Research on the Ability of Regional New Energy Consumption Based on the Coupling Coefficients of Time-series

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Abstract. In this study, a method for the investigation of the available capacity of new energy based on the time-series coupling coefficients of the combination of regional wind power, photovoltaic and load was proposed, with the aim of getting an in depth understanding of the regional new energy consumption capacity, and a more accurate amount on the regional potential installation capacity. The typical scenario of new energy high output in the area was determined based on the historical measured power and load data, and the time-series coupling coefficients of the combination of wind power, photovoltaic and load in the area were summarized. The regional new energy consumption capacity and the potential installation capacity for the next three years were quantitatively calculated based on the time-series coupling coefficients. The accuracy and reliability of this method compared with traditional methods were analyzed.

1. Introduction

With the depletion of traditional non-renewable energy sources and the increasingly ecological and environmental problems brought about by them, the development and utilization of new energy has become a key means to solve global energy problems [1-2]. Wind power, photovoltaic and load have certain randomness and periodicity [3-4]. The analysis of typical scenarios of power systems containing wind power and photovoltaic has great significance for accurately assessing the capacity of regional new energy consumption.

At present, domestic and foreign researches on the analysis of new energy consumption capacity mainly focus on qualitative analysis, and there is little researches on quantitative calculations. Quantitative calculation methods are mainly divided into two categories: no restriction on new energy output at all or a small amount of restriction on them. At present, domestic new energy power generation cannot be fully consumed, which has made it become an inevitable trend to allow a small amount of new energy output to obtain greater consumption capacity [5]. At present, the commonly used analysis methods are the typical day method, the stochastic production simulation method [6-11] and the sequential production simulation method [12-14]. The sequential production simulation methods are based on the actual wind power, photovoltaic output and load sequence, which are relatively accurate in short-term forecasting, but there are still large errors in the medium and long term.

This paper obtains the historical new energy consumption situation and the coupling coefficient of each key consumption factor in typical scenarios by analyzing the multi-year wind-light-load time series output data of the regional power grid, which has important engineering value and reference
significance for accurately analyzing the new energy consumption capacity of the region in the next few years.

2. Research on wind power - photovoltaic -load time series coupling coefficients based on historical data of regional power grid

2.1. Research method
According to the principle of power balance calculation, when the power output of a 220kV district grid is greater than the load level of the area at the same time, the surplus power is sent out through a higher voltage transformer or 220kV tie line.

\[ P_y = P_w + P_s + P_t - L \]

\( P_y \), regional delivery power; \( P_w \), wind power output; \( P_s \), photovoltaic output; \( P_t \), traditional power output; \( L \), load.

The characteristics of regional wind power output and photovoltaic output mainly depend on regional climate conditions, which is considered that there will be little change in a few years. The regional load level is determined by the economic development, and the load time series characteristics are determined by the economic structure. In the short term, the load level is considered to increase year by year, but the time series characteristics change little.

By referring to the time-series coupling characteristics of historical years, the regional delivery flow in the planning years is studied.

\[ P_y = S_{ng} \times N_{nx} + S_{tg} \times N_{tx} - L_g \times N_{lx} \]

\( S_{ng} \), the planning scale of new energy installations; \( N_{nx} \), the current new energy output coefficient; \( S_{tg} \), the planning scale of conventional machine; \( N_{tx} \), the current output coefficient of conventional machine; \( L_g \), the maximum planned annual load; \( N_{lx} \), the current load factor.

Through statistical analysis of the regional delivery flow data, the most serious typical scenario of the planned year's delivery flow is obtained, and the power output coefficient and load coefficient of the scene are also obtained.

2.2. Data sampling
(1) Sampling range
   a) New energy: Using sampling method, select typical power stations as representatives to obtain the output characteristics of wind power and photovoltaic in the area.
   b) Load: regional grid load.
   c) Conventional power: The conventional machines with large capacity in the regional power grid are counted.

(2) Sampling year: 2017, 2018, 2019.
(3) Sampling time interval: 5min.

2.3. Analysis of new energy output and load characteristics
The statistical analysis of the new energy output characteristics of Huai’yan Power Grid shows that the probability distribution of wind power and photovoltaic output in the city from 2017 to 2019 is highly similar, and the statistical characteristics of annual and daily power output are consistent. The city's load probability distribution is basically a normal distribution, and the interval where the maximum probability is located is slightly different in different years.

2.4. Analysis of wind power-photovoltaic-load coupling characteristics
Huai’an Power Grid has a high degree of consistency in wind power output, photovoltaic power output and load from 2017 to 2019. The data of 2018 is taken as a reference to analyze typical scenarios.
Perform statistical analysis on scene data whose outward transmission flow coefficient is higher than 0.4. The data points are divided into two scenes: daytime (8 o'clock to 16 o'clock) and night (17:00 to 7 o'clock).

Scenario 1 (30 hours): In this scenario, wind power output is relatively large, with photovoltaic output at about 70% and load at about 50%, Huaihua power plant and Jianghuai power plant at about 40%, and Huahuai power plant’s output at slightly higher than 30%.

| Delivery coefficient | Outgoing power (MW) | Data points 360 (30 hours) |
|----------------------|---------------------|----------------------------|
| 0.4                  | Wind power Photovoltaic Huairan Guohuai Huahua Jianghua Load |
| Average              | 2265                | 73.27% 77.83% 53.65% 0.22% 35.46% 38.42% 47.24% |
| Max                  | 2918                | 84.83% 99.93% 91.97% 0.22% 48.20% 55.40% 55.91% |
| Minimum              | 1901                | 54.80% 20.71% 29.89% 0.22% 14.65% 9.76% 42.98% |

