Optimal distribution network configuration considering wind-solar complementarity and power quality

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Abstract. With the proposal of the "dual carbon" goal in China, the randomness and fluctuation of the output of new energy units pose a severe challenge to the power quality of the distribution network. On the basis of considering the complementarity of wind and solar, this paper proposes a double layer optimization configuration model of wind and solar storage in the distribution network, which takes into account the influence of power quality. The power quality index is selected and the evaluation method of combining subjective and objective weight is adopted to obtain the comprehensive evaluation system of power quality PQ factor. The IEEE-33 node system is used to verify the above model. The results show that considering the correlation of wind and solar can guide the improvement of power quality of new energy grid-connected points, reduce the planning and construction cost and the economic loss caused by abandoning wind and light, further improve the economy of the overall system.

Keywords: The complementarity of wind-solar, Power quality factor, Two-layer optimal configuration.

1 Introduction

With the proposal of China's "double carbon" strategic goal, the competitiveness of renewable energy continues to increase, large-scale development and utilization of clean and efficient energy, and construction of clean and low-carbon energy system, has become the trend of clean energy transformation and development in China, and even some scholars have proposed to build a completely renewable energy power system in the future. According to the data released by the National Energy Administration, China's installed capacity of wind power in 2022 is about 370 million kilowatts, an increase of 11.2%, the installed capacity of photovoltaic power generation is about 390 million kilowatts, an increase of 28.1%, at the same time, China's renewable energy generation in 2022 is equivalent to reducing domestic carbon dioxide emissions of about 2.26 billion tons. The contribution of wind and solar generation to China's "carbon peak, carbon neutral" goal is obvious to all.

As both wind power generation and solar photovoltaic power generation have defects such as unstable power generation, the study considering the complementarity of wind power and solar power is one of the research hotspots that have attracted wide

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attention in recent years. At present, the research on the correlation between wind power and photovoltaic power plant output is mainly based on Copula theory[1].

At the same time, in recent years, with the continuous improvement of the penetration rate of new energy, the large-scale distributed renewable energy power station has not only changed the power flow distribution of the original grid, but also caused power quality (PQ) problems caused by random fluctuation and intermittently of its output[2]. At the same time, a large number of distributed new energy is connected to the distribution network, which has an increasing influence on the operation control of the distribution network and increases the regulatory pressure of the reactive voltage of the grid. The contradiction between these problems and the increasingly improved requirements of power supply quality of modern production equipment in the distribution network is becoming more and more obvious, and the power quality problem has become one of the bottlenecks restricting the large-scale grid connection of new energy.

Based on the consideration of wind-solar complementarity and power quality factors, this paper builds the optimal configuration model of wind-landscape storage and distribution network, and establish the PQ factor evaluation system of wind-landscape junction points, NSGA-II algorithm was used to solve the problem. Finally, simulation analysis is carried out in IEEE-33 node system. The results show that considering the wind-solar correlation can lead to the improvement of power quality and improve the economy of the whole system compared with not considering the wind-solar correlation.

2 Correlation model of wind and solar output

2.1 Copula correlation theory

In order to describe the random interdependence between wind and photovoltaic power generation with uncertain variables, the Copula function is used here to capture the correlation between them[3]. The Copula function is a multivariate cumulative distribution function, Sklar believes that for the joint distribution of N random variables, it can be decomposed into the respective edge distribution of these N variables and a Copula function, so as to separate the randomness and coupling of variables. In other words, the properties of a joint distribution with respect to correlation are entirely determined by its Copula function. The basis of Copula theory is defined as any K-dimensional random input variable $\{x_1, x_2, \ldots, x_K\}$, and the marginal function is $\{F_1(x_1), F_2(x_2), \ldots, F_K(x_K)\}$. The joint cumulative distribution function that expresses them in relation to each other by Copula is shown below.

$$F_K(x) = C\big(F_1(x_1), F_2(x_2), \cdots F_K(x_K)\big) \tag{1}$$

Taking the derivative of the above formula, we can obtain the joint probability distribution function $f(x)$ for variable x.

$$f(x) = C\big(F_1(x_1), F_2(x_2), \ldots, F_K(x_K)\big) \sum_{k=1}^{K} f_k(x_k) \tag{2}$$

2.2 Application of Copula theory to wind-solar correlation analysis

The two-dimensional Frank-Copula function can simultaneously describe the characteristics of negative correlation and non-negative correlation between variables, and has no limit on the positive and negative correlation and the degree of correlation. Therefore, this paper chooses the Frank-Copula function as the connection function of the joint probability distribution of the output of wind farm and photovoltaic power station, and its distribution function and probability density function are shown as follows[4].

$$C_F(u, v; \lambda) = -\frac{1}{\lambda}\ln\left(1 + \frac{\left(e^{-\lambda u} - 1\right)\left(e^{-\lambda v} - 1\right)}{e^{-\lambda} - 1}\right) \tag{3}$$

$$c_F(u, v; \lambda) = \frac{-\lambda\left(e^{-\lambda} - 1\right)e^{-\lambda(u+v)}}{\left[\left(e^{-\lambda} - 1\right) + \left(e^{-\lambda u} - 1\right)\left(e^{-\lambda v} - 1\right)\right]^2} \tag{4}$$

Where λ is a correlation parameter whose value is not zero, when $\lambda > 0$ represents a positive correlation between random variables u and v, when $\lambda \to 0$ indicates that the random variables u and v tend to be independent, $\lambda < 0$ represents a negative correlation between random variables u and v.

