Study on the allocation of congestion revenue under double-track pricing system

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Abstract. The introduction of nodal spot market has brought unneglectable problem of congestion revenue allocation in China. Meanwhile, the coexistence of market and regulation in nowadays power market in China added specialty when it comes to appropriately allocate congestion revenue in China. Based on thorough review and analysis on both the principle of congestion revenue allocation as well as the status quo of a typical provincial market in China, this paper attempts to tackle this problem with consideration on property right, with which the contribution to the grid network of electricity users are taken into account. The solution is established in two stages, which is based on the reality that the distribution of two types of users in each node remains currently unknown.

1. Introduction
Along with the gradual commencement of power spot market demonstration in China, the issue of congestion rent has emerged, leading to an unneglectable problem of imbalance in settlement. The construction of an appropriate solution to allocate congestion revenue still urgently awaits. In order to avoid huge fluctuation in power price with the advent of their power structural reform, the policymakers in China chose to start the power market among price-elastic players like generation group and large industrial users, leaving others out of the game to continue receiving a regulated price. The regulation-market double-track pricing system forms a certain uniqueness about Chinese power market design, and therefore it is necessary to come up with a suitable method to duly allocate the congestion revenue according to its property right, instead of copying the design already exists in other countries.

Mature power markets such as PJM, CAISO have already operated a financial transmission right (FTR) market equipped with the function to allocate congestion revenue for years [1-3]. Consideration about the allocation of congestion revenue has always been the core of their market design since the beginning of their power market reform, which was set by FERC in the Standard Market Design (SMD) [4]. The centrally dispatched market system by nature generates different locational marginal price (LMP) for various nodes in the system. When it comes to settlement for market participants, the gross amount of power expenditure from users would outnumber the gross amount of power revenue received by generation companies as the transmission constraints stop the cheapest source from delivering to every load sink. congestion rent, or congestion revenue, which is the discussion topic in this paper, is calculated as the difference between to two number mentioned above.
The original concept of congestion revenue allocation started with [5], in which Hogan introduced the concept capacity right, whose holder was entitled to receive congestion rental payments. Studies have also been carried out on tools for participants to hedge the congestion risk they potentially would face in a spot market, including fixed transmission right [6-8] and congestion revenue right [9]. Congestion revenue allocation has long been discussed in various studies. However, it has not been studied under China’s background.

The original allocation of congestion right under the background of double track situation in China is tackled in this paper. Property right has been blurred with such mechanism, and it is necessary to sort out the tangled problem to appropriately allocate the congestion right.

This paper is organized as the following structure. Section 2 gives a detailed review of congestion revenue allocation based on foreign mature practice experience. Section 3 analyses the status quo of China power market that will affect the allocation of congestion revenue allocation. Based on the analysis in the previous sections, section 4 puts forward a reasonable development path of congestion revenue allocation mechanism for China and conclusion is given in section 5.

2. Review of congestion revenue allocation

Congestion revenue allocation is reviewed in this section starting from a discussion in the perspective of different market forms, followed by a case study on PJM as an example to further illustrate the consideration on the allocation.

2.1. Congestion revenue allocation in different market forms

The congestion problem does not only exist in the reformed power market environment, and the congestion management under the planning system is implicit in the generation scheduling.

In a regulated market, generation companies receive a feed-in tariff for every kWh it produces, rooted from the fixed rate that paid by electricity users. The network congestion still exists physically, though financially ramped or digested by the grid company. In this case, congestion revenue is allocated to the grid.

In a deregulated market, as explained above, the price difference of various nodes is objective under the power market nodal price system. The congestion revenue exists because low-priced power cannot be sent out due to network constraints, so only higher-priced power can be scheduled. Before determining the attribution of the congestion revenue, it is best to first defining its property right. Coase’s theorem shows that as long as the property right is clear and the transaction cost is zero or small, the final result of market equilibrium will be efficient and achieve pareto optimality of resource allocation no matter who is given the property right at the beginning. From the perspective of property right, the users are entitled to receive a proportional part of congestion revenue based on their usage on the network, so long as they are under the same tariff regime. It is unfair that users who bear the same transmission tariff get different nodal prices due to congestion, and thus this part of congestion revenue should be returned to the affected users.

The emergence of FTR provides a tool for market players to actively manage congestion risks. In fact, FTR is used to optimize the allocation of congestion earnings by market mechanism, and at the same time, FTR can even be used to make profits, so as to improve the market playability and fully reflect the will of free market. However, in the early days of a deregulated market, it can also be risk associated with the introduction of FTR [10-11].

