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Study on reasonable curtailment rate of large scale renewable energy

Nan Li[1], Bo Yuan and Fuqiang Zhang

State Grid Energy Research Institute Co, Ltd, Beijing, 102209

[1] linanyz@163.com

Abstract. Energy curtailment rate of renewable energy generation is an important indicator to measure renewable energy consumption, it is also an important parameters to determine the other power sources and grids arrangement in the planning stage. In general, to consume the spike power of the renewable energy which is just a small proportion, it is necessary to dispatch a large number of peaking resources, which will reduce the safety and stability of the system. In planning aspect, if it is allowed to give up a certain amount of renewable energy, overall peaking demand of the system will be reduced, the peak power supply construction can be put off to avoid the expensive cost of marginal absorption. In this paper, we introduce the reasonable energy curtailment rate into the power system planning, and use the GESP power planning software, conclude that the reasonable energy curtailment rate of the regional grids in China is 3% -10% in 2020.

1. Introduction

In the past decade, the development of new energy in China was rapid. It plays an important role in promoting the implementation of clean alternative, effectively solving the fossil energy shortage, and meeting the growing energy demand. However, with the rapid development of new energy sources, China's new energy curtailment shows a growing trend year by year. In 2016, the curtailment amount of wind power reached 49.7 billion kWh. The average wind curtailment rate was 17%, and some areas exceeded 40%. The curtailment amount of solar power in the five northwestern provinces was 7.042 billion kWh, with the curtailment rate amount to 19.81%. High curtailment rate of new energy seriously reduces the utilization of new energy, and may affect China to achieve the targets to control the greenhouse gas emissions.

In different districts, at different time, the reasons of new energy curtailment may vary a lot [1-5]. If the curtailment is mainly due to the local supply surplus or power transmission restrictions, in this case, the reduction of renewable energy output is not the best choice, because through the system upgrade, reasonable scheduling, the development of negative electricity prices can be a good way to solve this problem. But if the curtailment only occurs in a specific situation, the situation is quite different. For example, most of California's renewable energy curtailment occurs in the spring because of the low spring load demand, the large output of water and strong wind [6]. Due to the anti-peaking characteristic of wind power, a small number of peak output of wind power mostly occur at the period of valley load, conventional powers have to reduction more output to absorb wind power spikes, in this case the system operating safety and economy are not guaranteed. From this point of view, in a system with high proportion of new energy, in the period of valley load, appropriate reduction of wind power output can reduce the peaking demand and to improve the operating efficiency of the entire system. At present, some scholars have been aware of this problem [7-8].They considered reasonable curtailment of wind power when researching wind power operation. However, if we consider reasonable curtailment only in the operational level, the economic benefits will be limited. We must start from the planning level, to achieve the maximize efficiency.

This paper introduces the reasonable curtailment rate into the power system planning, explores the reasonable curtailment rate that guarantees system to operate economically and safely. The power system planning software GESP is used in the power system planning and design. It is allowed to abandon a certain marginal power of new energy. Reasonable curtailment is reflected to the planning process to avoid the increase of expensive marginal cost of the peak in the power system. It should be noted that, the reasonable planning curtailment rates vary in different regions due to the discrepancy in the resource situation, power structure and load characteristics. This paper takes a regional power grid in China in 2020 as an example for the algorithm validation, the results can provide a reference for the power system planning.

2. Curtailment adjustment of new energy

In order to meet consumption and transportation of the large-scale new energy, it is needed to efficiently coordinate of various types of power resources. From the load side, the new energy power is equivalent to a negative load, so the net load is reduced, especially the reduced valley load puts forward higher requirements. Even when solar energy is installed too much, the original lunar peak may become a valley of net load, such as California's "duck curve" [9]. In this case, solar power meets a large part of the electricity demand during the day, power system operators only need to deploy a small part of the power, but in the evening, with the late peak, the photovoltaic output is reduced to zero, the net load will rise rapidly. Therefore, during the daytime, when the net load is at valley periods, appropriate consideration of solar energy curtailment will reduce the harsh power requirements of the peaking power, improve the system operating economy.

