Comparison of cost allocation models for transmission and distribution by voltage levels based on postage stamp method and peak load liability method

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Abstract. In order to make the allocation of transmission and distribution costs more reasonable, the cost allocation models for transmission and distribution of different voltage levels based on postage stamp method and peak load liability method are constructed. Two models are used to calculate and compare the transmission and distribution costs of different voltage levels in a power grid company. The results show that the peak load liability method is more reasonable than the stamp method to allocate transmission and distribution costs among different voltage levels.

1. Introduction

With the continuous advancement of China's electric power system reform, the transmission and distribution price reform policy, as one of the important parts of electric power reform, has also been constantly improved. In 2015, the National Development and Reform Commission of China issued the "Implementation Opinions on Promoting The Reform of Electricity Transmission and Distribution Price", which pointed out that an independent transmission and distribution price system should be established with clear rules, reasonable level and powerful supervision, so as to form a transmission and distribution price formation mechanism to ensure the safe operation of the grid and meet the needs of the electricity market. As the basic prerequisite for the establishment of transmission and distribution price, transmission and distribution cost allocation will become one of the key issues in the future reform of transmission and distribution price.

In terms of the method of transmission and distribution cost allocation, postage stamp method has become the current transmission and distribution cost allocation method adopted by various provincial power companies in China due to its simple calculation characteristics. In terms of research related to postage stamp method, the authors of [1] summarized the principles, advantages and disadvantages of postage stamp method. The authors of [2-3] applied the revised postage stamp method to the formulation of transmission and distribution price. The authors of [4] selected different parameters and used postage stamp method to allocate transmission cost. The authors of [5] combined postage stamp method and megawatt-kilometer method to share transmission and distribution cost. The authors of [6] introduced a variety of transmission and distribution cost allocation methods including stamp method and used these methods to calculate transmission and distribution cost respectively.
Although postage stamp method has the advantages of simple implementation, easy to understand and being able to recover the existing cost of electrical power system, it has some shortcomings in reflecting the fairness and effectiveness of users’ occupation of transmission and distribution network resources.

Therefore, based on the establishment of permitted income calculation model, cost allocation models for transmission and distribution of different voltage levels based on postage stamp method and peak load liability method are quantitatively established. And two methods are used to calculate transmission and distribution cost (TDC) of different voltage levels in a power grid company, so as to verify the superiority of peak load liability method in TDC allocation compared with traditional postage stamp method.

2. Permitted income calculation model

Before the allocation of TDC, permitted income of transmission and distribution networks (TDN) of different voltage levels should be calculated first.

According to the principle of "permissible cost plus reasonable income", permitted income of each voltage level TDN includes permitted cost, permitted income and the tax included in price, which can be expressed as follows:

\[ R_{t,m} = C_{t,m} + I_{t,m} + T_{t,m} \]  

(1)

Where, \( R_{t,m} \) is the permitted income of TDN with voltage level m in year t; \( C_{t,m} \) is the permitted cost of TDN with voltage level m in year t; \( I_{t,m} \) is the permitted income of TDN with voltage level m in year t; \( T_{t,m} \) is the tax included in price of TDN with voltage level m in year t.

Where, the permitted cost of TDN with voltage level m in year t can be further expressed as follows:

\[ C_{t,m} = D_{t,m} + O_{t,m} \]  

(2)

Where, \( D_{t,m} \) is the depreciation cost of voltage level m in year t; \( O_{t,m} \) is the operation and maintenance cost of voltage level m in year t.

For the permitted income of TDN with voltage level m in year t, it can be expressed as follows:

\[ I_{t,m} = k_t \times A_{t,m} \]  

(3)

Where, \( k_t \) is the allowable rate of return of the power grid company in year t; \( A_{t,m} \) is the effective assets of voltage level m in year t.

The formulas above can be used to calculate the permitted income of TDN of each voltage level, which is equal to the TDC borne by the power users of each voltage level, which can be expressed as follows

\[ UC_{t,m} = I_{t,m} \]  

(4)

Where, \( UC_{t,m} \) is the TDC borne by users with a voltage level of m in year t.

It should be noted that the TDC borne by users with different voltage levels determined by the permitted income have not considered the cost allocation of low voltage TDC to high voltage TDC.

