Reactive Optimization for Power System with High Proportion of Renewable Energy

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Abstract: Under the background of clean, low-carbon and intelligent energy revolution, renewable energy with high proportion has become the main development direction of power system, which has brought tremendous changes to the structure of power system. The power system with high proportion of renewable energy has complex structures. In the face of higher reliability and quality requirements of power supply, it is impossible to achieve safe and reliable operation, which makes the waste of power resources such as large vacancy of reactive power and low power factor increasingly prominent. Therefore, reactive power optimization of power system with high proportion of renewable energy is proposed. By establishing the mathematical model of reactive power optimization of power system and relying on the constraint equation of reactive power optimization of power system, the state variables and control variables of power system are solved to realize the reactive power optimization of power system with high proportion of renewable energy. The simulation experiment shows that the reactive power optimization of power system with high proportion of renewable energy proposed in this paper can reduce the waste of power resources by 40%.

Keywords: High proportion; Power system; Joint optimization; Resource waste

1. Introduction

Renewable energy refers to a variety of inexhaustible energy sources, including solar energy and wind energy. Its large-scale development and utilization have greatly solved the problems of energy shortage and environmental protection. Renewable energy is widely used in power system because of its characteristics of cleanness and environmental protection. However, the power system of renewable energy has a large fluctuation, which poses great challenges to the fully reliable operation of power system. Therefore, reactive power optimization of power system with high proportion of renewable energy is proposed. Reactive power optimization is to minimize the waste of power resources in power system by adjusting control variables such as reactive power output and voltage level under certain load and network structure, that is, under various constraints[1]. From the mathematical point of view, reactive power optimization of power system is a nonlinear optimization problem. By solving reactive power optimization, the power system can reduce the waste of power resources on the basis of ensuring the reliability and quality of power supply, thus achieving considerable economic benefits.

2. Establishing the Mathematical Model of Reactive Power Optimization of Power System

The ultimate goal of reactive power optimization of power system with high proportion of renewable energy is to minimize the waste of power resources of power system by adjusting control variables such as reactive power output and voltage level, that is, under various constraints.

2.1. Setting reactive power optimization variables of power system

The reactive power optimization model is essentially a mathematical model that minimizes the objective function by adjusting the variables. The reactive power optimization of power system is to reduce the waste of power resources and improve the economy of power system by reducing the loss of reactive power of power system on the basis of ensuring the stability and safety of the system voltage and ensuring the quality of power.

The methods of reducing reactive power loss of power system include reducing the line and the transformer load pressure. Therefore, the reactive power optimization variables of power system are divided into two categories: state variables and control variables[2]. The state variables are calculation variables, such as the voltage phase angle (excluding the voltage phase angle of the balanced node), the voltage modulus (excluding the voltage modulus of the nodes of generators and other reactive power compensation equipment), and the reactive power. The control variables are adjustable variables, such as the voltage of generator, the capacity of reactive power compensation equipment and the number of tap positions of transformer.

By setting the reactive power optimization variables of power system, the optimization objectives of power system are calculated, and the relevant reactive power optimization variables are also different for different optimization objectives.

2.2. Establishing the constraint equation for reactive power optimization of power system with high proportion of renewable energy

Relying on multiple constraints of reactive power optimization of power system, the constraint equation of reactive power optimization of power system with high proportion of renewable energy is established. The equation constraint equation (power flow equation, the most basic power system equation) is established as shown in formula 1:

$$\begin{cases} \Delta P_i = P_{Gi} - P_{Di} - V_i \sum_{j=1}^{n} V_j (G_{ij} \cos q_{ij} + B_{ij} \sin q_{ij}) = 0 \\ \Delta Q_i = Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{n} V_j (G_{ij} \cos q_{ij} - B_{ij} \sin q_{ij}) = 0 \end{cases} \quad (1)$$

In the formula, q_{ij} is the phase angle difference between node i and node j of the network voltage phase angle; V_i and V_j are the voltage modulus values of the node i and the node j respectively; G_{ij} and B_{ij} respectively represent the conductance and susceptance of the branch ij in the power system; P_{Gi} and P_{Di} are the useful work power and the reactive power of the power system; Q_{Gi} and Q_{Di} are the active power and reactive power of node i.

Relying on multiple constraints of reactive power optimization of power system, the inequality constraint equation is established as follows.

