Analysis of the "neck up" and "tail down" effects brought about by the development of high proportion of renewables

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Abstract. As the proportion of new energy in the power supply structure continues to increase, the supply capacity and adjustment capacity demand of the power system will change greatly, and the net load curve will show the characteristics of "neck" and "tail". In addition, large-scale new energy access has an increasingly significant impact on the safe and stable operation of the power system, and more consideration is given to the power value of new energy in the planning process while ignoring its capacity value, resulting in resource waste and over-investment. Based on the method of the net load persistence curve, this paper analyzes the trend and characteristics of regional supply and regulatory demand of the State Grid Company under the new situation and puts forward an improved ELCC method to analyze the new energy confidence capacity of each region.

Keywords: component; formatting; style; styling; insert (key words).

1. Introduction

With the increasing ratio of renewable energy in the power supply structure, the supply capacity and adjustment capacity demand of the power system will change greatly, and the net load curve will show the characteristics of "neck" and "tail" [1-3]. In addition, the impact of large-scale new energy access on the safe and stable operation of the power system is increasingly significant, and the planning usually considers the electricity value of renewable energy while ignoring its capacity value (that is, electricity from renewable energy is considered in the electricity balance, opposed to the power balance). Against the background of higher penetration of renewable energy, ignoring its capacity value will bring resource waste and over-investment [4-5]. The assessment of the value of new energy capacity is usually described in terms of credibility. Capacity Value (CV) or "credible capacity" is a metric for measuring the contribution of generation capacity to planning reserves and is normally employed by electricity system planners when they assess the reliability of the system from a long-term perspective. For instance, a 200 MW generator with a capacity value of 20% is considered to reliably contribute 40 MW of supporting capacity during the highest "risk" hours that are exposed to the risk of high loss of load probability (LOLP). Those hours are often with the highest net load, which is calculated by the load minus variable generation. The popular method for assessing the CV of renewbale generation, such as wind and solar, is a probabilistic approach based on the well-established LOLP and relevant reliability metrics. Traditional probabilistic methods are usually convolution-based LOLP or Effective Load Carrying Capability (ELCC) [6-9]. Based on the method of the net load persistence curve, this paper analyzes the trend and characteristics of supply and regulatory demand in each region of the State Grid Company and the confidence capacity of new energy in each region based on the improved ELCC method.

2. Confidence calculation method of new energy capacity

2.1 The Methodology of NREL

A reliability model or directly using historic hourly load and renewable energy generation data is normally employed to calculate ELCC. In the capacity expansion model developed by NREL, i.e., ReEDS [10], ELCC is calculated by directly using historic hourly data, because it is relatively easy to implement from the practical perspective, which will be introduced in the following part.This method utilizes load duration curve (LDC) and net load duration curve (NLDC). Figure 1 provides a graphic representation of this methodology. The load duration curve indicates the overall load in a targeted region and is sorted from the hours of highest load to those of lowest load, which is denoted by the blue line. The net load duration curve shows the overall load minus the time-synchronous contribution from renewable energy generators. Then, the obtained net load is sorted from highest to lowest, as displayed by the solid red line. The NLDC(δ), which is further addition of renewable energy capacity addition from the NLDC, can be calculated by net load duration curve minus the time-synchronous electricity generated by an incremental capacity. Similary, the resulting time series is then sorted from highest to lowest, which is denoted by the dashed red line.

