Optimal scheduling method of virtual power plant based on bi level programming

LIU Dunnan¹, Gao Yuan*, Wang Weiye¹, Liang Jiahao¹

¹State Key Laboratory of Alternate Electrical Power System With Renewable Energy Sources (North China Electric Power University), Changping District, Beijing 102206, China
*Corresponding author’s e-mail: 120192206982@ncepu.edu.cn

Abstract. Virtual power plant controls various types of flexible loads through information integration to realize efficient utilization of energy, which is an important channel to absorb high proportion of renewable energy. In this paper, an optimal scheduling method of virtual power plant based on bi level fuzzy chance constrained programming is proposed. The bi level chance constrained programming is used to describe the power price incentive strategy and the price response of the virtual power plant. The interactive mechanism between the power grid and the virtual power plant is visually displayed. The example shows that this method can realize the distributed generation and active negative of the virtual power plant. The effective scheduling of load.

1. Introduction

With the construction of high proportion of renewable energy, large-scale electric vehicles and information physical system, the operation cost of power system is becoming higher and higher, which is in contradiction with the goal of reducing the user's electricity price [1]. Virtual power plant can control multiple types of flexible loads through information integration, realize efficient energy utilization, and play the green and flexible value of distributed generation, distributed energy storage, micro grid and other resources, which is a means to effectively solve the above problems [2-3].

The virtual power plant connects flexible loads such as distributed generation, distributed energy storage, controllable load and electric vehicle through information physical network, so as to realize load integration and provide auxiliary services to the power system, strengthen the coordination and interaction between supply side and demand side of power system, and improve the mutual accommodation capacity between New energy and system [4]. At present, much research has been done on virtual power plant at home and abroad. Since the concept of virtual power plant was proposed in recent years, many scholars have made different definitions of virtual power plant. The virtual power plant defined in reference [5] is a fusion of a series of different technologies, which can be connected to different nodes of distribution network. The virtual power plant defined in reference [6] is a collection of multiple types of distributed generation. The virtual power plant proposed in reference [7] is a hypothetical entity with multi site and multi technology. For the optimization scheduling of virtual power plant participating in auxiliary service, the reference [8] constructs a fuzzy multi-objective optimal dispatching model of virtual power plant, which comprehensively considers the system security, power quality, operation cost and user satisfaction. The single objective optimization mainly aims at the minimum cost or maximum profit of virtual power plant [9]; there are also studies on the optimization objective of minimization of user power demand [10] or carbon emission [11].
When the virtual power plant with multiple flexible loads is optimized, the coordinated operation of multiple loads should be considered, and the optimal dispatching of each microgrid should be realized. Based on the introduction of the "wholesale and retail" two-level market trading system for virtual power plants, a two-level stochastic optimal scheduling method is proposed. The simulation results show that the proposed method is feasible.

2. "Wholesale and retail" two level market transaction system of virtual power plant

At present, virtual power plant mainly provides auxiliary services by scheduling flexible resources. With the gradual improvement of power market mechanism and the construction of electricity sales market, power sales companies with virtual power plants as the core will gradually participate in the power market transactions. In other words, as an independent market entity, virtual power plant operators can actively participate in the power market as flexible resources such as distributed energy, flexible load, energy storage system and so on.

In the power market trading system, the virtual power plant operators undertake the following responsibilities and enjoy corresponding benefits:

1) The external responsibilities of virtual power plant operators.

There is a principal-agent relationship between the virtual power plant operator and the internal components of the virtual power plant. The virtual power plant operator is the main body and medium of the two-way interaction inside and outside the virtual power plant. The virtual power plant operator is responsible for the information exchange between the virtual power plant and the external large power grid and power selling enterprises. It can not only act as a power selling enterprise, but also participate in the auxiliary service market as an auxiliary service provider to obtain auxiliary service compensation. At the same time, the power plant operators can actively respond to the demand of the whole power plant, such as peak hour and valley price. According to the characteristics of virtual power plant aggregating flexible resources, ancillary service transaction will be an important transaction type of virtual power plant. Based on the bi-directional decision-making of wholesale market and user call, the load integrator or the operator of virtual power plant can obtain the optimal decision-making scheme for participating in the market.