The voltage constraint equation is: $U_{Gi\min} \le U_{Gi} \le U_{Gi\max}$ [3]; The constraint equation for tapping of adjustable transformer is: $K_{t.\min} \le K_t \le K_{t.\max}$; The constraint equation of compensation capacity for reactive power compensation equipment is: $Q_{c.\min} \le Q_c \le Q_{c.\max}$; The node voltage constraint equation is: $V_{i.\min} \le V_i \le V_{i.\max}$.

Based on the determination of the reactive power optimization variables of power system, the established inequality constraint equation changes the reactive power optimization variables of the power system to realize the construction of the reactive power optimization mathematical model of power system.

3. Realization of Reactive Power Optimization of Power System with High Proportion of Renewable Energy

The reactive power optimization of power system with high proportion of renewable energy is a kind of nonlinear optimization problem. By solving the equality constraint equation and inequality constraint equation with multi-variable and multi-constraint conditions, the power system can reduce the waste of power resources on the basis of ensuring the reliability and quality of power supply, thus achieving considerable economic benefits[4].

3.1. Determining the constraint conditions of reactive power optimization of power system

After setting the reactive power optimization variables of power system, it is necessary to constrain the variables to ensure the accuracy of the model operation. With the rapid development of the economy and the rapid development of power system with high proportion of renewable energy, the proportion of power supply has been increasing, which has rapidly increased the load of power system, resulting in the collapse of power system caused by huge transmission capacity during the peak period of power consumption[5]. At the same time, in order to meet the requirements of high voltage quality, reactive power optimization of power system must be used to reduce the waste of power resources and maintain a reasonable voltage level.

By setting constraints of reactive power optimization in multiple power systems, the rationality of voltage level is ensured. The established mathematical model of reactive power optimization of power system aims at reducing the waste of power resources, and its constraints are voltage constraint, tapping constraint of adjustable transformer, compensation capacity constraint of reactive power compensation equipment and node voltage constraint. Since the voltage at the output of the power system is limited, changing the power of the power system affects the output voltage, so the voltage is constrained. At the same time, since the tap of the transformer is geared, changing the tap of the transformer will change the operating condition of the most basic power system, so the tap of the transformer is constrained[6]. Through the above four constraints, the reactive power optimization variables of the power system are constrained.

3.2. Solving the constraint equation of reactive power optimization of power system

Relying on the optimization model, the control variables and state variables are adjusted to solve the constraint equation of reactive power optimization of power system, so as to obtain the solution of the problem that satisfies the user's requirements, that is, the reactive power optimization algorithm of power system.

The reactive power optimization of power system with high proportion of renewable energy aims at minimizing the waste of power resources, so the established objective function expression is shown in formula 2.

$$\min h = \Delta P = V_i \sum_{j=1}^{n} V_j (G_{ij} \cos q_{ij} + B_{ij} \sin q_{ij}) \quad (2)$$

Under the constraint of four inequality constraint equations, the genetic algorithm is used to solve the objective function. First, the change variables and the control variables are coded to form a coding string, and the initial

value is given[7]. Then, the advantages and disadvantages of state variables and control variables are evaluated by the established equality constraint equation. Finally, the variables are hybridized and selected, so that the codes are recombined, and the codes with high value of the objective function are eliminated. Only the code with the lowest value of the objective function is retained, and the corresponding state variable and control variable are optimal solution respectively.
Through the reactive power optimization solution, the waste of power resources is minimized, and the economic benefits are maximized on the basis of ensuring the power quality and safety of the power system.

4. Simulation Experiments

In order to ensure the effectiveness of the reactive power optimization of power system with high proportion of renewable energy proposed in this paper, simulation experiments are carried out. During the experiments, the conventional power system is used as the simulation experiment object to simulate the power system's grid loss. In order to ensure the effectiveness of the experiment, the non-optimal operation of conventional power system is taken as a comparative object, several simulation experiments are carried out. Comparing the results of several simulation experiments, the experiments' data are presented in the same data chart.

4.1. Data preparation

The equipment and variables that need to be prepared for the experiment include two computers with identical configurations, simulation software and parameters range set by simulation. Because of the difficulty of field experiments and the high cost of experiments, the simulation experiments are carried out. The parameters range set by simulation is shown in Table 1.
The Autodesk software is used to simulate the conventional power system and calculate the minimum and maximum losses of the power system. At the same time, EXCEL is used to process the mean value of the results of multiple runs.