The literature [10] is based on an interview with the US National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL) and the California Electricity Dispatching Center (CAISO), believing that to abandon moderate new energy sources is considered acceptable. Because this strategy provide more flexibility for the power side to adapt to load changes. Of course, if the abandon new energy is above this threshold, that means the system is lack of flexibility, than need to take more measures to maintain the effective operation of the power system.The role of the new energy curtailment adjustment is fairly similar to the demand side response. The latter adapts the load to the power output by adjusting the time and demand of electricity, and the new energy adapts itself to the load scale from the power side by lowering the output at the load trough [11].

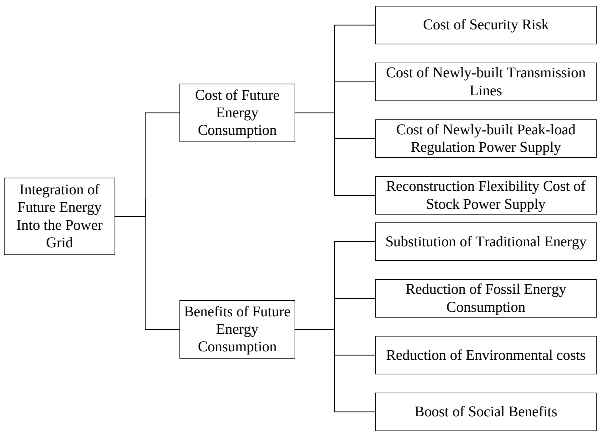

Figure 1. The impact of grid-connection new energy integration on system cost.

In fact, energy curtailment rate (EAR) can be divided into running EAR and planning one. Large scale operation of new energy integration will increase the uncontrolled output of power system, and affect the power system plan. Wind power, for example, the efficient use of wind power will reduce the operating costs of the whole system, decrease fossil energy consumption, and increase energy efficiency. However, in order to accommodate wind power, it may need to construct peaking power sources of higher flexibility or conduct the flexibility renovation of power stock. If the local load consumptive ability is limited, it also needs new construction or expansion of transmission lines. In addition, the security and stability of the system need to be considered too. Figure 1 shows the impact of new energy on system cost.

Considering the new energy consumptive cost and consumptive benefit, 100% new energy consumption in the power system planning is not necessarily the most economical choice. If a reasonable curtailment rate is found, thus we moderately discard some wind at load trough, which can reduce or delay the construction of peaking power and transmission line, and on the premise of assuring the almost full use of the new energy, improve the safety and economy of the power system. The corresponding rate here is the planning reasonable curtailment rate. The planning reasonable curtailment rate is the planning rate where marginal cost equals the marginal benefit in new energy consumption when the equivalent system load containing new energy is determined.

3. The calculation method of the planning reasonable curtailment rate

3.1. The idea of power system planning considering the planning reasonable curtailment rate

Using the optimal planning calculation by setting different levels of reasonable curtailment rate in the planning, we can get the total cost of power system in the planning period. Comparing the results obtained above, we can attain the planning reasonable discard rate at the lowest total cost of the system, which is shown in figure 2.

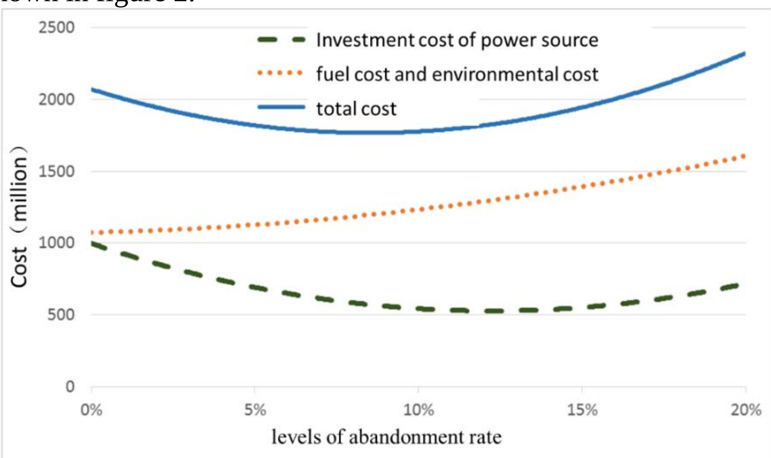

Figure 2. System cost under different levels of curtailment rate.

