PRICING THE POWER LOSSES IN ELECTRIC POWER SYSTEM

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ABSTRACT

This paper deals with major transmission cost allocation methods. Some of these methods are used widely by electric utilities, while others are still in developmental stages.

1. INTRODUCTION

An electricity market is a system for effecting the purchase and sale of electricity using supply and demand to set the price. Wholesale transactions in electricity are typically cleared and settled by the grid operator or a special-purpose independent entity charged exclusively with that function. Markets for certain related commodities required by (and paid for by) various grid operators to ensure reliability, such as spinning reserve, operating reserves, and installed capacity, are also typically managed by the grid operator. In addition, for most major grids there are markets for electricity derivatives, such as electricity futures and options, which are actively traded. These markets developed as a result of the deregulation of electric power systems around the world.

The competitive environment of electricity markets necessitates wide access to transmission and distribution networks that connect dispersed consumers and suppliers. Moreover, as power flows influence transmission costs, transmission pricing may not only determine the right of entry but also encourage efficiencies in power markets. For example, transmission constrains could prevent an efficient generating unit from being utilized. A proper transmission pricing scheme that considers transmission constraints or congestion could motivate investors to build new transmission and/or generating capacity for improving the efficiency. In a competitive environment, proper transmission pricing could meet revenue expectations, promote an efficient operation of electricity markets, encourage investment in optimal locations of generation and transmission lines, and adequately reimburse owners of transmission assets. Most important, the pricing scheme should implement fairness and be practical.

An efficient transmission pricing mechanism should recover transmission costs by allocating the costs to transmission network users in a proper way. The transmission costs may include running costs, past capital investment, ongoing investment for future expansion and reinforcement associated with load growth and additional transactions. This is very important to accurately determine transmission usage in order to implement usage-based cost allocation methods. However, determining an accurate transmission usage could be difficult due to the nonlinear nature of power flow. This fact necessitates using approximate models, sensitivity indices, or tracing algorithms to determine the contributions to the network flows from individual users or transactions.

2. TRANSMISSION COST ALLOCATION METHODS

Postage-stamp rate method is traditionally used by electric utilities to allocate the fixed transmission cost among the users of firm transmission service. This method is an embedded cost method, which is also called the rolled-in embedded method. This method does not require power flow calculations and is independent of the transmission distance and network configuration. In other words, the charges associated with the use of transmission system determined by postage-stamp method are independent of the transmission distance, supply, and delivery points or the loading on different transmission facilities caused by the transaction under study. The method is based on the assumption that the entire transmission system is used, regardless of the actual facilities that carry the transmission service. The method allocates charges to a transmission user based on an average embedded cost and the magnitude of the user’s transacted power.

The contract path method is also traditionally used by electric utilities to allocate the fixed transmission cost. It is likewise an embedded cost method that does not require power flow calculations. This method is based on the assumption that transmission services can be represented by transmission flows along specified and artificial electrical path throughout the transmission network. The contract path is a physical transmission path between two transmission users that disregards the fact that electrons follow physical paths that may differ dramatically from contract paths. The method ignores power flows in facilities that are not along the identified path. After specifying contract path, transmission costs will then be assigned using a postage-stamp rate, which is determined either individually for each of the transmission systems or on the average for the entire grid. As a consequence, the recovery of embedded capital costs would limited to artificial contract path.

The MW-km method is an embedded cost method that is also known as a line-by-line method because it considers, in its calculations, changes in MW transmission flows and transmission line lengths in km. The method calculates costs associated with each wheeling transaction based on the transmission capacity use as a function of the magnitude of transacted power, the path followed by transacted power, and the distance travelled by transacted power. The MW-km method is also used in identifying transmission paths for a power transaction. As such, this method requires dc power flow calculations. The MW-km method is the first pricing strategy proposed for the recovery of fixed transmission costs based on the actual use of transmission network. The method guarantees the full recovery of fixed transmission costs and reasonably reflects the actual usage of transmission systems.

The MVA-km method is an extended version of the MW-km method. The extension is proposed to include charges for reactive power flow in addition to charges for real power flow. It has been shown that monitoring both real and reactive power, given the line MVA loading limits and the allocation of reactive power support from generators and transmission facilities, is a better approach to measuring the use of transmission resources.

The counter-flow method argues that transmission users should be charged or credited based on whether their transactions cause flows or counter-flows with regard to the direction of net flows. The method suggests that if a particular transaction flows in the opposite direction of the net flow, then the transaction should be credited (i.e., the transaction would pay a negative charge). This suggestion differs from the traditional MW-km approach and other usage-based allocation pricing rules, where each transaction pays for its usage regardless of the flow’s directions. An example of the counter-flow method is zero counter-flow pricing, which proposes that only those that use the transmission facility in the direction of net flow should be charged in proportion to their contributions to the total positive flow. One of the difficulties in using this method is that it would be hard for transmission service providers to arrange payments to users with counter-flows.

