coffee grounds, generated during the preparation of the infusion, simply known as "Coffee". Around 900.6 million kilograms of spent coffee grounds are generated annually in Brazil. The objective of this article is to evaluate the theoretical energy recovery potential from spent coffee grounds through both routes, biochemical and thermochemical. The elemental analysis available in literature was used to estimate both, the theoretical biochemical methane potential (BMP), for anaerobic digestion using the Buswell stoichiometric equation and the theoretical high heating value (HHV), for the combustion process using the Boye equation. For biochemical route, the BMP obtained was 0,286 $Nm^3CH_4/KgTVS$, the HHV obtained was 16,660 MJ/Kg_{wet}, which is also close to values of other biomasses as eucalyptus and sugarcane bagasse. The literature presents cases of energy recovery of spent coffee grounds when available in large quantities, as in soluble coffee manufacturing industries, but no references in literature were found referring to recovery if the residue is generated in homes and cafes.

Keywords: coffee, biochemical, thermochemical, residue.

Introduction

The fruit of coffee tree, originary from Ethiopia and consumed for over a thousand years, arrived in Brazil in 1727, surrounded by interesting stories. Considered one of the most coveted trees in the world at that time, it was initially cultivated in the state of Pará, from a single tree brought from the French Guiana, and reached the point of representing 16% of Brazilian GDP in the mid-1920s. Presently it is part of a daily routine and culture of the Brazilian people, not only as a drink, but as one of the main agribusiness products in the country. (ABIC, 2016)

According to CONAB (2018), the Brazilian coffee crop in 2018, reached 59.90 million 60 kg bags of processed coffee (clean and dry beans). One third of this production is exported, while the remaining 2/3 is consumed by the internal market. (CONAB, 2018)

As described by Vegro and Carvalho (1993), coffee production process generates a large volume of residues throughout its production chain, which has been observed with more interest by the productive sector in recent decades. The main residues are peels, parchment, mucilage, pulp and sludge, which have already been used as fertilizer and for energy recovery as boiler fuel and bio methane from digesters.

Among the coffee residues, can be highlight the spent coffee grounds, generated at moment the infusion is prepared, which is the object of study of this article. Considering the annual production of 59.9 million bags (3.594 million kg), that 2/3 of this is consumed in Brazil, the reduction of 20% in mass during roasting, and that after the infusion, 47% of the mass of roasted coffee remains as spent coffee grounds (ABIC, 2016), an estimate of 900.9 million kg on wet basis of this residue per year is obtain.

The spent coffee grounds residue has some interesting characteristics for energy recovery by the biochemical route through anaerobic digestion, because it contains high moisture content, is particulate and homogeneous.

Another possible route for the energy recovery of spent coffee grounds is the thermochemical, after drying, it has interesting calorific potential, according to Coelho (2018).

The objective of this study was to evaluate the theoretical energy recovery potential from spent coffee grounds through the biochemical and thermochemical routes.

Materials and methods

This article uses elemental composition of the spent coffee grounds found in the literature to evaluate the energy recovery potential by calculating the theoretical BMP based in the stoichiometric equation proposed by Buswell and the theoretical HHV based in Boye's equation as detailed below.

Biochemical: - Anaerobic digestion, theoretical biochemical methane potential (BMP)

Through the elemental analysis of spent coffee grounds, it is possible to estimate its theoretical biochemical methane potential (BMP) using equation 2. The coefficients a, b, c and n in this equation are the stoichiometric coefficients obtained from Buswell's equations 1, where CnHaObNd represents the empirical chemical formula of the biodegradable compound in analysis (spent coffee ground) obtained by elemental analysis.

$$C_nH_aO_bN_d + \left(n - \frac{a}{4} - \frac{b}{2} + \frac{3d}{4}\right) \cdot H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3d}{8}\right) \cdot CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4} + \frac{3d}{8}\right) \cdot CO_2 + d(NH_3) \quad (1)$$

$$BMP = \frac{22{,}4 \cdot 1000 \cdot \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3d}{8}\right)}{12n + a + 16b + 14d} \quad (2)$$

Where BMP (N$mL\ CH4/g$TVS) represents the theoretical accumulated volume of methane per gram of volatile solids of the substrate.

Thermochemical - Combustion, theoretical high heating value (HHV).