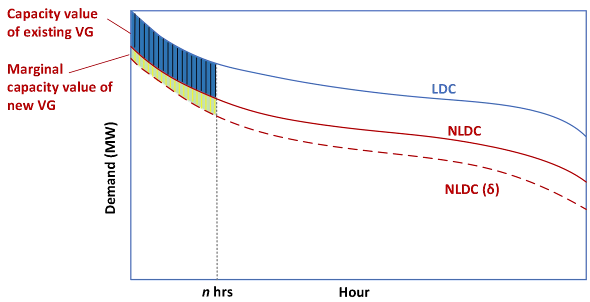


Figure1. Load duration curve (LDC) based approach to calculating CV

The load amount met by the existing renewable energy capacity at the same reliability level is called ELCC. It is calculated as the area difference between the load duration curve and net load duration curve during the top 100 hours of the duration curves (in this case, n is set as 100), as displayed by the blue area in Figure 1. These 100 hours are a proxy for the hours with the highest risk for loss of load, namely loss of load probability. In a similary way, the contribution of an additional capacity for meeting peak load is the area difference between the NLDC and the NLDC(δ), as displayed by the green area. Furthermore, a fractional annual-based CV result, also known as Capacity Credit can be abtained via dividing these areas by the corresponding installed capacity and number of top hours. In other word, the capacity value is treated as the average length of the black solid lines within blue shaded area. Please see Reference [11] for more detailed information.

2.2 The Proposed Improved Methodology

In our method, the distribution of the length of the black solid lines within blue shaded area is taken into consideration, based on which, a capacity value or credible capacity can be given under a certain confidence level.

The original load curve (η) and net load curve (ξ) is denoted by Equation (1).

$$\begin{cases} \eta = L(t) \\ \xi = N(t) \end{cases} \tag{1}$$

The cumulative distribution function (CDF), also known as cumulative probability distribution, of load curve, and net load curve is then represented by Equation (2) and illustrated in Figure 2, where φ is the ratio of n over total hours of the entire year, i.e., 8760.

$$\begin{cases} F(x) = P(\eta \le x) \\ G(x) = P(\xi \le x) \end{cases} \tag{2}$$

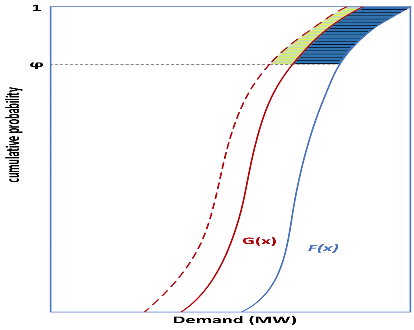
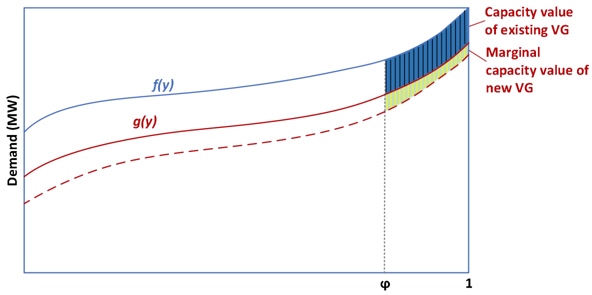


Figure2. CDF of a load curve and a net load curve

The inverse function of F(x) and G(x) are f(y) and g(y), respectively, shown in Figure 3.



Inverse function of cumulative distribution function of load curve and net load curve

The CDF of capacity value or credible capacity is then shown as Equation (3), which reflects the distribution of the length of black solid line within blue shaded area.

$$C_P(x) = P\{(f(y) - g(y)) \leq x, y \in [\varphi, 1]\} \quad (3)$$

where, x denotes the length of black solid line, $x \in [\min(f(y)-g(y)), \max(f(y)-g(y))]$. The inverse function of $C_P(x)$ is $c_p(y)$, and the Capacity Credit under a confidence level (σ) is thus calculated as follows.

$$\bar{c}_p(\sigma) = \frac{c_p(1-\sigma)}{C} \quad (4)$$

where, $\bar{c}_p(\sigma)$ is the Capacity Credit and C is the installed capacity of solar power or wind power. When the σ is set as 100%, the credible capacity corresponds to the minimum length of all the black solid lines.

In order to mitigate the impact that the uncertainty of renewable power and load will have on the Capacity Credit and thus increase the calculation robustness, we currently use massive wind, solar, and load data to calculate Capacity Credit.

