Transmission Expansion Cost Allocation Based on Economic Benefit and Use of System

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Abstract: In the deregulation power system, it is necessary to develop an appropriate pricing scheme that can provide the useful economic information to market participants, such as generators, transmission companies and customers. However, accurately assessment and allocating the transmission cost in the transmission pricing scheme is a challenge, although many methods have been proposed. The objective of this paper is to introduce a simple transmission expansion pricing scheme using proportional tree and economic benefit method, to allocate and price the transmission expansion among the participants. Numerical example using a test power system is presented to illustrate the effectiveness of the studied method.
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1. Introduction

The electric power market deregulation growth in many countries has allowed free competition. Markets have been deregulated and accordingly, generators, transmission, and distribution utilities should work as independent business units. Some markets have adopted locally marginal prices theory or transactions based on bilateral contracts. Open access to the transmission network is the key point that allows free competition in deregulated power markets. If there is open and nondiscriminatory access to transmission network, all generators are able to compete for supplying energy to any system customers.

In order to guarantee an open and nondiscriminatory access to the network, it is necessary to use methods that allow the network operator to recover its costs and to obtain an appropriate level of Benefit. On the other hand, payments should be fair and equitable for those participants who use the network. Network costs could be divided into two main components: one component that covers the operative costs and another component associated with transmission expansion.

Transmission expansion plays an important role in competitive power markets and in developing countries. In competitive markets, the expansion of the transmission system is necessary not only due to the growth of the demand but also due to geographical change of generation injection points. As there is competition, new generators can replace at the economic dispatch those generators that have higher operative cost. These changes produce a redistribution of load flows in the network that may produce the capacity overloads of some network facilities, and in some cases, it could be necessary to expand the network [1].

Several allocation methods have been proposed for the network expansion costs [2]–[3]. They are essentially extensions of allocation methods for existing transmission network costs, such as the ones discussed in [4], [5], and [6]. Some allocate the costs according to the contribution of each user to the network flows. Other methods allocate the costs according to the economic benefit each user receives from the network expansion.

This paper presents a new method to allocate and price transmission expansion among the users based on economic benefit and use of the system. The transmission expansion cost is allocated to all the power network users based on their actual contribution to line flows. The proposed method is illustrated using IEEE 9 bus system.

2. Necessity of the Transmission Expansion

Power transmission expansion cost allocation becomes an important issue due to the deregulation of the electric power industry. In this paper, we assume that there is transmission congestion in a power system. The cost of transmission line expansion is shared among participants for the new line based on the economic Benefit and use of system.

If the congestion occurs in the transmission line, the output of the related Genco will be curtailed, thereby reducing the profit of the Genco. However if the transmission line is expanded, the congestion will be relieved and the outputs of the Genco will increase as a result, which means that more electric power can be sold and more benefit of the Genco can be expected.

In the same way, if there is some congestion in the transmission lines, the electricity price purchased by the customers becomes expensive. However, when transmission line is expanded, the congestion will be relieved and the price becomes inexpensive so that customers can purchase more power from Gencos. Since all participants have Benefit due to the transmission expansion, the allocation expansion cost should be shared among them.

In some cases the cost allocation of the expansion transmission line between the participants are based to the economic benefit and in other cases based on the use of system. Each methodology has advantages and disadvantages that depend on their own features, the power system characteristics, and the price structure of the market. So the present a new method that overcome the disadvantages is essential.

3. Methodologies Based on Economic Benefit

This methodology to allocate transmission expansion costs is based on variations of economic Benefit that market users receive due to the network expansion. The economic benefit should be computed from the comparison of flows of money between the present system and the system with the expansion. Therefore, the method requires the simulation of the system operation during the study period with and without the new network facility.

