Power planning analysis for high proportion of renewable energy with multiple flexible resources

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Abstract. As the fossil energy depletion and environmental pollution problem is increasingly serious, pv, fan and other renewable power will occupy the main position in the future power ratio, how to dig in electric power system and use the multi-types resource flexibility, further planning and cost saving, reduced the wind light, is currently the focus of the high proportion of renewable energy power planning problem. First, the overall framework of power supply planning is established. Secondly, based on the analysis of various flexible resources, a storage-load flexible resource scheduling model based on energy storage batteries, electric vehicles and demand response was proposed. On this basis, the investment construction cost and operation cost are integrated, and the power planning-operation model is established. Finally, the effectiveness of the proposed model is verified by an example analysis.

Keywords: Power supply planning; Renewable energy; Flexible resources; Energy storage; Optimal operation.

1. Introduction

With the increasingly serious problems of fossil energy exhaustion and environmental pollution, photovoltaic, fan and other renewable power sources will occupy a major position in the proportion of future power sources. Europe, the United States and China are expected to achieve a high proportion of 100%, 80% and 60% renewable energy power system blueprints by 2050 [1]-[3].

As the proportion of renewable energy gradually increases, its randomness and volatility have an impact on the flexibility of the power system. Many scholars have carried out research on the planning of high-proportion renewable energy power under the access of large-scale fans and photovoltaic. In the context of large-scale fan and photovoltaic access, literature [4] established a power supply planning model considering the benefit of carbon emission reduction, aiming at the minimum comprehensive cost of power generation and carbon emission cost of various power sources. Literature [5] focuses on the complementarity of fan and photovoltaic output, and proposes a renewable energy planning model that takes into account the benefits of generators and the matching degree of the internal power of the cluster. Literature [6]-[7] focused on the analysis of the carbon reduction benefits of renewable energy access and the complementary effects between different types of renewable energy, but the analysis of flexible resources within the system needs further discussion.

However, whether the high-proportion renewable energy power system can run robustly in the future is dependent on the flexible resources in the system, such as energy storage devices, electric vehicles and demand response. How to excavate and utilize multiple types of flexible resources in the power system to further save planning cost and reduce wind and light abandonment is the focus of high proportion of renewable energy power planning at present.

At present, the research on new energy evaluation index mainly focuses on the high quality development and efficiency evaluation of new energy[8-10]. The development of new energy generally starts from one of the aspects, such as technological progress, power market and policy guidance, focusing on the promotion of large-scale development of new energy and the promotion of new energy consumption. Experts and scholars point out that "technology + market + policy" can promote the development of a high proportion of new energy. In terms of policies, it is necessary to strengthen planning and guidance and pay attention to optimizing the development mode and distribution of new energy, strengthen support for the renewable energy industry, promote the sustainable and rapid development of renewable energy, and solve the problem of new energy consumption by optimizing the development layout of new energy, strengthening the coordination of network and source, and strengthening the mode of dispatch and operation. The market should play an important role in optimizing the allocation of resources and promoting the consumption of new energy[11-12].

Index weight determination methods can be divided into subjective weighting method, objective weighting method and subjective and objective comprehensive weighting method. The subjective weighting method determines the weight according to the relative importance of the assessment indicators in the assessment of people's cognition, and the original data is obtained by the experts based on their subjective judgment. The commonly used subjective weighting methods include expert survey method (Delphi method), analytic Hierarchy Process (AHP), binomial coefficient method, sequential scoring method, least square method and so on. Subjective weighting method is a relatively mature method studied earlier. The advantage of subjective weighting method is that experts can reasonably determine the ranking of the weights of each attribute according to the actual decision problem and their own knowledge and experience. However, the weight result depends on the personal judgment of the experts and lacks objectivity, which may lead to the judgment result is not consistent with the reality. The calculation principle of objective weighting method is to maximize the difference between samples, so it is also called the weighting method based on the principle of "difference driven". Common objective weighting methods include principal component analysis, entropy method, deviation and mean square error. Method, multi-objective programming method, etc. The objective method is based on objective data and has non-inheritance because the weight calculation results will not be applicable when the sample data is changed. The subjective and objective comprehensive weighting method combines the two kinds of methods and obtains the weight coefficient of both subjective and objective information.

