Market Status and Development Prospects of Virtual Power Plants

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Abstract. With the development of new energies and smart grids, virtual power plants (VPPs) have gradually attracted the academia and industries all over the world. VPPs, which are expected to become the supporting framework of smart grid technologies considering new energy integration, break the boundary between power generation side and power consumption side in traditional power systems and makes full use of advanced technical means such as network communication, intelligent measurement and intelligent decision. The concept and characteristics of VPPs are first introduced as well as the market status and demonstration projects of VPPs in different countries. Then, the development prospects of VPPs are pointed out from the aspects of market scope, smart grid construction, demand side response, power trading curve and market potential. Finally, in terms of the unification of the concept, profit model, market potential, and market mechanism, the corresponding solutions to the urgent challenges of VPPs are proposed.

1. Introduction

With the development of new energies, it has brought great pressure to the operation of power grid because of its volatility and intermittence, so that more and more reserves are needed to ensure the safe and reliable operation of power systems. With the development of smart grids, virtual power plants (VPPs) provide opportunities for power grid to absorb high proportion of new energies¹-², which aggregate distributed generation, flexible load, energy storage and other distributed resources. A VPP is a regional multi-energy aggregation mode that realizes large-scale access of distributed resources to power grids through advanced information technologies and software system³-⁵. Unlike microgrids, distributed resources in VPPs can, regardless of geographical restriction, participate in the operation and dispatching of the power grids as a special power plant to achieve the goal of large-scale consumption and optimal allocation of distributed resources without changing the distributed grid-connected mode.

VPPs can effectively integrate various forms and characteristics of power supply and power load in the region without reforming the power grid structure, which can economically and efficiently control the power generation and consumption units in the region⁶-⁸. In recent years, many demonstration projects of VPPs have been extensively organized and implemented in various countries, and some practical experience has been accumulated in operation management, communication scheduling and other aspects. Works in [9] and [10] introduced the definition, characteristics and composition types of VPPs in detail, but did not consider the development prospect of VPPs. In [11], the whole structure of
operation control for VPPs was introduced, as well as its application examples in engineering practice, whereas possible problems and solutions in the development process of VPPs were not pointed out. The work in [12] pointed out the difficulties encountered by VPPs in the implementation of distribution system. In [13]-[14], the bidding strategy and model of VPPs were put forward.

To better emphasize the development prospects and challenges of VPPs, in this paper, the concept, characteristics and development status of VPPs are firstly introduced in Section 2. Then, the development prospects of VPP in terms of market scope, smart grid construction, demand side response, electric energy trading curve and market potential are proposed in Section 3. The possible problems to be urgently solved for VPPs as well as corresponding solutions are provided in Section 4. Section 5 is the conclusions of the paper.

2. Characteristics and Market Status of VPPs

Based on advanced information communication technologies and internet of things technologies, VPPs can organically integrate and regulate distributed power supply, controllable load and energy storage[12-14]. Broadly speaking, VPPs are not only limited to the aggregation of power generation units on the power generation side, but also can be combined with the controllable load and demand response technologies on the demand side. Theoretically, the distribution of individuals in the VPPs is not limited by regions. Each individual can be connected with the control center through the information network to make each individual in the VPPs controlled by the control center.

2.1. Characteristics of VPPs

Compared with traditional power plants and demand-side resources, VPPs have the following characteristics:

- The diversity of aggregated resources
  The aggregated resources of VPPs include controllable load, energy storage equipment, distributed generations, and so on. Specifically, controllable load includes electric vehicles, air conditioners, and other flexible loads.

- Environmental protection for the “power generation” of VPPs
  Among the aggregated resources of VPPs, the renewable energies have little impact on the environment. Moreover, because of the ability of energy saving and adjusting controllable load of VPPs, it can reach zero emission, which has little impact on the environment as well.

- Interactivity for the operation process of VPPs
  During the operation of VPPs, the difference in power generation caused by the dispersed state of aggregate resources in time and space is eliminated because of the information interaction with aggregate resources. At the same time, the VPPs can optimize their own external characteristic curves in time to meet the grid operation requirements considering the information interaction with the grid side.

- Competitiveness for market subjects of VPPs.
  The efficient aggregation of demand-side resources is realized by VPPs. VPPs directly participate in power market transactions as independent market subjects, which make orderly decision for internal and external sides according to the market price signal and have market competitiveness.

2.2. Market Status of VPPs

At present, VPP technologies have been developed in many regions and countries, for example, Europe and North America. Since 2001, projects of VPPs have been carried out by European countries, such as Germany, Spain, France, and Denmark, with the goal of integrating small-size and medium-size distributed generation units, for instance, the EU FENIX project[15-18]. While in North America, VPPs focus more on the controllable load on the demand side.

