The Comparison of Two Settlement Mechanisms in China's Pilot Power Spot Markets

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Abstract. The power market settlement mechanism is the core idea of the market design, and it's one of the most important parts of the power market rules system. This article analyzes the imperfection of the settlement mechanism in some pilot markets, compares two settlement mechanisms, and gives some settlement advice based on system simulation.

Keywords: component; settlement mechanisms; spot market; long-term contract

1 Introduction

Recently, the National Development and Reform Commission and the National Energy Administration jointly issued the "Electricity Spot Market Basic Rules" (Development and Reform Energy Regulation [2023] No. 1217). One of the highlights is the first time in the country to clarify the "full-time optimization" of the power market settlement. The power market settlement mechanism is the overall reflection of market economic relations as well as the core idea of the market design, and it's one of the most important parts of the power market rules system, hence there are many studies with some specific market as the research object and proposing settlement mechanisms advice [1-6]. At present, China's electric power spot market construction has just started, therefore the economic relationship has not gotten sufficient attention, so the spot market design has paid much effort to the market clearing process, which is closely related to the scheduling business. However, the settlement mechanism which is related to the core design of the market and the economic relationship has not received appropriate attention. This phenomenon is reflected in the market rules, that is the settlement mechanism content occupies a very low proportion.

Domestic market construction in various regions mainly adopts the centralized market model, which has full control of all generation decisions and employs locational marginal prices [7]. One of the multiple targets is to reflect the time and locational values of electricity commodities. However, due to the imperfection of the settlement mechanism, the locational signal of market clearing is almost erased.

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The article carries out an analysis of two settlement mechanisms adopted by pilot spot power markets, takes a simulation based on the IEEE 30-bus system and compares the simulation results. Finally, some suggestions on settlement mechanisms are addressed.

2 Research on the settlement model

Generally, there are two kinds of settlement mechanisms in China's pilot power spot markets. The first one settles long-term contracts with full contracts volume, adopted by Guangdong, Zhejiang, Shanxi, Shandong, Fujian, Sichuan and Gansu, although there are some subtle distinctions in the specific formulas. The second one settles long-term contracts as contract for difference (CFD), adopted by Western Inner Mongolia. The article takes Shanxi as a representative of the first settlement mechanism and makes detailed comparison with the one in Western Inner Mongolia market.

2.1 Spot market clearing model

The market optimization model adopts a unilateral bidding model on the power generation side. The following model is designed to minimise operating costs and startup costs,

$$Min \sum_{t \in T} \sum_{i \in I} \left(C(p(i,t)) + C_v^i v(i,t) + C_w^i w(i,t) \right) \tag{1}$$

Where,

$C(P(i,t))$ is the operating cost of unit i at period t,

C_v^i is the startup cost of unit i,

C_w^i is the shutdown cost of unit i,

$v(i,t)$ is the binary startup state of unit i at period t,

$w(i,t)$ is the binary shutdown state of unit i at period t.

And there are many constraints are considered in the market clearing model, including power balance constraints at every node,

$$g^t(p^t, \theta^t) = P_{Gn}^t + P_{Ln}^t + P_{INn}^t = 0 \tag{2}$$

$$P_{INn}^t = F_{nm}^t = \frac{1}{x_{nm}} (\theta_n^t - \theta_m^t) \tag{3}$$

minimum/maximum power production when committed,

$$u(i,t) p^{min}(i,t) \leq p(i,t) \leq u(i,t) p^{max}(i,t) \tag{4}$$

transmission limit constraints,

$$F_{nm}^t \leq F_{nm}^{max} \tag{5}$$

min up and down time constraints,

$$u(i,t) - u(i,t-1) = v(i,t) - w(i,t) \tag{6}$$

ramping constraints.

$$0 \le \delta_+(i,t) \le \delta_+^{max}(i) \quad (7)$$

$$0 \le \delta_-(i,t) \le \delta_-^{max}(i) \quad (8)$$

2.2 Settlement mechanism in Shanxi for generators

In the Shanxi power market, the electricity revenue includes the full volume of long-term contracts electricity revenue, and the spot market partial-volume electricity revenue. Guangdong, Zhejiang, Shandong, Fujian, Sichuan and Gansu are basically following this rule during their settlement except for some subtle distinctions in the specific formulas.

