Virtual Power Plant Scheduling Strategy Considering Clean Energy Consumption

Yin-han ZHANG[1,a], Yan-tao WANG[1,b,*] and Yi-nan HOU[2,c]

[1]School of Economic and Management, Northeast Electric Power University, Jilin, Jilin, China

[2]Jilin Petrochemical Company Organic Synthetic Plant, Jilin, Jilin, China

[a]13274617351@163.com, [b]wangyantao80@163.com, [c]3169870632@qq.com

*Corresponding author

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Abstract: As a form of efficient utilization of large-scale new energy power, virtual power plant plays an important role in flexible peak shaving and improving China's power market system. The allocation optimization of various resources in virtual power plant is an important premise for virtual power plant to participate in system dispatching. Under the complex situation of uncontrollable clean energy operation caused by the gradual increase of the capacity of renewable energy power generation connected to the power grid, the problem of how to optimize the internal resource allocation and realize active response of virtual power plant needs to be solved urgently. Therefore, a virtual power plant scheduling strategy based on the highest consumption of clean energy is proposed. Firstly, the schedulable resources of virtual power plant are modeled from the perspective of flexibility. Secondly, it expounds the cost of clean energy consumption. Finally, with the goal of minimizing the consumption cost of clean energy, a scheduling model is built to optimize the allocation of all kinds of resources that can be dispatched in the virtual power plant. The model can provide a theoretical basis for the active response of virtual power plant.

1. Introduction

The concept of virtual power plant was proposed by Dr. awerbuch in 1997 for more than 20 years. With the development of measurement and communication technology, the power system can use microgrid and virtual power plant to realize the coordinated control of distributed generation, so as to improve the resource allocation ability of power grid. The construction of microgrid mostly carries out local optimization and source load balance inward, while virtual power plant pays more attention to the external functions and effects, that is, optimize the combination of distributed generation to meet the needs of power system or power market[1-2]. Compared with microgrid, virtual power plant has many advantages. Virtual power plant is more in line with the construction requirements of energy Internet, more applicable in smart grid and power market, and more conducive to solving the consumption problem of renewable energy[3-4]. At present, the research and implementation of virtual power plants in North America and Europe are in a leading position in the world, and account for more than 90% of the installed capacity of global virtual power plants[5]. Tesla launched a virtual power station plan in California. It uses its solar roof and Powerwall to collect solar energy during the day. When users don't need electricity, it transmits idle power to the power grid. To reduce power grid pressure and try to reduce electricity charges [6]. In China, the research on virtual power plant started late. In December 2019, the first domestic virtual power plant demonstration project was put into use in State Grid Jibei Power Co., Ltd. With the vigorous promotion of renewable energy and new technologies, virtual power plants have completed the clean substitution by "Internet plus". The first municipal level virtual power plant of the southern power grid has completed the precise load resource adjustment based on the real-time operation state of power grids in Guangzhou, and has the following two functions: the response to the request and the real-time response. Accurate demand response to user load can be carried out

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according to the dynamic operation of power grid, which can be completed in one minute at the fastest. Of course, the development of virtual power plant also faces many problems. For example, compared with traditional controllable units, the power regulation ability of virtual power plant is poor. In the complex and changeable power market, the response speed to market signals is slow, it is difficult to obtain stable benefits, and even need to pay corresponding penalty fees. In this context, it is particularly important to improve the ability of virtual power plant to stably absorb clean energy and make it as controllable as traditional units.

At present, the research on VPP mostly focuses on optimal scheduling[7-8] and transaction bidding[9-10], while relatively little work has been done on the optimal configuration of VPP. Based on portfolio theory and considering the uncertainty of renewable energy output, reference studied the power capacity configuration of VPP; Literature established a VPP capacity optimal allocation model with conditional value at risk as a risk measure; For the configuration of energy storage system in virtual power plant, in the VPP with large-scale distributed photovoltaic, literature comprehensively considers the demand response of energy storage, peak shaving and valley filling and improving voltage quality, establishes a multi-objective function for the optimal configuration of energy storage system in virtual power plant, and uses mixed integer linear programming and particle swarm optimization algorithm to solve it. Literature divides interactive resource response electricity into risky and non risky assets, maps the resource response plan allocation problem to the asset weight allocation problem in portfolio theory, and measures the uncertainty of user response electricity by portfolio risk.

