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COVID-19 Challenges, Opportunities - A Valuable Lesson for the Future Sustainable Development of Energy Management

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The drastic variations in energy demand have a significant impact on the operation of energy networks. The COVID-19 pandemic led to changes in electricity demand profile, directly affecting the efficiency and in some cases the stability of the systems. An overview of these outputs underscores the importance of making effective policy decisions to promote the transition to more sustainable energy systems. The goal is for the systems to be able to withstand the effects of threats like the, still ongoing, pandemic, of extreme weather phenomena which occur more frequently due to climate change and the of potential risk of a looming global energy crisis. The purpose of this article is to present methodologies for creating a safer and more sustainable energy system during extreme situations like a lockdown.
The integration of distributed energy sources into the utility network paves the way for resilient urban grids and infrastructure. In this line of approach, a critical analysis of the energy management systems typologies and a SWOT/ PESTLE analysis to reveal the most important factors while managing an energy system, are presented. This analysis aids in the selection of the appropriate energy system by taking into account both internal and external factors, with a special focus on the social aspect in the context of resilience. The results indicate that, when permissible constraints allow, a centralized energy system is chosen to better deal with crisis scenarios, such as pandemic conditions.

1. Introduction

The purpose of an energy management system is to optimize the energy design, operation, and reliability of both the conventional grid system and the grid-connected microgrids for sustainable development. This growth is a part of the global energy transition and results in the development of distributed energy resources, which has brought the distributed energy system (DES) to the forefront in the energy sector (Theo et al., 2017). DES is a local energy system with multiple inputs and outputs with a group of distributed energy resources (Niu et al., 2020). It is mainly investigated in terms of central and decentralized coordination. Today, no matter how energy is generated, most energy management systems worldwide are designed to deliver power through a central distribution system. However, more advanced / new systems are beginning to emerge worldwide, laying the groundwork for decentralized energy systems (Chartier et al., 2022).
In recent years, energy management system (EMS) research has gotten a lot of attention. Several studies have examined the various types of EMS, but few have compared the strategies to achieve resilience even in emergency situations. Theo et al (2017) reviewed the DES from a techno-economic and environmental point of view supported by numerical and mathematical studies. A similar point of view is adopted in the review of Rathor and Saxena (2019), where the hierarchical system is proposed and studied as a distinct energy management system. Techno-economic and environmental assessment in a central and decentralized context is also considered in the study of Li and Zhang (2021), where although reference is made to social well-being, their response to external, unpredictable social factors is not investigated.
Beyond techno-economic and environmental analyses, further investigation covering social, legal, and political factors is required to further cover critical design details and handle factors of uncertainty. The study proposes the implementation of a SWOT/ PESTLE analysis as a tool to fill this research gap. SWOT/ PESTLE helps to the selection of the right methodology, as it examines all possible points of view of both the internal and external

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factors that affect the smooth operation of the network. Considering the lockdown during the COVID pandemic as a most recent case study that revealed the gaps of today's energy system, we examine the type of EMS that would help create and maintain a safe and sustainable energy system regardless the prevailing condition.

2. Centralized EMS

In a Central Control (CC) architecture, the central controller has the primary responsibility for maximizing the value of the network and aiming to optimize its operation. A key role in the EMS architecture of CC is: 1) the high-performance central controller and 2) a secure communication network responsible for managing energy usage. In this approach, the central controller plays the main role in managing the power flow between different micro-sources and the main grid.
The central controller can be an accumulator or an auxiliary program, which collects information such as Distributed Energy Resources power generation, weather phenomena, the energy consumption pattern of each load / consumer, other required information from market players, etc. from all nodes (Rathor and Saxena, 2020). After collecting the data and performing the required calculations, it determines the control action for all its units, through the execution of the optimization programs (Singh et al., 2019). The CC is therefore responsible for achieving the goal of efficient operation.

