Study on Economic Operation and Optimal Dispatching of VPP

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Abstract. Large scale grid-connected wind power will have a great impact on the power grid. In order to ensure the safety of power grid operation, it is necessary to quickly adjust the load of thermal power plants to stabilize the fluctuation of wind power output. The economy of thermal power unit is poor in low load operation, and the safety and service life of the unit will be reduced when the load is adjusted frequently. In order to solve the problems, wind and thermal power complementarity is proposed, and the wind farm and thermal power plant constitute a virtual power plant (VPP) to participate in the grid dispatching. A multi-objective optimal dispatching model of VPP considering economy and rapidity is established, which is solved by improving genetic algorithm. The results show that the multi-objective optimal dispatching model can make the economy of VPP the best on the premise of meeting the requirements of grid dispatching time through the simulation of different scenarios. Furthermore, the strategy of selecting the weight coefficient of multi-objective optimization model is given, and the wind power consumption capacity of VPP is analysed.

1. Introduction

With the development of renewable energy, large-scale wind power grid connection has become a development trend. Because of the uncertainty of wind resources, it will not only cause power system resonance and waveform distortion but also harm the secure and stable operation of power system[1]. At present, China's power supply is still dominated by mainly thermal power. Due to the large capacity of single unit and total installed capacity of thermal power units, the rapid climbing capacity can be improved by reducing the output of thermal power units. Although it can improve the capacity of wind power grid and suppress the fluctuation of wind power output, there are some difficulties in realizing the independent dispatching of all units. Moreover, when the thermal power units operate under low load conditions, the coal consumption of the units will be increased and the economy will get worse. In this paper, the concept of virtual power plant is introduced[2]. The thermal power plant and wind farm in a certain area are combined to realize the complementary scheduling of wind power and thermal power in the virtual power plant, so as to reduce the abandonment rate of wind farms and improve the economy of thermal power units.

At present, many scholars have studied the optimal scheduling of virtual power plants, but these studies are from a single economic point of view, not considering the rapidity of load regulation of thermal power plants. And rapidity is an important index for thermal power plants to stabilize wind
power fluctuations. In order to make the power grid absorb the wind power with the maximum capacity on the premise of safety and stability, and at the same time realize the maximization of the economic benefits of the power plant and the power grid, this paper proposes to establish a multi-objective optimal scheduling model of the virtual power plant considering the economy and rapidity. According to the simulation results of different scenarios, the selection strategy of the weight coefficient of the multi-objective optimal scheduling model is given, and the absorption capacity of wind power in the virtual power plant is analysed.

2. Composition of VPP
As shown in the figure 1, the virtual power plant consists of thermal power plant and wind farm. When the virtual power plant receives the power grid load command, the multi-objective optimization distribution system is used to optimize the load distribution of the thermal power unit according to the wind farm output and the operation characteristic parameters of the thermal power unit. And then it can quickly respond to the load fluctuation, reduce the number of thermal power units participating in the load regulation and avoid the frequent regulation of the units, and ensure the maximum economic benefits of the power plant.

3. Model and genetic algorithm

3.1. Optimal scheduling model
In this paper, the economy and rapidity of the thermal power plant after the wind fire complementary generation of the virtual power plant are considered synthetically, and the optimal scheduling model aiming at the fastest load regulation time and the largest economic benefit of the thermal power plant is established.

The economic index of thermal power plant operation is mainly measured by coal consumption of power supply. The fast response of thermal power unit to load change is the basis of ensuring the safe and stable operation of power grid. In this paper, the economic objective function and the fast objective function are expressed by coal consumption to directly reflect the importance of both. The optimal scheduling model of virtual power plant is shown in the formula (1).

$$\omega_e \min Q_e (P_{all,t}) + \omega_r \min Q_r (P_{all,t}) = \omega_e \min \sum [(P_{i,t} - P_e)/P_e]^2 + \omega_r \min \sum [(P_{i,t} - P'_{r})/P'_{r}]^2$$

where
- $\omega_e$ represents economic weight coefficient;
- $\omega_r$ represents speediness weight coefficient;
- $Q_e$ represents total coal consumption of thermal power plant in t period;
- $Q_r$ represents regulation time of thermal power plant response load in t period;
- $P_{e}$ represents the unit takes economy as the single objective optimal value;
- $P_{r}'$ represents the unit takes rapidity as the single objective optimal value;
Dispatching has a clear requirement for regulating time of power plant, that is to say, under the premise of meeting the assessment index of power grid, the power plant can obtain the maximum economic benefit. We suppose \( T_g \) as the dispatching time required by the grid, \( T_e \) as the adjustment time optimized by the economic objective function, \( T_r \) as the adjustment time optimized by the fast objective function, and \( T \) as the adjustment time optimized by the multi-objective function. The following conditions shall be met when selecting the weight coefficient of economy and rapidity:

- \( w_e + w_r = 1 \);
- when \( T_g > T_e \), only considering the economic target can meet the requirements of power grid dispatching, take \( w_e = 1, w_r = 0 \), then \( T = T_g \), the power plant is the most economical;
- when \( T_g < T_e \), only considering the Security target can meet the requirements of power grid dispatching, take \( w_e = 0, w_r = 1 \), then \( T = T_r \), the power plant is the fast;
- when \( T_r < T_g < T_e \), in order to meet the requirements of power grid dispatching time, the maximum economic benefits of the power plant can be obtained as much as possible. At this time, it is necessary to reasonably set the weight coefficient of economic and rapid objective function according to experience.

