A DISTRIBUTED ENERGY MANAGEMENT PROPOSAL BASED ON A PEER-TO-PEER MODEL

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Abstract: The demand for renewable energy has been increasing due to the growing concern about climate change. Building a model capable of enabling the use of different types of energy production integrated into a network is the objective of this work. To achieve this, we will use the State of Bahia as the research locus, aiming for a clustering model based on the k-means method for the decentralization of managing bases, interconnected in a point-to-point (P2P) network through a minimum spanning tree defined as the main matrix. This matrix will be constructed based on the Kruskal's algorithm with redundancy in minimal cliques. Preliminary results indicate the feasibility of capturing from various possibilities of energy production sources for any renewable energy park management scenario.

Keywords: State of Bahia; Renewable Energy; Clustering; Minimum Spanning Tree; Microgrids

UMA PROPOSTA DE GERENCIAMENTO ENERGÉTICO DISTRIBUÍDO BASEADO EM UM MODELO PONTO A PONTO

Resumo: A demanda por energia renovável tem aumentado em função da crescente preocupação com as mudanças climáticas. Construir um modelo capaz de viabilizar o uso de diferentes tipos de produção energética integrado em rede é o objetivo deste trabalho. Para isso, utilizaremos o Estado da Bahia como locus da pesquisa, visando um modelo de clusterização baseado no método k-means para a descentralização de bases gestoras, interligadas em uma rede ponto a ponto (P2P) através de uma árvore geradora mínima, definida como matriz principal, construída com base no algoritmo de kruskal e com redundância em cliques mínimos. Resultados preliminares indicam a viabilidade da captação sobre diversas possibilidades de fontes de produção energética para qualquer cenário de gerenciamento de parque de energia renovável.

Palavras-chave: Estado da Bahia; Energia Renovável; Agrupamento; Árvore Geradora Mínima; Microrredes.

1. INTRODUCTION

There is a growing demand for use of renewable energy and development of sustainable cities in order to achieve global goals for society and future generation. However, the pursuit for these goals come with a challenge, the problem of energy demand management – the Energy Management Models EMM - and how to efficiently use it.

In this regard, the use of different renewable energy sources combined with prosumer-based smart grid, could help in finding a solution for the problem of energy management. Also, since smart grid covers a wide range of technologies, that is combined with levels of automation, aiming for security, convenience, efficiency and sustainability in the supply of energy goods.

According to Rosero et al, 2021 [1], with future increase in demand of those energy goods, other factors are going to play key roles in the accomplishment of final customer needs, such as grid infrastructure improvements, updates, search and use of other technologies.

One example of how this management could be used applied with different types of technologies is showed by Talluri et. al, 2021 [2], where a mixed integer linear programming (MILP) algorithm is utilized to optimize the best scheduling for minimal operating costs, considering electricity prices, variable feed-in tariffs for PV generators and maximization of the self-consumption.

Another possibility of management is proposed by Rosero et. al, 2021, where real-time simulation platforms usage, connection to a virtual server for microgrid control and set the energy management system using cloud computing and machine learning. With that, another topic that worth mentioning is the price that these systems could have, some of them could be expensive. But that is the reason why companies are seeking for efficient manners of implementing these systems, in a non-intrusive monitoring way and to achieve dynamic power system operation and control, and maximized outcomes.

Energy management could be used not only for macro scenarios, but also for local ones. Smart home energy management system receives as inputs forecasts of demand, renewable energy sources including photovoltaics and wind turbine generations, and real-time prices (Koltsaklis et. al, 2022) [3]. Smart home energy management system could also be used with features that includes flexible appliances, energy storage units and electric vehicles.

Energy storage units, with the purpose of retaining the energy that could be provided by different renewable sources and then make it available for consumer usage. The challenge with those units is the project, how it can store energy in an efficient way and make available for consumers at any time, besides, the shape that it should have to maximize outcomes and consumer needs.

Mainly because the energy could be provided by different and varied sources, besides the photovoltaics and wind turbine generations mentioned earlier, it could also be solar heating, to provide hot water and heating all year round; air source heat pump, extracting energy from the air and using it to warm houses; hydroelectric systems and biomass systems, a low carbon way of burning organic materials.