2. Analysis and Model of Schedulable Resources in Virtual Power Plant

2.1. Analysis and Model of Rapidly Adjustable Resources

The traditional units represented by thermal power units rely on the stable tracking load of virtual power plants, but they can provide limited reliability due to the constraints of their own capacity, climbing rate and minimum output. The constraints of thermal power units are:

$$P_i^{Gmin} \le P_{i,t}^{G} \le P_i^{Gmax} \tag{1}$$

$$-P_i^{Gmin}(u_i^t - u_i^{t-1}) + R_i^{Gmin}u_i^t \le P_{i,t}^{G} - P_{i,t-1}^{G} \le P_i^{Gmax}(u_i^t - u_i^{t-1}) + R_i^{Gmax}u_i^{t-1} \tag{2}$$

$$\sum_{t' \in (t, t+T_i^{run}-1)} u_{i,t'} \ge T_i^{run} v_{i,t} \tag{3}$$

$$\sum_{t' \in (t, t+T_i^{stop}-1)} (1 - u_{i,t'}) \ge T_i^{stop} w_{i,t} \tag{4}$$

$$u_{i,t} - u_{i,t-1} = v_{i,t} - u_{i,t} \tag{5}$$

$$v_{i,t} + w_{i,t} = 1 \tag{6}$$

Where, P_i^{Gmin}, P_i^{Gmax} refers to the upper and lower limits of output of thermal power units; R_i^{Gmin}, R_i^{Gmax} is the upper and lower limit of unit climbing; $u_i^t$is the $0-1$ variable representing whether the unit participates in operation; T_i^{run}, T_i^{stop}represents the minimum operation time and minimum shutdown time of the thermal power unit; $v_{i,t}$, $w_{i,t}$ is the 0-1 variable representing the startup or shutdown of the thermal power unit.

Energy storage has attracted more and more attention with the grid connection of a large number of clean energy in recent years. Its rapid charging and discharging characteristics can send high-quality electric energy into the power grid or store excess electric energy, but it is still limited by its own inherent characteristics and power station operation conditions, and has specific operation characteristics and constraints.

$$P_i^{Smin} x_i^t \le P_{i,t}^{store} \le P_i^{Smax} x_i^t \tag{7}$$

$$P_i^{Dmin}(1 - x_i^t) \le P_{i,t}^{discharge} \le P_i^{Dmax}(1 - x_i^t) \tag{8}$$

$$E_{i,t}^{min} \le E_{i,t}^{store} \le E_{i,t}^{max} \tag{9}$$

$$E_{i,0} = E_{i,T} \tag{10}$$

Where $P_i^{Smin}, P_i^{Smax}, P_i^{Dmin}, P_i^{Dmax}$ represents the upper and lower limits of power under the charging and discharging states of energy storage respectively. η_S, η_D is the charge discharge conversion efficiency of energy storage.

2.2. Analysis and Model of no- Rapidly Adjustable Resources

For example, wind power and photovoltaic resources can not be adjusted quickly, and their output has strong intermittence and randomness. According to the predicted wind power, photovoltaic output curve and load prediction curve, the net load curve based on the new energy consumption capacity is obtained, and the predicted on grid power of wind power and photovoltaic is obtained.

$$\mathrm{P_f^{wind(i,t)} = P_{f,abandon}^{wind(i,t)} + P_{f,up}^{wind(i,t)}} \tag{12}$$

$$0 \le \mathrm{P_{f,abandon}^{wind(i,t)} \le P_f^{wind(i,t)}} \tag{13}$$

$$0 \le \mathrm{P_{f,up}^{wind(i,t)} \le P_f^{wind(i,t)}} \tag{14}$$

$$\mathrm{P_f^{pv(i,t)} = P_{f,abandon}^{pv(i,t)} + P_{f,up}^{pv(i,t)}} \tag{15}$$

$$0 \le \mathrm{P_{f,abandon}^{pv(i,t)} \le P_f^{pv(i,t)}} \tag{16}$$

$$0 \le \mathrm{P_{f,up}^{pv(i,t)} \le P_f^{pv(i,t)}} \tag{17}$$

$$\mathrm{\sum_{i=1}^{N} P_{f,up}^{wind(i,t)} + \sum_{i=1}^{N} P_{f,up}^{pv(i,t)} + \sum_{i}^{N} P_{i,t}^{G} + \sum_{i=1}^{N} P_{i,t}^{discharge} - \sum_{i=1}^{N} P_{i,t}^{store} = \sum_{i=1}^{N} P_f^{load(i,t)}} \tag{18}$$

$$\mathrm{-P_{i,t}^{Lmax} \le P_{i,t}^{L} \le P_{i,t}^{Lmax}} \tag{19}$$

$$\mathrm{P_{i,t}^{L} = (\theta_{m,t} - \theta_{n,t}) \div X_{mn}} \tag{20}$$

Where, $\mathrm{P_f^{wind(i,t)} P_f^{pv(i,t)}}$ are the predicted output of typhoon power and photovoltaic power in period T and I respectively. $\mathrm{P_{f,up}^{wind(i,t)}}$ is the predicted on grid power of typhoon I in period T. $P_{f,up}^{pv(i,t)}$ is the predicted on grid power of photovoltaic at time t.