Specifically, the Markov Chain Monte Carlo (MCMC) is applied to generate massive scenarios of 1-year hourly production of solar and wind power based on the statistical parameters observed from historic data. Then, the calculation is conducted for each individual scenario, following which, the average is calculated and treated as the general Capacity Credit of wind or solar power in a certain modelling region through multiple scenarios. Regarding the total number of scenarios, it is determined as the number when the convergence is achieved, namely, more scenarios can hardly change the Capacity Credit.

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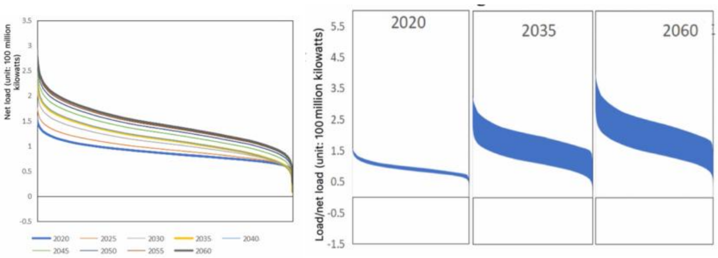
3. Analysis of the effect of "neck up" and "tail drop"

3.1 General characteristics

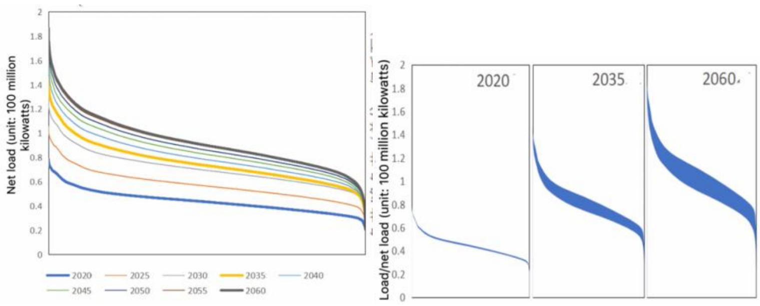
The effect of new energy on reducing peak load is limited, and the maximum net load in each region still maintains growth, showing the characteristics of "neck up", and the pressure to ensure supply continues to increase. For East China and North China in the eastern and central regions, considering the limited new energy resources in the region and the gradual saturation of electricity load, the maximum net load of the two regions will continue to increase by 2035, increasing by 140 million and 120 million kilowatts respectively compared with 2020. 2060 is basically the same as 2035. For the central, western and northern regions, the maximum net load in Central China, Northeast China, Northwest China and Southwest China will continue to increase from 2020 to 2060, and will increase by 81.87 million, 58.46 million, 110 million and 67.41 million kilowatts respectively in 2035 compared with 2020. 2060 will increase by 52.54 million, 32.23 million, 75.84 million and 40.42 million kW respectively compared with 2035.The characteristics of new energy anti-peak regulation are obvious, and the minimum net load value in each region continues to decline and the duration increases, showing a "tail drop" characteristic. After the carbon peak, the northwest, Northeast, East and North China regions drop below 0, and the regulatory pressure continues to increase. With the gradual increase of the proportion of new energy, the characteristics of anti-peak regulation of new energy are more obvious, the peak-valley difference of annual net load continues to increase, and the minimum duration of net load is getting longer and longer. Base-load power supply, waist-load power supply and peak-load power supply in each region [This study defines base-load power supply as having an annual utilization hour of more than 6,000; peak-load power supply refers to the annual utilization hour of less than 1000, and the utilization hour being between 1000 and 6,000.] The scale required and the role of supply adjustment undertaken vary, mainly in three categories, which are described in detail below.

