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Optimal Allocation of Embedded Cost of Transmission Transaction in Practical Power System

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ABSTRACT - In the competitive power market, it is obligatory to form a rational pricing scheme which can provide the appropriate cost-effective information to market participants, such as generation companies, transmission companies and customers. Proper transmission pricing scheme for transmission network will ensure reliability and secure operation of power system. A variety of methods and ideas have been tried for electricity price forecasting with varying degree of success. This paper exercised embedded cost allocation for transmission services based on optimal power flow approach. Most popular methods like MW-Mile, MVA-Mile and Postage stamp methods are simulated for practical power system. The objective of this study is to compute transmission cost in the form of price to recover embedded cost for transmission companies at the same time to assure system security and reliability of the power system. The proposed methodology is simulated for practical power system of 400 kV Maharashtra State Electricity Transmission Company Limited. The results are computed for several methods and possible conditions. Finally, the proposed optimal embedded MW-mile and MVA-mile methods ensured the economic advantages, system security and reliability for the transmission companies and helps in achieving transmission pricing objectives.

Keywords—Electricity market, Embedded Cost allocation ,transmission pricing methods, MW-Mile Method, MVA-Mile Method, Postage stamp Method, Optimal power flow

I. INTRODUCTION

The traditional power system that existed over the years involved an aggregation of the three major components of the power system as a single entity. The central governments of most countries realizing the very important role electricity plays in her socio-economic wellbeing and socio-political stability took full charge of the operation, control and management of all the power system components – generation, transmission and distribution – as a vertically integrated system. This arrangement has worked for some time in the past where the citizenry take whatever is offered to them as they have no option, but sparingly make requisite payment. Many issues were not apparent due to the fact that majority of the populace lived in abject poverty without the necessities of life that require electricity for their operation. In view of the foregoing, a lot of literature has emerged on the various cost allocation methods in connection with the transmission of electricity. According to [1], the objective of transmission pricing is to recover all or part of the existing and new cost of transmission system. In addition, pricing of transmission services plays a crucial role in determining whether providing transmission services is economically beneficial to both the wheeling utility and the wheeling customers. With transmission as the interconnecting link between the generation and distribution, a players action has consequences to other players which makes it difficult to investigate the component prices to each transaction participant [2],[3]. Various pricing approaches for transmission was first proposed in[4], the author identified three different pricing approaches for electricity transmission namely; the rolled-in pricing methods, the incremental pricing method and composite embedded and incremental pricing method, a combination of the first and second methods[5]. In the rolled in method, all the cost are added up into a single cost making it impossible to distinguish between costs. Nevertheless, the costs calculated are shared between users [6]. The various roll-in methods are Postage Stamp Pricing, Contract Path Pricing, MW-Mile Method and MVA-Mile Method. Postage stamp pricing is entails that all transmission users would pay a single rate, which covers the transmission transaction that occurs within a