To sum up, this paper analyzes a variety of flexible resources, and the user side to install photovoltaic willingness to user side subsidies - willingness to model is put forward, based on the meter and a variety of storage - load flexibility resource and user side will the high proportion of renewable energy power planning model, provides the important reference for planning personnel.

2. System Framework

2.1. Wind turbine generator

Generally, the simulation of wind speed mainly considers the medium and long term probability distribution and the overall characteristic quantity, that is, the simulated data should meet certain probability distribution characteristics. Assuming that the probability of wind speed follows the two-parameter Weibull distribution, the probability density function and distribution function of wind speed can be expressed as:

$$f(V) = (\frac{k_2}{k_1})(\frac{V}{k_1})^{k_2-1}\exp[-(\frac{V}{k_1})^{k_2}] \tag{1}$$

$$F(V) = 1-\exp[-(\frac{V}{k_1})^{k_2}] \tag{2}$$

Where, k_1 and k_2 respectively represent parameters measuring Weibull distribution scale and shape, and V represents wind speed at the impeller of the fan.

2.2. Photovoltaic

The basic idea of photovoltaic simulation is to calculate the timing sequence value of the radiation intensity of the surface of the photovoltaic panel and convert it into the timing sequence value of the photovoltaic output by considering the influence of weather factors on the lighting conditions of the location of the photovoltaic power plant and the influence of the installation parameters of the photovoltaic panel on the light in the program through a certain algorithm. Assuming that the illumination intensity follows Beta distribution, its probability density function can be expressed as:

$$f(r)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\cdot(\frac{r}{r_{\max}})^{\alpha-1}\cdot(1-\frac{r}{r_{\max}})^{\beta-1} \tag{3}$$

Photovoltaic power generation is usually achieved through photovoltaic arrays, which are limited by the intensity of the light. For M photovoltaic array with A battery module, the total output is:

$$P_M=r\eta_0\eta_{IE}\eta_{CEE}MS \tag{4}$$

Where, r is the intensity of illumination radiation, S is the area of a single photovoltaic device, η_0 is the photoelectric conversion efficiency of the photoelectric array, η_{IE} is the connection efficiency of the inverter, and η_{CEE} is the connection efficiency of the photoelectric array.

2.3. Electricity Storage

In the face of the current new energy consumption problem, energy storage has always been regarded as one of the most promising solutions. Especially in recent years, with the gradual breakthrough in the technology of energy storage devices and their initial application in the commercial sector, large-scale energy storage will become a reliable solution to the consumption problem of new energy within the foreseeable time.

Energy storage batteries play an important role in the spatio-temporal transfer of electric energy, and their scheduling costs in time period t are mainly related to their charging and discharging costs, which can be expressed as:

$$C_{i,\mathrm{ES}}^t=c_{\mathrm{ES(c)}}P_{i,\mathrm{ES(c)}}^t\Delta t+c_{\mathrm{ES(d)}}P_{i,\mathrm{ES(d)}}^t\Delta t \tag{5}$$

The relevant constraints :

$$E_{i,\mathrm{ES}}^{t+1}=E_{i,\mathrm{ES}}^t+P_{i,\mathrm{ES(c)}}^t\eta_{\mathrm{ES(c)}}\Delta t-\frac{P_{i,\mathrm{ES(d)}}^t\Delta t}{\eta_{\mathrm{ES(d)}}} \tag{6}$$

$$0\le P_{i,\mathrm{ES(c)}}^t\le P_{i,\mathrm{ES(c)}}^{\max} \tag{7}$$

$$0\le P_{i,\mathrm{ES(d)}}^t\le P_{i,\mathrm{ES(d)}}^{\max} \tag{8}$$

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

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

The electric vehicle model is similar to energy storage, except that the scheduling period is limited.