3.2 Category I

The demand for base-load power supply, waist-load power supply and peak-load power supply has increased. Mainly in the central and southwest regions, both of which still have a large space for electricity demand growth, and the conditions of new energy resources are poor. Therefore, in the medium and long term, the shape of the net load duration curve and the load duration curve are still similar, and the new energy supply cannot fully meet the new power demand, so that the demand for base-load power supply, waist-load power supply and peak-load power supply in these two regions is still increasing.



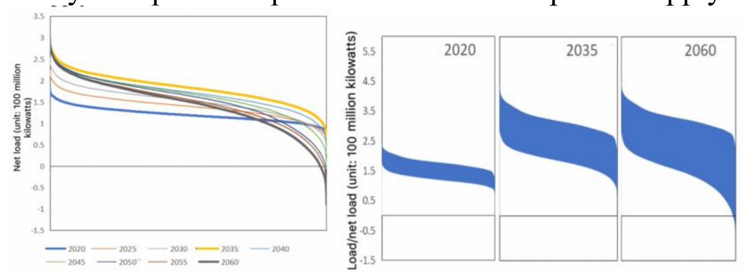
Change trend of continuous curve of net load in Central China



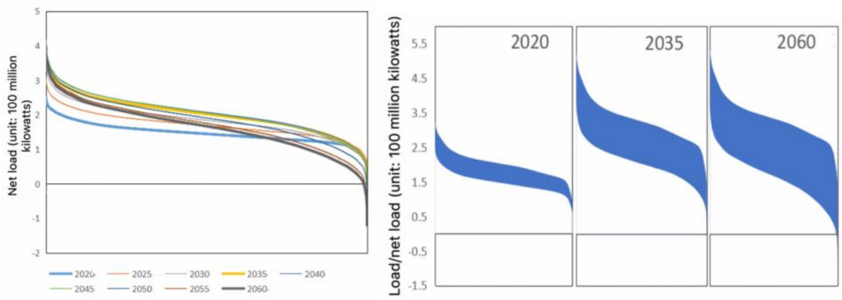
shows the trend of continuous curve of net load in southwest region

3.3 Second category

The demand for base-load power supply is basically unchanged, and the demand for waist-load power supply and peak-load power supply increases. Mainly in North and East China, the new energy in these two regions is mainly distributed photovoltaic and offshore wind power. Therefore, the shape of the net load duration curve in such areas is similar to that of the load duration curve, and the new energy mainly occupies the space of the base-load power supply.



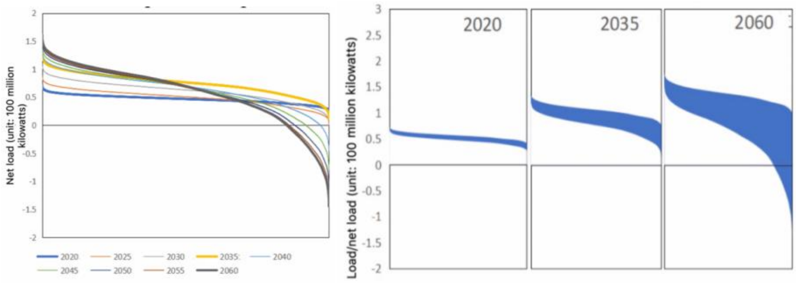
shows the trend of continuous curve of net load in North China



Trend of continuous curve of net load in East China

3.4 Third category

The demand for base-load power supply is greatly reduced, and the demand for waist-load power supply and peak-load power supply is greatly increased. Mainly in the northwest and northeast regions, due to the relatively large proportion of new energy in these two regions, the difference between the tail end of the load duration curve and the net load duration curve increases, and the difference between the two curves shows a "trumpet shape". Therefore, in 2060, the net load duration curve of both regions is less than 0 for thousands of hours, so that the space of base-load power supply and waist-load power supply is crowded, and the demand for peak-load power is still increasing.