Strengths and Opportunities

This method provides access to billions of people, especially in urban areas. It is easier to provide access to electricity through the expansion of the grid in urban areas due to the concentration of people and the generally higher incomes of potential consumers (Energypedia, 2018). Considering energy management in a conventional grid and not in a microgrid, central management is therefore the only possible reliance (Rathor and Saxena, 2020).
In the central management system, all functions are based on the central controller. The exclusive management means that less staff needs to be employed to maintain and repair errors, so it simplifies the process, enables a reliable prediction and handling of possible failures, and ensures safety. Further advantages of a central EMS include the real-time visibility of the entire system and the simple application. In addition, confidential and private information may be protected within the central unit (Espín-Sarzosa et al., 2020). Central EMS provides an overall optimization, thus ensuring a reduction in operating costs considering all the constraints. Most studies also come up with the conclusion that the centralized control achieves reductions of the total cost, i.e. capital and operational expenses, compared to the decentralized option (Li and Zhang, 2021). Thus, central control structure provides the best overall performance, still it also has some disadvantages.

Weaknesses and Threats

The source of the weaknesses lie in the absolute dependence of the system on the operation of the controller and the communication between the CC and the units to be controlled (Singh et al., 2019). As all information is collected and managed in one place, the computational load increases. The management hardware must feature the capacity needed to process a significant amount of data when making the right decisions (Rathor and Saxena, 2020). This implies significant installation and maintenance costs, but also an experienced administrator with knowledge in the maintenance of all the functions of the CC. High-bandwidth communication is required for the timely exchange of information with costly wide area telecommunications links, due to the exchange of large data between CC and subunits (Samadi et al., 2020). Low flexibility / scalability is another critical limitation of a central EMS. The central EMS's architecture is difficult to extend and can be interrupted when integrating a new source / component, which can lead to different operating costs and constraints (Rathor and Saxena, 2020). Therefore, continuous redesign of the entire EMS system with any change to individual controllers is required.
In addition, central management poses a key risk, that is, a central unit error can cause many system functions to be lost, including the provision of services (Espín-Sarzosa et al., 2020). Extending this threat and considering the difficulty in maintenance and the experienced staff required, it is advisable to consider the impact on the possibility of extreme situations (e.g., natural disasters, malicious attacks, etc.). In those situations where maintenance and control of human resources are considered dangerous and impossible, the central controller may cease to operate as well as all sub-facilities. Not least, possible topological fluctuations in the future electricity grid and the relevant communication network may degrade the effectiveness of the centralized approaches (Xu et al., 2015).
Finally, privacy concerns such as knowledge of energy demand, cost factors and system parameters must be dealt with for the network participants. The information disclosed (true or false information) by interested parties may be a potential problem due to privacy issues that affect the profitability of the entire system and the payment

of each participant in the grid (Li, 2021). Furthermore, in the field of privacy the participating large-scale prosumers may create difficulties in effecting the reasonable and fair allocation strategy (Li, 2021). The implementation of centralized coordination needs a trustable organization, due to the privacy issue (Li and Zhang, 2021). With ever increasing concerns on data privacy and safety, this is an aspect that cannot be overlooked.

3. Decentralized EMS

The decentralized EMS architecture is characterized by a distributed processing system where each node has autonomous control and peer-to-peer communication. In this configuration, local distributed energy resource controllers (LC) have the primary responsibility and thus work together or compete to meet local demand (Rathor and Saxena, 2020). These Decentralized Controllers (DC), depending on the method used, which can be hierarchical or distributed, perform network management actions, doing basic calculations, planning actions and finally making decisions (Samadi et al., 2020). These decisions are aimed at achieving the objectives of optimizing the output and determining the amount of power that will enter or leave the network (Harmouch et al., 2018). A decentralized approach is mainly based on a local parameter measurement (e.g. voltage and frequency values) so the decentralized controller needs a local information to perform the required control actions without fully knowing all the system parameters (Espín‐Sarzosa et al., 2020). Based on the level of decentralization and the available communication network, there are three categories of decentralized architecture. It can be categorized as fully independent, partially independent, and fully dependent.