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defined region, not minding the contractual origin or destination of transmitted electricity. The same rate applies to all customers [7]. This method is the simplest among all embedded cost method and easy to implement. It does not require power flow calculations and is independent of the transmission distance and network configuration. The rate paid in this case is calculated by adding all network costs and dividing it with the system peak demand. The customer's transmission charge is the product of the postage stamp rate and the peak demand of that customer. Its simplicity of calculation made it popular among embedded cost methods used by electric utilities. Its drawback includes that it sends the wrong economic signal to transmission suppliers and users, as well as does not encourage sitting future investment or the efficient use of the transmission infrastructure [8], [9]. In Contract Path Pricing a virtual path is created between the point of injection and removal of electrical energy for a wheeling transaction. The contract path is usually selected without a formal power flow study to identify the 'dedicated' path for the given transaction [10]. Like the postage stamp method this one is also easy to implement, only the transmission facilities in the 'dedicated' transaction path are taken into consideration. More so, neither reverse flows nor parallel flows are considered [8], [11]. The MW-Mile Method also referred to as line by line method entails that the embedded cost be allocated based on the magnitude of the transacted power and the air distance (in miles) between the point of injection and removal of power. That is the product of the power due to the transaction and the distance this power travels through the network [1]. It still has all the drawbacks of the two above-mentioned methods [5], and is DC power flow based. MVA-Mile Method is an extension of the MW-Mile method only that in this case both real and reactive power are considered unlike in the MW-Mile where only real power is treated. A transaction leading to more reactive power loading will be asked to pay more than others [7]. The second transmission pricing method is the Incremental Transmission Pricing Method composed of Short-Run Marginal Cost Pricing (SRMC), Long-Run Marginal Cost Pricing (LRMC), Short-Run Incremental Cost Pricing (SRIC) and Long-Run Incremental Cost Pricing (LRIC). Transmission infrastructures have both fixed cost and variable cost operations. The incremental cost approach deals with the variable costs. This approach does not include the embedded costs of energy transactions. For calculation of the incremental prices, [4] proposed the following methods respectively: A major motivation for the SRMC was to overcome the inefficiencies of fixed tariffs which fail to provide incentives for efficient energy usage. It assumes that all capacity is fixed [12]. Short-run marginal pricing scheme is based on establishing a price at each node called spot prices. Regarding the economies of scale, SRMC does not cover the fixed costs of networks even in theoretical situations implying the need for additional charges. LRMC scheme unlike SRMC includes the possibility of change for the transmission capacity. Long-run scheme implies that no costs are by definition fixed. All the factors characterizing production, transmission and consumption are to be variable therefore presenting an optimization problem which carries out calculations for the optimal cost transmission capacity. In general, long-run marginal costs are costs of changing the overall system capacity often represented in unit form. Such costs are also dependent on the estimation of the future energy consumption and peak loads [4], [5]. In this scheme, the marginal operating and reinforcement costs of the system are used to calculate the price for a transaction [1]. SRIC scheme is a different pricing scheme than the marginal methodologies because it differs in the terms of cost definition. While it may sound ambiguous, in incremental pricing methodology incremental transactions have to be evaluated unlike the computation of marginal costs in SRMC. All new expenses that may appear are incrementally added to the transactions that are established on the path of the energy transmission. A problem may occur in the compensation process of the real costs since revenues of this model cover only short-run costs assigned to specific transmission transactions. Authors propose the use of the optimal flow model (OPF) to determine all the constraints and stability issues for cost estimation. LRIC is an extension to the SRIC; minor difference is that the costs of the reinforcement for the network on long run view. Such costs are characterized as cost emanating from changes between current transaction charges and long-term transaction plans [4] &[5]. Composite Embedded/Incremental Pricing incorporates existing system costs and the incremental cost of transmission transaction. It solves the common problems associated with both by combining their advantages. This seems applicable in theory but problematic in practice. This study deals with modeling and implementation of embedded cost based transmission pricing electricity market.

II. PROPOSED EMBEDDED COST METHODS

The main objective has been to recover embedded cost of transmission. The embedded cost method includes methods namely (i) Rolled-in-embedded or Postage Stamp method; (ii) Contract Path method; (iii) Line-by-line or Distance based MW-mile methods ; (iv) Line-by-line or Distance based MVA-mile methods. The three embedded cost methodologies are summarized below.

i) Postage Stamp method: It simply allocates the wheeling charges based on the magnitude of the wheeled or transacted power [13]. The annual wheeling cost $WC_{Postage Stamp}$ of the transaction P_W is calculated as

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$$WC_{Postage\,Stamp} = \frac{P_w}{P_{peak}} \times \frac{C}{8760} \qquad (1)$$

where, C is the total transmission annual revenue requirement,

$$C = \sum_f C_f$$

ii) MW-mile method: The embedded transmission charges are assigned to the customer based mile distance between injection and receipt and the magnitude of transmitted power [13]. Two power flows executed successively, with and without the transaction 'T', yield $(\Delta MW_f)_T$ is the change in MW flows in all transmission line facilities. Many economists prefer the Megawatt-mile pricing concept because it encourages the efficient use of the transmission facility and the expansion of the system. The transaction cost $WC_{MW-mile}$ allocation to a transaction 'T' is given by,

$$WC_{MW-mile} = \frac{C \sum_f (\Delta MW_f)_T L_f}{8760 \sum_T (\sum_f (\Delta MW_f)_T L_f} \qquad (2)$$

Where,

ΔMW_f = $|MW_f$ (with transaction T)| - $|MW_f$ (without transaction T)|

$(MW_f)_T$ is the MW flow in facility f due to transaction T.

