AN OVERVIEW OF TRANSMISSION PRICING METHODS IN A POOL BASED POWER MARKET

[1]M. MURALI, [2]M. SAILAJA KUMARI, & [3]M. SYDULU

[1,2,3] Department of Electrical Engineering, National Institute of Technology Warangal, A.P, India-506004
Email: [1]murali233.nitw@gmail.com

Abstract—In a restructured power market, it is necessary to develop an appropriate pricing scheme that can provide the useful economic information to market participants, such as generation, transmission companies and customers. Proper pricing method is needed for transmission network to ensure reliability and secure operation of power system. Accurately estimating and allocating the transmission cost in the transmission pricing scheme still remains challenging task. This paper gives an overview of different costs incurred in transmission transaction, types of transmission transactions and the transmission pricing methodologies. Transmission pricing methods such as Embedded and Incremental cost methods are explained. It mainly focused on determining the embedded transmission cost by various methods and tested all the methods on IEEE14 bus system, New England39 bus system and Indian75 bus power system and then illustrated the results.

Keywords—Bialek Tracing, Embedded Cost, GGDF, Kirschen tracing, MVA-Mile, MW-Mile, Postage Stamp

I. INTRODUCTION

The rapidly changing business environment for electric power utilities all around the world has resulted in unbundling of services provided by these utilities. With the introduction of restructuring into the electric power industry, the price of electricity has become the focus of all activities in the power market. The objective of transmission pricing is to recover all or part of the existing and new cost of transmission system. Pricing of transmission services plays a crucial role in determining whether providing transmission crucial role in determining whether providing transmission services is economically beneficial to both the wheeling utility and the wheeling customers. Engineering analysis which deals mainly with determining the feasibility and the cost of providing transmission services is only one of many considerations in the overall process of pricing transmission services. So, it is important to distinguish between transmission costs and prices.

A. Categories of Transmission Transactions

The following are the categories [2, 3] of transmission transactions:

1) Firm Transmission Transactions

These transactions are not subject to discretionary interruptions and are specified in terms of MW of transmission capacity that must be reserved for the transaction. The transco makes arrangements for enough capacity on the network to meet these transaction needs. These could either be on a long-term basis, in the order of years or on short-term contracts (up to one year).

2) Non-firm Transmission Transactions

These transactions may be curtailable or as-available. Curtailable transactions are ongoing transactions that may be curtailed at the utility's discretion. As-available transactions are short-term, mainly economy, transactions that take place when transmission capacity becomes available at specific areas of the system at specific times.

3) Long-term Transmission Transactions

A long-term transaction takes place over a period span-ning several years. Long-term transmission transaction is long enough to allow building new transmission facilities. Transmission service provided as part of long –term firm power sales is an example of long-term transaction [3].

4) Short-term Transmission Transactions

A short-term transmission transaction may be as short as a few hours to as long as a year or two and as such are not generally associated with transmission reinforcements. Short term transaction may be a bilateral contract or pool trading [3].

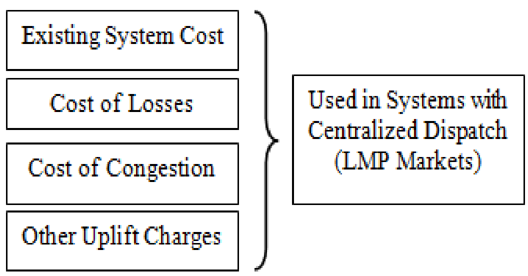
B. Components of the Transmission Cost

The major components of the transmission cost of transmission transactions are: [17]

i) Operating Cost
ii) Opportunity Cost
iii) Reinforcement Cost
iv) Embedded Cost or Existing System Cost

