Research on New Energy Consumption Capacity Based on Grid Aggregation Model

Shaoxiong Huang*, Jiwen Wang, Zhi Li, Shun Li, Can Wang
State Grid Anhui electric power company, 230001, China

*Corresponding author: huansx0014@ah.sgcc.com.cn

Abstract. In recent years, with the rapid development of wind power, photovoltaic and other renewable energy, the installed capacity of renewable energy in the power system is increasing day by day. When wind power and photovoltaic reach a certain scale, their inherent output intermittence and volatility will seriously affect the stability of the system. Therefore, based on the historical load and renewable energy output of a certain region, the load curve and new energy output curve are given. Based on the power grid aggregation model, the rationality of the regional power planning is evaluated. Finally, based on the evaluation results, the limit of renewable energy consumption capacity in the region is studied. The research results can provide reference for new energy consumption capacity evaluation and power planning.

1. Introduction
China is the first country in the world in terms of installed capacity of wind power and photovoltaic power generation. Wind power and photovoltaic power supply have [1-4] pittance and volatility bring instability to power system dispatching. In addition, voltage, harmonic and other aspects also bring new challenges to the stable operation of power system.

There are many methods to study the capacity of new energy grid connection, and the optimization method and production simulation method are the main two kinds. In order to meet the demand of renewable energy consumption, a new energy generation capacity optimization method is proposed. Each method has its own advantages and disadvantages.

Stochastic production simulation is an algorithm to simulate the dispatching process of power system by considering the fluctuation of power load and the random outage of units due to fault. The algorithm is widely used in cost analysis, unit operation planning and power system reliability analysis in the long-term operation of power system. However, the algorithm has the disadvantage of large amount of calculation [5]. To simplify the calculation, Fourier transform is developed for continuous load curve, and then convolution calculation of continuous load curve after Fourier transform is carried out in frequency domain, i.e. Fourier series method (M26); convolution calculation is carried out after subsection processing for continuous load curve (M27), but after subsection processing, numerical solution is unstable and calculation amount is large. [6] Mulative method is widely used in power system because of its high calculation efficiency and flexibility in dealing with problems. However mulative method is an approximate method, which could not estimate and control the error, especially when calculating the reliability index. The equivalent energy function method [7] can improve the calculation efficiency by replacing the convolution of the continuous load curve by the convolution of the power
function, which is suitable for the stochastic production simulation of the power system with multiple hydropower plants, but it is possible to calculate the reliability index (loss flow probability, LOLP). There are errors. Literature [8] through the preprocessing of historical data. The cluster-forecasting model of typical daily load curve is established by setting the initial clustering center and determining the optimal number of clusters. In reference [9], the autoregressive moving average model was used to describe the wind speed. On this basis, the wind farm output model with high accuracy was obtained by combining the stochastic production simulation of effective capacity distribution (available capacity distribution, ACD), the output of renewable energy is regarded as a negative load to carry out stochastic production simulation.

In this paper, based on the analysis of the factors affecting the consumption of new energy, the aggregation model is used to evaluate the new energy consumption capacity of a regional power grid in 2022 and the power planning results including wind power and photovoltaic power. Based on the evaluation, suggestions are given to improve the consumption of renewable energy in the region.

2. Analysis of new energy consumption capacity

The new energy consumption capacity calculation model must fully consider the operation and output characteristics of various conventional units in the actual power system, including the start-up and shutdown characteristics of the units, the climbing characteristics and the minimum force characteristics of the units. The objective function of the analysis of the new energy consumption capacity is to maximize the new energy consumption or to optimize the economic benefits in the optimization period.

The objective function of new energy consumption is

$$ f = \max \sum_{i=1}^{I} \sum_{n=1}^{N} P_w(t, n) $$

Where: $n$ is the total number of aggregate power grids contained in the system; $n$ is a certain aggregate power grid; $t$ is the total length of dispatching time; $t$ is the simulation time step size; $P_w(T, n)$ is the new energy output of aggregate grid $n$ in time period $T$.