Strengths and Opportunities

Many well-communicating controllers contribute to the higher reliability of a decentralized EMS architecture compared to the central one. The decentralized EMS architecture overcomes the limitations, making the system more fault tolerant, enhancing scalability and allowing more flexibility in operation. By flexibility is meant that the agent can choose from a set of actions the most appropriate one. This could be best illustrated by the ability to create a new design if a specific control action fails. In addition, there is flexibility in the way of design, as in contrast to the central management there is a variety of choice of the way of architecture and the number of controllers. The system is considered scalable as it can add new functions without changing the existing one. This feature has great added value. For example, a new agent is developed for the new job and easily integrated into the existing system (Harmouch et al., 2018). In addition, decentralized architecture provides the strength of low computational load and low response time (Espín-Sarzosa et al., 2020). The decentralized structure is more robust and less complex than the central one. Therefore, not only is communication and computation time minimized but it implies full compliance with the requirements of other various spare parts and operational performance (Samadi et al., 2020).

Moreover, LCs turn a major central optimization problem into many subproblems which leads to opportunities for further development. This separation has an impact on investment costs, which can be reduced by replacing many smaller control centers with lower computing loads instead of a large high-power central control center (Fallahzadeh-Abarghouei et al., 2018). Finally, from an environmental point of view, the higher degree of flexibility enables the selection of more environmental friendly solutions, for example Combined Heat Power systems in a decentralized approach consume more biogas and less natural gas compared to those in the central approach (Li and Zhang, 2021) and the combination of photovoltaics, local storage and grid provided electricity in clusters of buildings can lead to minimization of CO_2 emissions (Symeonidou et al., 2021).

Weaknesses and Threats

The main weakness of this control is the restriction of not being able to reach a global level of optimization. LCs cannot cope with large volumes of information and data due to lower computing power and the inability to communicate effectively with each other in this case. This includes setting up a smaller power plant and supplying it in a limited area (Energypedia, 2018). Therefore, these systems can only be used in small microgrids. Escalating installed capacity presents therefore a challenge. Moreover, the main profit from the operation of the central energy management both in grid-connected and islanding mode is more than the same in the decentralized energy management (Khavari et al., 2018).

Considering the threats, the decentralized method requires a big number of specialized human resources, responsible for each local administrator individually. Well trained personnel for the management and maintenance of these systems may be lacking in remote areas and is certainly costly. Furthermore, in pandemic situations, such as the COVID-19 that most societies were called upon to deal with, it is well possible that many of the key staff will have fallen ill or cannot access the utilities, making the maintenance a challenging issue. On the contrary, when the management is central, operations and maintenance can be carried out, even with some of the staff not being available.

From an environmental point of view, in the context of decentralized energy management, one must keep in mind that the carbon tax increases with the total emissions of the stakeholders, whilst it reduces the internal energy flow. Hence it can be a counterproductive solution. To maintain low emissions in a decentralized sharing environment, it is necessary to set the carbon tax within a reasonable range (Li and Zhang, 2021). In any case, there is no clear benefit, considering carbon taxation, for the decentralized energy management system.

4. SWOT/ PESTLE Analysis

Since management systems do not operate in a 'sterile' environment, one must identify the main external and internal factors that have an impact on the successful implementation of a grid energy management system. To achieve this task a SWOT/ PESTLE analysis is applied in this study. The reason for this choice, is that SWOT analysis can be a useful tool for the strategic planning process of environmental management, as it has been identified by a series of studies (Christodoulou and Cullinane, 2019), since in enables to consider:
a) the advantages from the plan implementation (strengths), b) obstacles to the successful implementation of the plan in accordance with the initial objectives (weaknesses/ controlled factors), c) opportunities and d) threats of the plan (external, uncontrollable factors) that prevent from fulfilling the mission. By recognizing the factors, the basic skills can be distinguished related to decision making, planning, and creating strategies. However, usually in cases where the systems are complex these methods have some disadvantages; the SWOT/ PESTLE analysis variation is the most popular for such complex systems. PESTLE is a mnemonic analysis which in its expanded form: Political, Economic, Social, Technological, Legal and Environmental criteria. It is an analytical tool which is used in business strategic planning, that analyzes all the external parameters. It is therefore used by organizations to assess the impact that the external environment may have on a project. A SWOT analysis can easily be combined with a Pestle one. The main advantage of using a SWOT/ PESTLE analysis is that it can cover most of the factors that are of importance for managing an energy system (Srdjevic et al., 2012).
Categorizing the factors of the SWOT analysis of the previous section into internal and external ones, in Table 1 is presented a SWOT/ PESTLE analysis for the two types of EMS. This enables a combined analysis of both internal and external factors that have an impact on the system, especially because the latter are beyond the control of the system and are more difficult to detect.