3. Cost Analysis and Model of New Energy Utilization in Virtual Power Plant

Mechanism of virtual power plant promoting new energy consumption is that in the power system including wind power and photovoltaic power, the system operation state is affected by both load and new energy output. The net load curve is calculated according to the superposition of load prediction curve, wind power prediction output curve and photovoltaic prediction output curve.

$$\mathrm{P_{net}(t) = \sum_{i=1}^{N} P_{i,t}^{load} - \sum_{i=1}^{N} P_{up}^{wind(i,t)} - \sum_{i=1}^{N} P_{up}^{pv(i,t)}} \tag{21}$$

The uncertainty of net load is caused by the predicted load demand and the change of wind power and photovoltaic output. In Figure 1, the solid line is the net load curve, the blue part is the adjustment interval of load fluctuation caused by the uncertainty of wind power photovoltaic actual output, and the dotted line is the output adjustment interval of virtual power plant by adjusting schedulable resources, It can be seen that: ① when the uncertainty is within the regulation range of the rapidly adjustable resources of the virtual power plant, the virtual power plant can be adjusted; ② When the uncertainty exceeds the regulation range of the rapid regulation resources of the virtual power plant, the virtual power plant is not adjustable.

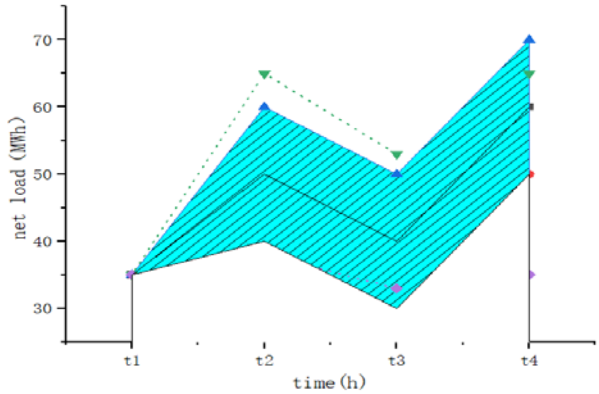

Figure 1 Schematic diagram of regulation section.

The objective function of the active response model of virtual power plant is to minimize the power generation cost (composed of startup cost, output cost and standby cost) and the amount of abandoned wind and light. Namely:

$$\min\{F_{GC} + F_{AB}\} \tag{22}$$

Among them, the power generation cost of rapidly adjustable resources can be expressed as:

$$F_{GC} = \sum_{t=1}^{T} \sum_{i=1}^{N} [C_i^t + S_i^t + q_i^t] \tag{23}$$

4. Active Response Model and Operation Mechanism of Virtual Power Plant

As shown in Figure 2, VPP exchanges information with thermal power, wind power, photovoltaic, energy storage and load through the control center and arranges the power output as a whole. Wind power and photovoltaic undertake the main power supply tasks. Thermal power and energy storage restrain the uncertainty of renewable energy output and ensure the continuous and stable power supply.

Considering the uncertainty of wind power and photovoltaic output, the virtual power plant's rapidly adjustable resources are used to reserve the current non rapidly adjustable resource members based on the adjustable range to meet the load demand. In addition, after unified scheduling, the remaining units can be combined to participate in other scheduling, so as to generate revenue.

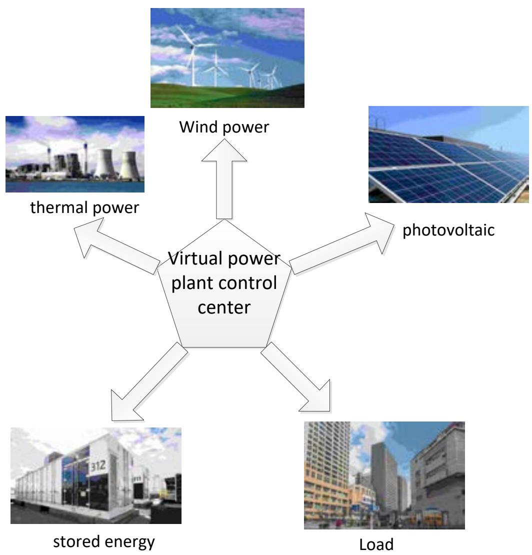

Figure 2 Control diagram of virtual power plant.

Non rapidly adjustable resources such as wind power and photovoltaic are the main factors leading to the unstable output of virtual power plants. The traditional solution is to use rotating standby to offset the impact of wind power and photovoltaic access on system scheduling. Virtual power plants also face this problem. They expand the adjustable margin of virtual power plants by mobilizing sufficient rapidly adjustable resources, but mobilizing too many rapidly adjustable resources will increase the system operation cost.

The traditional method to determine the reserve capacity is often to take the maximum capacity of a single unit or a fixed percentage of the load. According to the climbing rate, landslide rate and output upper and lower limits of resources that can be quickly adjusted to meet the standby demand of virtual power plant, so as to meet the load demand and consume clean energy. At the same time, the virtual power plant can further reduce the standby cost by scheduling the internal resources that are already in the output state for standby.

5. Conclusion

In order to better realize the efficient utilization of virtual power plant in new energy consumption, this paper analyzes the schedulable resources of virtual power plant, new energy consumption cost and operation mechanism of active response model, comprehensively considers the characteristics of schedulable resources, classifies them according to whether they can be quickly adjusted, and establishes the active response model of virtual power plant, It realizes the information exchange and overall output arrangement between the control center and thermal power, wind power, photovoltaic, energy storage and load. This idea can provide a theoretical basis for the actual operation of virtual power plant.

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