2) Internal responsibility of virtual power plant operators.

By aggregating flexible resources such as distributed generation, controllable load, electric vehicle and energy storage, the physical foundation of virtual power plant agent transaction is formed. From the perspective of load aggregation stage, it can be divided into three stages: natural combination, economic incentive and operation coordination, which are respectively three aspects: natural characteristics of load, flexible control of economic means and operation coordination and dispatching control. Through the three stages, intelligent integration of loads under different scenarios can be carried out. As for the key technologies of the operation mechanism of virtual power plants, at the same time, the operators of virtual power plants obtain profits by participating in market transactions through the integration of load agents. The value allocation is carried out by considering the value contribution of each flexible resource to the virtual power plant system. The factors that need to be considered include response time, regulation rate, adjustment depth, etc.

3. Bi level optimal scheduling model of virtual power plant

According to the hierarchical distribution characteristics of virtual power plants, a hierarchical stochastic optimal dispatch model of virtual power plants is established based on hierarchical optimization theory. The upper layer of the virtual power plant establishes the overall dispatching objective of the virtual power plant according to the power grid demand; the lower layer establishes the optimization model based on the characteristics of each flexible resource and fully considers the randomness and correlation of its internal intermittent distributed generation.
3.1. Optimal response model of lower level virtual power plant
The lower layer of virtual power plant comprehensively considers the overall interests of virtual power plant. Virtual power plant includes distributed power sources such as fossil fuel power plant and wind power plant, as well as active loads such as electric vehicle group and air conditioning group. They interact with power grid on the premise of ensuring their own power supply, so as to maximize the benefits of virtual power plant.

(1) Objective function.

\[
\max f_i = p q_i - c_i(x_i) - c_i(x_i, w_i) - f_i(v_i) + f_i(t_i) - f_i(\Delta d_i)
\]

\[
Cr \{ f_i \geq \tilde{f}_i \} \geq \alpha_i
\]

In the formula, \( f_i \) and \( \tilde{f}_i \) are the income and the optimistic value of the virtual power plant \( i \) respectively; \( \alpha_i \) is the confidence level of the optimistic value of the objective function of the virtual power plant \( i \); \( p \) is the electricity price; \( q_i \) is the power supply of the virtual power plant \( i \) to the power grid; \( x_i \) is the output of the fossil fuel power plant in the virtual power plant \( i \); \( c_i \) is the cost of the fossil fuel power plant in the virtual power plant \( i \); \( w_i \) is the output of the wind power plant of the virtual power plant \( i \); and \( c_i \) is the carbon emission cost of the virtual power plant \( i \); \( v_i \) is the discharge power of electric vehicle group in virtual power plant \( i \); \( f_i \) is the cost of electric vehicle group participating in dispatching in virtual power plant \( i \); \( t_i \) is the set temperature of air conditioning group in virtual power plant \( i \); \( \Delta d_i \) is the imbalance between supply and demand in virtual power plant \( i \); \( f_i^{\text{v}} \) is the benefit of power consumption of air conditioning group in virtual power plant \( i \); \( f_i^{e} \) is the cost of unbalanced supply and demand in virtual power plant \( i \). The cost of fossil fuel, electric vehicle and air conditioning are all expressed by quadratic function.

