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Review of Optimal Scheduling of Microgrid-Based Virtual Power Plants

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Abstract**-- The optimal scheduling of microgrid-based virtual power plants (VPPs) is a topic of growing interest and importance in the field of renewable energy integration and grid management. VPPs are emerging as a promising solution for efficiently managing distributed energy resources (DERs) in a coordinated and intelligent manner. The review of optimal scheduling techniques for microgrid-based VPPs encompasses various aspects related to resource allocation, demand response, and grid integration. One key objective is to maximize the economic benefits and operational efficiency of VPPs while ensuring reliable and stable power supply.**

Index Terms**– Virtual power plant, Optimal, Microgrid, Scheduling, DER.**

I. INTRODUCTION

A virtual power plant (VPP) is a concept that refers to a network of decentralized power generating units, such as solar panels, wind turbines, and energy storage systems, which are connected and coordinated through a central control system. By aggregating the capacities of these distributed energy resources, VPPs aim to function as a unified and flexible power plant [1].

The main idea behind virtual power plants is to optimize the management and utilization of these distributed energy resources. Instead of treating each individual unit separately, a VPP allows for the coordinated operation of multiple units to improve overall efficiency, reliability, and grid stability. The central control system can monitor and respond to changes in energy demand and supply, intelligently dispatching power generation and storage resources as needed [2].

VPPs often utilize advanced technologies such as smart meters, sensors, and communication networks to collect real-time data on electricity consumption, production, and grid conditions. This information helps in forecasting and optimizing energy flows within the VPP, enabling efficient balancing of supply and demand [3].

The benefits of virtual power plants include:

- *Flexibility and grid stability:* VPPs enable the integration of intermittent renewable energy sources into the grid by managing their variability and ensuring a balanced power supply.
- *Demand response:* VPPs can participate in demand response programs, adjusting electricity consumption in response to price signals or grid conditions, thus reducing peak demand and enhancing grid reliability.
- *Energy trading:* VPPs can participate in energy markets by selling excess power generated by distributed energy resources and purchasing electricity during periods of low generation.
- *Cost savings:* By optimizing energy production, storage, and consumption, VPPs can help reduce overall energy costs for both consumers and grid operators.
- *Environmental sustainability:* By integrating renewable energy sources, VPPs contribute to the reduction of greenhouse gas emissions and promote a cleaner energy mix.

Virtual power plants are gaining traction globally as renewable energy installations increase and decentralized energy systems become more prevalent. They play a crucial role in the transition toward a more sustainable and resilient energy system [4].

The optimal scheduling of microgrid-based virtual power plants (VPPs) involves determining the most efficient and cost-effective utilization of the available energy resources within the microgrid. This scheduling process aims to balance the supply and demand of electricity while considering various factors such as renewable energy generation, energy storage capacity, energy demand, and grid constraints [5]. Here are the key steps involved in achieving optimal scheduling for microgrid-based VPPs:

- *Forecasting and data collection:* Accurate forecasting of energy generation from renewable sources (such as solar and wind) and energy demand patterns is essential for effective scheduling. Historical data, weather forecasts, and load profiles can be used to predict energy generation and consumption patterns [6].
- *Optimization algorithm:* An optimization algorithm is used to determine the optimal schedule for the VPP. This algorithm takes into account the available energy resources, energy demand, and other constraints such as grid limitations, battery capacity, and system stability.

Various optimization techniques, such as linear programming, mixed-integer programming, or evolutionary algorithms, can be employed to solve the scheduling problem [7].

- *Objective function:* The optimization algorithm utilizes an objective function that represents the goal to be achieved. The objective function can be based on minimizing the total energy cost, maximizing renewable energy utilization, minimizing carbon emissions, or a combination of these factors. The choice of the objective function depends on the specific goals of the microgrid and VPP operator [8].
- *Constraints:* The optimization algorithm incorporates various constraints to ensure that the schedule satisfies operational limitations and grid requirements. These constraints may include renewable energy generation limits, battery charging and discharging rates, voltage and frequency limits, and contractual obligations [9].
- *Real-time monitoring and control:* Once the optimal schedule is determined, real-time monitoring and control systems are implemented to ensure that the VPP operates according to the schedule. Data from smart meters, sensors, and monitoring devices are used to continuously monitor the energy generation, consumption, and grid conditions. Any deviations from the schedule can trigger corrective actions, such as adjusting energy dispatch, modifying battery charging/discharging rates, or activating backup power sources [10].
- *Feedback and adaptation:* The scheduling process is iterative, with regular feedback and adaptation based on actual energy generation and consumption data. This allows for continuous improvement of the scheduling algorithms and strategies to optimize the VPP's performance over time [11].