Electric vehicles are important for the achievement of environmentally friendly goals, since they do not have Internal Combustion Engines, they emit no pollutants to the ambient. They could help not only with the emissions but also with the grid management system, in reference to charging the vehicle in specific scheduling for reduced electricity costs and optimal charging rate, but also providing energy for local infrastructures, such as houses, when needed, the V2G - vehicle-to-grid, helping the management of electricity and energy supply.

According to May R and Huang P, 2023 [4], one possible solution to add for the discussion is the incorporation of Peer-to-peer (P2P) community of prosumers with heterogeneous demand and supply profiles, considering battery storage into foundation as well.

Peer to peer is the architecture of computer network in which each one of them can function as both client and server, allowing sharing of services and data without the need of a central server and hierarchy. It could also feature P2P balancing, where each peer is a prosumer perceived as an individual entity, and virtual microgrids (VMGS) as clusters of peers (Koukaras et. al, 2022) [5], so each individual has structure and specific ways of utilizing it, but also contribute with the grid as a whole.

Many factors could contribute or impact in the structure of those storage units and grids. A well-designed dynamic pricing mechanism can organize the actors within such a system to enable the efficient trade of on-site energy, therefore contributing to the decarbonization and grid security goals alluded to above. However, designing such a mechanism in an economic setting as complex and dynamic as the one above often leads to computationally intractable solutions. (MAY R; HUANG P, 2023).

Considering Ahmed W. et. al, 2020 [6] the combination of a renewable energy sources and prosumer-based smart grids are a sustainable solution for the problem of energy demand management. However, dealing with the different and complex scenarios make this a really complex problem even considering machine learning methods and statistical models. So, in order to build an efficient energy management model (EMM) is important to understand the latent correlations in highly complex machine learning models for design those and EMM, taking in to consideration prosumer energy surplus, prosumer energy cost in association with grid revenues.

As stated by Inteha A. et. al, 2022 [7], the penetration of intermittent renewable energy into the grid changes prosumers load patterns with the need of demand side management. This generates a challenge for dynamic power system operations and control. In addition, this directly affects the future planning of network expansion, which is very dependent from short-term, midterm and long-term forecasting.

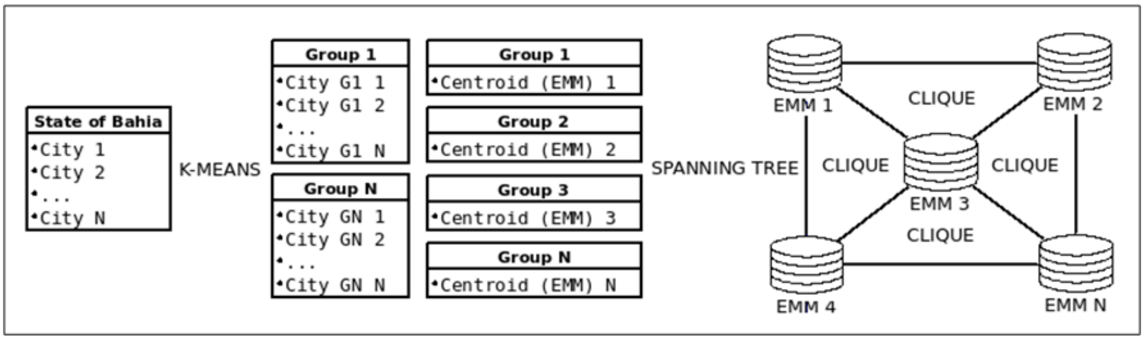
In order to manage the storage of those renewable sources of energy on microgrids, Talluri G. et. al, 2021 proposed a battery storage system controlled by three different modules composed by a machine learning-based forecasting algorithm, a mixed integer linear programming algorithm and a decision three algorithm. This method can illustrate how microgrid energy management and storage can be done and the relation between the prosumers energy consumption can be forecasted.

So, in order to provide a discussion and reduce the scope of applicability given energy management models and prosumers considering the state of Bahia, Brazil, the present article seeks through and focus on a clustering process through the state, for enabling the consideration of energy potential and interconnection of each cluster, based on P2P architecture, in such a way that it becomes possible to establish a minimum path for each existing neighborhood relationship within the identified clusters.