The full volume of long-term contracts electricity revenue for period t is the product of the volume and price of long-term contracts at period t. Hence, the formula for calculating the contract tariff is as follows:

$$\boldsymbol{R_{C,i}} = \sum_{\boldsymbol{t=1}}^{\boldsymbol{T}} \left(\boldsymbol{Q_{C,i}^t} \times \boldsymbol{P_{C,i}^t}\right) \quad (9)$$

Where,

$\boldsymbol{R_{C,i}}$ is the revenue of long-term contracts for unit i at period t,

$\boldsymbol{Q_{C,i}^t}$ is the volume of long-term contracts for unit i at period t,

$\boldsymbol{P_{C,i}^t}$ is the strike price of long-term contracts for unit i at period t.

The spot market partial-volume electricity revenue for period t is the product of the locational marginal price of the unit at period t and the settlement volume on the spot market of the unit at period t, which is the difference between the generation production and the long-term contract volume at period t. Hence, the formula for calculating the contract tariff is as follows:

$$\boldsymbol{R_{S,i}} = \sum_{\boldsymbol{t=1}}^{\boldsymbol{T}} \left(\boldsymbol{Q_{S,i}^t} \times \boldsymbol{P_{S,i}^t}\right) \quad (10)$$

Where,

$\boldsymbol{R_{S,i}}$ is the revenue of spot market for unit i at period t,

$\boldsymbol{Q_{S,i}^t}$ is the settlement volume of spot market for unit i at period t,

$\boldsymbol{P_{S,i}^t}$ is the location marginal price for unit i at period t.

As a result, the total electricity revenue of generation unit i is the sum of $\boldsymbol{R_{C,i}}$ and $\boldsymbol{R_{S,i}}$ in Shanxi power market.

2.3 Settlement mechanism in Western Inner Mongolia for generators

In the Western Inner Mongolia power market, the electricity revenue of the generating units during the spot operation period includes the spot market full-volume electricity revenue, and the long-term CFD electricity revenue. The former is the product of the unit's power generation at period t and the tariff of the node where the unit is located, and the latter is the product of the contracted volume of electricity and the difference between long-term CFD tariff and the customer-side regional settlement reference point tariff.

Hence, during the spot operation period, the electricity tariff of the generating unit:

$$\boldsymbol{R_{G,i}} = \sum_{t=1}^{T} \left(\boldsymbol{Q_{G,i}^{t}} \times \boldsymbol{P_{S,i}^{t}} + \sum_{j=1}^{M} \boldsymbol{Q_{C,i,j}^{t}} \times \left(\boldsymbol{P_{C,i,j}^{t}} - \boldsymbol{P_{R}^{t}} \right) \right) \quad (11)$$

Where,

$\boldsymbol{R_{G,i}}$ is the electricity revenue of the generating unit i,

$\boldsymbol{P_{S,i}^{t}}$ is the spot price at period t at the location of unit i,

$\boldsymbol{P_{R}^{t}}$ is the uniform settlement price for electricity users, as well as the reference price for the long-term contract,

$\boldsymbol{P_{C,i,j}^{t}}$ is the strike price of long-term contract j of unit i at period t,

$\boldsymbol{Q_{G,i}^{t}}$ is the power generation of unit i at period t,

$\boldsymbol{Q_{C,i,j}^{t}}$ is the volume of long-term contract j of unit i at period t.

Since there will be lots of congestion surplus following the above settlement during spot operation, the market has designed an adjustment mechanism to reallocate the congestion surplus.

$$\boldsymbol{R_{CS}} = \sum_{t=1}^{T} \left(\sum_{j=1}^{M} (\boldsymbol{Q_{U,j}^{t}} \times \boldsymbol{P_{R}^{t}}) - \sum_{i=1}^{N} \boldsymbol{Q_{G,i}^{t}} \times \boldsymbol{P_{S,i}^{t}} \right) \quad (12)$$

Where,

$\boldsymbol{R_{CS}}$ is the total congestion surplus for the whole period,

$\boldsymbol{Q_{U,j}^{t}}$ is the volume of consumption for user j at period t.