Optimal scheduling of microgrid-based VPPs is a complex task that requires sophisticated algorithms, accurate forecasting, and real-time monitoring capabilities. However, by effectively managing energy resources and demand, optimal scheduling can help maximize the benefits of VPPs, such as cost savings, grid stability, and increased renewable energy integration.

II. LITERATURE SURVEY

S. M. Tabatabaei et al.,[1] A stochastic framework for optimum coordination of a microgrid-based virtual power plant (VPP) that participates in day-ahead energy and ancillary service markets is the subject of this research. Microgrids often include a wide variety of decentralised forms of energy generation and storage.

In order to maximise the benefits of the virtual power plant while simultaneously minimising the expenses of energy acquisition for the Distribution System Operator (DSO), a two-stage optimisation formulation has been developed. The approach that is being suggested calculates the appropriate commitment scheduling of energy resources by taking into account the capacity withholding possibilities presented by the VPP and mandating that these opportunities be uncovered by the DSO. The method is evaluated for use on the 123-bus IEEE test system so that the efficacy of the suggested model may be determined. The findings indicate that the suggested strategy effectively maximises the profit from the virtual power plant while taking into account the penalty for capacity withholding.

A. K. Pandey et al.,[2] As countries work towards the critical goal of achieving maximum dependence on sustainable energy sources, now is the time to consider how to overcome the most significant challenges that are involved with the development of this developing energy system. It is important to mention that one of the primary challenges is the precarious existence of most renewable energy sources. The implementation of renewable energy sources (RES) for a world free of carbon emissions in the foreseeable future poses significant challenges for the current energy infrastructure. A dependable energy storage system that is able to handle resources is required for the use of intermittent and variable renewable-green electricity. A virtual power plant (VPP) may be a primary option to meet this demand. A virtual power plant (VPP) is a cloud-based dispersed power plant that combines the potential of multiple distributed energy resources (DER) originating from dissimilar areas in order to increase power output and facilitate the buying and selling of power in the electricity market. The purpose of this work is to make an effort to draw attention to the advantages of a virtual power plant and to examine the many advantages it has over a conventional power plant, particularly in regard to the reduction of harmful emissions, which are the major source of the disadvantages caused by the latter. It is anticipated that the establishment of VPPs would encourage the introduction and growth of renewable energy sources and contribute to the decarbonization of society.

Y. Han et al.,[3] The system that controls the electricity market is being gradually improved, which means that virtual power plant operators will soon be allowed to function as autonomous subjects and actively engage in the electrical markets. This will allow them to aggregate flexible resources, such as distributed production, adjustable loads, and energy storage facilities.

This study presents the pattern of virtual power plants engaging in demand response, with specific examples drawn from Jiangsu Province and Shanghai City. Next, the participation pattern of virtual power plants in the auxiliary service market in Northern Hebei Province is explored using that province as an example. The development of energy markets allows for the examination of the many conceivable configurations of virtual power plants that take part in the trade of green certificates and carbon.

J. Xu et al.,[4] Isolated microgrids that are powered by renewable energy sources, battery storage, and backup diesel generators need effective demand response in order to make optimum use of the energy that is available and limit the amount of diesel that is used. On the other hand, owing to problems with communication time delays, real-time demand-side management has become an extremely difficult task to do. Managing the demand for Electric Water Heater (EWH) units is the focus of this research, which presents a distributed model-free technique as a solution. In order to independently operate the 150 EWHs by using a virtual tariff, the distributed artificial intelligence technology that is based on Reinforcement Learning (RL) has been implemented. To produce the virtual tariff, two distinct methodologies are put out as possible options. In order to study the effect that communication time-delay has on the suggested RL algorithm when it is used in a real-time control situation, both of these methods are contrasted with one another.

A. Mnatsakanyan et al.,[5] Grid operators have significant issues when it comes to balancing the system in ways that are both cost effective and efficient when there is a large scale penetration of renewable production into electricity networks. The most frequent strategies for dealing with distributed variable generation include increasing reserve margins, using energy storage, utilising demand response resources, and temporarily curtailing renewable power, in addition to improving generation forecasting skills. Other strategies may also be used. In the same vein, the idea of a Virtual Power Plant (VPP), which involves the aggregation and control of various dispersed energy resources, is gaining more and more traction in Smart Grids.The results of a pilot VPP deployment into a vertically integrated utilities system in Dubai, United Arab Emirates, are presented in this body of work. demonstrating the successful incorporation of VPP into the grid using both actual and simulated assets as VPP coalition members is the purpose of this activity. It is a demonstration of the system architecture, several modes of operation, and various integration situations. The case study examines the aggregation of many different kinds of distributed energy sources, including microgrids and utility-scale batteries, with a total capacity of 1.8 megawatts (MW).