3.2. The calculation of the planning reasonable curtailment rate

The reasonable curtailment rate during the planning period is the rate corresponding to the minimum total cost of the system in the case of satisfying the system demand. The specific practice is to adjust the net load timely in the planning according to the installed power capacity and output of the wind power stations and PV plants, and manage conventional power plan and grid plan for the net load, then through a reasonable optimization method, to get optimal planning of the total cost and the corresponding new energy reasonable curtailment rate. The process is shown in figure 3.

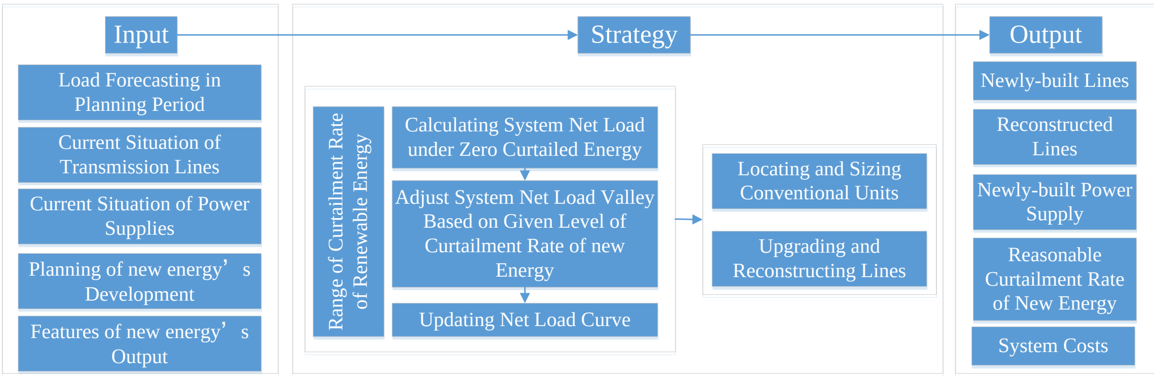

Figure 3. The power system planning process under the rational curtailment rate.

3.2.1. System net load curve processing. In the case of new energy without curtailment, the system load curve can be obtained according to the output characteristics of wind power and solar energy in the original load curve directly deducting the wind and PV output.

Setting λ as the new energy curtailment rate, the abandoned new energy is:

$$Q_c = (Q_{pv} + Q_w) \times \lambda \tag{1}$$

In the formula, Q_{pv} is for the solar energy generation per day, and Q_w for the wind power generation per day. The load curve at the specified level of curtailment rate is formed by adding the amount of abandoned new energy to the bottom of the net load curve of zero curtailment, as shown in figure 4.

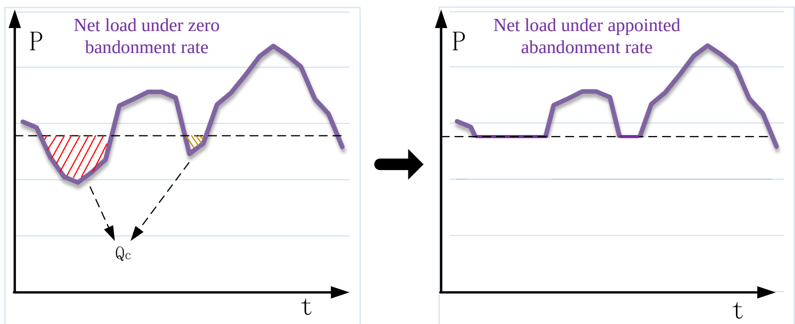

Figure 4. The net load curve at the specific level of curtailment rate.