The total congestion surplus is shared by generators and users according to the ratio of the total volume of electricity generated by power plants and the actual volume of electricity used by power users. The formula is as follows:

$$\boldsymbol{R_{CS,G}} = \boldsymbol{R_{CS}} \times \frac{\sum_{i=1}^{N} \boldsymbol{Q_{G,i}}}{\sum_{i=1}^{N} \boldsymbol{Q_{G,i}} + \sum_{j=1}^{M} \boldsymbol{Q_{U,j}}} \quad (13)$$

Where,

$\boldsymbol{R_{CS}}$ is the congestion surplus shared by all the generators,

$\boldsymbol{Q_{G,i}}$ is the volume of electricity generated by unit i in whole month,

$\boldsymbol{Q_{U,j}}$ is the volume of electricity used by user j in whole month.

The next step is to rebate the $\boldsymbol{R_{CS}}$ to every generation unit according to the volume of electricity it generates, and the difference between generation units' spot market locational marginal price and the uniform settlement reference point price. In the current stage, no rebate will be made to generation units whose locational marginal prices are higher than the settlement reference point price. This clearing process will be carried out hourly.

$$\boldsymbol{R}_{\boldsymbol{CS},i} = \boldsymbol{R}_{\boldsymbol{CS},G} \times \frac{\sum_{t=1}^{T}(Q_{G,i}^{t} \times (\boldsymbol{P}_{\boldsymbol{R}}^{\boldsymbol{t}} - \boldsymbol{P}_{\boldsymbol{S},\boldsymbol{i}}^{\boldsymbol{t}}))}{\sum_{i=1}^{N}\sum_{t=1}^{T}(Q_{G,i}^{t} \times (\boldsymbol{P}_{\boldsymbol{R}}^{\boldsymbol{t}} - \boldsymbol{P}_{\boldsymbol{S},\boldsymbol{i}}^{\boldsymbol{t}}))} \tag{14}$$

As a result, the total electricity revenue of generation unit i is the sum of $\boldsymbol{R}_{\boldsymbol{G},\boldsymbol{i}}$ and $\boldsymbol{R}_{\boldsymbol{CS},\boldsymbol{i}}$ in Western Inner Mongolia power market.

3 Example analysis

3.1 Simulation Scenarios

This article takes a simulation to compare the results following the two settlement mechanisms mentioned above. IEEE 30 bus is a medium-scale standard test system, so it is selected for the analyses. The IEEE 30-bus test system is shown in Figure 1. The system data is taken from reference [8].

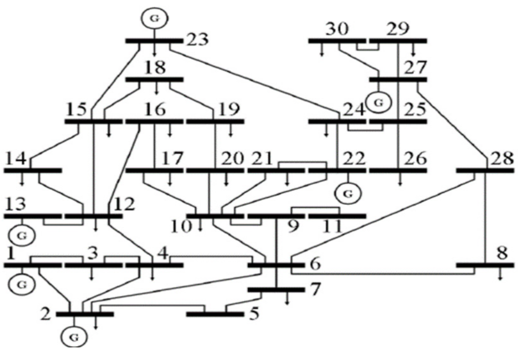

Fig. 1. The single-line diagram of the IEEE 30-bus system.

Long-term contracts affect the settlement results in many ways; hence this article carries out several simulation scenarios to portray the long-term contracts and analyses the settlement results in each simulation scenario.

Scenario 1: the long-term contracts are the same as the spot market generation in every period, and there is no deviation in volume.

Scenario 2: the long-term contracts are flat during the periods, but the total volume is the same as the spot market generation during the periods.

Scenario 3: the long-term contracts are 110% of the spot market generation in every period.

Scenario 4: the long-term contracts are 90% of the spot market generation in every period.

3.2 Results and Analysis

The power market clearing simulation results are shown in Figure 2.

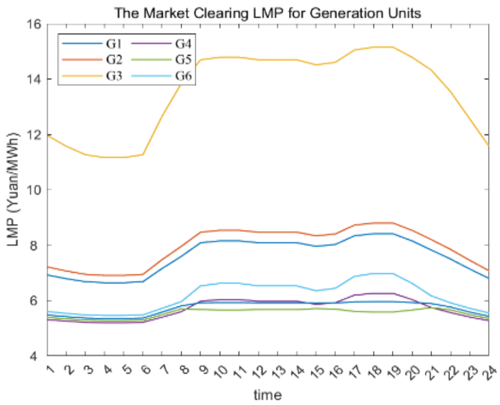

Fig. 2. The locational marginal price of the spot market.