(iii) MVA-mile method: This method can take into consideration active and reactive power loading of the transmission network by transaction and hence allocates the embedded cost of transmission accordingly [14]. Two power flows executed successively, with and without the transaction 'T', yield $(\Delta MVA_f)_T$ the change in MVA flows in all transmission lines facilities. The transaction cost $WC_{MVA-mile}$ allocation to a transaction 'T' is given by,

$$WC_{MVA-mile} = \frac{C \sum_f (\Delta MVA_f)_T L_f}{8760 \sum_T (\sum_f (\Delta MVA_f)_T L_f}$$

(3)

Where:

$\Delta MVA_f = |MVA_f$ (with transaction T)| - $|MVA_f$ (without transaction T)|

$(MVA_f)_T$ is the MVA flow in facility f due to transaction T.

III. A MATHEMATICAL FORMULATION

Many of the embedded cost methods i.e. Postage stamp, Contract path, MW-mile and MVA mile have been practiced using simple load flow studies. These methods have been focused more towards economic aspects of cost calculation rather than technical aspects of power system. The frequent increase in wheeling transaction under restructured electricity market can pose serious threat to integrated power system in many developing countries. Many developing and or transition countries are facing infrastructural problems in their electricity sector. So besides achieving economic efficiency, power system security must be ensured at the highest level. This paper presents new approach for formulating an efficient embedded cost method of transmission pricing based on optimal power flow concept. The said methodology is implemented for Postage stamp, Contract path, MW-mile and MVA mile methods more suitable for real power system of India. Various conditions of power system under open access is considered to compute transmission embedded charges in order to recover embedded cost. The problem is formulated as discussed in section IV.

IV. PROBLEM FORMULATION

The first objective of optimum power flow is to minimize the costs of matching the load demand for a power system while keeping security of the network [15].

A generation cost minimization problem is written in the following form,

$$F = \sum_{i=1}^{NG} F_i = \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{gi} + c_i)$$

(4)

Where,

Pgi is real generation on ith bus.
ai, bi, ci are the cost coefficient of ith generator.

The constraints to be satisfied are,

(a) Vector of equality constraint (real power flow balance) is,

$$P_i(V,\delta) - P_{gi} + P_{di} = 0 \qquad (i = 1, 2, \ldots\ldots, NB)$$

(5)

Where,

V is magnitude of voltage
δ is the voltage angle
P_{di} is the real demand on i[th] bus

(b) Vector of equality constraint (reactive power flow balance) is,

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$$Q_i(V,\delta) - Q_{gi} + Q_{di} = 0 \qquad (i=1,\ 2,....,\ NB)$$

(6)

Where,

Qgi is reactive generation on ith bus.

Q_{di} is the reactive demand on i^{th} bus

(c) The security related constraints are,

-limits on real power generations,

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (i=1,2,....,NG)$$

(7)

-limits on bus voltage magnitudes,

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad (i=NV+1,\ NV+2,....,NB)$$

(8)

-limits on voltage angles,

$$\delta_i^{\min} \le \delta_i \le \delta_i^{\max} \qquad (i=1,2,....,NB)$$

(9)

(d) The functional constraints are,

- limits on reactive power

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad (i=1,2,....,NG)$$

(10)

- limits on transmission line power flow (MVA) limits,

$$P_f^{\min} \le P_f \le P_f^{\max} \qquad (f=1,2,....,Noele)$$

(11)

The real power flow equation is

$$P_i(V,\delta) = V_i \sum_{j=1}^{NB} V_j \left(G_{ij}\cos(\delta_i-\delta_j) + B_{ij}\sin(\delta_i-\delta_j)\right)$$

(12)

The reactive power flow equation is

$$Q_i(V,\delta) = V_i \sum_{j=1}^{NB} V_j \left(G_{ij}\sin(\delta_i-\delta_j) - B_{ij}\cos(\delta_i-\delta_j)\right)$$

(13)

This methodology has been simulated and results are obtained for several conditions and constraints tested over a 400 kV Maharashtra State Electricity Transmission Company Limited (MSETCL) System, India.