Distribution factors are calculated based on linear load flows. In general, generation distribution factors have been used mainly in security and contingency analysis. They have been used to approximately determine the impact of generation and load on transmission flows. In recent years, these factors are suggested as a mechanism to allocate transmission payments in restructured power systems, as these factors can efficiently evaluate transmission usage. To recover the total fixed transmission costs, distribution factors can be used to allocate transmission payments to different users. By using these factors, allocation can be attributed to transaction-related net power injections, to generators, or to loads. These factors can be GSDFs (A) or GGDFs (D) factors [10].

Figure 1. represents a 5-bus test system with two generators and three loads. Numeric data are given in Table 1. and 2. Bus 1 is assumed the reference bus. The dc load flow solution is given in Table 3.

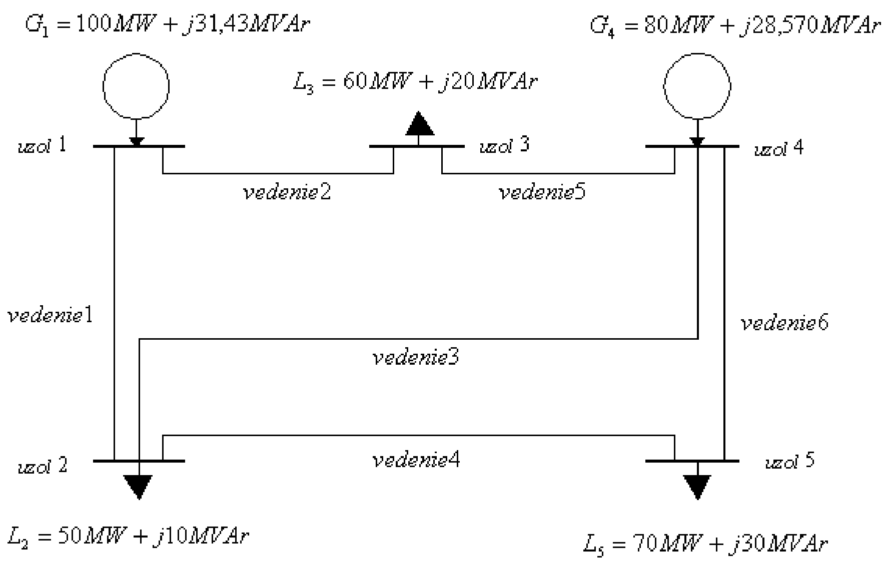

Fig.1. 5-Bus Test System

Table 1. System Data of the 5-Bus Example

Line No.	*From*	*To*	*R(Ω)*	*X*	*B/2*	$c_k L_k$
1	1	2	0,02	0,06	0,030	60
2	1	3	0,08	0,24	0,025	240
3	2	4	0,06	0,18	0,020	280
4	2	5	0,04	0,12	0,015	120
5	3	4	0,01	0,03	0,010	30
6	4	5	0,08	0,24	0,025	240

Table 2. Generation or load of each nodes

Node No.	P_L	Q_L	P_G	Q_G
1	0,000	0,000	100,000	31,43
2	50,000	10,000	0,000	0,000
3	60,000	20,000	0,000	0,000
4	0,000	0,000	80,000	28,570
5	70,000	30,000	0,000	0,000

Total	180,000	60,000	180,000	60,000

Table 3. Line Flows for the dc Load Flow Solution

Line No.	*From*	*To*	P_{ij}
1	1	2	81,8
2	1	3	18,2
3	2	4	-9,9
4	2	5	41,7
5	3	4	-41,8
6	4	5	28,3

Table 4. shows GSDFs and GGDFs of the test system, Table 5. shows transmission usage contributions of each generator based on GGDFs.

$$\Delta F_{1-2} = -81{,}8-(-75{,}8)=-6$$

$$A_{1-2,4} = \frac{\Delta F_{1-2}}{\Delta G_i} = -0{,}60\ , \quad \text{where } \Delta G_i = 10$$

$$D_{1-2,1} = \left\{ F^0_{1-2} - \sum_{\substack{i=1 \\ i \neq r}}^{5} A_{1-2,i} G_i \right\} / \sum_{i=1}^{5} G_i = 0{,}71816$$

$$D_{1-2,4} = D_{1-2,1} + A_{1-2,4} = 0{,}11816$$

Table 4. A Factors (GSDFs) and D Factors (GGDFs) of the 5-Bus

Line i - j	*A Factors*					*D Factors*	
	$A_{ij,1}$	$A_{ij,2}$	$A_{ij,3}$	$A_{ij,4}$	$A_{ij,5}$	$D_{ij,1}$	$D_{ij,4}$
1-2	0	-0,8667	-0,5333	-0,60	-0,7778	0,71816	0,11816
1-3	0	-0,1333	-0,4667	-0,40	-0,2222	0,26740	-0,12250
2-4	0	0,0889	-0,3556	-0,40	-0,0741	0,22720	-0,17280
2-5	0	0,0444	-0,1778	-0,20	-0,7037	0,31780	0,11780
3-4	0	-0,1333	0,5333	-0,40	-0,2222	-0,05089	0,45089
4-5	0	-0,444	0,1778	0,20	-0,2963	0,06805	0,26805

