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Virtual Power Plant: Challenges, Opportunities, and Profitability Assessment in the Current Energy Markets

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Abstract- **Virtual power plants (VPPs) are becoming more popular worldwide due to their diversified characteristics, the potential to provide energy flexibility, durability, and smarter electrical grid system, as well as economic benefits. Despite its significance, VPP currently has a very limited presence in the energy markets. A lack of systematic assessment of the multiple factors has been identified as the main reason for VPP's limited admittance into the energy markets. This necessitates research initiatives that consider superior approaches and frameworks for the sustainable future of VPPs. A novel multi-aspect framework (MAF) is proposed in this study to examine objectively multi-dimensional aspects. A STEEP (social, technological, environmental, economic, and political) analysis tool is used to assess the challenges, opportunities, and benefits of VPP in the energy market. The approach outlines the essential factors and actions needed to address the challenges of VPP admittance in the energy markets. This study demonstrated that there is still more work to be done to support the fast and wide-scale adoption of sustainable VPP applications. For this reason, a more favourable policy and regulatory framework based on social, technological, economic, environmental, and policy considerations are necessary to realize the genuine contributions of a VPP.**

Keywords- Distributed generator, Demand response, Distributedenergy sources, Virtual power plant

I. Introduction

Traditional power grid has a variety of challenges with its aging and inadequate infrastructure, which triggers power demand. Issues with network congestion are caused by the grid's failure to respond quickly to problems. Supply and demand imbalances tend to be expensive for utility firms due to communication challenges [1][2][3]. The need for individuals (households) to comprehend energy usage and to make the most financially prudent consumption decisions, as well as the inability of the existing grid to incorporate new emerging technologies like renewable energy, all contribute to the problem. Future distribution system will have to be more proactive with a fully utilized network and more effectively using DER and RE units. Therefore, we must first build our knowledge of the topic to understand the significance and benefits that VPPs can offer. Therefore, in the first place, we start with the main motivation and reason why VPPs are being set up. Power is in high demand in both national and international markets as technologies advance ever faster. Due to this reason, technical advancement is now being made to increase performance and improve the way electricity is consumed in the electrical grid [4][5].

It is therefore crucial to accommodate smart technology in the form of VPP to combat these challenges. Implementing VPPs is in this scenario the most well-liked electrical grid update [6][7]. A VPP is a unified platform that is being updated and upgraded by adding new technologies that would enable bidirectional communication between the supplier and consumer [8]. The introduction of VPPs into the existing power grid can improve the supply and reliability of power systems while also cost-effectively benefiting both the suppliers and consumers. To satisfy the necessary standards VPPs must be sustainable. Those VPPs that adhere to all three pillars of sustainable development are considered sustainable: (1) are capable of working economically in a cost-cutting manner, (2) are eco-friendly, and accommodating renewable energy sources, and (3) Permit bidirectional communication between the suppliers and the consumers [9][10].

II. Literature review

The research that was highlighted in the literature review as being relevant and intimately associated is listed below. The authors of [11] discussed the regulatory and market impediments to storage systems, including lack of definition, lack of legal framework, ownership ambiguity, operating standards, and benefit stacking regulations, which have hindered the adoption of storage systems and impeded the development of new storage technologies. The results demonstrated that benefit stacking regulations are not beneficial under EU law. It is an important method to maximize the value of energy storage. Utility companies and consumers should therefore adopt benefit stacking regulations to minimize the energy storage payback time. environment offers both technical and economic benefits. The authors of [12] proposed a power system conception that considers the roles and interactions of technical, economic, environmental, and social variables in an energy system. This conception aims to create a holistic and workable commercial model of the energy system that can be utilized to assist energy policy decisions in an efficient manner. The authors of [13] proposed a non-linear stochastic model for managing the energy of a VPP that incorporated both renewable and non-renewable energy sources, as well as energy storage technologies. The proposed model's objectives were to maximize VPP revenues and reduce emissions. The simulation results demonstrated that this model is beneficial in maximizing profit and minimizing emissions, which has a favorable influence on the environment. The authors of [14] presented a community-based VPP business model. It was found that the institutional and regulatory frameworks in place today provide significant challenges for the business model. Therefore, it is determined that institutional and regulatory reform that prevents CVPP projects has to receive more attention. The authors of [15], which takes into account both cooperative and non-cooperative game theory-based methodologies. The results revealed a direct correlation between energy market prices and the profitability of VPP to different resources in VPP. Although there are ongoing efforts to maximize clean energy supply around the world but the key enabling aspects which limit the ability of VPPs to enter the power markets are not being systematically evaluated. This ongoing challenge necessitates research efforts that take into consideration novel viewpoints, smarter and superior approaches, and models that might support the development and implementation of sustainable VPPs in the power markets. The aim of this study is to assess and investigate the challenges, opportunities, and benefits of VPPs in the current electricity markets.