C. Transmission Pricing Approaches

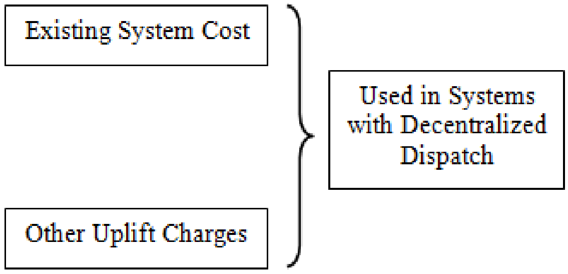
Approach 1:



This is a popular approach which was under practice mostly in US and European markets. Later it was found that, this approach is mostly suitable for recovering congestion cost and losses cost but major drawback of this approach is, it can recover only 20-

30% of existing system cost and other uplift charges. So another approach is proposed to overcome this drawback.

Approach 2:



The remaining 80% of existing system cost and other uplift charges of approach1 can be recovered with approach2 but it cannot account for congestion cost and looses cost. So a combination of approach1 and approach2 is required for a perfect transmission pricing mechanism and this type of mechanism is practised by PJM market in USA.

II. TRANSMISSION PRICING METHODS

The main objective of any transmission pricing method is to recover the transmission system cost plus some profit. Transmission pricing methods are the overall processes of translating transmission costs into overall transmission charges. These methods are shown in Figure 1:

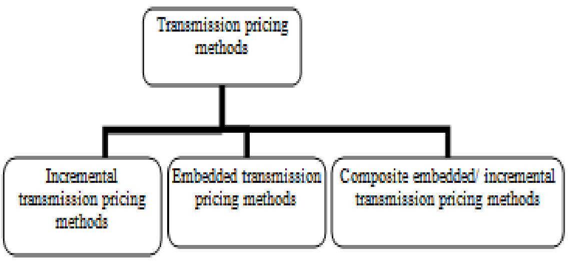


Fig. 1. Different transmission pricing methods

Operating cost, opportunity cost and reinforcement cost of section 1.3 constitute the incremental cost of the transmission transaction. Incremental costs are two types. They are short run and long run incremental costs. "Short-Run Incremental Cost" refer to operating cost and opportunity cost, "Long-Run Incremental Cost" refers to operating cost, opportunity cost and reinforcement cost. The pricing method adopted for these costs is Incremental Transmission Pricing method which comes under Approach1 of section 1.4. Embedded Transmission Pricing method accounts for Embedded Cost or Existing System Cost and this method comes under Approach2 of section 1.4. These two pricing methods are discussed below in detail. A combination of these two methods leads to proper pricing structure for any market. This paper mainly focuses on brief discussion of Embedded Transmission Pricing methods and their case studies.

D. Incremental Transmission Pricing

These pricing methods allocate the incremental cost (i.e., variable cost) of the transmission transaction. Figure 2 shows different types of incremental pricing methods.

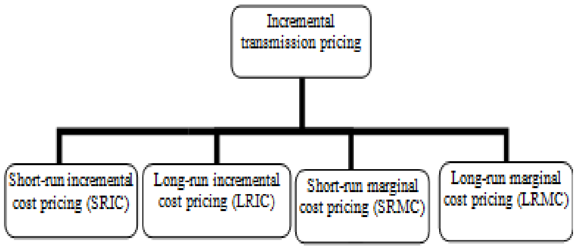


Fig. 2. Types of incremental transmission pricing methods

E. Embedded Transmission Pricing

These pricing methods allocate the embedded system costs i.e., fixed cost among transmission system users. Embedded pricing methods can be categorized as in Figure 3:

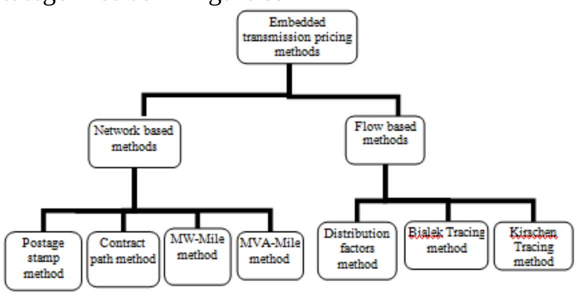


Fig. 3. Types of embedded transmission pricing methods

1) Network Based Methods

These methods depend on the structure of the transmission system but do not recognize the physical laws governing its operation [8].