2. METHODOLOGY

The suggested model proposes an energy management process based on the need to fragment the management bases, interconnected through a point-to-point model and with the objective of guaranteeing the availability and feasibility of services in a redundant manner. In this regard, for a methodological pathway, a compilation of procedures resulting from artificial intelligence and graph theory will be utilized, as shown in Figure 1.

Figure 1. Methodological Pathway



Source: The authors

In order to establish a practical model for the proposal, was decided to use the state of Bahia as the research locus, considering the 417 municipalities in the state as connecting elements for the analysis. These elements, delimited by latitude and longitude coordinates of their respective municipalities, represents the set of peers that configure the scenario.

To identify the clusters, an unsupervised machine learning model was utilized, result from a clustering process using k-means. Considering the need to identify a number of clusters (K) to obtain the amount of groups, it was used the Elbow model as a result of choosing an optimal output, considering the existing Euclidean distance between the peers in the scenario.

As a result of the clustering process, a center was generated for each group, which is used as a reference for identifying the management units, as well as the set of municipalities belonging to their respective group.

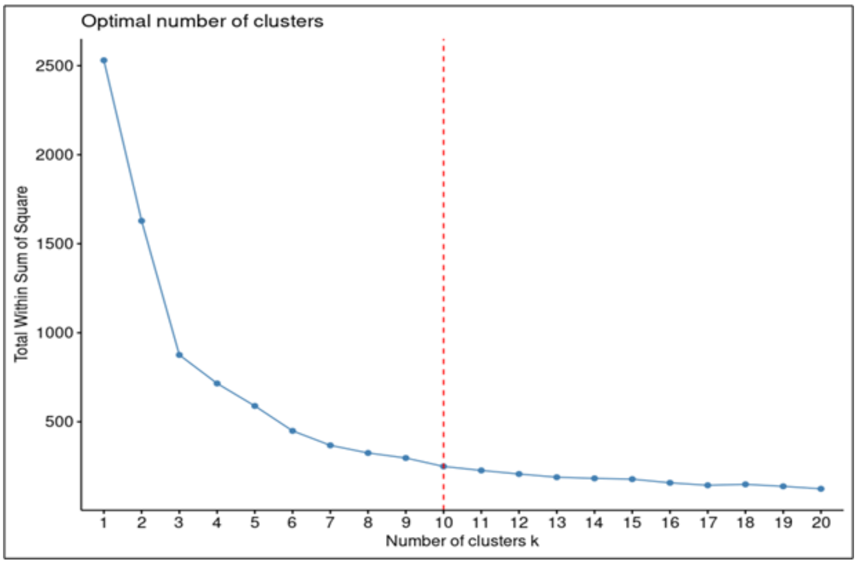
From the unification of the municipalities into just a single center, called a centroid, it was possible to establish a planar graph where all the centroids, now identified as network peers, could communicate with some other neighboring peers, in such a way that there was a redundancy over the connections.

For the application of this redundancy model, a graph was generated in which all the network peers were inserted in some clicks but with no possibility of having a disconnected graph derived from a fault on some network peer. Also, on the graph, considering the nature of energy production, a main matrix was calculated from the Minimum Spanning Tree plugin of the Gephi software, which uses the Kruskal algorithm to obtain the minimum spanning tree.

3. RESULTS AND DISCUSSION

From the need to obtain an optimal K on the number of clusters, it was identified through the Elbow method, Figure 2, two critical points of the curvature in which there is no significant gain in relation to the increase in clusters, which are points 3 and 10. When analyzing the number of municipalities and the sum of squares in each of the two possibilities, the value 10 (ten) was chosen, aiming for a better distribution of EMMs.