4.2. Result analysis

The loss values of power system based on the conventional power system non-optimal operation and the reactive power optimization method proposed in this paper are calculated, and the experiment data are plotted as shown in Figure 1.

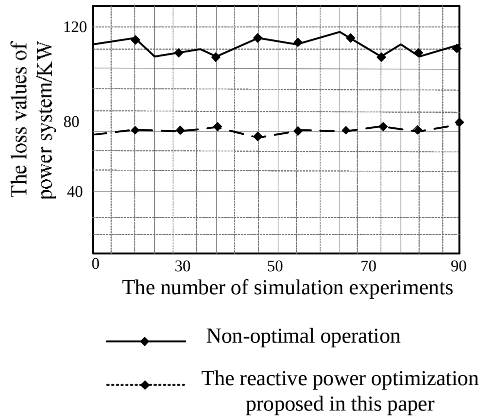

Figure 1. Summary of simulation experiments data

From Figure 1, it can be seen that the power loss values based on non-optimal operation of conventional power system is significantly higher than that based on reactive power optimization. At the same time, because the change range of power loss values is proportional to the change range of electric output, it can be seen from Figure 1 that the fluctuation range of electric output of power system based on non-optimal operation is larger than that of power system based on reactive power optimization. Because of the large number of simulation experiments, the data of Figure 1 are sorted out, as shown in Table 2.
The experiments data in Table 2 show that the reactive power optimization of power system with high proportion of renewable energy proposed in this paper reduces the variation of electric output and effectively reduces the waste of power resources by 40%.

Table 1. Parameters Set by Simulation

Item	Parameter	Item	Parameter
Rated power	600 kW	Analog electric output	/
Transmission voltage	220V	Transmission type	Double circuit transmission
Transformer	1	Tap	5
Capacitor capacity	50 kvar	Computer configuration	frequency is larger than 2.8GHz

Table 2. The Results of Simulation Experiments

Name	Non-optimal Operation	Reactive Power Optimization
The minimum of power loss value/kW	78.801	110.012
The maximum of power loss value/kW	78.822	110.662
The average of power loss value/kW	78.811	110.336

5. Conclusion

This paper proposes the reactive power optimization of power system with high proportion of renewable energy is proposed. By establishing the mathematical model of reactive power optimization of power system and relying on the constraint equation of reactive power optimization of power system, the state variables and control variables of power system are solved to realize the reactive power optimization of power system with high proportion of renewable energy. The simulation results show that the reactive power optimization of power system can effectively reduce the waste of power resources and improve the voltage stability. It is hoped that this paper can provide a reference for the optimization of power system.

References

[1] Qiu Yibin, Ouyang Yubo, Xu Bei, et al. Modeling of Wind and Solar Power Generation Correlation based on Mixed Vine Copula Model and Its Application in Reactive Power Optimization. Power Grid Technology. 2017, (03), 119-126.

[2] Qian Furu, Fan Yanfang, Liu Hongzheng, et al. Study on Reactive Power Optimization of Adaptive Particle Swarm Based on Logistic Chaotic Mapping. Power Capacitor & Reactive Power Compensation. 2017, (4).

[3] Sun Yuanzhang, Bao Yi, Xu Jian, et al. Discussion on Strategy of Stabilizing High Proportion of Renewable Energy Power Fluctuation. Chinese Science Bulletin. 2017, (10), 111-121.

[4] Sun Hongbin, Zhang Zhigang, Liu Yingshang, et al. Autonomous-Synergic Voltage Control for Complicated Power Systems: Key Technologies and Prospects. Power Grid Technology. 2017, (12), 6-14.

[5] Fu Yingjie, Wang Fang and Tan Yanghong. Reactive Power Optimization of Distribution Network Containing Distributed Generation Based on Pareto Optimal. Proceedings of the CSU-EPSA. 2017, (1), 18-23.

[6] Li Weiqi, Que Bo, Wang Wanliang, et al. Multi-objective Moth-flame Optimization Algorithm Based Optimal Reactive Power Dispatch for Power System. Computer Science. 2017, (S2), 513-519.

[7] Application of Zhang Xianglong, Zhou Hui, Xiao Zhihong, et al. Power Electronic Transformer in Reactive Power Optimization of Active Distribution Network. Power System Protection and Control. 2017, (4).