VPPs have developed rapidly in China, such as northern Hebei Province, Shanghai. VPPs in northern Hebei Province, combined with the region characteristics and resources, taking distributed generation as the aggregation subject, participate in the auxiliary service market as the third party independent subjects to promote of new energy accommodation. The project of “VPPs of Commercial Buildings” in Shanghai takes demand response as virtual power generation through control and communication
technologies. During the peak period of power consumption in winter and summer, the VPPs can reduce the power load and release electric energy for the power grid by flexibly adjusting the pre-set temperature of central air conditioners in commercial buildings. Besides, in the valley of electricity consumption, VPPs can also use the heat storage capacity and automatically adjust the parameter variables to store a part of the cooling capacity in advance, so that the utilization rate of the power system is increased.

3. Development Prospect of VPPs
New energy generation has become an inevitable trend of clean transformation to power systems. The power system needs to be equipped with a large number of adjustable devices because of randomness and volatility of the new energy generation. Different from traditional power generation, VPPs balance the supply and consumption of power systems from the demand side by adjusting energy storage equipment and controllable load, which is a new solution to the stable operation of power grids. On the basis of summarizing the research status of VPPs market, the development prospect of VPPs is summarized into five aspects, as shown in Figure 1.

- Expanding the scope of market players
VPPs can aggregate geographically dispersed and small demand-side resources, so that these scattered users who do not meet the market access conditions can participate in the power market through VPP aggregation. Besides, VPPs can cultivate the market awareness of power users, expand the scope of market players, and promote the depth and breadth of market-oriented reform.

- Being an important link to promote the construction of smart grid
Smart grid can solve the problems of energy security and environmental protection, ensure reliable, and efficient power supply and meet the diversified needs of economic development. VPPs are based on communication technology, coordinated control technology and intelligent metering technology, which are also the key technologies needed for the development of smart grid. Both VPPs and smart grid have the basic characteristics of informatization, automation and interaction. Generally speaking, the development of VPP technologies play an important role in promoting the construction of smart grid.

- Promoting demand-side resources to participate in electricity trading
At present, the power regulation capacity in the system is mainly contributed by thermal power plants and pumped storage power plants. VPPs have strong load regulation capacity, which can adjust the load in a short time. VPPs can also eliminate the boundary between power generation and power consumption in power trading, which can thoroughly mobilize the enthusiasm of demand-side resources to participate in power control and expand the market scope.

- Promoting the transformation of power trading from no curve to convention curve
By adjusting and managing the internal resources, the output curve of the VPPs can be stable which is also called the convention curve. In this process, it is conducive to promoting the transformation of power trading from no curve agreement to convention curve mode to cultivate the cognition of all parties on the time value of power energy and improve the level of social electricity management.

- Having great market potential
Taking VPPs in Shanghai as an example, which locate in an economically developed region in China, there are many commercial buildings that can be used as controllable resources. The development potential of residential communities is about 200 MW, while for the commercial buildings, there are about 2000 MW. With the development of integrated energy services and the innovation of business model of VPPs, distributed photovoltaic, electric vehicles, user-side power supply can also become the
main aggregation content of VPPs, with the development potentials as 800, 90MW, 5.3 MW. The proportion of development potential of various market objects in the VPPs is illustrated in Figure 2.

![Figure 2. Proportion of development potential of various market objects in VPPs](image)

4. Problems Faced by VPPs and Corresponding Solutions

With the vigorous promotion of new energy and emerging technologies, VPPs, which have broad development space, become an important type of players for energy aggregation for smart grid construction and global energy interconnection. However, there are several problems to be solved during the development process.

4.1. Problems Faced by VPPs

1. **Non-unified concept of VPPs**
   The concepts of VPPs in different countries and regions are not well unified. Thus, the concept of VPPs is supposed to be unified with more detailed rules, access conditions, technical parameters and so on.

2. **Ineffective profit models for VPPs**
   Since there is no clear and sustainable profit model of VPPs and the lack of incentive policy on VPPs, social capital investment might not be attracted. Therefore, only a small number of high-quality resources are involved to participate in the transaction, and it is difficult to mobilize the enthusiasm of most resources in society. Thus, it is necessary to formulate incentive policies for VPPs.

3. **Insufficient participation of flexible loads**
   According to the settlement results of the demonstration VPP in Shanghai, although there are many types of flexible loads involved in the VPP, which basically cover the main types of users, the total load involved is only 87 MW and the approved effective power energy is only 18.3 MWh, which cannot form an effective support for peak shaving and valley filling of regional power grids. Therefore, it is still necessary to expand the application scope of VPPs.

