Study on Operation of hybrid Wind-PV-ES power system In East China

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Abstract. The rapid development of wind power and photovoltaic power in East China has gradually eroded the margin of safe operation of the power grid in recent years. A Wind-PV-ES power system evaluation model is established in this paper, It simulates the production process of Wind-PV-ES power system, and the reasonable capacity ratio of scenery of Wind and PV, the reasonable matching plan and coordinated operation of Wind-PV-ES were carried out. This model effectively evaluates the impact and benefits of Wind-PV-ES power system In East China. The ultimate aim is to provide references for future energy structure adjustment in East China.

1. Introduction

The economy in East China has been growing steadily, the demand for energy from socio-economic development has continued to increase, and the development of the energy industry has accelerated in recent years [1]. At the same time, the contradiction between increasing energy demand and the depletion of fossil fuel resources has become increasingly prominent. To alleviate the contradiction, the utilization rate of non-fossil energy sources such as solar energy, wind energy and biomass energy in East China has gradually increased [2]. However, wind and solar power generation is greatly affected by many factors such as climate and geographical location. Unstable output, the Wind-PV abandonment, and disconnection from the grid directly affect the safe and stable operation of the power system. If a certain amount of energy storage facilities are deployed, it can not only effectively promote the application and development of renewable energy in the power system, but also improve the level of safe and stable operation of the power system [3].

Most domestic and foreign researches focus on the operating characteristics of separate power systems such as wind, PV, and storage, or the modeling, simulation, optimization, and control strategies of two energy complementary power systems at this stage. The operation of hybrid Wind-PV-ES power system is lacking in-depth research [4] [5]. A Wind-PV-ES evaluation model is established with the objective of optimizing the present value of the total cost of the power system, in order to explore the coordinated operation mode and reasonable ratio of Wind-PV-ES. The ultimate aim is to provide references for future energy structure adjustment in East China.
2. Operation characteristics of Wind and photovoltaic power

2.1. Operation characteristics of Wind
East China’s coastal areas are rich in wind energy resources, especially the offshore wind power development potential in Jiangsu Province is huge. The seasonal and incomplete random changes in wind speed directly cause the randomness, intermittency and fluctuation of wind [6]. According to the data analysis of 8760h wind power output in East China, Wind power output is greater in winter and slightly less in summer. The average annual output accounted for about 22.9% of the installed capacity. Wind power is mainly concentrated in below 50% section of the output. When the on-grid capacity of wind power is 50% to 60% of its installed capacity, the power generation accounts for about 94.3% to 97.8% of the annual power generation.

2.2. Operation characteristics of photovoltaic power
Due to the topographical differences, the solar energy resources of provinces in East China are different. The overall average annual total solar radiation in summer is higher than that in winter, and the daily distribution of solar radiation is basically similar. For the amount of solar radiation is directly related to the impact of weather, photovoltaic power output in East China also has the characteristics of random, intermittent and fluctuating. Based on the analysis of 8760h photovoltaic power output data in East China, the power output of photovoltaic power in winter is a low-value area, and the power output reach its peak in summer. The photovoltaic power is mainly concentrated in below 50% section of the output. When the on-grid capacity of photovoltaic power is 55% to 65% of its installed capacity, the power generation accounts for about 93.7% to 97.8% of the annual power generation.

![Figure 1. Relationship between on-grid capacity rate and accumulated power of wind](image-url)
Figure 2. Relationship between on-grid capacity rate and accumulated power of photovoltaic

In summary, the relationship between the on-grid capacity ratio of wind and photovoltaic power and the amount of power generation is conducive to the rational design of on-grid capacity of wind and photovoltaic, and it can reduce the sending supporting investment.

2.3. Complementary characteristics of wind and photovoltaic

Due to the different geographical condition and environmental climate, the speed of wind and radiation intensity and radiation amount of solar in East China are different, but the overall change trends and rules are still similar.

The average daily output of wind power in East China showed a state of "high morning and evening, low at noon". The output reached the high value of the day at about 0:00 to 4:00 and 19:00 to 23:00, and the output was the low value at 7:00 to 15:00. The overall output of wind power was relatively high from November to April in a year.

The average daily output of photovoltaic power is basically a parabola of "high at noon, no morning and evening". There is a small output from 5:00 ~ 6:00, then reaches the maximum value of the day from 11:00 ~ 13:00, later gradually decreases after 13:00, and after 19:00 The output is basically reduced to 0. The overall output of photovoltaic power was relatively high from July to October in a year.

The relationship curve between the on-grid capacity and the cumulative power of wind and photovoltaic power in East China is shown in Figure 3. As can be seen from the figure, if only wind power is taken into account, the on-grid capacity is considered as 55% of the installed capacity, the on-grid power accounts for 96.4% of the total power; if only photovoltaic power is taken into account, the on-grid capacity is considered as 55% of the installed capacity, the on-grid power accounts for 93.7% of the total power; if the wind and photovoltaic power is taken into account, the on-grid capacity is considered as 55% of the installed capacity, the on-grid power accounts for 99.4% of the total power.