a) Postage Stamp Method

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. The magnitude of the transacted power for a particular transmission transaction is usually measured at the time of system peak load condition:

$$R_{T}=TC*(P_t/P_{peak}) \qquad (2)$$

Where R_t is the transmission price for transaction t, TC is the total transmission charges and P_t and P_{peak} are transaction t load and the entire system load at the time of system peak load condition [13]. The main purpose of using this methodology is the entire system is considered as a centrally operated integrated system. This method is simpler. Since this method ignores the actual system operation, it is likely to send incorrect economic signal to transmission customers.

b) Distance Based MW-Mile Method

This method allocates the transmission charges based on the magnitude of transacted power and the geographical distance between the delivery point and the receipt point i.e., it is the product of power due to a transaction times the distance this power travels in the network [8]. This method is DC power flow based method.

$$TC_t = TC \times \frac{\sum_{k\in K} C_k L_k MW_{t,k}}{\sum_{t\in T}\sum_{k\in K} C_k L_k MW_{t,k}} \qquad (3)$$

In (3) TC_t =cost allocated to transaction t

TC =total cost of all lines in $

Lk =length of line k in mile

Ck =cost per MW per unit length of line k

$MW_{t,k}$ =flow in line k, due to transaction t

T =set of transactions

K =set of lines

2) Flow Based Methods

This approach allocates the charges of each transmission facility to a wheeling transaction based on the extent of use of that facility by the transaction. This is determined as a function of magnitude, the path, and the distance travelled by the transacted power. The flow based methods are Bialek tracing method and Distribution factors method.

a) Distribution Factors Method

Distribution factors are calculated based on DC load flows. These factors are used to determine the impact of generation and load on transmission flows. The various distribution factors are Generation shift distribution factors (GSDF's) and Generalized Generation/ load distribution factors (GGDF's/GLDF's) have been used extensively in power system security analysis to approximate the transmission line flows and generation /load values. GSDF's or A factors provide line flow changes due to a change in generation. These factors can be used in determining maximum transaction flows for bounded generation and load injections. GGDF's are applied to estimate the contribution by each generator [15,16] to the line flow on the transmission grid and GLDF's determine the contribution of each load to line flows.

b) Bialek Tracing Method

This algorithm works only on lossless flows when the flows at the beginning and end of each line are the same. The simplest way of obtaining lossless flows from the lossy ones is by assuming that a line flow is an average over the sending and receiving end flows and by adding half of the line loss to the power injections at each terminal node of the line [14].

The total flow P_i through node i (i.e., the sum of inflows or outflows) may be expressed, when looking at the inflows as [15]

$$P_{ij}^g = \frac{P_{ij}^g}{P_i^g}\sum_{k=1}^{n}[A_u^{-1}]_{ik} P_{Gk} ; j \in \alpha_i^d$$

(4)

In (4)

$$P_i^g = \sum_{j\in\alpha_i^u} \left|P_{ij}^g\right| + P_{Gi}$$

$[A_u]_{ij}$ = 1 i=j

= $-\frac{|P_{ji}|}{P_j}$ $j\in\alpha_i^u$

= 0 otherwise

and

P_{ij}^g = an unknown gross line flow in line i-j

P_i^g = an unknown gross nodal power flow through node i

A_u = upstream distribution matrix

P_{Gk} = generation in node k

α_i^d = set of nodes supplied directly from node i

α_i^u = set of buses supplying directly to bus i

c) Kirschen Tracing Method

This method is based on a set of definitions for domains, commons and links.