J. Lee et al.,[6] The technology behind virtual power plants (VPPs) are constantly being improved to accommodate the many different kinds of distributed energy resources (DERs), all of which come with their own inherent real-time uncertainties. In order to avoid unintended consequences for the power system as a result of the uncertainty, the VPP need to manage the unpredictability of its own internal resources in their entirety. This study presents an optimum operating approach for a VPP that is participating in the day-ahead and real-time energy markets. The goal of this work is to enable a distributed energy resource aggregation (DERA) to deal with real-time fluctuations caused by uncertainties while simultaneously maximising its profits. The strategy that has been presented incorporates competitive bidding methods for DERAs such as microgrids, demand response aggregation, and electric vehicle aggregation, in addition to the VPP. The VPP evaluates its real-time reactions to the day-ahead schedule and updates the suggested pricing function parameters in order to establish the internal prices that are applied to the DERA.

N. U. Padmawansa et al.,[7] This decade has seen a tremendous growth in the integration of renewable energy sources in an effort to meet clean energy production goals. Inverters are a popular tool that are used in the process of integrating renewable energy sources like solar and wind into the power grid. Synchronous generators are the foundation of more traditional forms of power production, such as coal, nuclear, and hydroelectric. The large-scale integration of renewable power plants is leading to a shift in the composition of the power system towards one that is dominated by inverters. This has the potential to have a major influence on the inertia response of the system. However, since inverters do not include rotating masses, they are unable to contribute to the overall inertia of the system. Inertia is provided by the rotating mass of traditional generators. The system's stability will be negatively impacted by the absence of inertia when it is subjected to shocks. As a direct consequence of this, the frequency of the system will shift outside its acceptable range. This makes it more difficult to incorporate renewable energy sources into existing systems. Inverters, on the other hand, have a rapid reaction and a great degree of controllability, thus they may simulate the effect of inertia. This study shows two innovative controllers that may be used to simulate the inertia response. Both of these controllers have been developed by the authors. The virtual inertia may be controlled by one controller, while the energy management can be handled by the second controller. In a simulated PV-Hydro microgrid operating with an imbalance between supply and demand, results are produced and analysed.

C. Meng et al.,[8] In order to realise the aggregation of distributed energy, this study incorporates a number of different distributed energy sources, such as wind farms (WPP), solar power plants (PV), and small hydropower stations (SHS), as well as incentive-based demand response. The term "distributed energy aggregation" refers to a "virtual power plant" (VPP), while "price-based demand response" (PBDR) refers to the response that is implemented on the user side. In the beginning, a VPP regular scheduling optimisation model is developed with the intention of maximising operating income while taking into consideration several restrictions. These constraints include load supply and demand balance, unit operation bundles, and working reserve. The next step is to construct a VPP risk avoidance optimisation model by using conditional value risk (CVaR) and the Lu Bar stochastic optimisation theory. This will allow you to characterise the uncertainty of WPP and PV. In the end, the verification is carried out by using an autonomous microgrid as an example, which is located in a park in the eastern region of China. The findings indicate that the following is true: (1) the features of various kinds of distributed power sources may be complimented by VPP to meet the objective of maximising energy utilisation, power production, and economic advantages; (2) for the risk of uncertainty, this study suggests the use of a hybrid system that combines distributed power sources with centralised power plants. According to the risk avoidance model, the risk is managed by appropriately calibrating the confidence and robustness coefficients.

C. P. Barala et al.,[9] Utilising the already linked network assets that are exemplified by variable demand, a virtual energy storage system (VESS) is an innovative and cost-effective solution to reflect conventional energy storage systems (ESSs). This is accomplished by reflecting ESSs in the form of a VESS. VESS is able to alleviate some of the difficulties associated with the operation of low-carbon power systems by coordinating the demand response (DR) loads from residential and commercial buildings' HVAC (heating, ventilation, and air conditioning) demands with load management techniques. In this work, an optimum operation model of a microgrid taking VESS into consideration is considered in an effort to lower the daily running cost. A mathematical model of VESS that makes use of the HVAC loads of residential and commercial buildings is developed as a contribution by this study. As an alternative to using binary values of power, the authors of this work suggest a mathematical framework that is based on a linear switching model for continuous power inputs. The findings show that the available capacity of VESS theoretically acts like electro-chemical batteries, which lowers the total cost of the microgrid without affecting the comfort of consumers.

G. Niu et al.,[10] The optimisation of the utilisation of energy has the potential to significantly enhance the overall operational benefit of the distribution court. At this point in time, the optimisation of energy usage in distribution courts is confronted with significant obstacles because to the presence of large-scale DG coupling. It is more difficult to achieve a worldwide optimisation of the energy usage in a distribution network that has various distribution courts. In this work, a thorough solution is offered in order to tackle the issue that has been presented. In the beginning, we will talk about the objectives for the optimal use of energy in the distribution court. The technology of the virtual power plant, the technology of the microgrid, and the technology of demand response are all presented and contrasted. An proposal is presented for the optimisation of energy utilisation in the multi-court distribution network by integrating and implementing the three major supporting technologies. Illustrated here are the structural composition, functional framework, and optimum control of the multi-court distribution network that will be used for the realisation of the proposal. A conclusion and some future considerations are included at the end.