Transmission usage allocation can be computed:

$$P_{ij}^{G_1} = D_{2-4,1} . G_1 = 22{,}7200 \text{ MW}$$

$$P_{ij}^{G_4} = D_{2-4,1} . G_4 = -13{,}8240$$

Table 5. Transmission Usage Allocation using GGDFs

Line	*i*	*j*	P_{ij}^{spolu}	$P_{ij}^{G_1}$	$P_{ij}^{G_4}$
1	1	2	81,2688	71,8160	9,4528
2	1	3	16,94	26,7400	-9,8000
3	2	4	8,896	22,7200	-13,8240
4	2	5	41,204	31,7800	9,4240
5	3	4	41,1602	5,08900	36,0712

6	4	5	28,249	6,8050	21,4440

Table 6. Allocation of Transmission Charges of the Two Methods

Line k	*Line costs €.km*	*DC Method (GLF)*		*GGDFs Method*	
		$c_k L_k MW_{1,k}$	$c_k L_k MW_{4,k}$	$c_k L_k MW_{1,k}$	$c_k L_k MW_{4,k}$
1	60	4908,000	0,000	4308,960	567,168
2	240	4368,000	0,000	6417,600	2352,000
3	280	0,000	2772	6361,600	3870,720
4	120	5004,000	0,000	3813,600	1130,880
5	30	0,000	1254	152,670	1082,136
6	240	0,000	6792	1633,200	5146,560
total	970	14280	10818	22687,63	14149,464
$\sum_{t\in T}\sum_{k\in K} c_k L_k MW_{t,k}$		25098		36837,094	
TC_t		551,900	418,099	597,414	372,585
Costs (€/MW)		5,519	5,226	5,974	4,657

Line cost for the 2nd line:

$$c_k L_k MW_{1,k} = 18{,}2 \cdot 240 = 4368{,}000€ \cdot km \cdot MW$$

For GGDFs method:

$$c_k L_k MW_{1,k} = 240 \cdot 26{,}7400 = 6417{,}600€ \cdot km \cdot MW$$
$$c_k L_k MW_{4,k} = 240 \cdot 9{,}8000 = 2352{,}000€ \cdot km \cdot MW$$

Allocation of transmission charges by MW-km method:

$$TC_t = TC \cdot \frac{\sum_{k\in K} c_k L_k MW_{t.k}}{\sum_{t\in T}\sum_{k\in K} c_k L_k MW_{t,k}} = 970 \cdot \frac{14280}{25098} = 551{,}900€$$

$$c_k = \frac{551{,}9}{100} = 5{,}519€ / MW$$

The *A* factor measures the incremental use of transmission network by generators and loads. We also notice that GSDFs are dependent on the selection of reference (marginal) bus and independent of operational conditions of the system.

GGDFs measure the total use of transmission network facilities produced by generator injections. GGDFs depend on line parameters, system conditions, and not on the choice of reference bus.

GLDFs are based on dc power flows too. *C* factors (GLDFs) measure the total use of transmission network facilities by loads are seen as negative injections. As in the case of GGDFs, GLDFs depend on line parameters, system conditions, and not on the reference bus location.

Many ac-based approaches have been proposed to allocate transmission cost. Among them there are flow sensitivity indices, full ac power flow solutions, and power flow decomposition. The ac flow sensitivity indices method uses the same logic as the dc flow distribution factors, but the sensitivity of transmission flows to bus power injections are derived from ac power flow models. The full ac power flow solutions method uses full ac power flows calculations or utilizes optimal power flow studies. In these methods, more detailed cost information is usually required to study the impact of wheeling transactions. The power flow decomposition method would decompose network flows into components associated with individual transactions plus one component to account for the nonlinear nature of power flow model. For each transaction, the algorithm determines real and reactive flow components of the contribution of participating generators to real-power-loss compensation.

3. CONCLUSIONS

Despite the fact that transmission charges represent a small percentage of operating expenses in utilities, the transmission network is a vital mechanism in competitive electricity markets. In a restructured power system, the transmission network is where generators compete to supply large users and distribution companies. Thus, transmission pricing should be a reasonable economic indicator used by the market to make decisions on resource allocation, system expansion, and reinforcement.

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