3. Cost allocation model for transmission and distribution of different voltage levels based on postage stamp method

On the basis of calculating the permitted income of TDN of each voltage level, cost allocation model for TDC of different voltage levels based on postage stamp method is built.

Postage stamp method is a cost allocation method originated from post and telecommunications system. It is characterized by average allocation. It only considers the power of each user without considering the structure of the TDN, the transmission and distribution path, and the location of the transmission and reception point of the TDN. Due to users of different voltage levels occupy different levels of the TDN, the low voltage TDN occupies part of the high voltage TDN resources during power
transmission. Therefore, in order to ensure the fairness and rationality of the cost allocation process, it is necessary to consider the cost of low voltage TDN to allocate the cost of high-voltage TDN when the TDC is allocated based on postage stamp method, which can be expressed as follows:

\[ F_{t,m} = UC_{t,m} + \sum_{l>m} UC_{t,l,m} - \sum_{m>n} UC_{t,m,n} \]  
(5)

\[ UC_{t,l,m} = UC_{t,l} \times \frac{L_{t,l-m}}{L_{t,l}} \]  
(6)

\[ UC_{t,m,n} = UC_{t,m} \times \frac{L_{t,m-n}}{L_{t,m}} \]  
(7)

Where, \( F_{t,m} \) is the cost of TDN borne by users of voltage level \( m \) in year \( t \), considering that users of low voltage class TDN allocate the cost of high voltage class TDN; \( UC_{t,l,m} \) is the cost of TDN of voltage level \( l \) allocated by users of voltage level \( m \) in year \( t \); \( UC_{t,m,n} \) has the same meaning as \( UC_{t,l,m} \); \( L_{t,l} \) is the total load transmitted by the TDN of voltage class \( l \) in year \( t \); \( L_{t,m} \) is consistent with \( L_{t,l} \); \( UC_{t,j,m} \) is the load transferred from the TDN of voltage class \( l \) to the TDN of voltage class \( m \) in year \( t \); \( L_{t,m-n} \) has the same meaning as \( L_{t,l,m-n} \).

4. Cost allocation model for transmission and distribution of different voltage levels based on peak load liability method

The central idea of using peak load liability method to allocate TDC is to find out the proportion of each voltage level user in the total load of the electric power system during the peak load period, and then allocate TDC according to this proportion. Since the cost of different voltage levels in the TDN is different, and the cost not only includes the cost of the voltage class, but also is related to the cost transferred down from the high voltage class, so the cost allocation should consider the transfer between costs to calculate TDC of a certain voltage class.

Cost allocation model for transmission and distribution of different voltage levels based on peak load liability method is built as follows: Suppose the load ratio of a certain voltage level during the peak load period of electric power system is \( k_i \), then \( \sum_{i=1}^{l} k_i = 1 \).

Except for the highest voltage level, other voltage levels should bear TDC of their own level as well as part of TDC of the higher level. Therefore, the cost allocation ratio among voltage classes can be expressed as:

\[ CAR = \begin{cases} 
  k_i & (i = 1) \\
  \frac{k_i}{\sum_{j=1}^{i-1} k_j} & (i \geq 2) 
\end{cases} 
\]  
(8)

When there are no users at a certain voltage level, then \( k_i = 0 \), \( CAR = 0 \), and TDC of this voltage level is accumulated to the next voltage level. Thus, the proportion of the total TDC that each voltage level should actually allocate can be calculated step by step from high voltage level to low voltage level.

As the highest voltage level, namely voltage level \( i=1, 220kV \) only bears TDC at this level. Then the calculation formula of the total cost of transmission and distribution actually borne by 220kV voltage level is as follows:

\[ C_i = CAR_i \times I_i \]  
(9)
Where, $C_i$ is the total cost of transmission and distribution borne by 220kV voltage level; $CAR_i$ is the cost allocation ratio of 220kV voltage level; $I_i$ is the permitted income of 220kV voltage level.