Therefore, the authors of this study have proposed a multi-aspect framework (MAF) to examine the challenges, opportunities, and benefits of VPP implementation in the existing electricity market. It then seeks to overcome the highlighted challenges by proposing solutions using a STEEP approach, which concentrates on the social, technical, economic, environmental, and policy dimensions of a VPP and its impacts on energy society. This work is significant because it presents a critical assessment of the challenges related to the VPP concept in the context of the power systems while taking into account the current situation and circumstances. This study provides a better understanding of the proposed multi-aspect framework of VPPs which are supposed to address the challenges and improve the situation leading to the widespread and sustainable development of VPPs in global power markets.

III. Methodology

The followed methodology is discussed in this section to propose a new multi-aspect framework. In order to accomplish this, the authors used a qualitative three-step approach shown in Fig 1.

- Firstly, an analysis of relevant and existing literature was carried out. The authors performed a comprehensive review of prior work suggesting the application of VPP in the energy market identifying the research gap tackled in this study. The authors searched recently published papers outlining the terms and keywords such as "virtual power plant," "challenges," "barriers," and "decentralized power system" in Google Scholar, Web of Science, Scopus, and Science Direct as the primary databases. Based on the analysis of these papers, the challenges were categorized into the following groups: social, technological environmental, economic, and political.
- Secondly, a retrieval and assessment of secondary data sources relevant to the study. For instance, governmental energy

policy documents on the viability of VPPs in the energy markets and industry best practices guidelines were also examined.

- Finally, in the third step, the authors suggested the design of a new multi-aspect framework, and then a STEEP analysis tool is used to analyze the data and address the highlighted challenges in an effort to bridge the observed research gap.

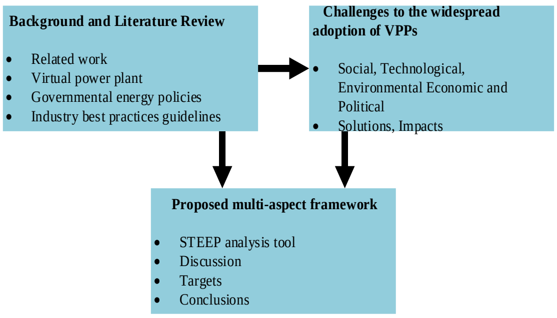

Fig 1. Followed Methodology

This study proposes a novel multi-aspect framework for the analysis of VPPs in the current electricity markets and then uses a STEEP analysis tool to investigate the challenges, opportunities, limitations, and advantages of a VPP business model as shown in fig 2. The social, technological, environmental, economic, and political dimensions of VPP will be assessed in this framework. This method examines internal and external factors to determine whether the aims of a VPP business model will be accomplished.

The STEEP, an analysis tool was chosen because it breaks down the various dimensions of a VPP business model into more manageable sections that can be understood and analyzed easily. Furthermore, applying a STEEP approach systematically details both the VPP challenges and economic benefits of sustainable VPPs. Hence, the envisaged STEEP approach focuses on the recurring challenges that decision-makers, developers and energy designers, academics, and all other interested parties must overcome to enable the future planning and long-term acceptance of VPPs.

This study shows that addressing the challenges (i.e., the VPP system) without any of the five STEEP model components leads to an inadequate solution. This is due to the fact that all of the aspects must cooperate in order to tackle the challenges and realize the required sustainable energy development, which is outside the scope of the conventional techno-economic viewpoint and which is one of the key features of the proposed multi-aspect framework.