It is possible to estimate the theoretical high heating value (HHV), through equation 3, known as Boye equation, which estimates this potential from the elementary analysis in dry basis (related to the total solids).

$$HHV_{dry}\ [kcal/kg\,TS] = 8400 \cdot C + 27766 \cdot H - 2649 \cdot O + 1500 \cdot N + 2672 \cdot S \quad (3)$$

Where:

HHV_{dry}: high heating value (HHV) of biomass on a dry basis (kcal/kgTS)

C: mass fraction of carbon in dry basis

H: mass fraction of hydrogen in dry basis

O: mass fraction of oxygen in dry basis

N: mass fraction of nitrogen in dry basis

S: mass fraction of sulfur in dry basis

Results and discussion

Elemental composition - Table 1 presents the elemental analysis of spent coffee ground reported by different authors.

Table 11 –Elemental composition of spent coffee grounds found in the literature.

References	C (%)	H (%)	O (%)	N (%)	S (%)	ASH (%)
COELHO (2018)	48.67	6.54	40.03	2.27	0	2.49
JUNIOR (2017)	49	7.02	36.69	2.86	1.43	3
KELKAR et al. (2015)	52.37	7.31	36.5	2.42	0.14	1.26
ROCCO et al. (2017)	71.6	6.3	17.12	2.03	0.02	2.93
LI et al. (2014)	54.5	7.1	34.2	2.4	0.1	1.7

Biochemical - Anaerobic digestion, theoretical biochemical methane potential (BMP)

The data obtained by Rocco et al. (2017), and presented in Table 1 were used for this evaluation since this author is the only that also presents the volatile solids content in relation to the total solids (36%).

The Buswell stoichiometric equation estimates the theoretical biochemical methane potential (BMP) based on the total volatile solids (TVS), so this information is essential for the evaluation.

Applying these data in equations 1 and 2 and considering that only 36% of the total solids is volatile, (the rest is composed of mineral or ash) concluding that for every 1 kilogram of dry spent coffee, the theoretical potential of CH4 generation by anaerobic digestion is 286.5 Normal liters

If these results are applied, the theoretical potential highlighted above in relation to the total generation of spent coffee grounds in Brazil, the theoretical total generation is about 258.02 million m^3 /year, through anaerobic digestion. According to CBIE (2019), these results represents a 0.71% of all Brazilian natural gas consume by year.

Table 2 compares the results of the theoretical biochemical methane potential (BMP) from spent coffee grounds, obtained by theoretical calculation using the Buswell equation to others theoretical biomass values found in the literature.

Table 12 - Biochemical methane potential (BMP) of spent coffee grounds and other biomass

Biomass	References	BMP ($Nm^3CH4/KgTVS$)
Spent coffee grounds	This article	0.286
Swine manure	IPCC (2006), adapted from AGRENER GD (2015)	0.290
Poultry manure	Euverink & Achinas (2016)	0.544
Vinasse	Souza et al. (2016)	0.350

Thermochemical - Combustion, theoretical high heating value (HHV).

To evaluate the theoretical high heating value (HHV) using Boye's equation the data presented by Junior (2017) described in table 1, was used because he presents de TS value of his original sample, (0.7706 g/g_{sample})

The HHV obtained is 21.62 MJ/kgTS.

Boye's equation estimates the theoretical high heating value (HHV) on dry basis, based on the total solids (TS) According to Junior (2017), these are 77.06% of the total mass of spent coffee grounds, so, for every 1 kilogram of spent coffee grounds *in natura*, it has a theoretical high heating value (HHV) of 16.66 MJ/kg (wet basis). If the theoretical potential highlighted were applied to the total of spent coffee grounds in Brazil (wet basis) the theoretical energy recovered would reach $1.51x10^{16}$ MJ/year.

Using the theoretical potential highlighted in relation to the total generation of spent coffee grounds in Brazil, assuming a thermal power plant with 25% of efficiency, 0.28MWh.Gj-1 as conversion factor and a LHV of 14.9Mj/Kg from the HHV, is reached a 864.03GWh/year.(DALMO, F.C; *et. al*., 2018).

According to EPE (2017), these results could supply 450 Brazilian average homes by year.

Table 3 compares the results of the theoretical high heating value (HHV) for spent coffee grounds, obtained through Boye's equation to others theoretical biomass values found in the literature.

Table 3 - Comparative high heating value (HHV) on dry basis between biomass.

Biomass	References	HHV $(MJ/kg)_{dry}$
Spent coffee grounds	This article	21.620
	JUNIOR (2017)	20.340
	LI et al. (2014)	23.200
Eucalyptus	CORTEZ &LORA (1997)	19.420
Sugarcane bagasse		17.330
Rice husk		16.140
Coconut shell		19.040

Conclusion

When comparing the theoretical results obtained in this article, with data from others theoretical biomass values found in the literature already widely explored nowadays, the spent coffee grounds has an interesting theoretical potential for energy recovery, by both routes analyzed in this article: biochemical and thermochemical.