Scenario 2 (5 hours): In this scenario, the wind power output is greater than 70%, the photovoltaic output is 0, and the load is about 35%. The output of Jianghuai power plant and Huairan power plant vary greatly, and the output of Huahuai power plant is about 40%.

| Delivery coefficient | Outgoing power (MW) | Data points 64 (5 hours) |
|----------------------|---------------------|----------------------------|
| 0.4                  | Wind power Photovoltaic Huairan Guohuai Huahua Jianghua Load |
| Average              | 2004                | 80.36% 0.06% 45.69% 0.22% 42.66% 18.42% 35.32% |
| Max                  | 2164                | 94.76% 3.19% 84.88% 0.22% 48.30% 50.01% 50.41% |
| Minimum              | 1900                | 71.23% -0.01% 38.80% 0.22% 33.14% 9.76% 29.08% |

Scenario 1 has more data points and includes the maximum delivery situation, which is more representative. Therefore, scenario 1 is selected as the typical scene of outward transmission flow. The probability distribution of each variable coefficient in this scenario is shown in figure 1~7.
According to the principle of maximum occurrence, and taking the extreme value of the interval coefficient, it can be seen that the wind power output, photovoltaic output, conventional plant output, and load coefficients are 75%, 90%, 40%, and 45%, respectively, in the most severe scenario of the power flow of Huai'an power grid. Taking into account the actual operating margin, the wind power output coefficient is adjusted to 80%, the photovoltaic output coefficient is adjusted to 90%, and the conventional plant output coefficient is adjusted to 45%.

3. Analysis of Influencing Factors of Installable Capacity of New Energy in Regional Power Grid
The installed capacity of new energy in the regional power grid is mainly affected by factors such as power grid security constraints, power quality constraints, power grid economic operation, and power grid operation management requirements. On the premise that there is no over-limit of the installed capacity of the main transformers of individual 220kV substations, this article only considers the hard constraints of the power grid-grid security constraints: the transmission capacity of the 220kV grid section and the capacity of transformers with higher voltage levels.

4. Case analysis
4.1. Typical scenario calculation methods and calculation results
Calculate the new energy consumption capacity of Huai'an from 2020 to 2022. Huai'an Power Grid includes North, South and Baoying. After analysis, we can see that the transmission capacity of the 220kV grid section in Huai'an is relatively sufficient, and the key factor restricting the consumption of new energy is the capacity of the 500kV Shanghe Substation.
According to the latest load forecast, the maximum dispatched load of Huai’an from 2020 to 2022 is considered in the following table. Conventional plants, wind power, photovoltaic and load factors are all selected as described in 1.3.

Table 3. The load of Huai’an Power Grid (2020–2022)

| Partition     | 2020      | 2021      | 2022      |
|---------------|-----------|-----------|-----------|
| North (MW)    | 2833.94   | 3032.78   | 3735      |
| South (MW)    | 1456.06   | 1557.22   | 1176      |
| Baoying (MW)  | 540       | 570       | 620       |

The scale of new energy capacity increases evenly according to the area’s distribution of new energy, until the capacity of the 500kV transformer reaches its limit. After removing the planned new energy scale in that year, the scale of capacity that can be newly increased in that year can be obtained, the results are shown in the following table.

Table 4. Scale of new energy installations (2020–2022)

| Category | 2020 | 2021 | 2022 |
|----------|------|------|------|
| Planned scale (MW) | 4785 | 4885 | 4885 |
| Installed scale that can be newly increased (MW) | Wind power | 93.5 | 195 | 513 | 1803 |
| | Photovoltaic | 83 | 173 | 456 | 1602 |

4.2. Traditional calculation methods and calculation results

The traditional calculation method takes the summer peak load and winter extreme trough load (30% summer peak load) respectively, regarding that wind power and photovoltaic output are 100%. When the load peaks, unified management plants supply runs at full output. When the load is low, the coal-fired generator is considered based on stopping one unit, and the remaining unit output rate is 60%, and the gas-fired generator is considered based on stopping one unit, and the remaining unit output rate is 70%. For non-unified management power supplies, the power output rate is considered as 30%. The calculation method is the same as 3.1, and the results are shown in the table below.

Table 5. Scale of new energy installations (2020–2022)

| Category | 2020 | 2021 | 2022 |
|----------|------|------|------|
| Planned scale (MW) | 3456 | 3875 | 3972 | 5318 |
| Installed scale that can be newly increased (MW) | Wind power | 4785 | 4885 | 4885 |
| | Photovoltaic | -1320 | -910 | -813 | 5332 |

4.3. Comparative analysis

(1) Under the typical scenario calculation method, the new energy consumption capacity of Huai’an Power Grid has been greatly improved.

(2) Under the traditional calculation method, the situation that new energy is difficult to be consumed mainly occurs in the extreme trough in winter (the load is 30% of the summer load). Taking 2018 as an example, the annual minimum load is 34.6% of the summer peak load, but the
probability that the load is lower than 40% is only about 0.49%, indicating that the traditional winter extreme trough calculation conditions are too strict and the probability of occurrence is too small.

5. Conclusion
(1) Through the analysis of the historical data of the regional power grid, the typical scenario of the largest outward transmission flow of the regional power grid can be obtained.

(2) The wind power-photovoltaic-load timing coupling coefficient obtained based on typical regional scenarios has regional characteristics and is closer to the actual operation of the regional power grid.

(3) The new energy capacity evaluation method proposed in this paper is more accurate and reliable, which can truly reflect the new energy consumption capacity of the regional power grid.

(4) The new energy capacity evaluation method proposed in this paper avoids the complicated calculations of various traditional operation modes such as summer peaks and winter troughs, which is more convenient and faster.

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