Evaluation Method of the Spatial-Temporal Complementary Characteristics Between Power Source and Load Based on Power Big Data

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Abstract. With the rapid development of the intermittent renewable energy power generations such as wind power and solar power and the new random load such as EV, the double randomness become a great threat the safe and stable operation of power system. It has become a hot issue raised increasingly concern from the academic and engineering fields that how to reduce the randomness and volatility of the two sides of the system by utilizing the spatial-temporal complementary characteristics of different energy resources and loads. In this paper, the evaluation model of complementary characteristics between power and load across time and space based on the Power Big Data theory is proposed. By simulating the complementarity of the power supply and load between Northwest China and European load centres from three dimensions: load-load complementarity, source-source complementarity and source-load complementarity, it proves there are great complementary benefit by interconnecting the grids with different regions across continents, which provides a theoretical basis for the next implementation of the Global Energy Interconnection.

1. Introduction
As a clean, efficient and convenient secondary energy, electricity plays an increasingly important role in promoting energy transformation in different countries. The Global Energy Interconnection (GEI) is aiming to connect different countries and continents with UHV power grid and clean energy and lead to the optimal allocation of global energy resources, which is an important strategic concept for global energy transformation, and which has been widely recognized internationally and is now entering the stage of strategic implementation [1, 2]. The principle of power system balance is to adjust the output of conventional power sources to track load changes in order to maintain dynamic balance. However, with the increase of dual randomness and fluctuation on both sides of source (such as wind and PV generations) and load (such as EV), how to maintain the real-time dynamic power balance under the influence of bilateral randomness has become a worldwide problem [3, 4].

The spatial-temporal complementarity of different energy resources and loads can reduce the randomness and volatility of both sides of the power grid, and improve the stability and comprehensive benefits of the system. There have been many literatures proposed relevant methods for how to use the complementary characteristics of wind power and photovoltaic to smooth the fluctuation of power output by bundling new and traditional energy sources, and to use the complementary characteristics of load to reduce the adverse impact on power system by using demand side management to cut peak and fill valley [5, 6]. However, these methods do not take into account...
the complementary optimal allocation of RE and load in a wide area and global time differences. With the continuous advancement of the GEI Strategy, the characteristics of source-load complementarity across countries, regions and even continents need to be studied in depth.

2. Methodology

2.1. Spatial-temporal complementarity

In this paper, the complementarity mainly refers to the spatial-temporal correlation between power generation of RE, and the loads in different regions. Renewable energy itself has good spatial-temporal complementarity in a wide area. If this complementarity would be utilized sufficiently, it can effectively alleviate the negative impact of intermittent and instability of VRE on power grid [7-9]. The spatial-temporal complementarity, breaking through national boundaries and time-zone constraints, conforms to the characteristics of global power generation resources and loads under the background of GEI [10].

Considering it need tremendous data to depict the characteristics of power source and load, a technical processing including statistics, identification, clustering and prediction of the wind power and photovoltaic power is necessary. Moreover, the characteristics changes on both sides of the power source and load are closely related to meteorological systems, in addition, statistical analysis of data in many fields involving different countries and regions inevitably results in inconsistent or even missing data, which needs to be fitted according to local historical data and future development trends, and classified according to unified standards. Therefore, the basic data of source and load can be aggregated to the cloud through the big data acquisition technology by using the big data theory. The complementary indexes of each scheme can be calculated by the big data visualization technology, the big data analysis and the front technology analysis. The real-time optimization and rational allocation of energy resources can be realized by combining the multi-energy flow complementary control technology [11, 12].

2.2. Complementary evaluation method

The correlation coefficient is the quantity used to measure the degree of association between two random variables. The weaker the degree of association, the smaller the value, which means that the complementarity is stronger. The formula is as follows:

\[
R_{XY} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}
\]

(1)

where \( R_{XY} \) is the correlation coefficient, \( X_i, Y_i \) are the time series at time scale interval \( i \) respectively, \( \bar{X}, \bar{Y} \) are the average value of the time series \( X_i \) and \( Y_i \).

The fluctuation of the time series can be described as the difference between adjacent time intervals \( \Delta P(t) \), which is calculated as follows

\[
\Delta P(t) = P(t) - P(t-1)
\]

(2)

where \( P(t) \) is the output or the load in the time period \( t \).

Smoothing effect coefficient \( S \): which is based on standard deviation of power generation sequence (normalized by installed capacity).

\[
S = \frac{\hat{\sigma}_{\text{single}} - \hat{\sigma}_{\text{cluster}}}{\hat{\sigma}_{\text{single}}}
\]

(3)

where the \( \hat{\sigma}_{\text{single}} \) and \( \hat{\sigma}_{\text{cluster}} \) are the indices to quantify the smoothness of the wind output fluctuation of the cluster field relative to single field.
3. Evaluation Model

The spatial-temporal complementary analysis model is mainly aimed at smoothing the fluctuation of VRE and load through wide-area cross-temporal complementary effect, reducing the randomness of both sides of the system, thus improving the efficiency of safe and stable operation of the system and the benefit of power investment. The model is mainly analysed from the three dimensions of "load-load complementarity", "source-source complementarity" and "source-load complementarity", as shown in figure 1.

