Efficient Transmission Cost Allocation by Composite MVA-Mile Method with Network usage Approach

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ABSTRACT
Transmission Cost Allocation (TCA) function will facilitate competitive electricity market by impartially providing energy transportation services to all energy buyers and sellers, while fairly recovering the cost of providing those services. The revenue reconciliation obtained by TCA should include both active as well as reactive power flow in the circuit along with variance in the utilization of the transmission network. The work in this paper proposes the MVA-mile method with variance in the usage of network to evaluate the TCA for efficient revenue reconciliation. This method adopted in this work shows more fairer and transparent way of allocation of transmission cost. MVA-mile method has an important aspect of deliberation of cost of reactive power flow in TCA. Overall recovery of Annual Revenue Reconciliation (ARR) of transmission facilities provision is higher with proposed MVA- mile component of TCA and lower with Postage Stamp (POS) component of TCA. The absolute, dominant and reverse variants of MVA flow through circuit are used to allocate the transmission cost to users. Standard six bus network is used with different cases of variance in network circuit usages in proposed simulation. It has been assumed the load consumer pays total cost of transmission services to the transmission owner. The TCA is evaluated for load users only.

Keywords
Transmission Cost Allocation; MVA-mile; Postage Stamp; Reactive Power Flow; Network Usage;

1. INTRODUCTION
Transmission Cost Allocation (TCA) is defined as a function which facilitates competitive electricity market by impartially providing energy transportation services to all energy buyers and sellers, while fairly recovering the cost of providing those services [6]. The objectives and major components of TCA are explained in details [8]. Transmission cost allocation paradigm is the overall processes of translating transmission costs into overall transmission charges [2]. Some of these paradigms such as rolled-in, incremental and embedded cost based TCA to user are illustrated [8]. As per the discussion based on TCA to users the methods are distinguished into two main categories rolled in (embedded) pricing method and incremental pricing method [8]. The combine evaluation of power flow based MW-mile approach with POS method of TCA is discussed [16]. MW-mile method of TCA is having number of variants of power flow such as; absolute, dominant and reverse are discussed and used to determine the cost of each circuit [15], [14]. The study based on evaluation of TCA to users shows power flow based MVA-mile method is more wistful. This method usage amount of active as well as reactive power transmitted through circuit in TCA to users. The proposed method offers several benefits like; practicality and fairness to all parties and ease of measuring electricity loss and protecting stockholders from free riders [1]. The simulation results are obtained on standard six bus system. This gives combined evaluation of power flow based MVA-mile component of TCA and POS component of TCA. The power flow analysis with cases of incremental demand in each circuit of the network is obtained with simulation. The cost parameters includes MVA-mile component, POS component of TCA to each demand customers. The most economical approach among the three variants of MVA flow is reverse variant which helps in reducing overloading of circuit and reliving transmission congestion [11]. This gives fair TCA signal to users as it is designed with net MVA flow impact on circuit for both real and reactive power in the circuit.

After introduction in section I, the paper presents MVA-mile method of TCA to users in section II, followed by POS method of TCA in section III and combined evaluation method in section IV. A six bus network used for simulation has been presented in V section. Simulation results are mentioned in section VI. An analysis on efficient allocation of TCA to users is mentioned in section VII. Finally the paper concludes in section VIII, followed by references.

2. COMPOSITE MVA-MILE METHOD
The power-flow-based MVA-mile method has shown its highlighted reflection in TCA and Annual Revenue Reconciliation (ARR) compared to MW-mile method as it considers both the active as well as reactive power flow in TCA to users [15]. This paper presents power flow based MVA-mile method of TCA to users in combination with postage stamp method. MVA-mile method includes the analysis of TCA for absolute, dominant and reverse variants of MVA flow. TCA to users discussed in relation with the cost of circuit. Indian Electricity Act 2003 laid down the guide lines towards the TCA in India. This act suggests that the TCA should sensitive to distance, direction and quantum of power flow [4]. The power flow based MVA-mile method is embedded cost based transmission pricing method. Generally under embedded cost based pricing method includes all the fixed or sunk costs of the transmission system allocated to existing users of the network [9]. The fixed or sunk costs are allocated, so as to reflect the level of both active and reactive power flow being transmitted along with the distance between the points of power being transmitted [3].

