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TRANSMISSION COST ALLOCATION BASED ON POWER FLOW TRACING CONSIDERING RELIABILITY BENEFIT

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ABSTRACT
Transmission cost allocation methods have been varied depending on local context of electricity supply industry. There is a common principle that transmission line capacity should be properly allocated to accommodate actual power delivery with adequate reliability margin. This paper, therefore, proposes a method that allocates transmission embedded cost to both generators and loads in an equitable manner, incorporating probability indices to allocate transmission reliability margin among users in both supply and demand sides. Probabilistic indices so called TIRM and TERM decomposed from TRM are introduced, making true cost of using overall transmission facilities. A numerical example on a simple six-bus system with multiple-circuit transmission lines which represent a characteristic of practical system is also presented to illustrate the application of the proposed method.

KEY WORDS
Cost allocation, Transmission pricing, Reliability benefit, Power flow tracing, Reliability margin

1. Introduction

The transmission network plays an important role in delivering electricity from generators to end-consumers. Such a transmission system must be able to flexibly accommodate the continuously growing demand for reliable and economical electricity. Then, it is quite burdensome for transmission grid owners and operators to maintain adequate system reliability margin and security.

Transmission costs encompass existing system cost (capital investment), operating cost and reinforcement cost. All these costs are embedded into a single value which will be allocated among the system users in proportion to the extent of using transmission facilities. In recent years, varied cost allocation methods have been introduced with three distinguished methods- i) Postage Stamp, ii) Contract Path, and iii) MW-Mile methods [1]. For the first method, transmission charge is uniformly average which is simple to be implemented. However, it does not provide any economic signal of facility usage. Contract path method represents transmission flow along specified and artificial electrical path regardless of power flow calculation. In reality, the physical path may be different from the contract path because of the physics law of electron movement. Therefore, the actual capacity usage may not be captured and the recovery of embedded cost would be limited to artificial contract path only. Lastly, the MW-Mile method considers changes in transmission MW flow and line lengths in mile. As such, this method requires power flow calculation and it is the first pricing strategy proposed to recover fixed transmission cost based on actual use of transmission network. However, since MW flows come from various generators and are delivered to loads at extensive points the transmission cost allocation methodology should be able to identify the contribution of each transmission user.

Bialek [2] proposed a tracing method based on the assumption that nodal inflows are shared proportionally among nodal outflows. This method uses either the *upstream-looking* or the *downstream-looking* algorithm. In the upstream-looking algorithm, the portion of capacity used by each generator is identified while downstream-looking algorithm provides the portion of capacity used by each load. This method provides an easily understandable calculation of distribution factors for allocating transmission usage and supplementary charges.

It is well accepted that the maximum transfer capability, in theory, is limited by the amount of spare transmission capacity or reserve required to maintain the reliability of overall system and ensure secure operation. It is also significant that the rational transmission tariff considering transmission reliability margin (TRM) should be established in order to respond to the true cost of using transmission system.

Initially, Yu and David [3] present the cost allocation method entailing two parts. One is the transmission capacity usage charge and the other is transmission reliability charge which is calculated by the circuit provides to the whole system for a particular transaction. Weighing factors for these two cost components were introduced but these factors cannot be easily determined in practice. Nonetheless, this research has motivated several researchers to price the TRM.

Hur et al [4] examine the probabilistic approach to calculate contributions of market participants to the TRM by considering the force outage rate of each circuit across the network. Reliability cost allocation method is extended from MW-Mile method and force outage rate of all circuits is also considered. In addition, they extend their previous research to formulate an equitable transmission cost allocation method for various demand levels at load buses [6].

Chung et al [5] adopt Kirchen's tracing method to quantify the contribution of individual generators to the line flows under normal conditions and attempt to allocate reliability cost considering force outage rate and line outage impact factor.

From the literature survey, transmission reliability cost has been allocated to supply side only and transmission link is always assumed to have a single circuit. This paper, therefore, presents a method to allocate transmission usage and reliability cost to both generation and consumer side adopting Bialek's tracing method tested on a multiple-circuit six-bus transmission system.