The economic benefit (EB) obtained by a consumer d_i caused by the use of the new network facility is (terms indicated with apostrophe correspond to the system with the network expansion)

$$EB_{di} = d_i \rho_i - d_i^{'} \rho_i^{'} \quad (1)$$

The expression of Benefit obtained by generators is similar, but the production costs C_{gi} should be decreased

$$EB_{gi} = g_i^{'}(\rho_i^{'} - C_{gi}) - g_i(\rho_i - C_{gi}) \quad (2)$$

It should be noted that in (1) and (2), demand power d_i and generated power g_i are positive. To compute Benefit, negative benefit components should not be taken into account. There is no reason for allocating surplus pay for users that received additional revenue when the network capacity was not adapted. Finally, the expansion costs have to be paid by users proportionally to the benefit that they receive. This method results are attractive due to its economic basis and to the fact that it is appropriate to evaluate facilities not connected in series such as parallel compensators. Although this method is simple from the conceptual point of view, its main disadvantage is the complexity in the calculation to determine Benefit. The benefit received by each market user caused by network expansions is extremely variable hour by hour.

4. Methodologies Based on Use of System

Various methods for allocation of transmission cost have been reported in the literature. The most common and simplest approach is the postage stamp method, which depends only on the amount of power moved and the duration of its use, irrespective of the supply and delivery points, distance of transmission use. Contract path method proposed for minimizing transmission charges does not reflect the actual flows through the transmission grid [7].

As another, MW-Mile methodology was introduced in which different users charged in proportion to their utilization of the grid [7-8]. The key feature in MW-Mile method is to find the contribution or share of each generator and each demand in each of the line flows. One of the significant methods reported for finding the share and contribution of generators and demands is flow based. J.Bialek has proposed a tracing method based on topological approach resulting in positive generation and load distribution factors [9].

D. Kirschen et al proposed a method to find the contributions of generators and loads by forming an acyclic state graph of the system making use of the concepts of domains, commons and links [10]. Other methods that use generation shift distribution factors are dependent on the selection of the slack bus and lead to eristic results.

This paper utilizes a new tracing algorithm, the proportional tree (PT) method to allocate and price transmission uses among the transmission participants based on proportional sharing principle that can be found in details in [11].

Essential data required for proportional tree tracing are the proportion of branch inflow in the node flow and the proportion of branch outflow in the node flow. The node flow is defined as either the total power flow entering a node or the total power flow leaving a node. The branch flow leaving a node is designated branch outflow and the branch flow entering a node is designated branch inflow in this paper.

The proportion of branch outflow for branch b and node n is represented by $p_{b,n}^{o}$. The proportion of branch inflow for branch b and node n is represented by $p_{b,n}^{i}$.

4.1 Downstream Transmission Pricing

To calculate the price paid by generators, the transmission uses of generators are determined using downstream proportional tree tracing. In the downstream proportional tree tracing, the transmission loss of a transmission line is allocated to the sending bus of the line as the additional load of the bus.

4.1.1 Generator Contribution Factors

The contribution factor from generator i to line j through path k $\left(p_{gi,lj}^{k}\right)$ can be calculated using the following equation:

$$p_{gi,lj}^{k} = \prod_{b\in Nb_k} p_{b,n}^{o} \tag{3}$$

where Nb_k is the set of branches in path k.

The total contribution factor from generator i to line j through all the related paths is:

$$p_{gi,lj}^{'} = \sum_{k\in Np_{gi,lj}} p_{gi,lj}^{k} \tag{4}$$

where $Np_{gi,lj}$ is the set of paths that connect generator i to line j.

4.1.2 Generator Share in Line Flow

The share of generator i in the flow of line j can be calculated using the following equation:

$$s_{gi,lj} = \frac{p_{gi,lj}^{'}\cdot p_{gi}}{\sum_{k=1}^{N_g} p_{gk,lj}^{'}\cdot p_{gk}} \tag{5}$$

where N_g is the number of generator nodes and p_{gk} is the power output from generator k .

4.2 Transmission Cost Allocation

The price paid by generator i for using transmission line j will be:

$$\rho_{gi,lj} = s_{gi,lj}.x.TC_j \tag{6}$$

where TC_j is total cost for line j. assume that a generator pays x percent and a load pays (1-x) percent of the total cost of a transmission line.