(2) Constraints
The constraints of the virtual power plant include the opportunity constraints of supply and demand imbalance, the upper and lower limits of wind farm output, the upper and lower limits of electric vehicle output, the upper and lower limits of air conditioning power, and the upper and lower limits of air conditioning temperature and fossil fuel power plant output.

\[
Cr \{ s_{\text{min},i} \leq \Delta d_i \leq s_{\text{max},i} \} \geq \beta_{1,i}
\]

\[
Cr \{ w_{\text{min},i} \leq w_i \leq w_{\text{max},i} \} \geq \beta_{2,i}
\]

\[
Cr \{ v_{\text{min},i} \leq v_i \leq v_{\text{max},i} \} \geq \beta_{3,i}
\]

\[
Cr \{ e_{\text{min},i} \leq e_i \leq e_{\text{max},i} \} \geq \beta_{4,i}
\]

\[
t_{\text{min},i} \leq t_i \leq t_{\text{max},i}
\]

\[
x_{\text{min},i} \leq x_i \leq x_{\text{max},i}
\]

Where \( s_{\text{max},i} \) and \( s_{\text{min},i} \) are the upper and lower limits of the imbalance between supply and demand in virtual power plant \( i \); \( t_{\text{max},i} \) and \( t_{\text{min},i} \) are the upper and lower limits of air conditioning temperature in virtual power plant \( i \); \( x_{\text{max},i} \) and \( x_{\text{min},i} \) are the upper and lower limits of power generation power of
fossil fuel power plant in virtual power plant i; $\beta_{1,i}, \beta_{2,i}, \beta_{3,i}$ and $\beta_{4,i}$ are the confidence levels of four chance constraints in virtual power plant i.

3.2. Optimal pricing strategy model of upper power grid

The goal of the upper power grid is to minimize the cost of electricity purchase and the cost of imbalance between supply and demand.

(1) Objective function:

$$\min F = \sum_{i=1}^{N} p_q i + F(\Delta D)$$

$$C_r \left\{ F \leq \bar{F} \right\} \geq \alpha_0$$

In the formula, $F$ and $\bar{F}$ are the grid cost and its optimistic value respectively; $\alpha_0$ is the confidence level of the optimistic value of the grid cost; $N$ is the number of virtual power plants; $\Delta D$ is the difference between the generation capacity and the load of the whole network; $F'$ is the cost of unbalanced supply and demand of the power grid.

(2) Constraints

$$C_r \left\{ S_{\min} \leq \Delta D \leq S_{\max} \right\} \geq \beta_0$$

$$p_{\min} \leq p \leq p_{\max}$$

In the formula, $S_{\max}$ and $S_{\min}$ are the upper and lower limits of the power grid supply-demand imbalance; $\beta_0$ is the confidence level of the opportunity constraint conditions of the power grid supply-demand imbalance; $p_{\max}$ and $p_{\min}$ are the upper and lower limits of the electricity price.

4. Example simulation

The proposed method is verified by the test system shown in Figure 1. The distributed generation of the test system includes fossil fuel power plant and wind power plant, and the active load includes electric vehicle and air conditioner. They form three virtual power plants to supply power to the grid. $x_{\min,i}, x_{\max,i}, w_{\min,i}, w_{\max,i}, \gamma_{\min,i}, \gamma_{\max,i}, e_{\min,i}, e_{\max,i}$ of power plant 1, 2, 3 are 5,10,5; 25,50,80; 5,5,5; 20,25,30; -10, -10, -10,10,10; 1,1,1; 15,15,15, 15, with the unit of MW.

![Figure 1. Test system](image_url)

The interaction between virtual power plant and power grid. Assuming that the electricity price varies from 0.2 yuan / (KWH) to 0.6 yuan / (KWH), the optimal response of internal distributed generation
and active load is obtained after optimization of each virtual power plant. The power grid calculates the cost under different electricity prices according to the power response of each virtual power plant. The results are as follows.