Figure 2. Elbow method for optimal K definition



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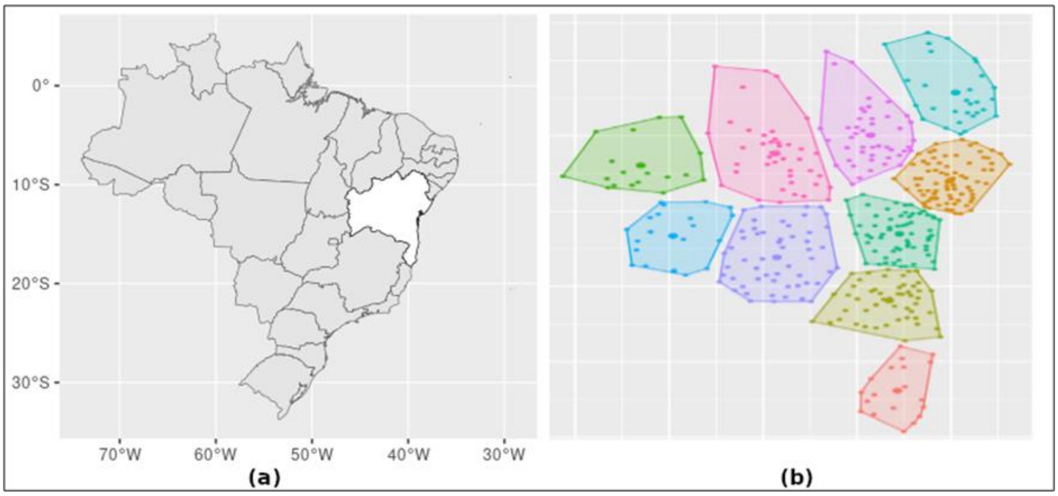
After choosing the total number of groups, the k-means algorithm was applied to the municipalities in the State of Bahia, highlighted on the map of Brazil, Figure 3(a). These 10 groups constitute a set of parts of Bahia, Figure 3(b), which will receive the EMMs, considering the energy potential of each region, but which was not highlighted in the study.

Figura 3. State of Bahia on the map of Brazil and your respective clusters.



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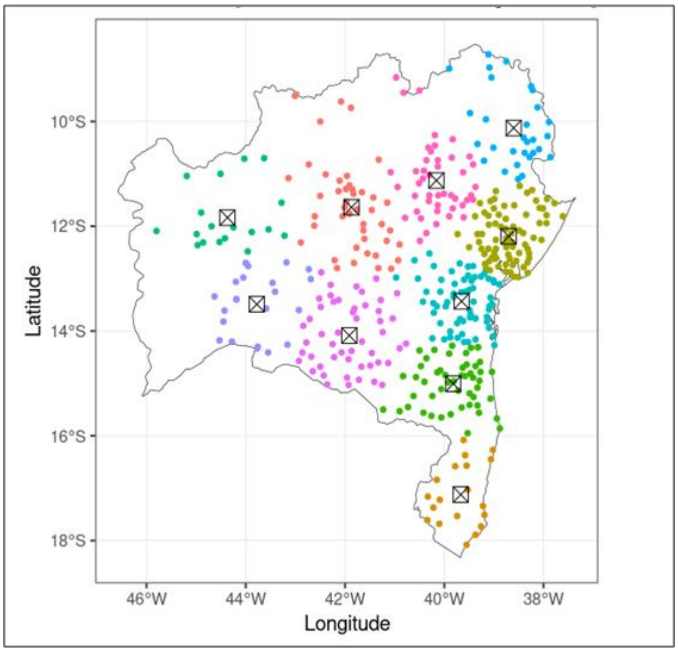
After applying the clustering model, the EMM Units were highlighted within the State of Bahia, Figure 4, with their respective coordinates, as shown in Table 1, establishing the optimal energy management points for each set of municipalities in the State.

Table 1. Latitude and Longitude coordinates of EMMs (Centroids)

Centroid	Longitude	Latitude
1	-39.66789	-17.12158
2	-38.70312	-12.19403
3	-39.81843	-15.00627
4	-44.36944	-11.83500
5	-39.62951	-13.43984
6	-38.60138	-10.12483
7	-43.77864	-13.48909
8	-41.87519	-13.99444
9	-40.15889	-11.12667
10	-41.89707	-11.55220