A domain is a set of buses that obtain power from a particular generator. A common is a set of contiguous buses supplied by the same set of generators. Links are branches that interconnect commons. The rank of a common is defined as the number of generators supplying power to the buses comprising this common. It can never be lower than one or higher than the number of generators in the system. Based on these definitions, the state of a system (an acyclic state graph) is represented by a directed graph that consists of commons and links, with directed flows between commons and the corresponding data for generation/loads in commons and flows on links. The method assumes that the proportion of inflow traced to a particular generator is equal to the proportion of outflow traced to the same generator. As, in Bialek's tracing method, Kirschen's tracing method can determine contributions from individual generators to line flows, and determine contributions of individual loads to line flows. The method is applicable to both ac and dc load flow solutions. This traceable allocation method does not rely on a linearized model of the network and is therefore not limited to incremental changes in injections. The method starts by calculating line flows through an optimal power flow.

To calculate the contribution of each generation to commons and line flows, the method calculates the inflow to each common. The inflow to common *k* is the sum of gen eration at common *k* and the flow to common *k* from other commons with a lower rank ***j***. Mathematically

$$I_k = g_k + \sum_j F_{jk} \qquad (5)$$

where,

I_k = inflow of common k

g_k = net generation in common k

F_{jk} = flow (from j to k) in a link connecting commons j and k

The next step is to recursively calculate relative contributions by each generator to the load and outflow of each common, starting from the root common (that has rank 1). Relative contributions are calculated based on absolute contributions to a common. Let

R_{ij} = relative contribution of common i to the load and the outflow of common j

A_{ij} = absolute inflow contribution of common j to common i

N_c = number of commons

F_{ki} = flow between commons k and i

III. RESULTS

In this section different case studies and their results are discussed. IEEE14 bus system, New England39 bus system and Indian75 bus Power system (Uttar Pradesh State Electricity Board data i.e., 400kV and 220kV grid data) are used as the case studies to demonstrate some of the above discussed methods. IEEE14 bus system [18] has 2 generators. New England39 bus system [20] has 10 generators. Indian75 bus Power system [30] has 15 generators. In this paper line lengths are assumed to be proportional to the line reactance for 14 and 75 bus systems whereas for 39 bus system lengths are given in the data file. For transformers line lengths are taken as 1 km for all the three systems. DC optimal power flow is used to get line flows in all the methods. Postage stamp method doesn't consider system line lengths, and hence gives a very inferior result compared to other methods. MW-Mile method, GGDF method, Bialek Tracing method and Kirschen Tracing method accounts for line lengths. GGDF method uses Power transfer Distribution factors for pricing and are used to approximately determine the impact of generation and load on transmission flows. Bialek tracing method uses proportional sharing principle based algorithm and it traces the actual power flow of each line by each participant. Kirschen Tracing method uses domains and commons for tracing the line flow in each line by each generator. The results shows that, power flow tracing based methods present more accurate pricing compared to Postage stamp method, MW-Mile method and GGDF method. Bialek tracing method is a topological approach to determine the contribution of individual generators to every line flow based on the calculation of topological distribution factors. But one drawback of this method is the results obtained by this method are not 100% accurate. Finally it is observed that among the tracing methods; results obtained by Kirschen tracing method are 100% accurate and so this method considered to be the best way of transmission pricing.

Tables I to III illustrate cost per MW generation for each generator using various methods for 14, 39 and 75 bus systems. In all the methods for all bus systems transmission charges are allocated to generators only.

TABLE I. COMPARISON OF VARIOUS METHODS FOR IEEE14 BUS SYSTEM

	G1	G2
Postage stamp method Total cost = 5746.08 $		
Trans. cost ($)	100	100
Cost ($/MW)	0.69	0.85
MW-Mile method Total cost = 70077.11 $		
Trans. cost ($)	1386.67	1386.67
Cost ($/MW)	9.03	13.13
GGDF method Total cost = 71796.6 $		
Trans. cost ($)	1722.062	1051.287
Cost ($/MW)	11.22	9.96
Bialek tracing method Total cost = 70082 $		
Trans. cost ($)	1871.6	901.7
Cost ($/MW)	12.19	8.54
Kirschen tracing method Total cost = 69302.82 $		
Trans. cost ($)	1846.08	927.26
Cost ($/MW)	13.00	7.92