When the voltage level $i>2$, in addition to bearing TDC of this level($C_{ii}$), part of TDC of the higher voltage level($C_{ji}$) must also be allocated, so the total cost of transmission and distribution actually allocated by this voltage level is as follows:

$$C_i = C_{ii} + C_{ji}$$  \hspace{1cm} (10)

Where, TDC of this voltage level is:

$$C_{ii} = CAR_i \times I_i$$  \hspace{1cm} (11)

TDC of higher voltage level is:

$$C_{ji} = CAR_i \times \left[ \frac{C_{i-1}}{CAR_{i-1}} \times (1 - CAR_{i-1}) \right]$$  \hspace{1cm} (12)

Then the total cost of transmission and distribution actually allocated by the voltage level can be concluded as follows:

$$C_i = CAR_i \times \left[ \frac{C_{i-1}}{CAR_{i-1}} \times (1 - CAR_{i-1}) \right] + I_i$$  \hspace{1cm} (13)

Where, $C_i$ is the total cost of transmission and distribution borne allocated by a certain voltage level; $CAR_i$ is the cost allocation ratio of voltage level $i$; $CAR_{i-1}$ is the cost allocation ratio of higher voltage level; $I_i$ is the permitted income of voltage level $i$; $C_{i-1}$ is the total cost of transmission and distribution allocated by higher voltage class.

To sum up, the actual total cost of transmission and distribution of each voltage level can be calculated as follows:

$$C_i = \begin{cases} CAR_i \times I_i, & (i = 1) \\
CAR_i \times \left[ \frac{C_{i-1}}{CAR_{i-1}} \times (1 - CAR_{i-1}) \right] + I_i, & (i \geq 2) \end{cases}$$  \hspace{1cm} (14)

5. **Example analysis**

5.1. **Basic data**

In this section, some data in reference [7] are analyzed by example, and the fixed asset depreciation rate of the power grid is set as 7%; the operation and maintenance fee is set at 10% of the net value of fixed assets; the permitted rate of revenue is set at 6%.

The net value of fixed assets of the grid in 2015 is shown in Table 1.

| Voltage levels   | The net value of fixed assets (A hundred million yuan) |
|------------------|------------------------------------------------------|
| 220 kV           | 930,531                                              |
| 110 kV           | 928,107                                              |
| 20 kV            | 2,686                                                |
| 10 kV            | 1,280,000                                            |
| 1kV and below    | 150,200                                              |
| **Total**        | **3,291,524**                                        |

The daily power consumption and maximum load of each voltage level are obtained in the three peak days from June to August in summer, as shown in Table 2 and Table 3.
Table 2. Power consumption of each voltage level on peak days from June to August (kW·h)

| Voltage levels   | June 19th | July 23rd | August 10th | Mean value |
|------------------|-----------|-----------|-------------|------------|
| 220kV            | 3,395,268 | 3,631,624 | 3,590,527   | 3,539,140  |
| 110kV            | 4,327,029 | 5,192,539 | 4,807,027   | 4,775,532  |
| 20kV             | 724,638   | 902,414   | 949,970     | 859,007    |
| 10kV             | 181,512,144 | 197,393,407 | 200,505,408 | 193,136,986 |
| 1kV and below    | 55,332,246 | 59,596,194 | 59,589,908 | 58,172,783 |
| Total            | 245,291,325 | 266,716,178 | 269,442,840 | 260,483,448 |

Table 3. Maximum load of each voltage level on peak days from June to August (kW)

| Voltage levels   | June 19th | July 23rd | August 10th | Mean value |
|------------------|-----------|-----------|-------------|------------|
| 220kV            | 159,000   | 167,000   | 174,300     | 166,767    |
| 110kV            | 223,000   | 266,000   | 252,800     | 247,267    |
| 20kV             | 41,000    | 51,000    | 54,900      | 48,967     |
| 10kV             | 11,500,000 | 11,500,000 | 8,592,300  | 10,530,767 |
| 1kV and below    | 3,899,000 | 4,460,000 | 3,600,000   | 3,986,333  |
| Total            | 15,822,000 | 16,444,000 | 12,674,300 | 14,980,100 |

5.2. Example results

According to the permitted cost, permitted income and the tax included in price, the permitted income calculation model is used to calculate the permitted income of each voltage level TDN of the grid, as shown in Table 4.

Table 4. Permitted income of each voltage level

| Voltage levels   | Permitted income (A hundred million yuan) |
|------------------|------------------------------------------|
| 220kV            | 269,854                                  |
| 110kV            | 269,151                                  |
| 20kV             | 779                                      |
| 10kV             | 371,200                                  |
| 1kV and below    | 43,558                                   |
| Total            | 954,542                                  |

The permitted income for the TDN of each voltage level obtained in Table 4 is TDC of power users of each voltage level.