Source: The authors

Figure 4. EMM Units after clustering process

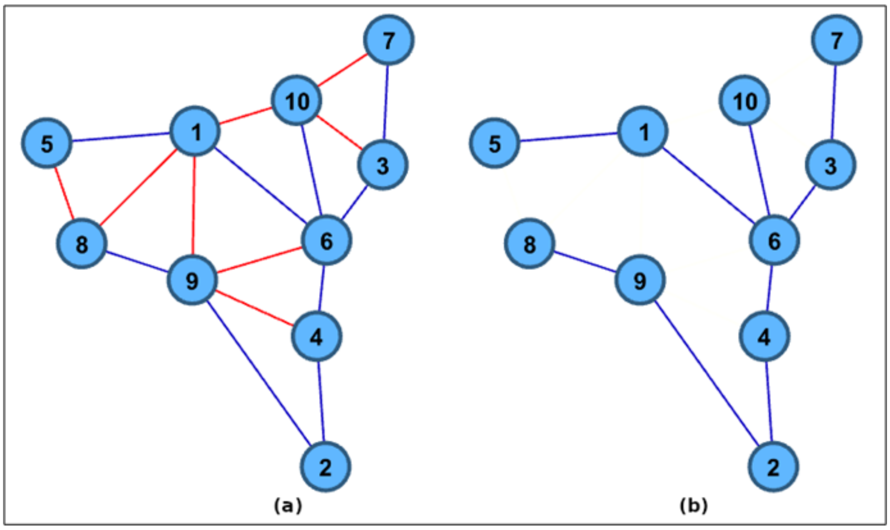


Source: The authors

Based on the coordinates of the EMM Units, identified by the centroids generated in the clustering process, a planar graph was constructed, Figure 5(a), enabling communication between all the EMMs through clicks, aiming at the impossibility of transforming this graph into disconnection in case of unavailability of a critical peer in the frame.

The graph also generated, a main connection matrix, based on the aforementioned information, Figure 5(b), constituted from the Kruskal algorithm, thus establishing a minimum spanning tree, which corresponds to a minimum model of integration between the network peers.

Figure 5. EMMs Planar graph defined over neighboring and connection with clicks.



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4. CONCLUSION

When analyzing the generated clusters and their representatives in the planar graph, it becomes evident that the interconnectivity of the EMM Units can result in a wide distribution and use of the most diverse renewable energy inputs, covering different specifications and demands. This characteristic is fundamental when dealing with the coverage of a large area, in which the dependence of this interconnectivity becomes even more evident.

Considering the presented model, inputs and services will have greater ease of flow and control within these grids. This interconnectivity also gives grids a “mobility” feature, providing control alternatives to supply regions and cities.

Another characteristic to be highlighted is the mutability of these clusters, which can have their numbers changed due to different specificities, adapting to local and regional contexts.

Thus, for the state of Bahia, the 10 EMM Units generated will be of great importance for the management of microgrids present in the state, in addition to fostering the creation of renewable energy sources to meet specific supply demands by the state.

5. REFERENCES

[1] ROSERO, D. G.; DÍAZ, N. L.; TRUJILLO, C. L. Cloud and machine learning experiments applied to the energy management in a microgrid cluster. **Applied Energy**, v. 304, p. 117770, 2021.

[2] TALLURI, Giacomo et al. Optimal battery energy storage system scheduling within renewable energy communities. **Energies**, v. 14, n. 24, p. 8480, 2021.

[3] KOLTSAKLIS, Nikolaos et al. Smart home energy management processes support through machine learning algorithms. **Energy Reports**, v. 8, p. 1-6, 2022

[4] MAY, Ross; HUANG, Pei. A multi-agent reinforcement learning approach for investigating and optimising peer-to-peer prosumer energy markets. **Applied Energy**, v. 334, p. 120705, 2023.

[5] KOUKARAS, Paraskevas et al. An interdisciplinary approach on efficient virtual microgrid to virtual microgrid energy balancing incorporating data preprocessing techniques. **Computing**, v. 104, n. 1, p. 209-250, 2022.

[6] AHMED, Waqar et al. Machine learning based energy management model for smart grid and renewable energy districts. **IEEE Access**, v. 8, p. 185059-185078, 2020.

[7] INTEHA, Azfar et al. A data driven approach for day ahead short term load forecasting. **IEEE Access**, v. 10, p. 84227-84243, 2022.