shows the trend of continuous curve of net load in northeast China

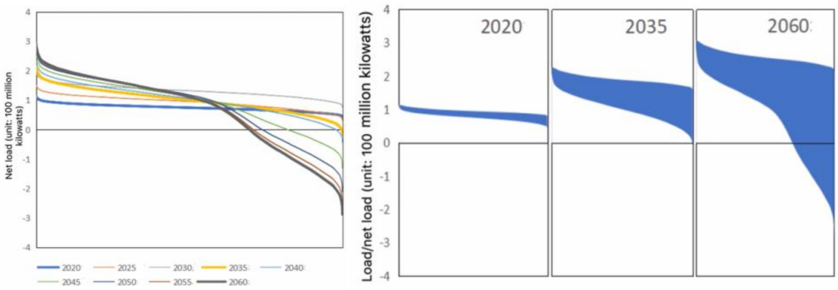


Figure9. shows the trend of the continuous curve of net load in the northwest region

3.5 Reliability of new energy capacity in each region

Wind power capacity credibility by region, at 97% confidence level, "Sanhua" region wind power capacity credibility is 3.5 percentage points higher than other regions. The average reliability of wind power capacity in North, East and Central China is 10.0%, and the average value in Northeast, northwest and southwest (except Tibet) is 6.5%. In recent years, the reliability of wind power capacity in different regions has been shown in the figure.

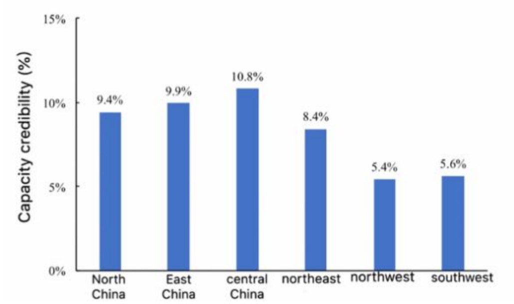


Figure10 Reliability of wind power capacity in different regions under 97% confidence level

Solar power capacity reliability by region, under the 97% confidence level, eastern China has the highest solar power capacity credibility, reaching 13.9%, followed by 12.7% in North China, 9.1% in Southwest China, 6.6% in central China, 3.7% in Northeast China and 0.5% in Northwest China. In 2019, the reliability of solar power generation capacity in different regions of the State Grid operation is shown in the figure.

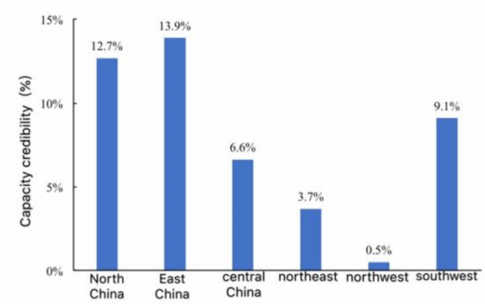


Figure11.97% confidence level of solar power capacity of the State grid operating areas

4. Suggestions on measures to cope with the changing trend of "neck tilt" and "tail drop"

4.1 Suggestions for alleviating the effect of "neck tilt" and "tail drop"

Overall guarantee and new energy consumption, the most economical approach is to be borne by the lowest cost of controllable power supply at different horizontal positions. With the high proportion of new energy connected to the grid, the shape of the net load duration curve changes dramatically. The different horizontal positions of the net load duration curve determine the functional positioning and economic screening criteria of the controllable power supply. Based on the trend of levelized kilowatt cost (LCOE) of various types of power supplies under different level years and different utilization hours, compared with the newly built controllable power supplies in 2035, the utilization hours in that year are less than 1500 hours, and gas power is equivalent to extraction and storage, which is more economical than coal power. The new type of energy storage is far more expensive than pumping storage according to life, and it is not the best choice from the peak load alone.