2.2. Congestion revenue allocation in PJM

FTR was introduced in the early days of the PJM spot market. At that time, FTR was directly allocated to network transmission customers and fixed point to point users. FTR holders at that time can be directly allocated congestion revenue, i.e. the difference between nodal price due to transmission congestion. In 2003, PJM introduced Auction Revenue Right (ARR), whilst opening FTR to be auctioned by all market participants and the revenue that was distributed changed from the difference in nodal prices to the
difference in congestion components of LMP. The reform, while retaining the basic compensation for transmission users, adds a congestion risk management tool for all market players.

Nowadays in PJM, congestion revenue is not allocated directly to the users, instead of which is combined with auction mechanism of FTR. FTR is auctioned and obtained by those successful bidders, who are eligible to be allocated the corresponding congestion revenue of the transmission line they bid on. The FTR auction revenue is allocated to ARR holders, is a mechanism to distribute the annual FTR auction proceed and is distributed annually to firm network service users. The purpose of introducing ARR is to improve the long-term distribution mechanism of FTR market, and the fundamental purpose is to enable transmission network investors to recover part of the cost in advance, so as to achieve a virtuous cycle. ARR is allocated according to the use of the network or the reservation of transmission services by transmission users in the historical reference year. The entities eligible for ARR are transmission service users who pay for the construction cost of the power grid transmission system, which can be specifically divided into network integrated service users and firm point-to-point users. This mechanism provides more long-term certainty for the operation of PJM market, and also provides more flexible hedging path for users, making the market mechanism more gaming.

The profit gained by ARR is in fact the cost that FTR investors are willing to pay to buy the FTR, which is essentially the expected value of the congestion revenue. FTR profits are the difference between the actual value of the congestion revenue and the expected value of the earnings. Consequently, the profit of ARR can be seen as the difference between the actual value of congestion revenue and FTR profit.

To sum up, the FTR-ARR mechanism is a two-step method to allocate congestion revenue while simultaneously introduce a tool for market participants to hedge against the congestion risk they are confronted with, which has gone beyond congestion revenue allocation. The existence of ARR and FTR is complementary to each other.

3. Situations in China

Although it was laid down on Document No.5 issued in 2015 [12] that the power market structural reform was aimed at the national level, the development pace for every province is different with some provinces already operating spot market and others do not, thus it is best to analyse the problem by taking a stereotype as an example. As introduced above, all provincial markets in China are adopting regulation-market double track mechanism to make a smooth adjustment to the new arrival of market. This article intends to take Guangdong province as an example to demonstrate the market situation in China, which is designed as a spot market with nodal price mechanism and has encountered the congestion revenue allocation problem.

3.1. Status quo

Guangdong adopts the settlement method of decoupling the regulated portion of electricity from the marketized portion [13]. Generating units in Guangdong are divided into type A and B: type A units do not participate in the market, receiving regulated tariff; mainly consisting of coal and gas units, type B units partly participate in the market, with both regulated portion and marketized portion of their generated volume. As it remains unknown that how marketized and regulated users are distributed in each node, the unified settlement price for the users are the weighted average nodal price based on total load in each node, which potentially assumes that marketized users and regulated users distribute evenly in the entire network.

Trail settlement has already been commenced in May 2019 Guangdong. Many users would have been profitable at the market price, but eventually lost money after considering the allocation of negative congestion revenue. Through analysis, it is found that this is because the regulated generation units under the double-track mechanism occupies the transmission channel but does not pay the corresponding congestion cost.
3.2. The existing problems in the current allocation mechanism

The congestion revenue is theoretically a positive value, as the existence of transmission constraint stops the network from making full use of the cheapest generation units. However, the fact that marketized users potentially distribute in higher-priced nodes but still pay weighted average price has resulted in negative congestion revenue. Moreover, the coexistence of regulated power increases the complexity of congestion revenue, adding to the imbalance settlement in the power spot market settlement.

The fact that congestion value being negative is difficult for market players to understand and accept, which may even result in the loss of the electricity retailers. Under extreme conditions, when the marketized units are all distributed on high-priced nodes and the marketized users are still settled by the weighted average nodal price, then it is possible that paid electricity charge being unable to cover the cost of those marketized units.