2. Methodology

The total transmission capacity is divided into two parts. One is the transmission usage capacity based on the 'extent of use' of transmission network facilities which is obtainable from AC load flow program. The other part is the transmission reliability charge concerning transmission reliability margin which is reserved for security purpose and not used in normal cases. This paper divides transmission reserve margin into two components – (i) the Transmission Internal Reliability Margin (TIRM) determined based on N-1 criterion and (ii) the Transmission External Reliability Margin (TERM) of a particular line that is reserved for situations when other lines use its capacity.

2.1 Transmission Usage Capacity

In this paper, two algorithms of Bialek's tracing method [2] are implemented. Firstly, upstream looking algorithm will find contribution of individual generator to line flows while conversely downstream looking will determine the utilization factor of loads to line flows.

The Bialek's tracing method is the electricity flow tracing method that base on the proportional sharing principle illustrated in Fig. 1 where two inflow lines and two outflow lines are connected to bus 3. The inflow powers of line 1-3 and line 2-3 are 40 MW and 60 MW respectively. The outflow powers of line 3-4 and line 3-5 are 70 MW and 30 MW respectively. Therefore, the total inflow power is 40+60 = 100 MW of which 40% is supplied by G1 through line 1-3 and 60% by G2 through line 2-3. From the proportional sharing principle, it is assumed that inflow power from G1 and G2 are combined perfectly at bus 3. Hence, the outflow in line 3-4 of 70 MW consists of 28 MW from line 1-3 (40% of 70 MW) and 42 MW from line 2-3 (60% of 70 MW). Similarly, the outflow in line 3-5 of 30 MW consists of 12 MW from 1-3 (40% of 30 MW) and 18 MW from line 2-3 (60% of 30 MW).

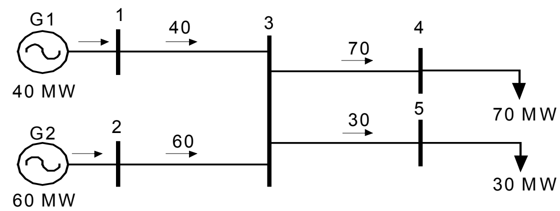

Figure 1. Proportional sharing principle

Table 1
Proportional sharing principle matrix

	Power Supplied by G1 (40 MW)	Power supplied by G2 (60 MW)
Line *3-4* (70 MW)	28 MW	42 MW
Line *3-5* (30 MW)	12 MW	18 MW

2.1.1 Upstream looking algorithm

The upstream looking algorithm allocates the transmission cost to each generator by tracing the power flow in the individual lines supplied by each generator. From Fig. 1, the power flow in line 3-4 consist of 28 MW from G1 and 42 MW from G2. Similarly, the power flow in line 3-5 consist of 12 MW from G1 and 18 MW from G2.

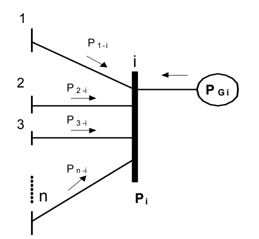

Figure 2. Upstream looking algorithm

Fig.2 shows the upstream looking algorithm considering *n* transmission lines connected to the generator Gi at bus *i*. P_i is total power flow to bus *i*.

2.1.2 Downstream looking algorithm

Conversely, the downstream looking algorithm allocates the transmission cost to each load by tracing the power flow from each generator to individual loads. From Fig. 1, the power supplied by G1 is 28 MW of which it flows to line 3-4 and 12 MW of which it flows to line 3-5. Similarly, the power supplied by G2 is 42 MW of which it flows to line 3-4 and 18 MW of which it flows to line 3-5.