D. C. Urcan et al.,[11] A thorough analysis of the virtual power plant (VPP) idea is provided in this work. This study discusses the definitions of virtual power plants, as well as their components and the framework that supports them. It also emphasises the many strategies that may be used for VPP operation optimisation. At the conclusion of the work, a virtual power plant infrastructure will be presented. This infrastructure will be accessible via a web interface, and it will be possible to control a virtual micro-grid. The micro-grid will acquire data from virtual smart metres, which will provide multiple load profiles for load consumption and distributed generation points.

X. Gao et al.,[12] The V30 power plant is one of the successful means of integrating decentralised sources of electricity into power distribution networks in a way that is safe, dependable, and cost-efficient. This work presents a summary and description of the idea, operating principle, and regulating techniques of a virtual power plant. It also compares and contrasts a virtual power plant with a micro grid. An introduction is given to the uses of virtual power plants as well as the benefits that come with using them to integrate resources, power market trading, and demand response. In conclusion, an examination of the primary technologies required for the development of virtual power plants as well as the potential applications of virtual power plants is presented.

III. CHALLENGES

The optimal scheduling of microgrid-based virtual power plants (VPPs) faces several challenges. These challenges arise from the complex nature of microgrids, the variability of renewable energy sources, and the need to balance multiple objectives. Here are some key challenges in achieving optimal scheduling for microgrid-based VPPs:

1. Renewable energy variability: Microgrids often rely on renewable energy sources such as solar and wind, which exhibit inherent variability and uncertainty. The intermittent nature of renewable energy generation poses challenges in accurately forecasting and incorporating these fluctuations into the scheduling process. Dealing with this variability requires advanced forecasting techniques and robust scheduling algorithms that can adapt to changing conditions.
2. Demand uncertainty: Energy demand within microgrids can be uncertain due to factors like weather conditions, seasonal variations, and unexpected load changes. Incorporating demand uncertainty into the scheduling process adds complexity and requires the development of robust scheduling models that can handle these uncertainties and adjust the energy dispatch accordingly.
3. Multi-objective optimization: Microgrid-based VPPs often have multiple objectives to consider, such as minimizing energy costs, maximizing renewable energy utilization, reducing carbon emissions, and ensuring grid stability. Optimizing across these conflicting objectives can be challenging, as changes made to improve one objective may adversely affect others. Achieving a balance between these objectives requires sophisticated multi-objective optimization techniques and the consideration of trade-offs.
4. Grid constraints: Microgrids are interconnected with the larger power grid, and there are often constraints imposed by the grid operator or regulatory bodies. These constraints may include limits on energy export/import, voltage and frequency stability requirements, and other grid operational constraints. Incorporating these grid constraints into the scheduling process adds complexity and requires coordination between the microgrid and the grid operator.
5. Communication and coordination: VPPs rely on real-time communication and coordination between multiple distributed energy resources, energy storage systems, and load centers. Ensuring reliable and timely data exchange, control signals, and coordination among these entities is crucial for achieving optimal scheduling. Issues such as communication delays, data inaccuracies, and equipment failures can impact the scheduling performance and require robust communication and control systems.
6. Scalability and computational complexity: As the number of distributed energy resources and complexity of the microgrid increase, the computational complexity of the scheduling problem also grows. Finding the optimal schedule in real-time becomes computationally challenging, especially when considering the high-resolution data, multiple time intervals, and numerous operational constraints. Efficient algorithms and optimization techniques are needed to handle the scalability and computational complexity of large-scale microgrid-based VPPs.

Addressing these challenges requires a multidisciplinary approach, combining expertise in optimization, forecasting, control systems, and grid integration. Ongoing research and development efforts are focused on developing advanced algorithms, predictive analytics, and real-time control strategies to overcome these challenges and enable efficient scheduling for microgrid-based VPPs.

IV. CONCLUSION

The review evaluates the impact of optimal scheduling on various performance metrics, such as cost reduction, peak load shaving, voltage stability, and carbon emission reduction. It also highlights the potential challenges and barriers to implementing optimal scheduling techniques, such as computational complexity, data privacy, and regulatory frameworks. The review of optimal scheduling of microgrid-based VPPs provides valuable insights into the state-of-the-art techniques and research directions in this rapidly evolving field. The findings contribute to the development of efficient and sustainable energy systems that leverage the potential of distributed renewable resources and enable a smooth transition to a cleaner and more resilient power grid.

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