The price paid by generator i for using the transmission network will be:

$$\rho_{gi} = \sum_{j\in Ng_i} \rho_{gi,lj} \tag{7}$$

where Ng_i are the set of lines used by generator i.

4.3 Upstream proportional trees

If loads pay the costs, the transmission uses are allocated to each load using upstream proportional tree tracing. In the upstream proportional tree tracing, the transmission loss of a transmission line is allocated to the sending bus of the line as the extra negative generation of the bus.

4.3.1 Load contribution factors

The contribution factor from load i to line j through path k $\left(p_{di,lj}^{k}\right)$ can be calculated using the following equation:

$$p_{di,lj}^{k} = \prod_{b\in Nb_k} p_{b,n}^{i} \tag{8}$$

Where Nb_k is the set of branches in path k.

The total contribution factor from load i to line j through all the related paths is:

$$p_{di,lj}^{'} = \sum_{k\in Np_{di,lj}} p_{di,lj}^{k} \tag{9}$$

where $Np_{di,lj}$ is the set of paths that connect generator i to line j.

4.3.2 Load share in line flow

The share of load i in the flow of line j can be calculated using the following equation:

$$s_{di,lj} = \frac{p_{di,lj}^{'}\cdot p_{di}}{\sum_{k=1}^{N_d} p_{dk,lj}^{'}\cdot p_{dk}} \tag{10}$$

where N_d , is the number of generator nodes and p_{dk} is the power output from generator k.

4.4 Transmission cost allocation

The price paid by load i for using transmission line j will be:

$$\rho_{di,lj} = s_{di,lj}.(1-x).TC_j \tag{11}$$

It is assumed that generators and customers in the market equally share the total transmission cost (x=0.50)

5. Relation between Economic Benefit and Proportional Tree

The comparison of network cost allocation methods has been the aim of many studies in order to find their advantages and disadvantages. The proportional tree method measure the marginal use of the network, and the economic benefit method computes the benefit caused by the use of the network on the base of marginal prices. Thus both methods are depending.

In the case of combining both methods, it is necessary to simulate the test system in both present and expansion states. Then decision will be made proportional one of the following states.

A. Participant uses the expansion line and has economic benefit

B. Participant uses the expansion line and hasn't economic benefit
C. Participant doesn't use the expansion line and has economic benefit
D. Participant doesn't use the expansion line and hasn't economic benefit
Therefore we define the cost allocation expansion matrix: $CAEM = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$

In the state D: the expansion cost is equal to zero (D=0)
In the state C: the expansion cost is calculated with the economic benefit method
In the state B: the expansion cost is calculated with the proportional tree method
In the state A: the expansion cost is calculated with the composition of two economic benefit and proportional tree method by the following relation:

$$\%x = \alpha.PT + (1-\alpha).EB \qquad 0 \le \alpha \le 1 \qquad (12)$$

Where α is weight factor that depends on market structure and will be determined by ISO.

5.1 Transaction Pricing

If a bilateral transaction t utilizes a utility owned transmission network, the price paid by the transaction can be calculated using the following equation:

$$\rho(t) = \sum_{i \in N_d^t} \omega_{di}(t) \sum_{j \in N_{di}} \rho_{dilj} + \sum_{i \in N_g^t} \omega_{gi}(t) \sum_{j \in N_{gi}} \rho_{gilj} \qquad (13)$$

where N_d^t and N_g^t are the set of load buses and the set of generator buses involved in the transaction, respectively, $\omega_{di}(t)$ is the percentage of the transaction load in the total load at bus i and $\omega_{gi}(t)$ is the percentage of transaction injection in the total generator injection at generator bus i.

6. Test Case

The IEEE 9 bus test system is analyzed to illustrate the proposed technique. The system contains 3 generating units and 9 transmission lines that shown in fig 1. The system configuration data can be found in [12]. All the generators are supposed to be marginal generators and for all transmission lines capacity are equal 150 MVA.
It is supposed that there are two bilateral transactions in the market. Let T1 representing the bilateral transaction of 45 MW power between seller at G1 and customer at L5. The bilateral transaction of 50 MW power between seller at G3 and customer at L7 is represented as T2.