4. **Imperfect market mechanism for VPPs**
   At present, VPPs can participate in market transactions through demand response and ancillary services. Market-oriented transactions of VPPs should be based on making full use of the controllability and adjustability of VPPs. The ecological model of VPPs should be built considering market mechanisms. Corresponding access standards and transaction modes of VPPs should be improved and the types of transactions should be enriched. At the same time, the potential of VPPs in peak shaving auxiliary service, reserve auxiliary service and demand side response should be developed.

5. **Conflict of interests between the agents in the power market**
   Besides VPPs, there are other market players including electricity companies who sales electricity to customers, comprehensive energy service companies. Under this circumstance, the whole market will be shared among these market players which increases operation pressures for VPPs.

4.2. Corresponding Solutions to the Problems Faced by VPPs

1. **Define the concept of VPPs**
   - Define the organizational form of VPPs
     VPPs can serve as operators, which aggregate distributed generation, controllable load and energy storage equipment.
   - Define the external characteristics of VPPs
To dispatch VPPs for power grids, the minimum requirements of external characteristics of VPPs should be determined, such as ramping rate, start-stop interval, charging power, discharging power, adjustable capacity, maximum power storage, response speed and maximum response time.

- Define the internal characteristics of VPPs

To make internal aggregated resources controlled by VPP operators, there should be basic capability requirements in VPPs, such as the interconnection of information among internal resources, accurate and reliable measurement of parameters, as well as the accurate and quick control instructions from VPPs to internal aggregate resources.

(2) Define the ways and conditions for VPPs to participate in power trading

- Define the identity of the market subject

VPPs should be included as one of the main subjects in power market. VPPs can enjoy the same rights and responsibilities as other market entities to participate in the power market after going through the registration formalities and filing in the trading center.

- Define the access conditions for participating in the market

In order to meet the needs of trading varieties in various markets, the minimum technical conditions for VPPs should be set, such as ramping rate, charging power, discharging power and adjustable capacity. Besides, the business conditions of VPPs need to be formulated as well, for example, the responsibility relationships between the VPP operators and the aggregated demand side resources, the registered capital and enterprise credit of the VPP operators.

- Define the varieties of trading

VPPs can start by participating in peak regulation market at the initial stage of the market. Then, it can expand to medium-term and long-term power trading, frequency regulation and other auxiliary service trading. VPPs can participate in spot market and power financial transactions in the future.

- Define the statement method

Since there are various kinds of aggregated resources in VPPs, a fair and equitable distribution mechanism should be designed for internal statement method. Under the corresponding distribution method and statement method stipulated in an agency contract, the VPP operators and their internal resources can settle accounts by themselves, or through the VPP operation management platform of the trading center, where the trading center can be used as the settlement center for unified settlement.

(3) Define the mode and standard of VPPs in power grid operation

- Define the responsibilities and obligations of VPPs

VPPs participate in power grid operation as a power plant with regulation ability. The performance requirements, scale and technical parameters of VPPs, such as generating capacity, frequency deviation and voltage deviation should be defined. Besides, VPPs should enjoy the same rights and responsibilities as other power generation entities, such as peak shaving obligations and primary frequency modulation obligations. In the initial stage of the promotion of VPPs, in order to cultivate market players and expand the participation scale of VPPs, their responsibilities and obligations can be appropriately reduced or exempted.

- Define the ways of VPPs participating in power grid operation.

The ways of VPPs participating in power grid operation are flexible. According to the different aggregated resources, they can participate in power grid operation by means of demand side management and auxiliary service providers such as power supply, peak shaving and frequency regulation. It should be emphasized that the main function of VPPs is providing reliable regulatory resources for power grid operation.

- Define the relevant standards for the construction of virtual power plants

The relevant standards for the construction of VPPs should be defined to formulate standards, such as intelligent terminals, information interaction, remote control, and system interfaces. Besides, all market entities should be encouraged to build power management systems according to unified standards that meet the requirements of VPPs.

5. Conclusions

With the increasing demand of electricity and the serious shortage of energy around the world, VPPs have become an effective tool to promote the accommodation and efficient utilization of renewable
energies. In this paper, the concept and characteristics of VPP as well as the market status are introduced. Then, the development prospects of VPPs are proposed from five aspects, including market scope, smart grid construction, demand side response, power trading curve and market potential. Finally, the urgent problems and challenges of VPPs are pointed out, such as the unification of the concept, profit model, market potential, and market mechanism. The corresponding solutions are provided as well, which can be utilized for decision making of VPPs.

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