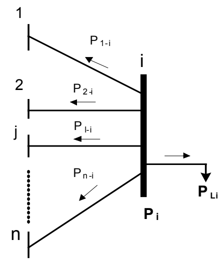

Figure 3. Downstream looking algorithm

2.2 Transmission Reliability Margin

Transmission reliability margin (TRM) is the capacity left from the normal usage. It is required to maintain security and reliability of transmission system under both normal and contingent circumstances and its determination is given as;

$$TRM_l = TTC_l - mpf_l \tag{1}$$

where, TRM_l is transmission reliability margin of line l, TTC_l is total transfer capacity of line l, and mpf_l is maximum power flow to line l. TRM as used in this paper consists of two parts which are TIRM and TERM. TIRM of line l can be found from;

$$TIRM_k = \begin{cases} \dfrac{TTC_k}{N_k} & ; N_k > 1 \\ 0 & ; N_k = 1 \end{cases} \tag{2}$$

where, N is the number of parallel circuit(s).

TIRM is reserved to secure operation in the case that any circuit of line l is failed. TERM of line l is the transmission capacity reserved for the case that the other line (suppose line k) is disconnected and it can be found from (3).

$$TERM_k = \begin{cases} \dfrac{TTC_k}{N_k}\left(N_k - 1\right) - mpf_k & ; N_k > 1 \\ TTC_k - mpf_k & ; N_k = 1 \\ 0 & ; \textit{for redial line} \end{cases} \tag{3}$$

Fig.4 explains three main components of embedded transmission cost by observing the costs of line 3. At line 3, the total transmission line cost (TTLC) is divided into three components – Transmission Usage Cost (TUC), TIRM Cost (TIRMC), and TERM Cost (TERMC) in \$/MW. The first two components are determined from Bialek's tracing method and transmission line capacity configuration. The last one will be allocated from $TERMC_3$ to line 1 ($TERMC_3^1$) and line 2 ($TERMC_3^2$) in proportion to their use on line 3 when line 1 and line 2 are out of service, respectively.

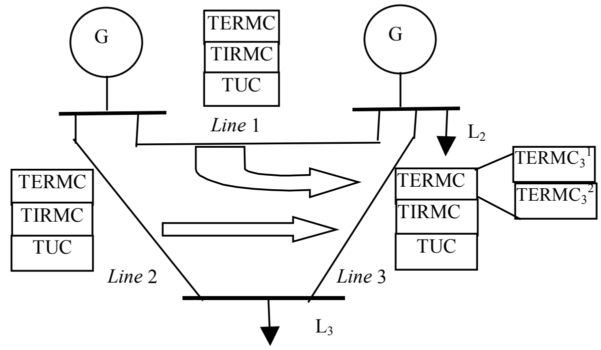

Figure 4. Reliability cost contributions of other lines to TERM of line 3

$TERM_l$ will be distributed only among other transmission lines that use capacity of line l based on the Line Outage Impact Factor (LOIF) proposed by Hur et al. $LOIF_l^k$ is an index indicating the effect on line l when line k is disconnected and thereby increasing the line flow of line l. It means that line k affects line l and thus the users of line k in normal situations (before line k is out) should be responsible for TERMC of line l. On the contrary, if the outage of line k does not increase power flow of line l, the users of line k in this case will have no need to pay for TERMC of line l. The expression of $LOIF^k{}_l$ is as;

$$LOIF_l^k = \begin{cases} \dfrac{\left|mpf_l^k\right|}{\left|mpf_l^0\right|} - 1; & \left|mpf_l^k\right| > \left|mpf_l^0\right| \\ 0 \quad ; & \left|mpf_l^k\right| \le \left|mpf_l^0\right| \end{cases} \tag{4}$$

where, mpf_l^0 and mpf_l^k are maximum power flow of line l under the normal condition and the case of failure of line k, respectively.