IV. Proposed multi-aspect framework

The authors of this study have proposed a multi-aspect framework (MAF) to examine the challenges, opportunities, and benefits of VPP implementation in the existing electricity market. And the reason for using a STEEP framework in this study is because it takes into ac-count social and political/policy aspects in addition to technological, economic, and environ-mental ones, which are equally important for understanding the successful future implementation of VPP projects. A detailed methodology and analysis of social technological, environmental, economic, and political factors of the VPP implementation in the power systems are provided as follows:

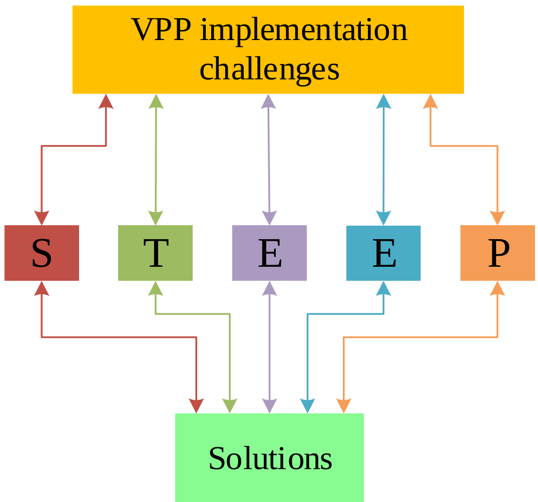

Fig 2. STEEP model application

V. Social aspects

The social acceptance by individual citizens (attitude, behavior, and tolerance) towards VPPs, which is relatively a new concept of energy management can change our energy system. It would result in economic gain for both the energy generator and the consumer. The proposed energy technology's social acceptance is a key aspect that will determine the degree of societal participation in the energy market. For example, awareness about the social benefits of VPPs strengthens consumer choice and energy community cohesion. This shows the value of integrating stakeholders and the community in the energy development phase. Therefore, it is imperative to engage the community. Without social acceptance, it is quite challenging to lead new, innovative concepts in any form of the power industry, including the smart grid. Since the majority of the public is unaware of what VPPs are, what they perform, or what benefits they might provide, it is generally not important for most people whether or not VPPs are implemented Therefore, it is essential to realize that education also plays a significant part in this situation. Public education on the adoption of VPPs technology and its social benefits, even at modest scales, can be accomplished through successful awareness programs or defining infrastructure ownership.

VI. Technological aspects

Technological aspects deal with technological developments that may have positive or negative impacts on the function of the power system. The productivity of the power sector is significantly impacted by the emergence of new technologies. In a broader context, it can also contribute to retaining skilled personnel, particularly young researchers and scientists. In the power sector, the implementation of new technologies, particularly smart grids and VPPs Improve the energy efficiency of electric power generation and usage and reduces the complexity and inflexibility of distributed generation.

The UK has made considerable progress in lowering CO_2 emissions through technological advancements and their adoption by industry with no obvious effect on the general public. This should persist, but the government needs to concentrate more on making it simpler for people to accept new technological innovations and alter their consumption patterns. We must reduce demand and change transportation modes to reach net zero emissions and the long-term environmental objectives of the UK.

VII. Environmental aspects

The environmental effects of power plants are a subject of growing concern. Massive industrial facilities known as power plants generate electricity for distribution. Electricity can be generated from a variety of sources, although most power plants worldwide generate electricity by burning fossil fuels including natural gas, oil, and coal. These sources of energy carbonize the environment, causes pollution and global warming. Other sources of energy generation such as wind, solar, wave, nuclear, and hydroelectric power, each of which presents its own set of advantages and disadvantages in terms of environmental concerns and human well-being. VPPs enable you to supply an alternate, clean source of energy to the grid and the energy community when demand is high. This results in less reliance on fossil fuels for energy. It's a greener, more environmentally friendly energy solution that makes the most of renewable resources, thereby boosting their power. We can benefit from VPPs by having cleaner air, better health, reduced electricity bills, less CO_2 emissions, and improved quality of life for end users.

The UK enacted the landmark Climate Change Act, pledging to achieve net zero emissions by 2050. Scotland has been given a 2045 net-zero target because of its relatively stronger ability to cut emissions compared to the rest of the UK. It has been proposed that by 2050, greenhouse gas emissions in Wales should be reduced by 95%. As we know that VPPs integrate renewable energy sources, as a result, secure a pivotal position in improving the flexibility and reliability of the UK's energy systems. VPPs are expected to play a major role in the UK's energy markets in the future.