At this time, TDC of power users of various voltage levels have not yet considered the load conduction relationship between higher voltage level TDN and lower voltage level TDN, specifically: users of 110kV voltage level need to allocate the cost of TDN at 220kV voltage level; users of 20kV voltage level need to allocate the cost of TDN at 220kV and 110kV voltage levels; users of 10kV voltage level need to allocate the TDN costs of 220kV, 110kV and 20kV voltage levels; users with voltage levels of 1kV and below only need to share the cost of the TDN at the voltage level of 10kV. Therefore, TDC determined by the permitted income need to be further allocated according to the load transmission relationship among the TDNs of various voltage levels.

On the basis of obtaining the permitted income of each voltage level, the peak load liability method is used to allocate TDC of each voltage level.

1. Calculate the peak load ratio and mean value of each voltage level based on the maximum load of each voltage level on peak days from June to August, as shown in Table 5.

Table 5. Peak load ratio of each voltage level on peak days from June to August

| Voltage levels | June 19th | July 23rd | August 10th | Mean value |
|----------------|-----------|-----------|-------------|------------|
| 220 kV         | 1.00%     | 1.02%     | 1.38%       | 1.13%      |
| 110 kV         | 1.41%     | 1.62%     | 1.99%       | 1.67%      |
20 kV 0.26% 0.31% 0.43% 0.33%
10 kV 72.68% 69.93% 67.79% 70.14%
1kV and below 24.64% 27.12% 28.40% 26.72%

(2) The mean peak load ratio of each voltage level in the three peak days is taken as the basis for TDC allocation in the next step. The cost allocation ratio of each voltage class is calculated according to Equation (8), and the results are shown in Table 6.

Table 6. Cost allocation ratio of each voltage class

| Voltage levels | Cost allocation ratio |
|---------------|-----------------------|
| 220 kV        | 1.13%                 |
| 110 kV        | 1.69%                 |
| 20 kV         | 0.34%                 |
| 10 kV         | 72.41%                |
| 1kV and below | 100.00%               |

(3) According to Equation (14), the actual TDC allocated by each voltage level are calculated and compared with those calculated by postage stamp method, as shown in Table 7. Figure 1 compares the allocation ratio of TDC calculated by the two methods.

Table 7. TDC and allocation ratio to be allocated by each voltage level

| Voltage levels | TDC (A hundred million yuan) | Allocation ratio |
|---------------|------------------------------|------------------|
|               | Peak load liability method   | Postage stamp method | Peak load liability method | Postage stamp method |
| 220kV         | 3,054                        | 2,434             | 0.32%                     | 0.25%               |
| 110kV         | 9,074                        | 7,010             | 0.95%                     | 0.73%               |
| 20kV          | 1,814                        | 1,268             | 0.19%                     | 0.13%               |
| 10kV          | 649,554                      | 629,981           | 68.05%                    | 66.00%              |
| ≤1 kV         | 291,046                      | 313,849           | 30.49%                    | 32.88%              |
| Total         | 954,542                      | 954,542           | 100.00%                   | 100.00%             |
Figure 1. The allocation ratio of TDC calculated by the two methods

From the comparison results, it can be seen that for voltage levels that peak loads account for a relatively large amount such as 10kV, when the peak load liability method is used for TDC allocation, the allocation ratio has increased by 2.05% compared with the postage stamp method; As for the voltage level of 1kV and below, although it needs to allocate part of TDC of the high voltage level, its allocation ratio is also reduced by 2.39% compared with the postage stamp method when considering the proportion of peak load, which comprehensively reflects the use of electric power system resources of the TDN of this voltage level.

Therefore, TDC allocation model based on peak load liability method not only considers the power consumption, but also pays more attention to the contribution to the electric power system peak load, which makes the cost allocation among different voltage levels more reasonable.

6. Conclusion
This paper constructs the cost allocation models for transmission and distribution of different voltage levels based on postage stamp method and peak load liability method respectively, and compares the transmission and distribution cost calculated by the two methods through example analysis. The results shows that compared with postage stamp method, peak load liability responsibility method can more reasonably allocate the transmission and distribution costs of different voltage levels because it takes the electric power system's peak load factors into account comprehensively.

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