Impact Factor (LORIF) of line k that affects flow of line l can be determined from;

$$LORIF_l^k = LOIF_l^k \times FOR^k \tag{5}$$

where, FOR^k is force outage rate of line k. Then, the reliability cost of line l will be allocated to line k with respect to the overall effect due to other lines to line l as normalized line outage impact factor that can determine from;

$$NLORIF_l^k = \frac{LORIF_l^k}{\sum\limits_{j=1, j\neq l}^{n} LORIF_l^j} \tag{6}$$

Transmission usage cost of line k expressed as;

$$TUC_k = \frac{mpf_k}{TTC_k} \times TF_k \tag{7}$$

where, mpf_k is maximum power flow on line k, TTC_k is total transfer capacity of line k (MW), TF_k is total fixed cost of transmission line k (\$/MW).

From (2), Transmission Internal Reliability Margin Cost (TIRMC) can determine from;

$$TIRMC_k = \frac{TIRM_k}{TTC_k} \times TF_k \qquad (8)$$

From (3), Transmission External Reliability Margin Cost (TERMC) can determine from;

$$TERMC_k = \frac{TERM_k}{TTC_k} \times TF_k \qquad (9)$$

TERMC ($/MW) allocated to line k weight by NLORIF of line k is expressed as;

$$TERMC'_k = \sum_{l=1, l\neq k}^{n} NLORIF_l^k \times TERMC_l \qquad (10)$$

Therefore, the Total Transmission Charge Price (TTCP, $/MW) of line k can be written as;

$$TTCP_k = TUC_k + TIRMC_k + TERMC'_k \qquad (11)$$

At this stage, it is prompted to allocate costs to generators and loads based on transmission network usage determined by Bialek's tracing as follows;

$$\begin{aligned} TC_{Gi,k} &= \alpha_G (TTCP_k \times P_{Gi,k}(gross)) \\ TC_{Dd,k} &= \alpha_D (TTCP_k \times P_{Dd,k}(net)) \end{aligned} \qquad (12)$$

where,

$$\alpha_G + \alpha_D = 1 \qquad (13)$$

$TC_{Gi,k}$ is the transmission cost assigned to generator i due to usage of line k ($) and similarly $TC_{Dd,k}$ the transmission charge assigned to load d due to usage of line k ($); $P_{Gi,k}(gross)$ is the gross usage of generator i on line k (MW) and $P_{i,k}(net)$ is the net usage of load d on line k (MW). α_G and α_D are the generator and load transmission costs proportional factor that are determined by a regulator or authority agency.

3. Numerical Example and Case Study

Fig.5 shows a modified 6-bus test system adopted from Chung et al with the line parameters given in Table II. This simple system is chosen to illustrate the procedure of the proposed methodology. Cost of transmission lines, AC power flow solutions and FORs are provided in Table III. Table IV and Table V give the contributions of generators and loads to line flows. The calculation procedures are illustrated as follows:

3.1 Step 1: calculation of line outage impact factor

A full AC load flow program is executed to assess all system parameters. Then, the same load flow program is repeated for each line based on N-1 criterion and used to test network reliability for outage of a particular line. In this step, the LOIFs are calculated according to (4) and depicted in Table VII.

Table 2

Line Data For a 6-Bus Test System

Line No.	From Bus	To Bus	No. of Circuit	R (P.U.)	X (P.U.)	Bc (P.U.)
1	1	2	3	0.0012	0.0150	0
2	1	4	2	0.0230	0.1380	0.2710
3	1	6	3	0.0150	0.0920	0.1810
4	2	4	4	0.0010	0.0120	0
5	2	5	2	0.0170	0.1660	0.3260
6	3	4	2	0.0150	0.0920	0.1810
7	3	5	3	0.0020	0.0240	0
8	3	6	2	0.0120	0.0150	0
9	5	6	1	0.0230	0.1380	0.2710

R: Line resistance; Xl: Line reactance; B_c: Shunt susceptance

3.2 Step 2: allocation of total transfer capacity

The total transfer capacity (TTC) of each line is allocated to TUC based on real MW line flow and total fixed cost of each transmission line. Likewise, it is also allocated to TIRMC and TERMC based on transmission internal reliability margin and transmission external reliability margin respectively. Table III illustrates figures to be used for the calculations.