Table 1: SWOT/ PESTLE Analysis for Centralized and Decentralized EMSs

SWOT/ PESTLE	INTERNAL FACTORS	EXTERNAL FACTORS
Political	• Clear energy policy and management objectives, goal	• Influence of the stakeholders • Financing opportunities - CC will be able to reach at global optimization • Grid-specific plan
Economic	• Reduction in overall operating costs – improvement of profitability (CC) • Investment cost can be reduced (DC)	• Competitive advantage (commitment to sustainable development) • Additional funds • Higher Profit of CM in both islanding and grid-connected modes
Social	• Top management commitment (CC) • Continuous training of staff • A big number of specialized human resources (DC) • Significant increase in social welfare	• Integration of energy efficiency management in the grid's activities • Wrong application of the energy management plan (due to organizational culture or staff/management resistance) - The information disclosed might be false by interested parties (CC) • In case of emergency, it is impossible to maintain and repair any problem of the CC • In Pandemic situations when most managers have fallen ill, the maintenance is considered impossible (DC) • Specialized human resources may be lacking in rural areas (DC)

Table 1: SWOT/ PESTLE Analysis for Centralized and Decentralized EMSs (continued)

SWOT/ PESTLE	INTERNAL FACTORS	EXTERNAL FACTORS
Technological	• Real-time observation (CC) • High computing load (CC) • Flexibility/ scalability (DC) • Reliability and Stability (DC) • Low Response Time (DC) • A central unit error can cause entire network to be shut down (CC)	• Development of new energy efficiency technologies (Hybrid methods) • Possible topological fluctuations in the future- enhance effectiveness of DC • CC is the only possible reliance in conventional grid, DC in microgrids
Legal	• Compliance with existing energy policies, regulations • Privacy issues (energy demand, cost factors and system parameters) must be provided for interested	• Meeting future energy-related regulations • Needs a trustable organization due to the privacy issue (CC)
Environmental	• Reduction of energy consumption and related emissions • Establishment of an energy baseline • Combination of renewable and highly efficient conventional systems can be operated in the most effective way	• Reduced impact of air pollutants on human health and climate change • The carbon tax increases the total emissions of stakeholders, reduces the internal energy flow (DC)

5. Conclusions

Implementing the energy transition presents a huge challenge, since it calls not only for improving energy efficiency and shifting from fossil fuels to renewables, but also shifting from centralized to decentralized and more flexible energy systems, that will be efficient and reliable whilst operating with bidirectional energy flows. Such systems are, even under normal conditions, not easy to manage, let alone under extreme conditions as those emerged in the first period of the COVID pandemic.

Selecting the most suitable type of system is not an easy task, as one must consider technical, economic, legal, social, and environmental criteria and at the same time one must respect geographic, geological, and climatic restrictions. To evaluate the energy management systems, one has therefore to utilize flexible and comprehensive tools, like those offered by advanced forms of the SWOT analysis, the SWOT/ PESTLE variation being a very suitable approach.

The SWOT/ PESTLE analysis of centralized and decentralized EMS coordinating systems was presented in this study, leading to some first conclusion. The CC has a clear advantage considering economic and political aspects but displays low levels of flexibility and requires high levels of organization; additionally, there are issue with the management of sensitive personal data. On the other hand, being technologically more sophisticated, DC provides the benefit of flexibility while also offering opportunities for enhanced environmental management. In critical situations like the one during the COVID pandemic, attention shall be paid to the social and humanitarian factors. In lockdown situations, both in urban areas and in islanding modes CC seems to respond better. In contrast, in locations where extreme weather events are frequently observed and reliability and resilience are inevitably challenged, DC is preferable. Therefore, where local constraints allow, it is recommended to choose a CC system to better come with such 'irregular' situations.

Future works include the extensive comparison of the different EMSs, by applying the proposed methodology for different combinations of hybrid systems, and the modelling and simulation of the resulting scenarios for the assessment of their resilience, under both normal operation and crisis situations.

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