The joint probability distribution of wind farm and photovoltaic power plant output is obtained according to the wind-solar output correlation model, as shown in the figure 1.

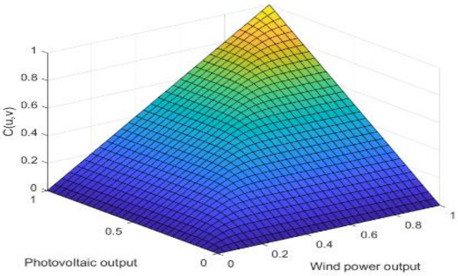

Fig. 1. Frank-Copula distribution function diagram

3 PQ factor evaluation method

There are many related indexes of power quality in power grid, the selection and evaluation process of each indicator is complicated and cumbersome, so it is necessary to select and comprehensively evaluate the indicators according to the specific operation conditions of wind turbines and photovoltaic power generation units.

The evaluation method of CRITIC calculates the objective weight of the evaluation object by introducing the comparison intensity and conflict of indicators, and comprehensively considers the difference and relevance of each indicator. Index contrast intensity(CI), conflict of indicators(CT) and amount of information(G_j) are calculated as follows.

$$\begin{cases} CI = S_j \\ CT = \sum_{j=1}^{n} (1 - r_{ij}) \\ G_j = S_j \sum_{j=1}^{n} (1 - r_{ij}) \end{cases} \tag{5}$$

The comprehensive weight q_j can be obtained from the following equation.

$$q_j = \frac{s_i o_j}{\sum_{i=j=1}^{n} s_i o_j} \tag{6}$$

4 Two-layer model and numerical example analysis

4.1 Model constraint

The overall system power flow constraint is shown in the following formula.

$$\begin{cases} P_i = U_i \sum_{n=1}^{N} U_j (G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}) \\ Q_i = U_i \sum_{n=1}^{N} U_j (G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}) \end{cases} \tag{7}$$

P_i and Q_i indicates the active and reactive power injected into a node, U_i ,U_j indicates the actual voltage of node i and j, G_{ij} , B_{ij} and θ_{ij} is the conductance, susceptance and power factor Angle between the two nodes.

4.2 Two-layer model

In this paper, the objective function of the upper layer model is to establish the lowest total economic loss of wind and light abandonment, the lowest annual investment and operation cost of the power generation system, and the optimal PQ factor of the connecting point of the wind farm and photovoltaic power station. The purpose of the lower level operation optimization model is to minimize the total operation cost of the power generation system of wind turbine and energy storage unit.

4.3 Model solving algorithm

NSGA-II, an improved non-dominated sorting genetic algorithm considering elite strategy, not only reduces the complexity of the algorithm compared with the original non-dominated sorting genetic algorithm, but also makes the individuals in the Pareto optimal solution frontier extend evenly to the entire Pareto domain while ensuring population diversity. Then, a non-dominated solution set with good diversity and more uniform distribution is obtained[5].

4.4 Example analysis

According to the algorithm mentioned above, the comprehensive weight value of PQ factor at the wind-wind grid connection can be obtained as shown in the following Table 1.

Table 1. PQ factor comprehensive weight value

Installation position	Voltage harmonics	Voltage flicker	Voltage deviation
Wind power junction	0.322	0.268	0.224
Photovoltaic junction	0.418	0.271	0.308

In order to verify the effect of wind-solar correlation on the power generation system, the results are analyzed according to two cases with and without correlation in. Case 1 does not consider correlation, Case 2 considers correlation.

Table 2. Capacity and cost of wind-solar grid connection

	Wind power plant PQ value	Wind farm capacity (MW)	PV power station PQ value	PV power station capacity (MW)	Total annual cost(10^3 yuan)	Abandonment of wind and light economic loss (10^3 yuan)
Case 1	2.450	4.793	2.121	4.238	1085.428	59.273
Case 2	2.106	2.273	1.052	3.462	712.176	35.609

Through the analysis of the data in Table 2, it is not difficult to see that the introduction of wind-solar correlation analysis can effectively improve the power quality of the connecting points and reduce the economic losses caused by wind and solar abandonment.

5 Conclusions

According to the above, The evaluation results of PQ power quality factor comprehensive evaluation model proposed in this paper can accurately reflect the power quality of parallel points， it is not difficult to find that considering the wind-solar correlation in the model helps to improve the power quality of the grid connection and improve the economy of the overall system compared to the wind-solar output alone.

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