Table 3

Transmission Fixed Cost, Forced Outage Rate and AC Power Flow Solution

Line k No.	TF_k ($/Year)	FOR^k (hr/year)	TTC_k (MW)	Pf_k (MW)
1	300,000	12	300	130.15
2	4,000,000	15	200	35.302
3	5,850,000	24	300	125.18
4	720,000	36	400	266.84
5	3,000,000	48	200	73.288
6	5,200,000	30	200	61.981
7	810,000	18	300	156.74
8	2,000,000	18	200	55.24
9	1,000,000	20	100	20.123

Table 4

Contribution of Generators to Line Flow

Line No.	Contribution of generators to line flow (P.U.)						
	1	2	3	4	5	6	Total
1	1	0	0	0	0	0	1.0
2	1	0	0	0	0	0	1.0
3	1	0	0	0	0	0	1.0
4	0.3424	0.6576	0	0	0	0	1.0
5	0.3424	0.6576	0	0	0	0	1.0
6	0.4192	0.5808	0	0	0	0	1.0
7	0.1227	0.1700	0.7073	0	0	0	1.0
8	0.1227	0.1700	0.7073	0	0	0	1.0
9	0.7313	0.0521	0.2166	0	0	0	1.0

Table 5
Contribution of Loads to Line Flow

Line No.	Contribution of loads to line flow (P.U.)						
	1	2	3	4	5	6	Total
1	0	0.1053	0	0.5580	0.3034	0.0333	1.0
2	0	0	0	0.7948	0.1577	0.0475	1.0
3	0	0	0	0	0.1117	0.8883	1.0
4	0	0	0	0.7948	0.1577	0.0475	1.0
5	0	0	0	0	1	0	1.0
6	0	0	0	0	0.7686	0.2314	1.0
7	0	0	0	0	1	0	1.0
8	0	0	0	0	0.1117	0.8883	1.0
9	0	0	0	0	1	0	1.0

Table 6
Revenue of Transmission Use

Line No.	Revenue (M$/year)			
	TUC	TIRMC	TERMC′	TTLC
1	0.1302	0.1	0.3747	0.6049
2	0.7061	2	0.0319	2.7386
3	2.4409	1.95	0.9.738	5.3647
4	0.4803	0.18	1.8061	2.4664
5	1.0993	1.5	1.1417	3.7410
6	1.6115	2.6	0.3180	4.5295
7	0.4232	0.27	0.8461	1.5393
8	0.5524	1	0.1247	1.6771
9	0.2012	0	0.0179	0.2191
Total	**7.6451**	**9.6**	**5.6349**	**22.88**

3.3 Step 3: revenue reconciliation

From Table III, total transmission fixed cost is 22.88 M$/year. The cost of each transmission line is decomposed into three parts; TUC, TIRMC and TERMC as shown in Table VI. The total TUC is 7.6451 M$/year (33.41% of total cost), total TIRMC is 9.6 M$/year (41.96%) and total TERMC is 5.6349 M$/year (24.63%). It is observed that revenue collectable from line 1 is greater than its cost. This means that reliability reserve margin of line 1 is shared by the others. In contrast, revenue of line 2 is lower than its cost which means that it uses reliability reserve margin of other lines more than its own. It is also noted to observe that this proposed method could fully recover the overall cost.

3.4 Step 4: allocation of transmission cost to users

Transmission charges are distributed to generators and loads in three cases as shown in Table VIII to X. In Case 1, all transmission charges are passed on to generators only while loads are fully responsible for transmission charges in Case 2. Case 3 gives solution for both generators and loads side that transmission charges are assumed to be equally distributed ($\alpha_G = \alpha_D = 0.5$) as shown in Table X.

3.5 Step 5: analysis of results

The average transmission charge at generator and load buses in terms of $/MW /year is found from the allocated total transmission line charge at a particular bus divided by the maximum power at that bus as given in Table XI. It is evident that the transmission charge of generator G_1 (bus1) is highest because it uses whole capacity of line 1, 2, and 3 during normal operation. In addition, it utilizes more transmission lines (in this case) than the others. Thus, it has to be more liable to greater reliability charge.