The constraints are as follows:

1. The regional load balance constraint is

$$ \sum_{j=1}^{J} P_j(t, n) S_j(t, n) + P_w(t, n) + L_i(t) = P_l(t, n) $$

Where: $\sum_{j=1}^{J} P_j(t, n)$ $S_j(t, n)$ is the aggregate grid $n$ in the $T$ period $j = 1 L_i(t)$ is the transmission power of the $i$ transmission line in the period of $t$; $P_l(t, n)$ is the power load of segment $t$ of the aggregate grid $n$.

2. The transmission capacity of the line is constrained by

$$ -L_{i,\text{max}} \leq L_i(t) \leq L_{i,\text{max}} $$

Where: $-L_{i,\text{max}}$ and $L_{i,\text{max}}$ are the upper and lower limits of the transmission capacity of the $i$ interconnection line. Set the current reference direction as: the inflow area is square. The outflow area is negative. Therefore, $L_i$ take positive and negative values, and the positive and negative values represent the direction of power transmission.

3. The unit output constraint is

$$ 0 \leq \Delta P_j(t, n) \leq [P_{j,\text{max}}(t, n) - P_{j,\text{min}}(t, n)] \ast S_j(t, n) $$

$$ P_j(t, n) = P_{j,\text{min}}(t, n) S_j(t, n) + \Delta P_j(t, n) $$
Where $\Delta P_j(t, n)$ is the optimized power of conventional unit; $S_j(t, n)$ is the operation state of unit $j$ in time $t$, which is a binary variable. 1 indicates that the unit is in operation and 0 indicates that the unit has been shut down.

(4) The optimal power ramp rate constraint is

$$P_j(t + 1, n) - P_j(t, n) \leq \Delta P_{j,up}(n)$$

$$P_j(t, n) - P_j(t + 1, n) \leq \Delta P_{j,down}(n)$$

The climbing rate of the unit is $\Delta P_{j,up}(n)$ and $\Delta P_{j,down}(n)$ respectively.

(5) The output constraint of heating unit during heating period.
According to the definition of heat supply unit and the actual situation of the development of cogeneration in China, the mathematical models of backpressure cogeneration thermal power unit and extraction steam cogeneration thermal power unit are respectively carried out. There is a linear relationship between the power generation and thermal output of the backpressure cogeneration thermal power unit.

$$P_{BI}(t) = C_{j,b}Q_j(t)$$

$$Q_j(t)C_{j,b} \leq P_{CQ}(t) \leq P_{CQ,max} - Q_j(t)C_{j,v}$$

Where $C_{j,b}$, $C_{j,v}$ are thermoelectric ratio coefficient; $Q(t)$ is thermal output; $P_{BI}(t)$ is output during heating period of back pressure unit; $P_{CQ}(t)$ is power of extraction steam unit during heating period.

(6) New energy constraints output

$$0 \leq P_w(t, n) \leq P_w^*(t, n)$$

In formula (10), $P_w^*(t, n)$ is the output of new energy time series with a certain installed capacity at time $t$.

(7) The unit start and stop times are constrained to

$$0 \leq S_j(t, n) \leq S_{j,max}(n)$$
3. Analysis on output characteristics and load characteristics of new energy

3.1. Analysis of photovoltaic output in a certain area

By the end of 2018, 14 provincial dispatching photovoltaic power stations have been put into operation in the region, with a total installed capacity of 852 MW. According to the distribution of completed photovoltaic power stations and solar energy resources in the region, a photovoltaic power station that has been put into operation is selected as a typical object to study and analyze its output characteristics. Figure 2 shows the monthly output of a photovoltaic power station in 2018.

It can be seen from Figure 2 that the maximum output of the photovoltaic power station is relatively stable, which is maintained above 80% of the installed capacity, and the maximum output from April to September can reach 100%.

![Figure 2. Monthly and monthly output curve of a photovoltaic power station in 2018.](image)

Figure 2. Monthly and monthly output curve of a photovoltaic power station in 2018.

It can be seen from Figure 3 that the maximum output of photovoltaic power station in spring, summer and autumn is close to 80% of the installed capacity. The power generation period is from 7:00 a.m. to 7:00 p.m., and the maximum output value in winter is relatively low. At the same time, the power generation period in winter is from 8:00 a.m. to 5:00 p.m., which is relatively short.