The flow of each transmission line from AC power flow solution can be calculated. Power flow is performed using MATPOWER software [12].
The locational marginal price of each bus should be assessment in order to calculate the congestion costs. Table 1 presents LMPs results based on the contributions of generators to line flows and the assumed generator marginal prices before and after expansion. After the expansion supposed that one line with the 150 MVA is parallel with the path 2-8 for congestion relief.

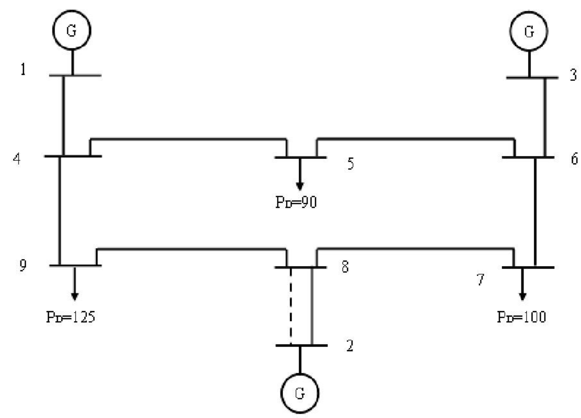

Figure 1. The single-line diagram of the IEEE 9 bus system

This case study illustrates that the proposed transmission pricing scheme can provide economic signals to each market participant about energy transactions. Table 2 shows the revenues of generation companies.

The transmission price for bilateral transaction can be calculated from its proportion in the node generation and demand. Table 3 shows the percentage of transmission costs that allocated to bilateral contracts T1 and T2.

The results obtained are compared with the three methods adopted to allocate the expansion cost allocation.

These are reflected in Tables 4 to 6 for the $(\alpha = 0.4, 0.5, 0.6)$ 9 bus system.

Table 1. Locational Marginal Price of each bus

Bus	LMP before expansion $/MWh	LMP after expansion $/MWh
1	27.000	27.000
2	21.388	26.133
3	26.384	26.335
4	27.000	27.000
5	27.305	27.287
6	26.384	26.335
7	26.491	26.438
8	26.196	26.133
9	27.262	27.249

Table 2. Revenues of Generation Companies

	Before expansion				After expansion			
Generator	Sale Price ($/h)	Energy Sale (MWh)	Total cost (Fix, var & start up) ($/h)	Earnings ($/h)	Sale Price ($/h)	Energy Sale (MWh)	Total cost (Fix, var & start up) ($/h)	Earnings ($/h)
1	27.000	93.41	1576.80	945.22	27.000	88.44	1452.59	935.30
2	21.388	149.89	2689.49	516.22	26.133	155.00	2828.13	1222.54
3	26.384	75	1099.06	879.72	26.335	75	1099.06	876.10

Table 3. Transmission Costs Allocation for Bilateral Transaction (%)

Line	From	To	T1		T2	
			Seller at G1	Buyer at L5	Seller at G3	Buyer at L7
1	1	4	15.276	10.71	0.0	0.0
2	4	5	10.71	10.71	0.0	0.0
3	5	6	0.0	4.36	4.36	0.0
4	3	6	0.0	4.36	16.666	12.276
5	6	7	0.0	0.0	12.276	12.276
6	7	8	4.483	0.0	0.0	4.483
7	8	2	0.0	0.0	0.0	0.0
8	8	9	4.493	0.0	0.0	4.493
9	9	4	4.52	0.0	0.0	4.52

Table 4. Transmission Expansion Cost allocations for the new line 2-8 that added the system with $\alpha = 0.4$

	$\% G_1$	$\% G_2$	$\% G_3$	$\% D_5$	$\% D_7$	$\% D_9$
Proportional Tree	0	48.48	0	0	25.58	25.94
Economic Benefit	0	98.806	0	0.226	0.741	0.227
Composition PT+EB	0	78.6756	0	0.1356	10.6766	10.5122