V. FLOWCHART

Algorithm for implementing embedded cost methods (MW-Mile, MVA-Mile and Postage stamp) is shown in the figure 1. A complete program for OPF is written in MATLAB software. To calculate actual transmission usage for each transaction, OPF has been applied twice; first one without transactions and in the second with related transaction. The difference between power flows in transmission facilities are considered as actual transaction usage. The cost is allocated in the form of Annual Revenue Requirement (ARR) computed bt transmission company. Finally transmission transaction cost is computed for MW-mile and MVA-mile methods with MATLAB software.

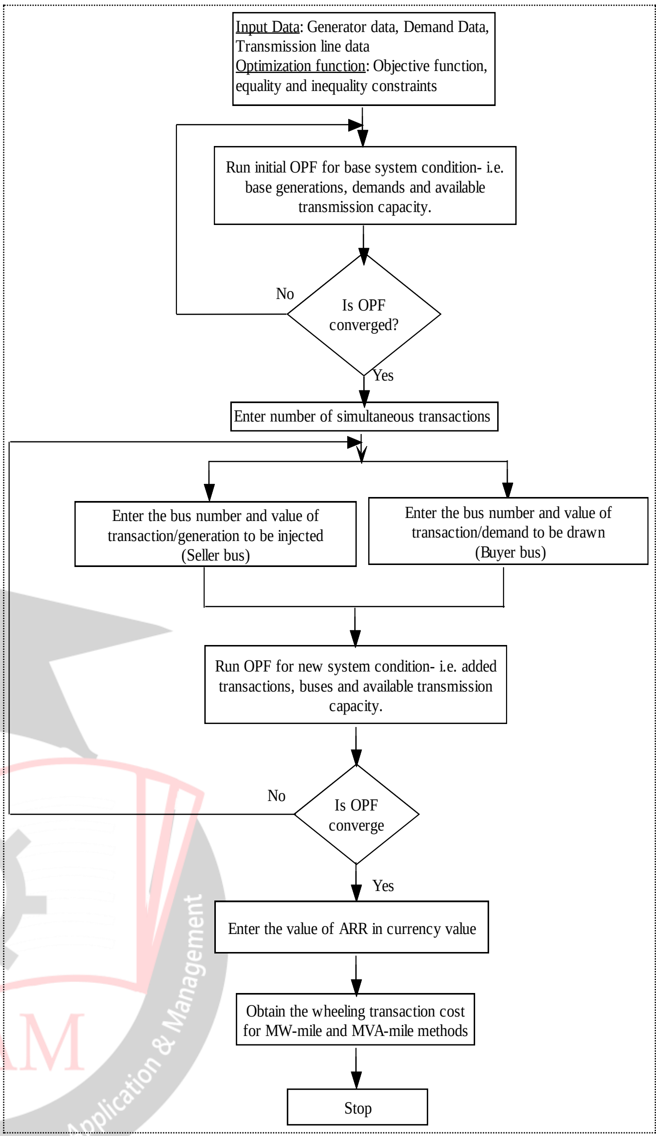

Figure 1 : Flow chart of embedded cost method

VI. PROBLEM SIMULATION AND RESULT

In this section a practical power system problem is simulated in MATLAB and results are analyzed. A real power system i.e. a 400 kV Maharashtra State Electricity Transmission Company Limited (MSETCL) is as shown in Figure 2. In that system, from generator buses power is purchased to fulfill the load demand. In order to calculate wheeling charges of transmission transaction, the Annual revenue requirement (ARR) data submitted by real power system considered under study.