Then the revenues of each generation unit are calculated according to the market clearing price and settlement mechanism of Shanxi (as a representative of the others) market and Western Inner Mongolia market respectively. The revenues of each scenario are shown in Figure 3.

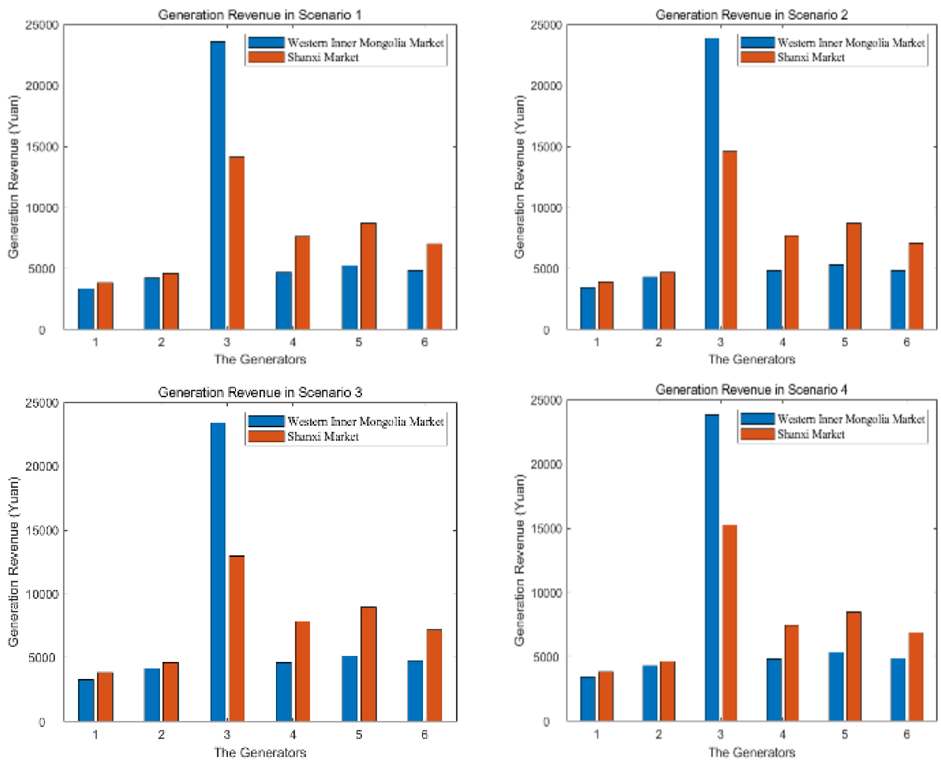

Fig. 3. The revenues of generation units.

The revenues of generation units show that the two settlement formulas for the same example, the settlement results are quite different. For generation unit 3 near the load centre, the revenue from Western Inner Mongolia market is much higher than that from Shanxi market. However, for generation unit 4, 5 and 6 far from the load centre, their revenues from Western Inner Mongolia market are significantly lower than that from Shanxi market. The revenue difference for generation unit 1 and 2 are relatively small. Besides, the revenues in difference scenarios are quite similar.