2.4. Constraints on the number of invested/retired units

According to the definition of the investment decision variable, the number of units of the 1st renewable power/energy storage device in the 1st month must be an integer and not less than 0. At the same time, the number of units put into operation each year and at the end of the planning period of the power plant is limited by the number of units allowed to be put into operation and the total number of units. That is to say, the power plant is limited to put into operation without restraint due to the better economy. In fact, the power plant needs a certain construction time.

$$X_{i,m} \in \mathrm{N} \tag{11}$$

$$\underline{N_{i,k}} \le X_{i,m} - X_{i,m-12} \le \overline{N_{i,k}} \tag{12}$$

$$\sum_{m=1}^{M} X_{i,m} \le N_{i,M} \tag{13}$$

2.5. Constraints on installed capacity of new energy

The installed capacity of renewable energy in each year shall not be less than the specified installed capacity requirement. By changing the value of ρ_m, the proportion of new energy installed capacity in the total installed capacity of the system can be adjusted

$$\sum_{m=12(\mathrm{k}-1)+1}^{12k} \sum_{i \in \mathrm{WT} \cup \mathrm{PV}} X_{i,m} P_i^{\max} \ge \rho_k P_{\mathrm{load},k}^{\max} \tag{14}$$

The remaining relevant constraints are not given due to space constraints.

3. Results Analysis

Yangzhong is one of the high-proportion new energy demonstration cities approved by the National Energy Administration and the only county-level city with the whole photovoltaic industry chain in China. In 2016, the National Energy Administration approved Jinzhai in Anhui Province, Xigaze in Xizang Province, Dunhuang in Gansu Province and Yangzhong in Jiangsu Province as high-proportion new energy demonstration cities, aiming to build urban models for large-scale production and local consumption of renewable energy such as wind and light. There are no thermal power plants in Yangzhong, and the energy supply mainly relies on external power supply, which is imported from the external power grid through cross-river overhead lines and cross-river cables. There are 5 cross-river steel towers in total, with an annual transmission capacity of 1.8 billion KWH. Yangzhong now has 3 220 kV substations, 9 110 kV substations and 2 35 kV substations, with a total installed capacity of 1,617,100 kW. In July 2018, Yangzhong City put into operation 28,000 kW grid-side energy storage power stations in Xinba, Sanyyue and Changwang to discharge full power, adopt a more flexible peak adjustment method to solve the power balance problem, improve the practical level of distribution automation, and further promote the consumption of new energy.

By September 2020, fans, photovoltaic and energy storage in Yangzhong area are equipped with 0.01MW, 209MW and 28.5MW respectively. Taking month and week as unit planning cycle and unit operation cycle, confidence capacity coefficient and static capacity reserve coefficient are 0.85 and 0.1, respectively. The installed capacity of new energy in 2021-2025 occupies 0.35, 0.4, 0.5, 0.7 and 0.85, respectively. The power grid side purchase and sale price are respectively 0.39 yuan /kWh and 0.7 yuan /kWh, the annual discount rate is 0.048, the life period conversion coefficient is 0.75, the installed capacity and unit capacity cost of each fan are 2MW and 6 yuan /W, respectively, the installed capacity and unit capacity cost of each photovoltaic device are 33kW and 4 yuan /W, respectively.

By using Yalmip and CPLEX solver for modeling and simulation on MATLAB platform, the annual installed number and capacity of fan, photovoltaic and energy storage devices in Yangzhong area in 2021-2025 are shown in Table 1 and Table 2 respectively.

Table 1 Number of installed renewable energy and energy storage units in 2021-2025

object	2021	2022	2023	2024	2025
WT	48	0	0	0	0
PV	3620	1995	146	141	173
ES	0	0	0	0	0

Table 2 Installed renewable energy and energy storage capacity by 2021-2025 (unit: MW)

object	2021	2022	2023	2024	2025
WT	95.99	0	0	0	0
PV	119.45	65.84	4.82	4.65	5.71
ES	0	0	0	0	0

It can be seen that the number of energy storage devices in 2021-2025 is always 0, because the construction cost and scheduling cost of energy storage are relatively high, and the original energy storage is enough to meet the flexibility of load adjustment. The number and capacity of fans will only be planned in 2021, with 48 and 95.99MW respectively. This is because Yangzhong needs to reach the planned capacity of 100MW fans in the next five years. The earlier the installation time, the greater the benefit in the planning period. The planned number of photovoltaic units in 2021-2025 is 3620, 1995, 146, 141 and 173, and the capacity is 119.45MW, 65.84MW, 4.82MW, 4.65MW and 5.71MW.

The power balance result of the planning result is shown in Figure 1.