![Evaluation model of spatial-temporal complementary between power source and load.](image)

Load-load complementarity: firstly, it is need to forecast the electricity consumption and maximum load of the target region in the future according to the factors such as population, GDP level, industrial structure, electricity consumption per capita. Secondly, it is need to simulate the future load curve according to the local historical curve, combined with changes in its industrial structure and utilization mode, and get some important information such as the maximum and minimum loads and peak-valley differences at different time scales (year, season, month and day). Finally, comprehensive analysis is focused on load fluctuation, peak-valley characteristics, seasonal complementarity and annual complementarity.

Source-source complementarity: firstly, it is need to statistic the natural characteristics and variation rules of the different RE resources in different time scales (hours, seasons, years), then simulate the power output of different RE generation based on the typical unit model, and the different RE generation power characteristics within different time scales (hours, years) are established. Secondly, based on the statistical characteristics of power big data, the characteristics of RE power generation output can be simulated considering the external factors such as climate conditions, topography, grid-connected conditions and technology maturity in different regions. Finally, the complementary characteristics analysis is focusing on the fluctuation of output, the hours of power generation utilization, and the penetration of RE, etc..

Source-load complementarity: based on the analysis of load-load complementarity and source-source complementarity, and considering the impacts of RE grid-integrated and the interaction...
mechanism between local source-grid-load is considered as well, the comparative analysis of source-load coordination among the different RE in different regions is done based on the power big data theory. Focusing on the performance of source-load complementarity among regions in improving RE permeability and reducing peak-valley difference, and comprehensive complementary evaluation is carried out.

4. Case Study

Considering the GEI strategy, the distribution and characteristics of RE resources in China, the northwest China and the European region represented by Britain, France and Germany are chosen to make the case analysis of cross-regional source-load complementarity.

4.1. Load-load complementarity

The typical daily load curves of Northwest China and European Centres are selected for complementary case study. Considering the economic and social development, the increasing proportion of electricity used in high-capacity industries, the perfection of electricity market mechanism, and the popularization and application of demand side management, it could be expected that the annual load of Northwest China and European Centres will be slowed down with the seasonal variation, the seasonal imbalance rate will be increased, and the daily minimum load rate and daily imbalance rate will be increased. Based on the historical load curves of Northwest China and European Centres, the load characteristics are analysed by network fitting simulation according to the statistical characteristics of power big data theory. The results are shown in figure 2. After interconnection, the load curves are more stable and the peak-valley difference is significantly reduced. According to the current load level, 5GW power generation and about 20 billion RMB of investment can be saved.

![Figure 2. Daily load complementary characteristics between China and Europe: a) summer; b) winter.](image)

4.2. Source-source complementarity

Northwest China is one of the most abundant areas of RE resources in Asia, and there have been several tens of gigawatt RE generation bases, the potential for future development is also enormous. On the basis of fully complementarity of local power supply, it is of tremendous benefits by interconnecting the power grids across continents using the 7-8 time zones between China and Europe, which can not only better meet the demand of power consumption between the two places, but also greatly reduce the fluctuation and randomness of wind power.

The characteristics of the combined output considering the wind and PV complementarity before and after the interconnection between China and Europe are shown in figure 3. The PV output period is all-day, and the maximum output is 17:00-19:00 Beijing time; the wind power output is generally large at night and small at noon, and the distribution of wind power and PV power output sequence is complementary. Comprehensive analysis shows that the interconnection of power grids between China and Europe can effectively reduce the fluctuation and randomness of RE generation, and increase the utilization hours of power generation, RE penetration and output assurance rate. Compared with the wind power, the complementary effect of solar power generation is more significant.

![Figure 3. Combined output characteristics between China and Europe: a) before interconnection; b) after interconnection.](image)
4.3. Source-load complementarity

From the analysis of load-load and source-source complementarity separately, China and Europe have great complementary potential after interconnection. Based on the principle of energy near utilization, the output curve of RE generation is deducted from the local load curve firstly to form the new curve, then the complementary effect of source-load is measured by comparing the extreme value and the standard deviation of the difference of new curve before and after the grid interconnection.

As shown in table 1, compared with the independent operation of two regional power grids, the extreme value and standard deviation of the difference of source-load characteristics can be greatly reduced by interconnecting the two regions, which makes the output characteristics of RE output and load characteristics curve better coordinated, to accommodate more RE, and reduces the reserve capacity for peak-valley load regulation. According to the formula (3), the Smoothing Effect Coefficients $S$ of China and Europe are 0.48 and 0.67 respectively, which indicates that the fluctuation of wind and PV output is greatly reduced after grid-interconnection.

Table 1. Complementary characteristics of power and load between China and Europe

|                  | Max Source-load Difference | Min Source-load Difference | Standard Deviation |
|------------------|----------------------------|----------------------------|--------------------|
| China            | 0.52381                    | 0.00318                    | 0.1626             |
| Europe           | 0.66309                    | 0.03767                    | 0.2568             |
| China-Europe     | 0.23252                    | 0.06841                    | 0.0848             |

5. Conclusions

In view of the expanding scale of the power system and the increasingly prominent fluctuation and randomness problems from the load side and power supply side, this paper proposes the evaluation model of complementary characteristics between power and load across time and space based on the Power Big Data theory. By simulating the interconnection of Northwest China and European load centres, it proves that China and Europe have great potential of complementarity from three dimensions: load-load complementarity, source-source complementarity and source-load complementarity, which provides theoretical basis for the implementation of the Global Energy Interconnection strategy in the next step.
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