For the demand side, load at bus 6 is entitled for the greatest transmission charge because it uses capacity of line 3 which has the highest embedded cost in a very large portion. On the contrary, load at bus 2 pay the cheapest transmission charge since most of its demand is directly served by generator G_2 while the remaining is delivered from generator G_1 through line 1 which has cheapest cost. Load at bus 1 is not required to pay any transmission charge since it is fully powered by generator G_1.

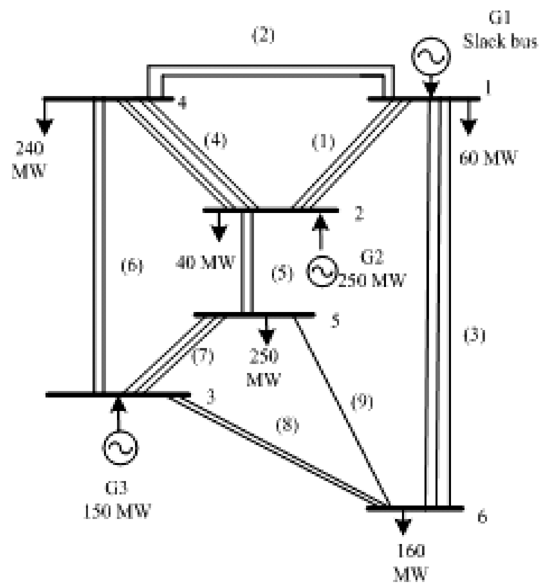

Figure 5. A 6-bus test system for case study

Table 7
Line Outage Reliability Impact Factor $LORIF_l^k$

Impacted line	Failed line									
	1	2	3	4	5	6	7	8	9	Total
1	0	0.1317	0.7378	0	0	0	0.1158	0	0.0146	1.0
2	0.1338	0	0.0631	0.8023	0	0	0	0	0.0009	1.0
3	0.1096	0.0092	0	0.3880	0.2480	0.1723	0	0.0729	0	1.0
4	0	0.1199	0.3963	0	0.4836	0	0	0	0.0002	1.0
5	0	0	0.2128	0.4067	0	0.1432	0.2270	0	0.0102	1.0
6	0	0	0.4893	0.0360	0.4732	0	0	0	0.0016	1.0
7	0.0447	0	0	0	0.7124	0	0	0.1566	0.0864	1.0
8	0	0	0.5542	0	0	0	0.4458	0	0	1.0
9	0.0457	0.0027	0	0.0043	0.2504	0.0115	0.6855	0	0	1.0

Table 8
Transmission Charge of Case 1

Line No.	Case 1 : Transmission charge at generator buses (M$/year)						
	1	2	3	4	5	6	Total
1	0.6049	0	0	0	0	0	**0.6049**
2	2.7380	0	0	0	0	0	**2.7380**
3	5.3647	0	0	0	0	0	**5.3647**
4	0.8444	1.6220	0	0	0	0	**2.4664**
5	1.2808	2.4602	0	0	0	0	**3.7410**
6	1.8988	2.6307	0	0	0	0	**4.5295**
7	0.1889	0.2617	1.0888	0	0	0	**1.5393**
8	0.2058	0.2851	1.1862	0	0	0	**1.6771**
9	0.1602	0.0115	0.0475	0	0	0	**0.2191**
Total	**13.2865**	**7.2711**	**2.3225**	**0**	**0**	**0**	**22.88**