![Figure 3.](image)
3.2. Analysis of wind power output in a certain area

At the end of 2018, there are 20 unified regulation wind farms in the region with an installed capacity of 14307 MW. According to the operation of wind power in the region in 2018, the average utilization hours of wind power is about 2141h. In this paper, a wind farm put into operation is selected as a typical object to study and analyze its wind power output characteristics.

In figure 4 it can be seen that the probability of wind farm installed capacity is less than 10% of rated capacity in 2018, and the probability of wind farm installed capacity is less than 10% in 2018, the average annual output of wind farm is about 24.3%, and the annual utilization hours are 2153 H.

It can be seen from Figure 5 that the typical daily output characteristic curve of wind farm in spring and summer is stable in autumn and winter. The daily output fluctuates greatly in autumn and winter, with higher output in the morning and night in autumn, and lower output in noon and afternoon; in winter, the output is lower in daytime and higher in night. Wind power output have strong randomness, which is closely related to the local real-time wind resources.
3.3. Load characteristic analysis

In 2018, the maximum power consumption load of the whole grid unified dispatching was 17713mw (occurred on August 25). An increase of 69% compared with 16570 MW in the same period of 2017, the minimum load in 2018 was 3641 MW (appeared on February 13). Which decreased by 1017% compared with 4053 MW in the same period in 2017; the maximum peak valley difference in 2018 was 8682 MW (occurred on January 22), 497% higher than 8271mw in the same period of 2017; the average load rate of electricity consumption in 2018 was 7821%. Compared with 7792% in the same period of 2017, it increased by 092 percentage points.

In recent years, during the Spring Festival (February) period, the wind power generation capacity in the peak period (February) and the valley period is the largest, and the wind power generation capacity in the peak period (February) is the largest. During the Spring Festival, the peak valley is large, so it is difficult to adjust the peak load. The thermal power units in the whole network have great pressure to adjust the peak value. During the main flood season, the hydropower generation of the whole network is large, and some thermal power plants cannot fully output due to poor coal quality, so it is difficult to adjust peak load. However, with the four pumped storage units in pumped storage power plant put into operation one after another, the difficulty of peak load regulation has been effectively alleviated. It can be seen from Figure 6 that the maximum load in April, May and October is relatively small. While the maximum load in July and August in summer and November, December and January in winter is relatively large, the trend of minimum load is consistent with the maximum load, and February is the lowest load in the whole year.

![Figure 6. Minimum and maximum load curves of a power grid in 2018.](image)

As shown in Figure 7, the daily load curve of the power grid presents the characteristics of double load peak, and the first load peak mostly appears at 11:00 am. The second load peak appears at 17:00-19:00, and the second load peak in winter mostly appears at 21:00 in the evening. The power load level in summer and winter is higher than that in spring and autumn. According to the statistical data of load in recent years, the double peak characteristics of daily load gradually change from the maximum load at noon to the maximum load at night higher than that at noon.

![Figure 7. Typical daily load curve for four seasons in 2018.](image)
Based on the load characteristics, wind and solar power output characteristics, hydrothermal power output characteristics, and considering the installation of new power sources and load growth, this paper carries out production simulation for 8760 hours in 2022.

In 2022, the predicted maximum load of the region is about 33000 MW. The planned total installed capacity of photovoltaic power will reach 2000 MW. The total installed capacity of wind power will reach 7109 MW; the total installed capacity of thermal power will reach 27580 MW. The total installed capacity of hydropower will reach 22567 MW. There will be another pumped storage power plant with an installed capacity of 1200 MW. The output of the hydropower station is greatly affected by the meteorological conditions of that year. So it is necessary to comprehensively consider the wet season dry season irrigation and rainfall, etc. In this calculation, April May is the wet season, February, March, October December are the dry season, and the rest months are the normal season between the wet season and the dry season.

According to the wind power abandonment rate of 189660 MW*h, the wind power abandonment rate is 189653 MW*h, and the wind power abandonment rate is 7.37 MW*h, which is 189.3% of the total wind power generation in the area.

4. Conclusion

In the process of evaluating the new energy installed capacity in the region, it is found that the planned new energy installed capacity in 2022 is far from reaching the limit of renewable energy capacity of the power grid in the region. In addition, under the background of large-scale new energy access to the grid, it is necessary to study the sensitivity of external power and new energy integration, and increase the consumption of new energy through reasonable external transmission strategy.

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