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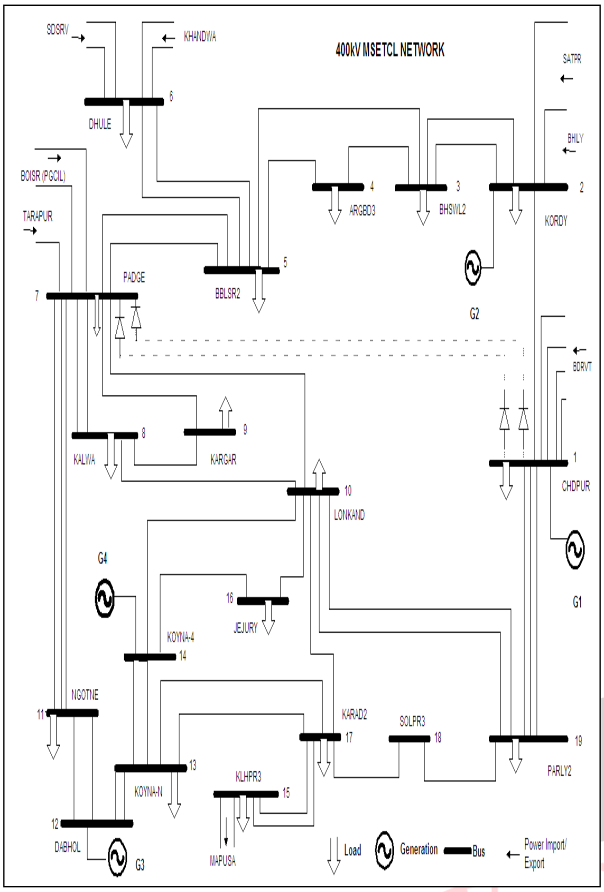

Figure 2 : A 400kV MSETCL system

The simulated results of OPF based MW-Mile, MVA-Mile and Postage stamp method under normal condition are shown in table 1, table 2 and table 3.

Table 1: A 400 kV MSETCL system: OPF based MW-Mile method

Transaction value (MW)	From	To	Wheeling cost (Rs./kWh)	Total wheeling cost (Rs./hour)
	Bus No. (Bus Name)	Bus No. (Bus Name)		
Case-1:Two simultaneous transactions of same value at different generators and load buses				
100 MW	1 (CHDPR)	4 (ARGBD3)	0.5540	55,400.0
100 MW	2 (KORDY)	3 (BHSWL2)	0.5875	58,750.0
Case-2:Two simultaneous transactions of different value at different generator and load buses				
150MW	1 (CHDPR)	4 (ARGBD3)	0.3500	52,500.0
200 MW	2 (KORDY)	3 (BHSWL2)	0.3083	61,660.0
Case-3:Two simultaneous transactions of same value served by low cost generator at different load buses				
100 MW	1 (CHDPR)	19(PARLY 2)	0.4181	41,810.0
100 MW	1 (CHDPR)	5 (BBLSR2)	0.7235	72,350.0
Case-4:Two simultaneous transactions of same value served by high cost generator at different load buses				
100 MW	20 (BHLY)	19(PARLY 2)	0.3659	36,590.0
100 MW	20 (BHLY)	5 (BBLSR2)	0.7757	77,.570.0
Case-5:Two simultaneous transactions of same value on single generator at nearest and far away load buses				
100 MW	2 (KORDY)	3 (BHSWL2)	0.1788	17,880.0
100 MW	2 (KORDY)	7 (PADGE)	0.9628	96,280.0

The total wheeling costs obtained by this method are based on difference in transmission line flows, distance between seller (injected transactions) and buyer (drawl transaction) and cost characteristics of generators participated in the given transactions. This method exhibits true cost of transmission and wheeling cost varies for small or bulk transaction. So, altogether different wheeling transaction costs are obtained.