Many works have been found where spent coffee grounds are used as a biomass for energy recovery through the thermochemical route as a technological application.

The current energy use of spent coffee grounds in Brazil is still very small, and only when available in a large scale, as in the soluble coffee industry, little has been observed regarding small-scale utilization, as in bars and residences.

Considering the theoretical potential of spent coffee grounds, it is possible to estimate that adding it to the other organic waste generated in the same bars and residences mentioned above, would make it possible to devise a collection system for this biomass, thus available in reasonable quantity to turn it into a feasible alternative for energy recovery, providing gains for society as a whole, both in energy potential and in reducing the discarded organic fraction.

Referencies

ABIC – **Associação Brasileira da Indústria do Café**. Disponível em, <http://abic.com.br/o-cafe/>. Acesso em <21/03/2019>

AGRENER GD 2015 10º **Congresso sobre Geração Distribuída e Energia no Meio Rural**

CBIE – **Centro Brasileiro de Infraestrutura.** Disponível em, <https://cbie.com.br/artigos/quanto-o-brasil-consome-de-gas-natural/>. Acesso em <02/11/2019>

CIBIOGÁS-ER - **Centro Internacional De Energias Renováveis. Plataforma De Informações Para Energias Renováveis**. Manual De Equações E Metodologias Do Simulador, 2009.

COELHO, R. S. **Aproveitamento da borra de café em processos termoquímicos** Santo André Universidade Federal do ABC, 2018

CORTEZ, L. A. B., LORA, E. S. **Tecnologias de Conversão Energética da Biomassa**. EDUA/FEI: Manaus, Série Sistemas Energéticos vol 2, 1997.

DALMO, F.C; *et. al*. **Energy recovery overview of municipal solid waste in São Paulo State, Brazil.** Journal of Cleaner Production 212 (2019) 461 – 474, Brazil, 2018IPCC - **Intergovernernmental Panel on Climate Change. Guidelines for National Greenhouse** Gas Inventories. Chapter 10: Emissions from Livestock and Manure Management, 2006.

EPE – **Empresa de Pesquisa Energética**. Disponível em, <http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-160/topico-168/Anuario2017vf.pdf>. Acessado em <23/11/2019>.

JUNIOR, R. B., **Pirólise da Borra de Café: Cinética Química e Operação em Leito Fixo**. Dissertação de Mestrado. Universidade Federal do Triângulo Mineiro. Uberaba, 2017.

KELKAR, S. *et al*. **Pyrolysis of spent coffee grounds using a screw-conveyor reactor**. Fuel Processing Technology, September 2015

ROCCO, V. *et al.* **Anaerobic digestion of coffee grounds soluble fraction at laboratory scale**: Evaluation of the biomethane potential. Dpt of Industrial Engineering, University of Rome Tor Vergata, Via Del Politecnico 1, 00133 Rome, Italy, 2017.

SOUZA et al. **Estimativa de geração de energia elétrica a partir de biogás de vinhaça**. Anais da X SEAGRO, Paraná, 2016

VEGRO, R. L. C., CARVALHO, C. F. XXXI **Congresso da Sociedade Brasileira de Economia e Sociologia Rural** (SOBER). Bahia, 1993.

PROGRESS OF INSTALLED PHOTOVOLTAIC GENERATION CAPACITY IN NATIONAL TERRITORY

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ABSTRACT

This paper shows the analysis of the progress and spatial distribution of installed photovoltaic capacity in the Brazilian states. The QGIS software is used to map this distribution of power generation capacity in the Brazilian territory. The study shows the need to implement a policy of increasing and better distribution of installed capacity.

Keywords: energy capacity, photovoltaics, qgis.

Introduction

The theme of sustainability has been highlighted in recent years due to climate change observed on the planet, promoting the use of clean energy such as solar energy that has been gaining prominence as a substitute in the planet's energy matrices, as a renewable and clean energy source. In Brazil, photovoltaic systems connected to the grid began in the late 1990s (PINHO, 2014). The installed capacity was insignificant until 2012, when the Normative Resolution 482/2012 of the National Electric Energy Agency (ANEEL - Agência Nacional de Energia Elétrica) was published, which regulated the general conditions for access to distributed microgeneration and mini-generation (NÓBREGA et al, 2018). Since then there has been a large increase in installed capacity, however yet far below other renewable sources such as wind (BEN, 2018). The presented work makes a research of the installed photovoltaic capacity in the country, evaluating its development between 2012 and 2017 and also how it is the distribution in the national territory.

