Mechanism of wind power and solar photovoltaic power participation in the electricity spot market considering the guaranteed capacity factor

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Abstract. At present, with the increasing penetration rate of renewable energy in China, it is necessary to consider renewable energy in the electricity spot market. However, wind power, solar photovoltaic power, etc. are the kind of “priority power generation”, which uses the catalogue price for the part of the guaranteed capacity factor and the market price for the rest part. The above two pricing mechanisms need to be coordinated in renewable energy consumption. This paper proposes a mechanism of renewable energy participation in the electricity spot market, which enables renewable energy participating in the spot market as other conventional energy sources under the policy of “priority power generation”.

1. Introduction
In order to promote renewable energy consumption, wind power, solar photovoltaic power, etc. are the kind of “priority power generation” in China [1]. The power production (capacity factor) of wind power and solar photovoltaic power consists of the following two parts, as shown in Figure 1. The first part is the catalogue price part within the guaranteed capacity factor, whose price is determined by every province under the policy of “priority power generation”. The other part is the market price part, whose price is determined in the electricity market [2].

The (annual) capacity factor of renewable is the number of utilization hours. For example, if the renewable power plant generated renewable power by the power of capacity all the year round, the capacity factor is 8760h (the number of all hours in the year). The power production of the capacity factor is all the generated electricity.
As the proportion of renewable energy installed in China continues to increase, the problem of renewable energy consumption in some areas is becoming more and more serious, such as Shandong Province. The current economic and environmental costs of peaking shaving for renewable energy are very high. It has become the norm that the conventional thermal power units of million-kilowatt level start up and shut down frequently for intraday peaking shaving, making the demand that renewable energy participates in the spot market more and more intense.

One reason why the country does not issue wind power and solar photovoltaic power guaranteed capacity factors are the restrictions on wind power curtailment, so the power utility limits the abandonment of wind and power and solar photovoltaic power, such as Shandong Province. The participation of renewable energy in the market will help to use the renewable energy deviation assessment mechanism to collect the deviation assessment fee for renewable energy, which uses to compensate for the frequency regulation and peak shaving cost of thermal power.

This paper proposes a mechanism of renewable energy participation in the electricity spot market considering the guaranteed capacity factor. The proposed mechanism enables renewable energy to participate in the spot market as other conventional energy sources under the policy of “priority power generation”

2. The coordination of renewable energy participation in the electricity spot market and guaranteed capacity factor

The current electricity spot market mechanism does not consider the coordination of the guaranteed capacity factor of renewable energy. The intrinsic reason is that the electricity spot market and guaranteed capacity factor are the concepts of “electricity power” and “electricity production”, respectively. For example, in the beginning stage of the Shanxi electricity spot market in China, renewable energy generators report on the forecast curve of the next day in the day-ahead electricity market, which is considered to be all part of the guaranteed capacity factor. Then, renewable energy in the day-ahead electricity market is still settled according to the catalogue price. The deviation between the actual power generation and the bidding curve in the day-ahead electricity market is settled based on the price in the real-time electricity market.

Since renewable energy is settled according to the catalogue price in the market, all the renewable power production is regarded as the part of the guaranteed capacity factor in Shanxi Province. The result is an increase in the price of renewable energy in the spot market. In fact, it has raised the price of renewable energy in the electricity spot market. Since renewable energy generation is a kind of “priority power generation”, the improper mechanism will affect the revenue of the grid utility or renewable energy consumption. This is also the problem that this paper focuses on.

To simplify the discussion, this paper does not consider the medium and long-term electricity market. The collaboration mechanism between the spot market and the guaranteed capacity factor is
discussed in this paper. After a simple adjustment, the method proposed in this paper is also applicable to the medium and long-term electricity market.

3. The proposed models
In this section, two models are proposed to solve the problem of renewable energy participation in the electricity spot market considering the guaranteed capacity factor. One is the financial contract model and the other is the power decomposition model. The principles of the two models are explained separately and compared.