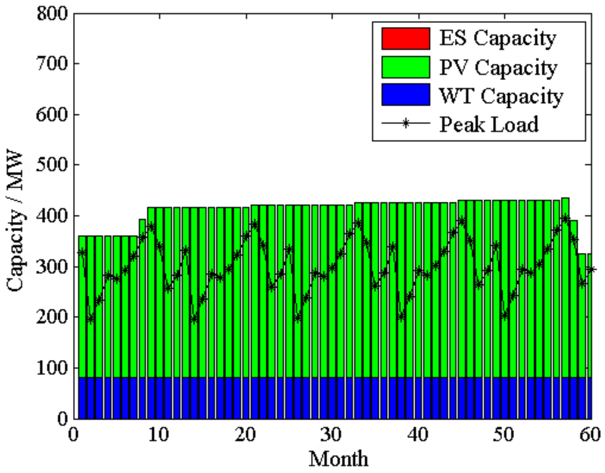

Fig. 1. Base optimization planning scheme monthly power balance.

Select 90%, 80% of the load in turn for sensitivity analysis, and get the planning scheme of each type of equipment as shown in Figure 2.

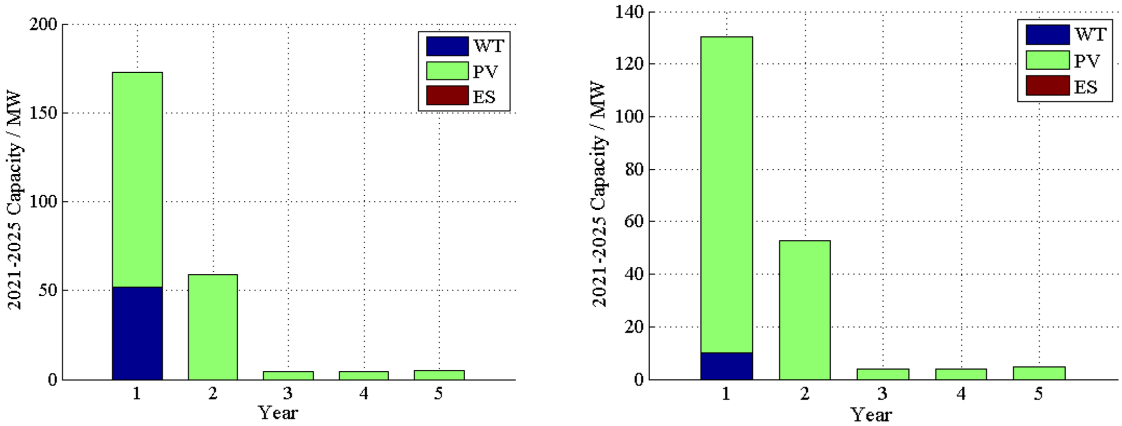

Fig. 2. Sensitivity analysis of planning scheme.

As can be seen from Figure 2, as the percentage of load gradually decreases, the fan capacity planned by the system becomes less and less. This is because the planned fan is more cost-effective when the system load is low, and the fan is more cost-effective when the system load is high.

4. Conclusion

The main work and conclusion of this paper are as follows: the output model of distributed fan and distributed photovoltaic is studied. The two-parameter Weibull distribution was used to simulate the wind speed probability distribution of the fan, and the fan output model was established according to the relationship between the fan output and the wind speed. Assuming that the light intensity follows Beta distribution, the photovoltaic output model is established. Finally, the predicted annual output curves of a 40MW wind farm and a 20MW PV power station are simulated in the case analysis. This paper introduces the optimal scheduling mathematical model of flexible resources such as energy storage device, electric vehicle and demand side response, and analyzes the corresponding call cost when they participate in the scheduling, which mainly involves the charge and discharge cost of energy storage and electric vehicle, charge and discharge amount and load side adjustment cost, adjustable electric quantity, etc. Among them, the optimal scheduling of electric vehicles is only limited to the non-driving stage. By establishing the optimal scheduling cost model of flexible resources and considering the organic combination of multiple flexible resources in power supply planning, it is expected to further reduce the total cost required for new energy planning.

1.The optimal scheduling mathematical model of flexible resources such as energy storage device, electric vehicle and demand-side response was established to analyze the corresponding call cost when they participated in the scheduling.

2.In the context of high proportion of renewable energy, we consider month as the time scale, integrated planning and operation, and studied the optimal decision-making method of new energy investment.

3.Through the establishment of a mathematical model to analyze the years of investment return of photovoltaic and fan, it is concluded that both of them have a higher investment recovery rate. In addition, the earlier the installation time, the greater the benefit of the planning period.

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