Table 5. Transmission Expansion Cost allocations for the new line 2-8 that added the system with $\alpha = 0.5$

	$\% G_1$	$\% G_2$	$\% G_3$	$\% D_5$	$\% D_7$	$\% D_9$
Proportional Tree	0	48.48	0	0	25.58	25.94
Economic Benefit	0	98.806	0	0.226	0.741	0.227
Composition PT+EB	0	73.643	0	0.113	13.1605	13.0835

Table 6. Transmission Expansion Cost allocations for the new line 2-8 that added the system with $\alpha = 0.6$

	$\% G_1$	$\% G_2$	$\% G_3$	$\% D_5$	$\% D_7$	$\% D_9$
Proportional Tree	0	48.48	0	0	25.58	25.94
Economic Benefit	0	98.806	0	0.226	0.741	0.227
Composition PT+EB	0	68.6104	0	0.0904	15.6444	15.6548

7. Conclusion

Based on economic benefit and use of system, we proposed a scheme for cost allocation of transmission line expansion to tool with congestion problem in the network. To examine the proposed approach, a case study with a market model is used as a demonstrated example. As a further research topic, it is necessary to take into account detailed information as well as regulation policy in electric power market with large-scale systems for transmission expansion cost allocation. Based on proposed theory, the allocation takes into account the physical and economic impacts of the new transmission assets. The payments made by each participant are calculated using the economic benefit and use of system and are based on the increase in social welfare brought about by the new assets, the pre-investment surpluses of the players, and the influence the different market participants may have on the expansion decision. Reimbursements are provided where necessary, so that all firms have incentives to support the expansion. The numerical example demonstrates that the presented method is a simple, direct and fast way to determine the transmission expansion cost in the basis of the electric power market.

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References

1. Reta R, Vargas A, Verstege J. Allocation of Transmission Costs Areas of Influence Method versus Economic Benefit Method. EEE Trans Power Syst. 2005;20(3):1647-1652.
2. Evans F, Zolezzi J, Rudnick H. Cost Assignment Model for Electrical Transmission System Expansion: An Approach Through the Kernel Theory. IEEE Trans. Power Syst. 2003;18(2): 625–632.
3. Zolezzi J, Rudnick H. Transmission Cost Allocation by Cooperative Games and Coalition Formation. IEEE Trans. Power Syst. 2002; 17(4):1008–1012.
4. Galiana F, Conejo A, Gil H. Transmission Network Cost Allocation Based on Equivalent Bilateral Exchanges. IEEE Trans. Power Syst. 2003; 18(4):1425–1431.
5. Pan J, Teklu Y, Rahman S, Jun K. Review of Use Based Transmission Cost Allocation Methods Under Open Access. IEEE Trans. Power Syst. 2000;15(4):1218–1224.
6. Rubio F, Arriaga IP. Marginal Pricing of Transmission Services: A Comparative Analysis of Network Cost Allocation Methods. IEEE Trans. Power Syst. 2000;15(1):448–454.
7. Shahidehpour M, Yamin H, Li Z. Market Operations in Electric Power System Forecasting Scheduling and Risk managements. John Wiley and Sons Ltd, New York.
8. Bialek J. Topological generation and load distribution factors for supplement charge allocation in transmission open access. IEEE Trans Power Syst. 1997;12(3):1185-1193.
9. Kirschen DS, Allan RN, Strbac G. Contributions of individual generators to loads and flows. IEEE Trans. Power Syst. 1997;12(1):52-60.
10. Yi M, Benjamin J. Investigation of Transmission Cost Allocation Using a Power Flow Tracing Method. Power Engineering Society General Meeting 2007;24-48.
11. Wang P, Xiao Y. Transmission Cost Allocation Using Proportional Tree Methods. IPEC Singapore, 2005.
12. Zimmerman RD, Murilli CE, Gan D. MATPOWER user's manual. Version 3.1b2, 2006.

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