Consequently, a reasonable congestion revenue allocation needs to be designed, not only to achieve deal with the problem of negative congestion revenue for marketized users, but also to consider the property right of the congestion revenue.

4. Congestion Revenue allocation under Chinese background

As the distribution of regulated and marketized users in different nodes remains unknown, it is impossible to calculate each user’s congestion revenue they are entitled to be allocated. This paper proposes a two-stage mechanism that takes into account the property right and the available data, aiming to allocate congestion revenue in the most appropriate way.

4.1. Allocation principle

4.1.1. The consideration of negative congestion revenue and imbalance settlement. The appearance of negative congestion revenue is caused by directly calculate the marketized users’ tariff based on the weighted average price of all users. The assumption behind such calculation method is to consider the two types of users distribute evenly in every node, which is actually not the fact. Considering the congestion merely on the marketized side is essentially meaningless as congestion revenue is a definition considering the system as a whole. When the actual distribution of the users is unknown, a more reasonable way is to calculate the settlement price of marketized users based on the weighted average price of generation side as well as the marketized part of total congestion revenue. After the distribution of the users is obtained, as the two types of users each has their own settlement relationship with the corresponding generation units, their respective congestion revenue can be calculated based on their local spot price.

4.1.2. The consideration of property right. According to the nature of the congestion revenue, the property should be allocated proportionally to the users based on their contribution to the network. The users in PJM are under the same transmission tariff, and thus the congestion revenue was allocated based merely on their historical peak load, which reflects their usage level on the network. However, not only does the users in China have different peak load, they also face different transmission tariff based on their voltage level, which is the so-called cross compensation in China. As congestion revenue should be allocated based on the contributions, the diverse transmission tariff should also be considered.

The tricky part in China is that the transmission tariff is charged independently for regulated users, instead of which is contained implicitly in their categorized power tariff. Here we attempt to strip the transmission charges for regulated users using the gross fee paid by regulated users and the gross fee the grid company should pay generators. As the difference between fixed tariff paid by users and received by generation companies should be what grid company is entitled to receive, it can also denote the total contribution of regulated users to the network. When it comes to individual contribution, the proportion of the respective electricity charges in the total electricity charges can be used as a multiplier. Therefore, individual contribution of regulated user to the transmission network can be describe as follow equation:
$$T_{ri} = \left( \sum_{j=1}^{n} P_{rj} \times Q_{rj} - G_i \right) \times \frac{P_{rj} \times Q_{rj}}{\sum_{i=1}^{n} P_{rj} \times Q_{rj}}$$

(1)

$T_{ri}$ and $P_{rj}$ are the transmission charge and the fixed electricity charge paid by individual regulated user $r_j$ respectively, $Q_{rj}$ is the electricity volume used by $r_j$, $G_i$ is the gross generation fee received by regulated generation companies.

As for marketized users, the transmission fee structure is much more transparent. Along with the launching of the power market structural reform, the transmission fee for different voltage level is devised. It is relatively easy to obtain each marketized user’s contribution to the network:

$$T_{mi} = \sum P_{mi} \times Q_{mi}$$

(2)

$T_{mi}$ and $P_{mi}$ are the transmission charge and the transmission tariff rate bore by individual marketized user $m_i$ respectively, $Q_{mi}$ is the electricity volume used by $m_i$.

After the contributions to the network of the two types of users are calculated, we can then utilize the value as numerator to obtain the proportion of congestion revenue they are entitled with.

For individual regulated users, the proportion can be described as:

$$V_{ri} = \frac{\left( \sum_{j=1}^{n} P_{rj} \times Q_{rj} - G_i \right) \times \frac{P_{rj} \times Q_{rj}}{\sum_{i=1}^{n} P_{rj} \times Q_{rj}}}{P_{mi} \times Q_{mi} + \sum_{j=1}^{n} P_{rj} \times Q_{rj} - G_i}$$

(3)

For individual marketized users, the proportion can be described as:

$$V_{mi} = \frac{P_{mi} \times Q_{mi}}{\sum P_{mi} \times Q_{mi} + \sum_{i=1}^{n} P_{rj} \times Q_{rj} - G_i}$$

(4)

### 4.2. Scenario setting

Let us consider a simplified scenario to discuss the allocation problem (See Fig. 1). Assume a three-node network with two transmission lines, one has a constraint of 50 MW and 100 MW of the other. There are three generation units in the network, with $G_1$ and $G_2$ being regulated units and $G_2$ being a marketized unit. The load in both node A ($L_A$) and node B ($L_B$) is 150 MW while in node C ($L_C$) is 300 MW. Here we assume that the average fixed tariff ($P_{r_{fu}}$) for regulated users is 1.4 and average feed-in tariff ($P_{r_{fg}}$) for regulated unit is 1.2. Transmission tariff ($T_{mu}$) for marketized users is 0.4.