VIII. Economical aspects

When it comes to customer benefits, VPPs must address a number of challenges. These include demand response to reduce load during an emergency situation, small generator market entry, dynamic pricing, stringent reserve capacity, and localizing DERs for better grid balancing. establishing a wholesale market from which utilities can purchase DR or DERs from consumers, ultimately complicating the entire power system. A VPP can combine the output of many small generators, to increase market flexibility and benefit consumers. This kind of integration enables utilities to find the best consumers for them. The utilities can choose the most appropriate VPPs out of the operational portfolios by utilizing the plant-like characteristics of VPP. Another advantage of VPP for consumers is the reduction in forecasting risk that results from allocating individual VPPs in various transmission zones. A specific forecasting value is assigned for each zone, improving forecasting reliability and providing utilities with better data. Most significantly, the idea of VPP has contributed to the development of more effective interaction between utilities and customers, resulting in a more flexible market. This shows a democratic environment of a VPP and support small-scale participants access to the electricity market.

IX. Political aspects

Around the world, different electric grid setups exist. Some electric setups are deregulated, while others are subject to regulation. The markets in deregulated electric networks can operate in different ways. With regard to a VPP's operational characteristics, the laws and regulations in different zones do vary significantly. A VPP can experience operational challenges in the electricity market because of regulatory reasons. Participation in the grid-balancing market is important since it is based on wholesale energy trading, particularly, when a VPP is presented at a utility-scale. As the utilization of VPPs are on the rise, adequate laws and policies are needed due to the immense complexity and cost of providing electricity to large facilities and innumerable consumers.

The proposed STEEP analysis tool captures a number of complex challenges, which must first be understood by decision-makers and stakeholders to generate feasible solutions. These challenges must then be minimized in order to support sustainable growth in VPPs. Therefore, it is essential to address the public’s unfavourable perception of the VPP concept in order to sustain its future participation in the energy markets.

This approach provides a comprehensive mechanism for capturing the challenges, and supportive factors of energy systems and their solutions, VPPs may be better understood and their future contributions to the energy markets can be increased. The solution to the global challenge will be considered unsatisfactory if one of the five factors of the STEEP analysis model is missing. This is so that the intended sustainable development of VPPs can be accomplished by combining all the characteristics. Therefore, due to the interconnectivity of the contributing aspects, a coordinated effort is required for a successful outcome.

The results of this study also show that a number of stakeholders are engaged in diverse STEEP analysis areas and have the capacity to persuade the market's future direction. For example, the UK government is arguably the largest of these stakeholders with its participation in formulating policies and regulations, the environment, granting licensing, and providing financial support. as long as they remain fully committed to the development and implementation of the VPP in the energy sector, the general public will at least have a positive attitude and tolerance in the near future.

It is evident that VPPs are important to the national and global energy balance and that they have a big impact on attempts to meet zero-carbon ambitions. VPPs enable the synchronization of demand and supply with the greatest efficiency and flexibility. Integrating the readily available energy-balancing assets, and fostering peer-to-peer energy exchange which helps regional energy output and utilization by reducing carbon emissions.

X. Conclusions

This study has presented a multi-aspect framework (MAF) to objectively evaluate the prospects, benefits, and limitations of VPP implementation within the existing electricity markets. The conclusions are as follows:

1. Behaviour change is required across the entire population to achieve net zero and avoid environmental damage. government involvement and policies are essential to achieve this level of improvement, which will result in several other health and human well-being advantages.
2. Utilizing cutting-edge technology, such as information and communication technologies (ICTs), artificial intelligence (AI), and machine learning can enable VPPs better understand, monitor, and quantify their energy consumption. These algorithms enable better predict future energy patterns.
3. VPPs integrate clean sources of energy including wind turbines (WTs) and photovoltaics (PVs), which are more environmentally friendly to benefit consumers with cleaner air, better health, reduced electricity bills, and less CO2 emissions.
4. VPPs provide a platform that enables profit-making participation in the electricity markets from both energy producers and consumers.
5. A more favourable policy and regulatory framework based on social, technological, economic, environmental, and policy considerations are required in order to realize the true contributions of a VPP in the power markets.

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