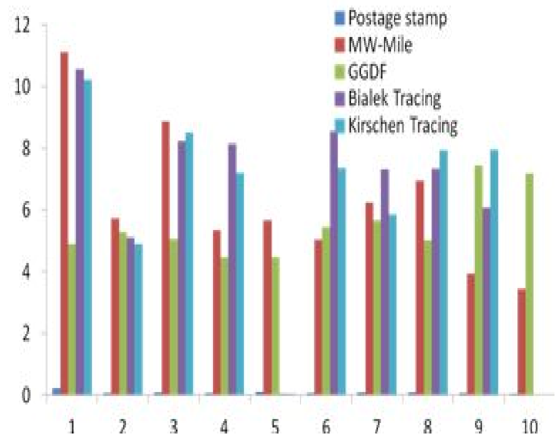


Fig. 4. Comparison of 14 bus system results for different methods

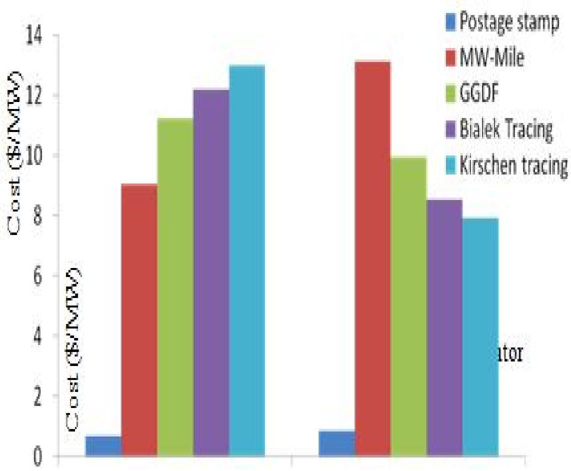


Fig. 5. Comparison of 39 bus system results for different methods

TABLE: 2COMPARISON OF VARIOUS METHODS FOR NEW ENGLAND39 BUS SYSTEM

	G30	G31	G32	G33	G34	G35	G36	G37	G38	G39
Postage stamp method Total cost = 128595.18 $										
Each transaction cost ($)	46	46	46	46	46	46	46	46	46	46
Cost ($/MW)	0.24	0.074	0.08	0.071	0.099	0.0652	0.079	0.081	0.06	0.042
MW-MILE method Total cost = 7093660.3 $										
Each transaction cost ($)	3443	3443	3443	3443	3443	3443	3443	3443	3443	3443
Cost ($/MW)	11.12	5.72	8.88	5.35	5.66	5.04	6.25	6.94	3.94	3.44
GGDF method Total cost = 3.15519e+7 $										
Each transaction cost ($)	1316.45	3204.07	3733.75	2899.00	2720.66	3366.31	3289.92	2934.61	5229.86	5735.32
Cost ($/MW)	4.89	5.27	5.07	4.46	4.47	5.45	5.66	5.03	7.43	7.19
Bialek Tracing method Total cost = 6.942306519917834e+006 $										
Each transaction cost ($)	1407.87	3109.02	6044.35	5297.95	30.14	6029.68	4267.31	4128.45	4115.18	0
Cost ($/MW)	10.55	5.10	8.23	8.15	0.049	8.55	7.31	7.33	6.06	0
Kirschen Tracing method Total cost = 6763923.0 $										
Each transaction cost ($)	2247.50	2987.06	6382.59	4681.94	30.94	4458.03	2380.45	5068.88	6190.69	0
Cost ($/MW)	10.21	4.90	8.51	7.20	0.05	7.36	5.86	7.92	7.96	0