Material and Methods

The data used in the research were obtained from the National Energy Balance (BEN) reports of the years of study, with information on the installed capacity for photovoltaic generation by federation unit (states). For presentation and comparison of the distribution of installed capacity in the national territory maps were made showing the installed capacity by state, each one representing a federation unit. For the elaboration of the maps the program QGIS version 3.4 - Madeira was used, based on the information obtained in the National Energy Balance (BEN), and using a base map of the national territory with the political-administrative divisions by state, obtained in the website of the Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística), in shapefile format.

Results and Discussion

The values of total installed capacity in each year were tabulated (Table 1). In 2012, the installed capacity was 2 MW, reaching 24 MW in 2016. Between 2016 and 2017, the installed capacity shows a significant increase reaching 935 MW.

Table 1. Installed capacity each year in MW

Installed photovoltaic capacity						
Ano	2012	2013	2014	2015	2016	2017
Cap.	2	5	15	21	24	935

It can be seen that in 2013 the installed capacity was 5 MW. With the information of values by state, the map (Figure 1) shows the distribution among the federation units. The only Brazilian states with the most significant values were: Bahia, Ceará and São Paulo. The state of Bahia led this year with 3 MW of installed capacity.

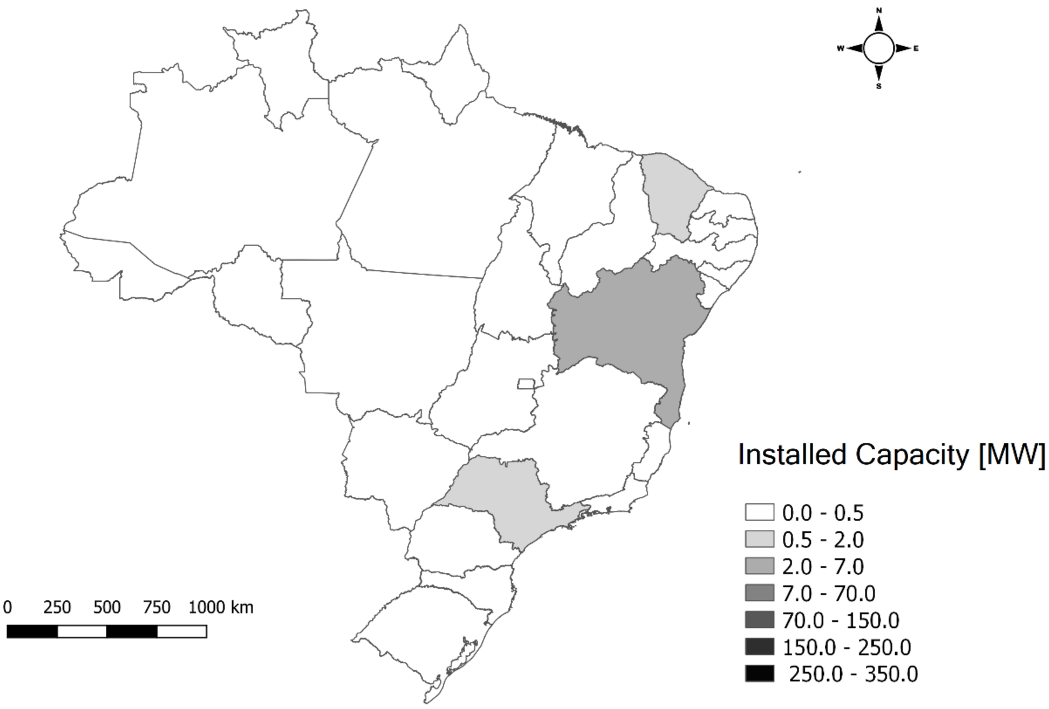

Figure 1. Map of installed capacity distribution in 2013

In 2017, there is a significant increase in installed capacity values (Figure 02). More states have significant values. In the leadership appears again the state of Bahia, but now with 319 MW. The increase in capacity observed in 2017 is significant, showing a photovoltaic capacity installed in the whole territory reaching 935 MW. The maps show large concentration of installed capacity in a few states, which in addition to providing a little economic use of the potential for receiving solar radiation.

Concentration also ends up not promoting social and economic development in many regions, with possible economic gains and job creation.