Table 2: A 400 kV MSETCL system: OPF based MVA-Mile method

Transaction value (MW)	From	To	Wheeling cost (Rs./kWh)	Total wheeling cost (Rs./hour)
	Bus No. (Bus Name)	Bus No. (Bus Name)		
Case-1:Two simultaneous transactions of same value at different generators and load buses				
100 MW	1 (CHDPR)	4 (ARGBD3)	0.3668	36,680.0
100 MW	2 (KORDY)	3 (BHSWL2)	0.7747	77,470.0
Case-2:Two simultaneous transactions of different value at different generator and load buses				
150MW	1 (CHDPR)	4 (ARGBD3)	0.2044	30,660.0
200MW	2 (KORDY)	3 (BHSWL2)	0.4174	83,480.0
Case-3:Two simultaneous transactions of same value served by low cost generator at different load buses				
100 MW	1 (CHDPR)	19(PARLY 2)	0.0384	3,840.0

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100 MW	1 (CHDPR)	5 (BBLSR2)	1.1031	1,10,310.0
Case-4:Two simultaneous transactions of same value served by high cost generator at different load buses				
100 MW	20 (BHLY)	19(PARLY 2)	-0.0128	-1,280.0
100 MW	20 (BHLY)	5 (BBLSR2)	1.1544	1,15,440.0
Case-5:Two simultaneous transactions of same value on single generator at nearest and far away load buses				
100 MW	2 (KORDY)	3 (BHSWL2)	0.0814	8,140.0
100 MW	2 (KORDY)	7 (PADGE)	1.0601	1,06,010.0

The MVA-Mile method considers the effect of reactive power associated with the transaction. As transmission ratings are in MVA, hence this method is known to be the best one, as it gives fair allocation of cost to simultaneous wheeling transactions in any condition.

Table 3: A 400 kV MSETCL system: Postage Stamp method

Transaction value (MW)	From	To	Wheeling cost (Rs./kWh)	Total wheeling cost (Rs./hour)
	Bus No. (Bus Name)	Bus No. (Bus Name)		
Case-1:Two simultaneous transactions of same value at different generators and load buses				
100 MW	1 (CHDPR)	4 (ARGBD3)	0.0021	210.0
100 MW	2 (KORDY)	3 (BHSWL2)	0.0021	210.0
Case-2:Two simultaneous transactions of different value at different generator and load buses				
150MW	1 (CHDPR)	4 (ARGBD3)	0.0031	465.0
200MW	2 (KORDY)	3 (BHSWL2)	0.0042	840.0
Case-3:Two simultaneous transactions of same value served by low cost generator at different load buses				
100 MW	1 (CHDPR)	19(PARLY 2)	0.0021	210.0
100 MW	1 (CHDPR)	5 (BBLSR2)	0.0021	210.0
Case-4:Two simultaneous transactions of same value served by high cost generator at different load buses				
100 MW	20 (BHLY)	19(PARLY 2)	0.0021	210.0
100 MW	20 (BHLY)	5 (BBLSR2)	0.0021	210.0
Case-5:Two simultaneous transactions of same value on single generator at nearest and far away load buses				
100 MW	2 (KORDY)	3 (BHSWL2)	0.0021	210.0
100 MW	2 (KORDY)	7 (PADGE)	0.0021	210.0

In Postage Stamp method as shown in Table-3 the transmission tariff remains same for all transactions whether the transaction is small or bulk in nature or the transactions are served by lost cost generator. So this transmission tariff method does not motivate bulk customers. As peak load condition changes with respect to time, the tariff obtained by this method varies hourly.

VII. CONCLUSION

In this paper, various transmission-pricing methods were reviewed with particular attention given to the embedded cost transmission methods. A computational evaluation of three different embedded transmission-pricing methods was carried out. The Methods were implemented and simulated using MATLAB Programming. The results of OPF based MW-Mile, MVA-Mile and Postage stamp method under normal condition and are simulated over a real power system i.e. a 400 kV Maharashtra State Electricity Transmission Company Limited (MSETCL), India.

MVA-mile has advantage over MW-mile as it gives fair allocation cost of wheeling transaction. In order to know the impact of future transmission transactions and how to enhance possible competition in wholesale electricity market in State, numerical study has been shown in Table 1-2. This study concluded that transmission pricing is decreases, if heavy generation is added in a 400 kV MSETCL system.

This study can be useful to ensure the economic advantages, system security and reliability for the transmission companies and help in achieving transmission tariff objective.

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