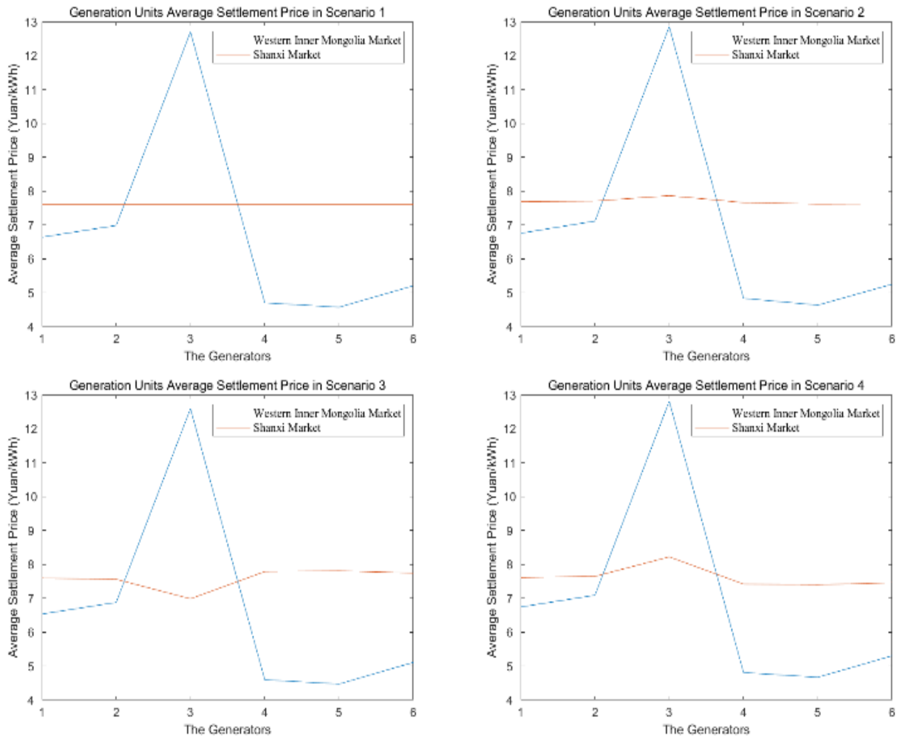

Fig. 4. The average settlement price for generation units.

The situation is quite similar in the average settlement price for generation units. The average settlement prices for generation units are almost the same in Shanxi market but vary in Western Inner Mongolia market, as shown in Figure 4. For generation unit 3 near the load centre, the average settlement price is much higher than the average level. For generation unit 4, 5 and 6 far from the load centre, their average settlement prices are significantly lower than the average level. The average settlement price for generation unit 1 and 2 are close to the average level.

For the same economic relationship model gives two different settlement results, there must be at least one settlement formula problem. Intuitively, the settlement formula of Western Inner Mongolia is more reasonable because the average price of the generation unit that is far from the load centre (like unit 4, 5 and 6 in this example) is lower than the unit near the load centre (like unit 3 in this example), which realizes price-guided resource allocation and encourages the construction of power plants in the load centre. The reason is if the generation unit signs a long-term contract, the use of the user's node tariffs as a settlement reference point price. In this situation, the long-term CFDs are for the user to provide hedging services, however, the generation units must bear the risk of the congestion from its node to the settlement reference point. The settlement formula for Shanxi is wrong because there are two reference nodes, the users are using the settlement reference node appointed in the contract, while the generation units are using their node as the settlement reference point, which does not fully implement the long-term contract [9].

The problem with Shanxi power market settlement is that only a small volume of spot market electricity with the locational signal, while most volume of the spot market electricity with a long-term contract does not have the locational signal. In this case, without this part of the locational signal, there will be an unreasonable phenomenon that power generators with different locational prices have the same settlement revenue for the same with the same long-term contract. According to the economic laws, and the simulation results of the above 4 scenarios, power generators with higher locational marginal prices should get more revenue. The pilots' practice also found that the full amount settlement for long-term contracts ignoring the locational signal, on the one hand, will cause the generation units near the load centre (like unit 3 in this example) to intentionally not sign a long-term contract, which leads the locational signal benefit to be seized, and raise the spot market to protect their interests. on the other hand, it will result in the generation units far from the load centre (like unit 5 in this example) will try to sign more long-term contract to collect the locational signal benefit from the load centre units, and lower offer prices in the spot market to grab more volume, which will eventually intensify the congestion of the whole power grid. On the consumption side, the principle of intensifying grid congestion by only one settlement reference point for all users is like the principle described above for the generation side. This also shows that the selection of the settlement reference point in the pilots determines that the long-term contract is a hedge for the electricity user, not the power generators.

4 Conclusion

In the process of power market construction, there is no universal model that fits all situations, but there are common market concepts and economic relations in the market, and the economic relations model must be consistent with the settlement mechanisms. Hence, each polit should follow the two settlement mechanisms given in the basic rules and choose the settlement mechanisms suitable for the local market design to modify their settlement formula. For the power generation side to fully reflect the different values of electricity generated by units; for the consumption side, it should also be appropriate to promote the reform, and as far as possible to show a certain degree of locational signals.

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