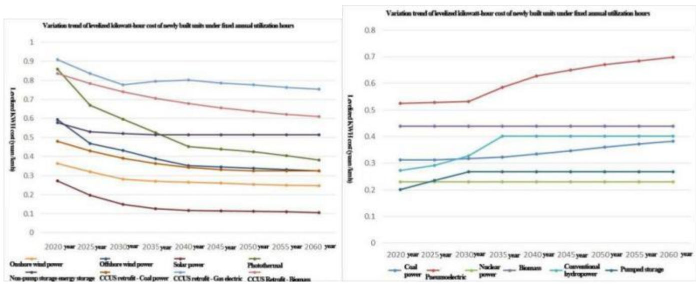


Figure12.The chart shows the trend of the levelized kilowatt-hour cost of newly built units under the fixed annual utilization hours

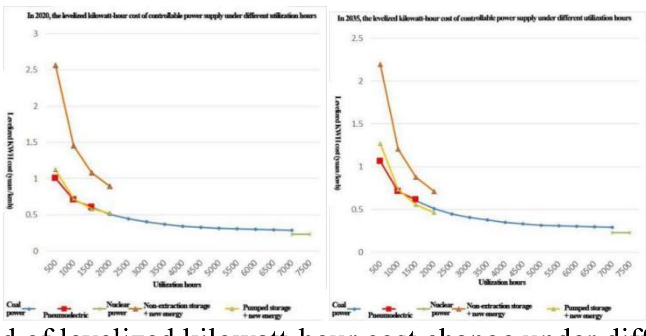


Figure13. shows the trend of levelized kilowatt-hour cost change under different utilization hours of controllable power supply

In the case of each power source performing its own duties, the economy of coal power or nuclear power can also be improved through the "shaping" of energy storage. There is a threshold at which new storage is added, beyond which new storage costs do not lead to greater coal power economics . Although the optimal economic utilization position of coal power is the longest (as shown in the "Trend of levelized KWH cost change under different utilization hours of controlled power supply" chart), the lower the annual utilization hours, the higher the coal consumption and KWH cost. Energy storage "shaping" is not to save coal power, but to absorb new energy, and replace the corresponding power position to coal power, in order to improve the load rate of coal power, so as to improve the economy of coal power.

From the most economic point of view of the system, the net load peak power supply capacity arrangement, in order of increasing cost, is used to improve the base load and waist load power supply economic "shaping" and "passive" energy storage capacity; The second is the confidence capacity of renewable energy, the power capacity of the base load and the adjustable power capacity of the waist load that must be absorbed under the constraint of low carbon. Third, demand-side response capacity; Fourth, other peak power capacity.

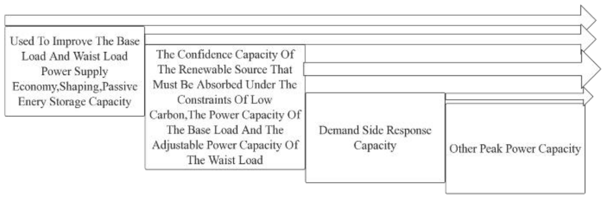


Figure14. net load high peak power supply capacity arrangement

4.2 Proposals to consider the value of new energy capacity in electricity planning

(1) Fully consider the value of new energy capacity in the planning guidelines and planning process. By evaluating the reliability of new energy capacity, the capacity value of new energy can be considered in the planning stage. The reliability evaluation module of new energy capacity can be incorporated into the current power system planning process to realize the power planning considering the value of new energy capacity, which is conducive to reducing the cost of power supply.

(2) Optimize the new energy location and capacity plan with the goal of maximizing the capacity value. The reliability of new energy capacity can be considered at the same time in the planning stage, and the optimal layout of national new energy can be realized by determining the location and capacity of new energy. In addition, the contribution of new energy power generation in different regions to the capacity of the peak load section of the system can be compared horizontally, thus assisting the planning and location of large-scale new energy power generation.

(3) The value of new energy capacity should be considered when determining the system standby capacity. The capacity reliability of new energy describes its contribution to the capacity adequacy of the power system, which is reflected in the load capacity during the peak load period, and provides a reference for the power balance in the planning and the determination of the system backup capacity.

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