3.1. The contract for difference model
The contract for difference (CFD) model refers to the establishment of a CFD mechanism for wind power and solar photovoltaic power generation. Renewable energy obtains (annual) CFD guarantee (with government or electricity purchaser) in the electricity market through bidding. The benchmark income of CFD is the actual power generation revenue of renewable energy (including the part within the guaranteed capacity factor income and the part of market price). The market price can use “weighted average market clearing price”). On this basis, renewable energy participates in the electricity spot market competition and gains. Renewable energy reports and all electricity participate in the spot market. In the electricity spot market, wind power and solar photovoltaic power generation are not quoted but are accepted as price (or report “floor price”).

Wind power and solar photovoltaic power generation distinguish between the catalogue part and the market price part in the settlement. The portion of the competitive gains in the spot market (compared to the benchmark earnings) is supplemented by the government or the electricity purchaser. The portion of the profit that exceeds the contract is returned to the government or the purchaser.

3.2. The power decomposition model
The power decomposition model is based on the annual forecast of renewable energy, which is partially decomposed into monthly (weekly). According to the forecast of renewable energy monthly (weekly) and the number of guaranteed capacity factors, the proportion of the amount of renewable energy in the renewable energy of the month (week) is approved. In the day-ahead electricity market, a power curve of the renewable that participates in the spot market is determined based on the forecast results of renewable energy. The renewable energy reports the power production and only the market part participate in the electricity market as a price acceptor (or report "floor price"). The part within the guaranteed capacity factor is directly purchased by the grid utility.

System operators update the completion of the renewable energy guaranteed capacity factor on a monthly (weekly) basis and adjust the proportion of the market price of the renewable energy in the future month (week) plan.

4. Comparison of the two proposed models
In the aspect of “electricity that participates in the market”, “price of the market part” and “completion method of guaranteed capacity factor”, the proposed two models have the following differences. All renewable power production participates in the electricity market. By contrast, only the power production within the guaranteed capacity factor participates in the electricity market in the power decomposition model. In the aspect of “the price of the market part”, all renewable energy weighted average market clearing price is used in the contract for difference model. By contrast, the market-clearing price corresponding to the market part is used in the power decomposition model. In the aspect of “the completion method of guaranteed capacity factor”, contract for difference model uses the settlement in the annual CFD to complete the guaranteed capacity factor. By contrast, the power decomposition model updates the completion of guaranteed capacity factors monthly or weekly.
Table 1. Comparison of the two proposed models.

| The electricity that participates in the market | The contract for difference model | The power decomposition model |
|-----------------------------------------------|----------------------------------|--------------------------------|
| Price of the market part                      | All renewable energy weighted average market clearing price | The market-clearing price corresponding to the market part |
| Completion method of guaranteed capacity factor| One-time settlement in the annual CFD | Monthly (weekly) adjustment based on cumulative completion |

This paper uses an example to explain the proposed two models. Assuming that the number of the actual capacity factor of renewable energy is 2000h (2000 hours) and the number of guaranteed capacity factor is 1500h. In the CFD model, 2000 hours of renewable energy generation participated in the market. At the end of the year, the benchmark income of the CFD is 1500h catalogue price portion and 500h market price portion (weighted average market clearing price). The actual income in the market and the benchmark income of the CFD are settled according to the CFD. In the power decomposition model, the 1500h guaranteed capacity factor part does not participate in the market. The 1500h guaranteed capacity factor part is decomposed to the monthly (weekly) settlement. The 500h market price portion is settled on a monthly (weekly) basis according to the corresponding market-clearing price.

When the proportion of guaranteed capacity factor is the same every month (week) and equals the number of guaranteed capacity factor divide by 8760 (the number of all hours in the year), the result of the power decomposition model is consistent with the result of the CFD model.

The implementation of the CFD model is simple. The disadvantage is that the expected income settlement should be carried out at the end of the year. The power decomposition model implementation process is more complicated, and the advantage is that the expected return can be obtained (received) on a monthly (weekly) basis.

5. Conclusion
This paper focuses on the mechanism of wind power and solar photovoltaic power participation in the electricity spot market considering the guaranteed capacity factor. Two proposed models, i.e., contract for difference model and power decomposition model are proposed and discussed in this paper. Finally, the proposed two models are compared and an example is introduced to explain the proposed two models.

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