For stage 1, it is known that there are 200 MW of marketized load ($L_m$) and 400 MW of regulated load ($L_r$), however the exact node distribution of the load is unknown. Correspondingly, marketized generation volume ($G_2$) is 200 MW and regulated generation volume ($G_1$ and $G_3$) is 400 MW.

For stage 2, 200 MW of the 300 MW in node C is marketized ($L_m$), while the rest of the load in other nodes are regulated ($L_r$).

The weight average price ($P_{\text{avg}}$) on users’ load can also be calculated based on Figure 1. As the generated volume in each node is the same, then:

$$P_{\text{avg}} = \frac{L_A^{1.4} + L_B^{1.5} + L_C^{1.6}}{L_A + L_B + L_C} = 1.425$$

(5)
4.3. Stage 1: allocation when distribution of users is unknown

In stage 1, is it unable to obtain the accurate distribution of the different types of users, the two parts of congestion revenue cannot be calculated accordingly, and the settlement step of bearing congestion cost first and then allocating congestion cost cannot be realized. Therefore, the theoretical value of the total congestion revenue is directly calculated, and then distributed to market and regulated users according to the proportion calculated above.

4.3.1. Calculate the congestion revenue for the two types of users. Firstly, the theoretical value of total congestion revenue is calculated and divided into two parts according to the proportion of two types of contribution to the network. The total congestion revenue ($C_{total}$) can be calculated as follows:

$$C_{total} = P_{avg} \times L_{total} - \left( G_1 \times P_1 + G_2 \times P_2 + G_3 \times P_3 \right)$$

$$= (1.425 \times 600) - (200 \times 1.6 + 200 \times 1.5 + 200 \times 1)$$

$$= 35 \text{ (6)}$$

Therefore, the regulated part of congestion revenue can be calculated as the multiple of the regulated proportion and total congestion.

$$C_r = V_r \times C_{total} = \frac{\sum_{j=1}^{n} P_{rj} \times Q_{rj}}{\sum_{i=1}^{n} P_{mi} \times Q_{mi} + \sum_{j=1}^{n} P_{rj} \times Q_{rj} - G_r} \times C_{total}$$

$$= \frac{1.8-1.2}{1.8-1.2} \times 200 + 0.4 \times 400 \times 35$$

$$= 21 \text{ (7)}$$

where $V_r$ is the percentage of congestion revenue that regulated users are entitled to receive.

Similarly, the marketized part of congestion revenue can be calculated as follows:

$$C_m = V_m \times C_{total} = \frac{P_{mi} \times Q_{mi}}{\sum_{i=1}^{n} P_{mi} \times Q_{mi} + \sum_{j=1}^{n} P_{rj} \times Q_{rj} - G_r} \times C_{total}$$

$$= \frac{1.8-1.2}{1.8-1.2} \times 300 + 0.4 \times 400 \times 35$$

$$= 14 \text{ (8)}$$

4.3.2. Calculate receivable electricity charges. The 2nd step is to calculate receivable charges for the users based on the congestion revenue, added with the correspond unit charge.

$$S_{m1} = G_m + C_m = (200 \times 1.5) + 14 = 314 \text{ (9)}$$

Where $S_m$ is marketized users’ receivable charge.
\[ S_{r1} = G_r + C_r = (400 \times 1.2) + 21 = 501 \] (10)

Where \( S_r \) is regulated users’ receivable charge.

The unified settlement price \( (P_m) \) of marketized users is calculated according to the receivable charges of market users:

\[ P_m = \frac{S_m}{L_m} = 1.56 \] (11)

The price difference settlement of medium-long term contracts shall be settled accordingly. After the adjustment of the unified settlement price, the income of the generation side may be affected to some extent, comparing to the previous calculation method.

4.3.3. Congestion revenue returning. As the congestion revenue should eventually be allocated back to the users, after the users should be returned the same amount of congestion revenue after the user settlement price has been obtained. The actual expenditure of the users is the correspond generation revenue \( G_m \) and \( G_r \).