TABLE II. COMPARISON OF VARIOUS METHODS FOR INDIAN 75 BUS POWER SYSTEM

	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15
Postage stamp method Total cost = 159228.088 $															
Cost ($/MW)	0.079	0.33	0.22	0.4	0.23	0.29	0.4	0.35	0.62	0.35	0.30	0.059	0.065	0.25	0.11
MW-MILE method Total cost = 496661.8 $															
Cost ($/MW)	0.36	0.69	0.83	2.08	9.37	1.06	1.46	1.30	0.56	1.30	1.12	0.16	0.35	0.93	0.51
GGDF method Total cost = 1.06717e+6															
Cost ($/MW)	0.51	0.62	0.77	0.77	1.04	1.04	1.07	0.99	0.49	0.58	0.75	0.47	0.48	0.8	0.75
Bialek Tracing method Total cost = 4.7064e+5															
Cost ($/MW)	1.085	0.685	0.67	0.201	0.612	0.383	0.866	0.538	1.003	0.418	0.529	0.725	0.275	0.574	0.359
Kirschen Tracing method Total cost = 473190.824															
Cost ($/MW)	1.0065	0.684	0.671	0.282	0.606	0.38	0.856	0.538	0.935	0.4	0.526	0.75	0.275	0.33	0.36

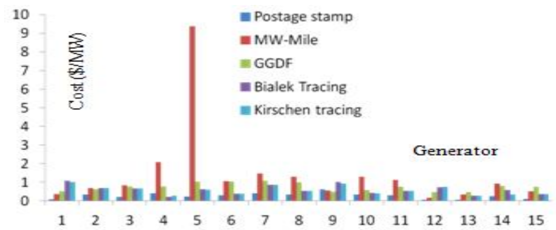


Fig. 6. Comparison of 75 bus system results for different methods

IV. DISCUSSIONS

Figures 4, 5, 6 of 14, 39 and 75 bus systems show the cost per MW flow to be paid by generators to Transco for utilizing transmission network. Since postage stamp method values are near to zero, they are not clearly visible in the graphs. From figure 6 it can be observed that transmission cost (cost per MW flow paid by generator to Transco for utilizing the transmission network) allocated to generator5 through MW-Mile method is very high. Because in MW-Mile method the transaction cost allocated to the transactions is not proportional to the generation of the generator belongs to that transaction. All the transactions owed equal transaction cost in this method. Since power generation for generator5 is 25MW only which is a minimum value and transaction cost is 234.35$ which is uniform to all transactions; the generator5 has to pay 9.37$ as cost per MW flow to Transco which is the highest value among all other transactions. This is a major drawback of MW-Mile method. This drawback can be overcome with flow based methods. Another observation is, in table4 (39bus system results) for Bialek and Kirschen tracing methods the value of cost per MW allocated to generator39 is equal to zero. Because the power generated from generator39 is totally supplied to the load connected to bus39. So the power of this generator39 is not flown into any of the lines connected to bus39. Thus transaction cost and cost per MW allocated for this generator39 should be zero which is obtained in Bialek and Kirschen tracing methods only. With this example the authors claim that tracing methods produce most accurate results for tracing and pricing than all other methods.

CONCLUSIONS

In this paper embedded cost based methods of transmission pricing with DCOPF have been discussed. Different cost components incurred by the transmission transaction were explained. Case studies of Postage stamp method, MW-Mile method, Distribution factors method, Bialek tracing method and Kirschen tracing method for IEEE14 bus system, NewEngland39 bus system and Indian75 bus Power system are presented. Postage stamp method for calculating embedded cost provides very poor results. Among all the embedded transmission pricing methods, flow based methods are proven to be better than network based methods for pricing. Next among all these flow based methods, Kirschen tracing method is the best method because it gives most accurate and reliable results of tracing and also for transmission pricing. It can be concluded that embedded pricing methods only cannot recover total transmission cost; a combination of incremental and embedded pricing methods could result in the recovery of true transmission system cost.

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