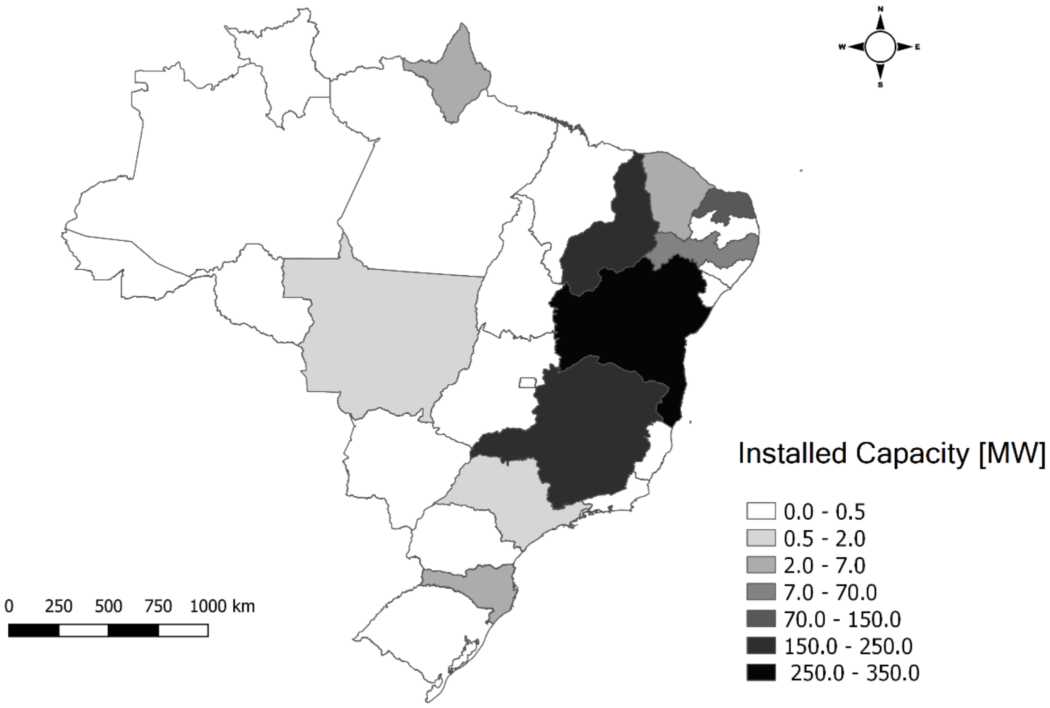

Figure 2. Map of installed capacity distribution in 2017

Conclusion

Photovoltaic energy is an important renewable source of electricity and should be further explored in the coming years, as can be seen from the increase in installed capacity in recent years. The installed capacity distribution data show that in many states there is no significant installed power for photovoltaic power exploration. The analysis indicate to the need for an incentive policy in the installation of photovoltaic modules in states with less expressive values, in order to promote regional development and make better use of the full potential of solar energy in the national territory.

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References

EPE, Empresa de Pesquisa Energética (Brasil). BEN – Balanço Energético Nacional 2018: Ano base 2017. Ministério de minas e energia. Rio de Janeiro: EPE, 2018, 292 p.

______. BEN – Balanço Energético Nacional 2017: Ano base 2016. Ministério de minas e energia. Rio de Janeiro: EPE, 2017, 292 p.

______. BEN – Balanço Energético Nacional 2014: Ano base 2013. Ministério de minas e energia. Rio de Janeiro: EPE, 2014, 288 p.

IBGE, Instituto Brasileiro de Geografia e Estatística. Mapa: Brasil - Unidades da Federação 2018. Disponível em: https://portaldemapas.ibge.gov.br/portal.php#mapa222184. Acesso em: 01 abr. 2019.

PINHO, João Tavares e GALDINO, Marco Antônio (Orgs.). Manual de Engenharia Para Sistemas Fotovoltaicos. Rio de Janeiro: Grupo de Trabalho de Energia Solar, GTES– CEPEL – DTE – CRESESB, Edição revisada e atualizada, Março 2014, 530 p.

NÓBREGA, Baldoino Sonildo et al.Desempenho de um sistema solar fotovoltaico com diferentes inclinações e orientações azimutais em cidades da Paraíba. Revista Principia n. 43, Fevereiro 2018.

MALHEIRO, C. T. et al. Avaliação de locais com potencial para a implantação de GD fotovoltaica sob a perspectiva do desenvolvimento sustentável. Santo André, s.d. UFABC. Disponível em: http://eventos.ufabc.edu.br/siimsps/files/id110.pdf. Acesso em: 29 abr. 2019.

VELAYOS, Javier G. et al. Metodología para la localización óptima de instalaciones de energia solar fotovoltaica em la Isla de Tenerife, España. Congreso nacional de medio ambiente – Conama 2018. Nov. 2018.