4.4. Stage 2: allocation when distribution of users is obtained

After the actual distribution of users is obtained, the congestion revenue that the two types of users should respectively shoulder can be accurately calculated, and then the theoretical value of each part of the congestion revenue can be directly calculated, and then distributed to the market and the plan in a balanced way according to the electricity quantity ratio. The specific methods are as follows:

4.4.1. Calculate the congestion revenue for the two types of users. Firstly, the total congestion revenue \( (C_{total}) \) can be calculated as follows:

\[ C_{total} = P_{avg} \times L_{total} - (G_1 \times P_1 + G_2 \times P_2 + G_3 \times P_3) \]
\[ = (1.425 \times 600) - (200 + 200 + 200 \times 1.5 \times 1.6 \times 1) \]
\[ = 35 \] (12)

At this moment, the congestion revenue of marketized users can be calculated using their own nodal price:

\[ C_m' = LMP_c \times L_{m2} - LMP_b \times G_2 = 320 - 300 = 20 \] (13)

Similarly, the congestion revenue of regulated users can also be calculated as follows:

\[ C_r' = LMP_A \times L_1 + LMP_B \times L_2 + LMP_C \times L_{3r} - LMP_A \times G_1 - LMP_C \times G_3 \]
\[ = 535 - 520 = 15 \] (14)

4.4.2. Calculate the congestion revenue of planned and market expenditures. The receivable charges for the users can again be calculated similar to stage 1.

\[ S_{m2} = G_m + C_m' = (200 \times 1.5) + 20 = 320 \] (15)

Where \( S_m \) is marketized users receivable charge.

\[ S_{r2} = G_r + C_r' = (400 \times 1.2) + 15 = 495 \] (16)

Where \( S_r \) is regulated users receivable charge.

The unified settlement price of marketized users is calculated according to the receivable charges of market users:

\[ P_m = \frac{S_m}{L_m} = 1.6 \] (17)

4.4.3. Calculate the congestion revenue that should be returned by the plan and the market. The users who have paid the electricity price for transmission and distribution, including the plan and the market,
shall enjoy the transmission right corresponding to their contribution to the network, so the congestion revenue shall be returned according to the their proportion between the plan and the market.

The returnable congestion revenue for the users are the same as that calculated in stage 1, while the regulated users should be returned 15 and 20 for that of marketized users.

Therefore, the actual electricity charge for the two types of users is different from that of the correspond generation revenue, which is calculated as follows:

$$H_m = S_{m2} + C_m = 320 - 14 = 306 \quad (18)$$

$$H_r = S_{r2} + C_r = 495 - 21 = 474 \quad (19)$$

Where $H_m$ and $H_r$ are the actual charge for marketized users and regulated users, respectively. At this moment, the actual charge of the users is different from what the units would receive, creating a certain amount of settlement surplus or deficit. In this case, there would be a settlement surplus of 6 for marketized side and a deficit of 6 for regulated side.

Moreover, if the fixed tariff is set at 1.4 for regulated users, they explicitly would pay $1.4 \times 400 = 480$ while implicitly should only pay 474, which requires adjustment mechanism.

4.5. Analysis

The two-stage mechanism of congestion allocation is designed to deal with the urgent problem of unbalance settlement while taking property right of congestion revenue into account.

In the first stage, the users’ distribution cannot be accurately obtained, therefore the unified settlement price of market users is reversely calculated according to the theoretical value of electricity charges of market users, which allocated congestion revenue based on each type of user’s contribution to the network. The contribution proportion is calculated based on their payment on transmission, so as to realize the precise allocation of congestion revenue. In this stage, there is no need to adjust the regulated electricity price, and the settlement is also balanced, but it is different from the congestion revenue allocation under the actual distribution condition.

In the second stage, the distribution of users in each node is obtained, therefore the corresponding the unified settlement point price can be accurately calculated according to the distribution of market users. Under this stage, there would be difference between the fixed tariff and their receivable charge calculated based on congestion revenue, which requires a dynamic adjustment mechanism to the fixed tariff to reflect the influence of network congestion.

5. Conclusion

Along with the introduction of power market deregulation, it is necessary that China establish an efficient congestion revenue allocation mechanism with imbalanced settlement as well as property right being collectively considered. However, the mechanism put forward in this paper is designed under the assumption that marketized and regulated parts of the market are decoupled. Further study should be carried out on the reasonable allocation of congestion revenue considering the coupling of the two parts.

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