Figure 2. Optimal response of power supply and load to electricity price in virtual power plant

Figure 2 shows the optimal response of various power sources and active loads to different electricity prices in virtual power plant 1. It can be seen from the upper limit that no matter how the electricity price of wind power changes. This is because the proposed model does not consider the cost of wind power generation. When the electricity price is low, the charging efficiency of electric vehicles and the comfort benefits of air conditioning are higher than that of selling electricity. Therefore, when the electric vehicles are in charging state, the air conditioning will be set to a more appropriate temperature. With the increase of electricity price, the output of fossil fuel power plant gradually increases, the charging power of electric vehicle gradually decreases and then changes to discharge mode. Air conditioning will also reduce the power consumption to increase the total power transmission power from virtual power plant to power grid. When the output of fossil fuel units and the discharge power of electric vehicles reach the upper limit, and the power consumption of air conditioning reaches the lower limit, the total power transmission power of virtual power plant will not increase with the increase of electricity price.

Figure 3. Variation of power grid cost with electricity price

Figure 3 shows the changes of power purchase cost, power imbalance cost and total cost with electricity price. With the increase of electricity price, the output of each virtual power plant is increasing, so the power purchase cost is increasing. When the electricity price is low, the sum of the output of each virtual power plant is less than the grid load; with the increase of the electricity price, the output of the virtual power plant gradually increases, and exceeds the load demand of the grid when the price is high.
Therefore, the unbalanced cost first decreases and then increases with the increase of electricity price. The total cost of power grid decreases first and then increases with the change trend of electricity price. With the increase of electricity price, the cost of power grid reaches the minimum under a certain price, which is the optimal price.

5. Conclusion
In this paper, an optimal scheduling method of virtual power plant based on bi level fuzzy chance constrained programming is proposed. The bi level chance constrained programming is used to describe the power price incentive strategy and the price response of the virtual power plant. The interactive mechanism between the power grid and the virtual power plant is visually displayed. The example shows that this method can realize the distributed generation and active negative of the virtual power plant The effective scheduling of load.

References
[1] MABEE W E, MANNION J, CARPENTER T. Comparing the feed-in tariff incentives for renewable electricity in Ontario and Germany[J]. Energy Policy,2012,40(1):480-489.
[2] LECHE R H, DOTZAUER E, OLE J H, et al. The interaction between electricity disclosure and tradable green certificate[J]. Energy Policy,2012,42:419-428.
[3] Romo-Fernandez L M, Lopez-Pujalte C, Vicentep, et al. Analysis of Europe's scientific production on renewable energies[J]. Renewable Energy, 2011,36(9):2529-2537
[4] Sovacool B K. Replacing tedium with transformation: why the US Department of Energy needs to change the way it conducts long term R&D [J]. Energy Policy,2008,36(3): 923-928.
[5] H. Saboori, M. Mohammadi, R. Taghe. Virtual power plant (VPP), definition, concept, components and types[C]. Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific, 2011: 1-4.
[6] S. Mohammad, S. Soleymani, B. Mozafari. Scenario-based stochastic operation management of MicroGrid including Wind, Photovoltaic, Micro-Turbine, Fuel Cell and Energy Storage Devices[J]. Electrical Power and Energy Systems, 2014, 54: 525-535.
[7] D.Pudjianto, C.Ramsay, G.Strbac. Virtual power plant and system integration of distributed energy resources[J]. Renewable Power Generation, IET,2007,1(1):10-16.
[8] F. Bignucolo, R. Caldon, V Prandoni. The Voltage Control on MV Distribution Networks with Aggregated DG Units (VPP)[J]. Proceedings of the 41st International,2006,1:187-192.
[9] H. Morais, M. Cardoso, L. Castanheira, et al. A decision-support simulation tool for virtual power producers[C]. IEEE International Conference on Future Power Systems, Amsterdam(Netherlands),2005:1-6.
[10] Asmus, Peter. Microgrids, virtual power plants and our distributed Journa1,2010,23(10):72-82,future[J]. The Electricity
[11] ROOSSIEN B, WARMER J C, KAMPHUIS G I. The power match: multiagent control of electricity demand and supply[J].IEEE Intelligent Systems,2006,21(2):89-90