3.2. Predatory genetic algorithm

The genetic algorithm based on predator-prey search strategy is a kind of calculation method to simulate the predator-prey strategy of animals [6]. The algorithm first searches globally in the whole search space until it finds a better solution, and then searches locally near the solution; if it does not find a better solution, it abandons the local search, and then returns to the whole search space for global search, so on, until it finds a better solution Until the optimal solution (or approximate optimal solution). This algorithm can well balance the relationship between local search and global search, and avoid the shortcomings of traditional genetic algorithm in the process of solving the convergence rate is not ideal, and it is easy to fall into local optimum or premature.

When using predator-prey genetic algorithm to search, the global search is carried out with a larger probability of crossover and a smaller probability of mutation, and the local search is carried out with a fixed smaller probability of crossover and a larger probability of mutation. The probability of crossover and the probability of variation are shown in formulas (2) and (3), respectively.

\[
\begin{align*}
    f_c &= f_{max} - (f_{max} - f_{min}) \times i / G_e \\
    f_d &= f_{max} - (f_{max} - f_{min}) \times i / G_e
\end{align*}
\]

where \( f_c \), \( f_{max} \), \( f_{min} \) represents crossover probability, maximum crossover probability, minimum crossover probability; \( f_d \), \( f_{max} \), \( f_{min} \) represents mutation probability, maximum mutation probability, minimum mutation probability; \( i \) represents contemporary evolutionary algebra; \( G_e \) represents maximum evolution algebra;

4. Analysis of simulation results

In this paper, three scenarios (the ratio of we and WR is 1:0, 0.6:0.4 and 0:1 respectively) are selected for calculation and analysis according to the different weight ratios of economy and rapidity. Through the calculation of the multi-objective optimization model, the 24-hour power generation load command of the thermal power unit is obtained. According to the coal consumption characteristic parameters, the total coal consumption of each period in three scenarios of the thermal power plant is calculated. It is concluded that in any period of time, the greater the economic weight, the smaller the total coal consumption of the power plant. It can be seen that when the weight coefficients of the two objectives of economy and speediness are considered comprehensively, the system speediness index
can be met, and the system economy can be considered to maximize the economic benefits of thermal power units.

The output deviation of the unit can reflect the speed of the unit following the load command, that is, speediness. The simulation results show that the larger the economic weight coefficient is, the higher the deviation of the total output of the thermal power plant is in most periods, and the slower the load regulation speed of the unit is. Therefore, according to the time requirements of system scheduling, the scheme with the optimal proportion of economic and rapid weight should be selected.

5. Conclusion
Through theoretical analysis, a multi-objective optimal scheduling model considering the economy and rapidity of the virtual power plant is established, and the model is solved by predator-prey genetic algorithm. Different scenarios of step change of wind power output in the virtual power plant are simulated, and the load adjustment time of the thermal power plant and the wind farm wind abandonment under different weight coefficients are analysed how to select the weight coefficient to meet the demand of network scheduling to provide decision support for economy and rapidity has a certain engineering practical significance.

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References
[1] Cui, Y., Liu, J., Yan, G.G. (2014) Evaluation of the Influence of the Power Fluctuation of the Connected Wind Power on the Power System Frequency. Acta Energiae Solaris Sinica., 318:617–623
[2] Li, Y.N., Yang, P., Wang, H.J. (2017) Influence of Large-scale Wind Power Grid Connection on Power Grid and Solutions. Journal of South-Central University for Nationalities(Natural Science Edition)., 270:84-89.
[3] Hong,Z.W., Jun, J., Ma, A.S. (2014) A survey of Virtual Power Plant Research. Proceedings of the CSEE., 513-517:5103-5111.
[4] Liu, H.Y., Li, M.Y., Lang, Y.(2017) Virtual Considering the Aggregation characteristics of Air Fire SystemStudy on Economic Dispatch of Power Plant. Journal of Engineering for Thermal Energy and Power., 167:61-65.
[5] Wang,Z., Yang,P., Liu,S.Y.(2017) Virtual Environment Considering Demand Response and Multi Energy ComplementationPower Plant Coordination and Optimization Strategy. Electric Power Construction., 172:60-66.
[6] Zhang, D.X., Guan, Z. H.,Liu, X.Z. (2008) Research on genetic algorithm based on predation search strategy. Application Research of Computers., 340:1006-1012.