It shows that wind and photovoltaic have a certain complementary role. After integrating wind and photovoltaic power into the power grid, it can reduce the overall output fluctuation, reduce the impact on the power grid, and improve the utilization of capacity and electricity of wind and photovoltaic power.
3. Study on Proportion and Operation of hybrid Wind-PV-ES power system

3.1. Evaluation model of hybrid Wind-PV-ES power system

Firstly, the power supply planning of the East China Power Grid is studied, and the reasonable allocation scale is solved. The Wind-PV-ES ratio obtained on this basis is the ratio of various types of power sources interacting together, then some additional wind and photovoltaic power capacity are added, and the research the storage capacity. At this time, the ratio of the increased Wind-PV-ES power capacity can be considered as a reasonable ratio in East China Power Grid.

In order to avoid the influence of other factors, based on the characteristics of Wind-PV-ES system, a pure operation model of Wind-PV-ES system was established to analyse the coordinated operation mode under different conditions of ratio.

3.2. The simulation results

Through the simulation analysis of Wind-PV-ES increment optimization model, it can be known that when the reasonable ratio of Wind-ES is 3:1~3.4:1, the present value of the total cost of the power system is in a low range during the calculation period; the new part of photovoltaic power generation will not increase the consumption burden of East China Power Grid. From the point of view of meeting the demand of the power system, there is no need to increase the energy storage capacity.

| Project | Total capacity of Wind-PV | Capacity of wind | Capacity of PV | Capacity of ES | New ratio of Wind-ES | Annual coal consumption | Present value of total cost |
|---------|---------------------------|-----------------|---------------|---------------|---------------------|------------------------|---------------------------|
| Option 2 | 128000                    | 54000           | 74000         | 43300         | /                   | 32726                  | 42675                     |
| 1       | 70667                     | 77333           | 48910         | 6            | 3:1                 | 31668                  | 42080                     |
| 2       | 70000                     | 78000           | 48510         | 6.1           | 3:1:1               | 31685                  | 42089                     |
| 3       | 69000                     | 79000           | 48310         | 6.1           | 3:1:1               | 31709                  | 42103                     |
| 4       | 67333                     | 80667           | 47310         | 6.1           | 3:1:1               | 31751                  | 42127                     |
| 5       | 14800                     | 64000           | 84000         | 46510         | 3:1:1               | 31828                  | 42173                     |
| 6       | 60667                     | 87333           | 45510         | 3:1:1         | 3:1:1               | 31907                  | 42219                     |
| 7       | 59000                     | 89000           | 44700         | 3:1:1         | 3:1:1               | 31948                  | 42243                     |
| 8       | 58000                     | 90000           | 44510         | 3:1:1         | 3:1:1               | 31972                  | 42257                     |
| 9       | 57333                     | 90667           | 44100         | 3:1:1         | 3:1:1               | 31989                  | 42267                     |
Table 2. Present value of power system cost of East China Power Grid in 2030
(Reasonable proportion of PV-ES)

| Project  | Total capacity of Wind-PV | Capacity of Wind | Capacity of PV | Capacity of ES | New ratio of PV-ES | Annual coal consumption | Present value of total cost |
|----------|---------------------------|------------------|----------------|----------------|-------------------|------------------------|---------------------------|
| Option 1 | 128000                    | 54000            | 74000          | 43300          | -                 | 32726                  | 42675                     |
| Option 2 | 148000                    | 54000            | 94000          | 43300          | N:0               | 32067                  | 51553                     |
| Option 3 | 168000                    | 44000            | 114000         | 43300          | N:0               | 31407                  | 61273                     |

Through the simulation analysis of the pure Wind-PV-ES operation model, it is known that when the capacity ratio of Wind-ES is about 3:1, the total capacity or total investment of the system is in the low value range; when the capacity ratio of PV-ES is 5–7:1, the total capacity or total investment of the system is in the low value range.

Figure 4. The influence of the change of the ratio of Wind-ES on the total investment

Figure 5. The influence of the change of the ratio of PV-ES on the total investment
Figure 6. The influence of the change of the ratio of Wind-PV-ES on the total investment

Based on the analysis results of the increment optimization model and the pure Wind-PV-ES coordinated operation model, it is suggested that the reasonable proportion of Wind-ES in East China is about 3:1, small-scale photovoltaic power generation does not need to be specially equipped with energy storage facilities, and the reasonable proportion of large-scale PV-ES is 5~7:1.

4. Conclusion
The evaluation model of Wind-pv-es is established with the goal of optimizing the present value of the total cost of power system, the reasonable proportion and coordinated operation mode in East China are studied. The research results show that by controlling the reasonable on-grid capacity rate of wind and photovoltaic power and reasonably arranging the operation mode of the power according to the recommended ratio, the new energy consumption capacity in East China can be improved and the safe, stable and economic operation of the power system can be promoted.

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