3.2.2. System investment operation cost calculation. The system cost included in this model are the total investment (I) during the planning period, the residual value (S) of the new fixed assets during the planning period, the fixed operating cost (F), the system variable operating cost (V), the system environmental cost (E), i.e.:

$$\min Z = I_\lambda - S_\lambda + F_\lambda + V_\lambda + E_\lambda (\lambda = 1\%, 2\%, \cdots, \lambda_{\max}) \tag{2}$$

In the formula, λ is the new energy curtailment rate.

(1) The total investment during the planning period

$$I = \sum_{t=1}^{TY} \frac{1}{(1+r)^t} \Big[\sum_{i \in new\ plants} K_{ti} \Delta R_{ti} + \sum_{j \in new hydraulic\ constructions} C_{tj} + \sum_{k \in newlines} K_{tk} \Delta R_{tk} \Big] \tag{3}$$

In the formula, *TY* is the total planning year, *r* is the social discount rate; ***I*** is the set of new thermal power plants, nuclear power plants, hydropower stations (including pumping storage), *J* is the collection of new hydropower units, *K* is the set of new transmission line; K_{ti} is the unit capacity investment of the *i-th* power plant in the year of *t*, K_{tk} is the unit transmission capacity investment of the *k-th* new transmission line in the first year of *t*; ΔR_{ti} is the new installed capacity of the *i-th* power plant in the year of *t*; ΔR_{tk} is the new transmission capacity of the *k-th* new transmission line in the first year of *t*; C_{tj} is the total investment of hydraulic construction of the new hydropower plant in the year of *t*(mainly for dam construction).

(2) The residual value of the new fixed assets during the planning period

In the planning period, when the economic life of some newly installed units, hydraulic structures, and transmission lines is not over yet at the end of planning period, it is needed to deduct the residual value of these new fixed assets after the planning period from the total cost of the system.

$$S = \frac{I}{TL}[TL - (TY - \omega + 1)] \tag{4}$$

In the formula, *I* is the cost of capital construction, *TL* is the life of equipment, ω is the investment period of the equipment. The residual value should be deducted from the total investment in the planning period. With this process, the equipment of different life and input time in the planning period can be put together to consider.

(3) The fixed operating cost

The fixed operating costs of the system are proportional to the installed capacity of the power plant and the line and the investment in the hydraulic construction, and independent of the amount of electricity generated. This portion includes the fixed operating costs of the new fixed assets (FN) and the fixed operating costs of the existing fixed assets (FO).

$$F = \sum_{t=1}^{TY} \frac{1}{(1+r)^t}[F_{Nt} + F_{Ot}] \tag{5}$$

(4) The system variable operating cost

The system variable operating cost mainly refers to the unit fuel costs of thermal power, and coal consumption per day of thermal power units is divided into three parts:

1) The part related to power generation.

2) The part related to units' start-up capacity.

3) The part related to units' start and stop fuel.

The coal consumption curve of the thermal power units can refer to the literature [12]. For the available start and stop units, the start and stop capacity of which can be determined based on the system's peaking balance capacity, then combined with the start and stop costs of unit capacity, we can calculate the operating costs increased by units' start and stop.

4. Example analysis

Taking a planning of a region in China in 2020 for example, it is expected in 2020 that the region's social electricity consumption will achieve 524.9 billion kWh, and the maximum load 78.34 million kW. To promote the realization of national strategic objective in 2020 that new energy consumption will accounts for 15%, the planned wind power installation capacity in this region is 34.16 million kW, and the solar power 5.22 million kW.

Multiple scene conditions are constructed according to the load and the output of wind and PV in this region. Because the solar output adopts the typical output curve at sunny day, which changes little over the whole year. For the year of 2020, we use the power planning software GESP, set the level of curtailment rate from zero to 15%, and get the total cost of the system, which is shown in figure 5.