Table 9
Transmission Charge of Case 2

Line	Case 2: Transmission charge at load buses (M$/year)						
	1	2	3	4	5	6	Total
1	0	0.0637	0	0.3375	0.1835	0.02016	**0.6049**
2	0	0	0	2.1762	0.4318	0.1300	**2.7380**
3	0	0	0	0	0.5993	4.7654	**5.3647**
4	0	0	0	1.9604	0.3890	0.1171	**2.4664**
5	0	0	0	0	3.7410	0	**3.7410**
6	0	0	0	0	3.4813	1.0482	**4.5295**
7	0	0	0	0	1.5393	0	**1.5393**
8	0	0	0	0	0.1874	1.4897	**1.6771**
9	0	0	0	0	0.2191	0	**0.2191**
Total	**0**	**0.0637**	**0**	**4.4741**	**10.7716**	**7.5705**	**22.88**

Table 10
Transmission Charge of Case 3

Line No.	Transmission charge at generator buses (M$/year)			Transmission charge at load buses (M$/year)				Total
	1	2	3	2	4	5	6	
1	0.30245	0	0	0.031846	0.16877	0.091752	0.010081	**0.6049**
2	1.369	0	0	0	1.0881	0.21589	0.064999	**2.7380**
3	2.6823	0	0	0	0	0.29966	2.3827	**5.3647**
4	0.42222	0.81101	0	0	0.98019	0.19448	0.058553	**2.4664**
5	0.6404	1.2301	0	0	0	1.8705	0	**3.7410**
6	0.94939	1.3154	0	0	0	1.7407	0.52408	**4.5295**
7	0.094431	0.13083	0.54441	0	0	0.76967	0	**1.5393**
8	0.10288	0.14254	0.59312	0	0	0.093679	0.74486	**1.6771**
9	0.080110	0.005703	0.023731	0	0	0.10954	0	**0.2191**
Total	**6.6432**	**3.6355**	**1.1613**	**0.0318**	**2.2371**	**5.3858**	**3.7853**	**22.88**

Table 11
Average Transmission Charge at Buses

Generator ($/MW/year)			Load ($/MW/year)			
1	2	3	2	4	5	6
18946	14542	7741.7	796.16	9321.1	21543	23658

4. Conclusion

One of challenges in electricity supply industry is to develop transparent and equitable transmission service pricing where the importance of reliability and security should be fairly allocated among users. The same mechanism should be able to recover the full amount of embedded transmission costs. The transmission system operator should also guarantee adequate transmission reliability reserve margin to secure an operation even in case of contingency.

This paper attempts to differentiate the base capacity and reliability capacity reserved for both internal and external line use which is transparent and fair to all users. The charge for both capacities is calculated based proportionally on its portion of their use with the help from Bialek electricity tracing approach and the LORIF index. The proposed method reflects right economic efficiency and also gives right signal for transmission expansion and probably be appropriate for the users to select the location of power stations. It also enables transmission grid owners to fully recover the embedded cost of the transmission system.

Acknowledgements

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References

[1] J. Pan, Y. Teklu, S.Rahman and K.Jun., "Review of Usage-Based Transmission Cost Allocation methods under Open Acess," *IEEE Transaction on Power Systems*, 2000. 15(4): p. 1218-1224.

[2] J. Bialek., Topological generation and load distribution factors for supplement charge allocation in transmission open access, "*IEEE Transaction on Power Systems*," 1997. 12(3): p. 1185-1193.

[3] C.W. Yu, A.K.David, Pricing Transmission Services in the Context of Industry Deregulation, "*IEEE Transaction on Power Systems*," 1997. 12(N0.1): p. 503-510.

[4] Don Hur , J.-K.Park, Won-goo Lee , Balho H. Kim, Young-Hwan Chun, "An alternative method for the reliability differentiated transmission pricing." *Electric Power Systems Research*, 2004. 68: p. 11-17.

[5] K.-H. Chung, B.H. Kim, D. Hur and J.-K. Park, "Transmission reliability cost allocation method based on market participants' reliability contribution factors," *Electric Power Systems Research*, 2004.

[6] D. Hur,C.-I. Yoo, B.H. Kim and J.-K. Park, "Transmission embedded cost allocation methodology with consideration of system reliability," *IEE Proc-Gener Transm Distrib*, 2004. 151(4): p. 427-432.