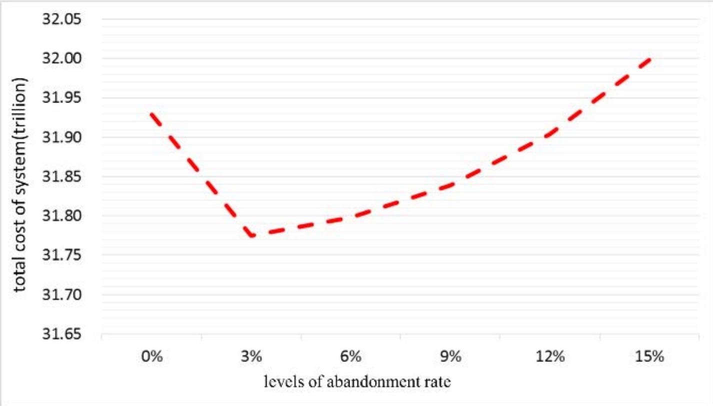

Figure 5. The system costs under different levels of curtailment rate.

As can be seen from the figure, the region's planning curtailment rate in 2020 is 3%. The total system cost is 31.77 trillion. The system net load under a certain operating condition is shown in figure 6.

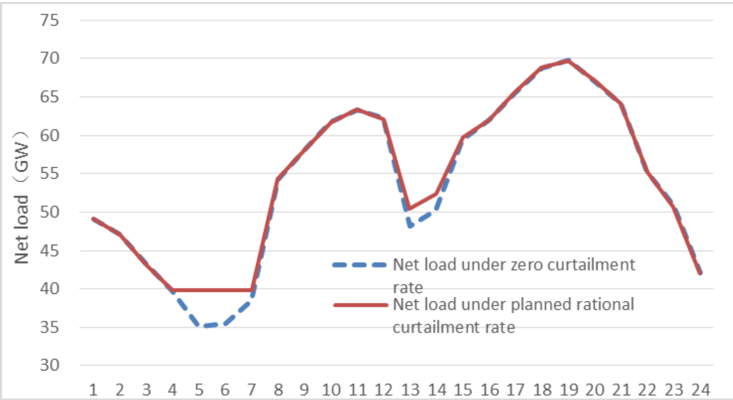

Figure 6. The net load under the rational planning curtailment rate.

On this basis, if the curtailment rate is increased, the peak shunt power investment will reduce accordingly, and fuel cost and environmental cost will go up; on the contrary, if the curtailment rate is reduced, although the environmental costs will decline, the peak power supply investment will ascend and the fuel costs brought by deep peak shaving will rise too.

The same method is used to calculate the reasonable curtailment rate of several other regional power grids in our country. Some of the data comes from the literature [13]. We have obtained a reasonable disposition rate of 3% -10% in each region in 2020. Considering the resource situation, the power structure, the transmission channel and the load characteristics, the planning curtailment rate of the eastern region is relatively low, while that of the western region is relatively high.

5. Conclusions

Moderate curtailment of wind and PV outputs can increase the flexibility of the system, and reduce the peak shaving demand and other ancillary services. Reflecting the reasonable curtailment to the planning level, it is capable to not only effectively save the system flexibility costs, but also improve the over construction of conventional units and power grid, and to particularly avoid the investment of power grids and flexible power supplies when new energy consumption is reduced in a fairly short time only under specific operating conditions. The reduction means the new energy in actual use is less than that in possible use, but in the case of appropriate systems and policies in place, operators can use cuts to actually increase the overall benefits of new energy. The strategic use of reduction requires modern grid infrastructure and supportive regulatory and compensation policies.

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The propose of planning reasonable curtailment rate is complementary to the state's security policy that encourages new energy's generation and grid-connection, that is the force for the power grid companies to purchase the electricity powered by new energy, should obey the power system running characteristics of safety, economy and stabilization. To study the system planning program, we should give full consideration of the overall security and economy of the system, put the reasonable curtailment rate into the planning objectives for the whole consideration, and provides theoretical decision support for the power grid planning and construction.

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