2.1 MVA-mile Component of TCA
Embedded cost includes all the fixed or sunk costs of the transmission system or network [9]. As per suggestion of act TCA should sensitive to distance, direction and quantum of power flow. MVA-mile component of TCA to user is

embedded cost and amount of power flow based. The fixed or sunk costs are allocated, so as to reflect the level of both active and reactive power flow being transmitted along with the distance between the points of power being transmitted. MVA-mile component of TCA to each individual user C_k, is being calculated by using following equation.

$$C_k = \sum_{i=1}^{N} \frac{L_i \cdot F_i \cdot P_i^k}{\overline{P}_i} \quad (1)$$

where,

C_k : TCA to individual user k,

L_i : Length of circuit i,

F_i: Unit cost reflecting the cost per km of circuit i,

$\overline{P}_i$: Capacity rating of circuit i,

P_i^k : Power flow imposed on the circuit i, by user k,

N : Numbers of transactions or user demands,

i : Total number of circuits in the system.

The act suggests that the TCA should sensitive to direction MVA flow. Following approaches are suggested to calculate the energy transportation charges based on the direction of MVA flow.

(i) Absolute Approach

An absolute approach calculates the energy transportation charges based on the magnitude of MVA flow and distance in miles of circuit used with ignoring the direction of the power flow imposed on the circuit by the user. The power flow imposed on the circuit i, by the user k, P_i^k is treated based on the following condition,

$P_i^k = |P_i^k|$ for direct and reverse power flows.

This method ignores the direction of reverse MVA flow by considering positive value of MVA for both the directions either forward or reversed flow.

(ii) Dominant Approach

The dominant approach is a hybridization of the absolute and reverse approaches. In this approach the network users are only charged on the basis of direct power flow impose on each line. Reverse power flows are not counted so users responsible for the reverse power flows do not receive any credit like reverse MVA-mile approach and do not pay any charge like the absolute MVA-mile approach. In the dominant MVA-mile approach, power flow imposed on the circuit i, by the user k, is treated based on the following condition [9].

$P_i^k = |P_i^k|$ for direct power flows

or

$P_i^k = 0$ for reverse power flows

(iii) Reverse Approach

The reverse power flow based MVA-Mile approach takes into account of the power flow in reverse direction and the power transportation charge of each circuit is analyzed based on the net flows. The reason is that the reverse power flow reduces the burden on circuit and reliefs congestion [9]. Power flow imposed on the circuit i, by the user k, $P_i^k$is treated based on following condition. This method considers direction as well magnitude of MVA flow in evaluation of TCA to users

P_i^k = Positive (+)for direct power flows

&

P_i^k = Negative (-)for reverse power flows

2.2 Postage Stamp Component of TCA

After evaluation of TCA to all users by MVA-mile method of transmission network in this study it has been proved that this method fails to reconcile the expected revenue. Under utilization of the circuits below their capacities may be one of the reasons behind this. Residual revenue reconciliation is also addressed in this problem. [16]. A postage stamp TCA to user of transmission network is calculated by multiplying the ratio of total unremunerated revenue to system peak demand with load demand of that user. Thus postage stamp TCA to user is producing flat amount per MVA transport. Postage stamp method is used to reconcile the residual annual revenue, which will be apportioned to each user based on its demand and reduces with network uses. The TCA to individual user k by postage stamp method to user k, is calculated by using following equation;

$$R_k = \frac{\Delta TC. P_{LK}}{P_{LT}} \quad (2)$$

where,

R_k: TCA to individual user k by POS method,

P_{LK}: Load demand of user k,

ΔTC: Total unremunerated revenue,

P_{LT} : Total load of all users.

3. TCA TO USER BY COMPOSITE MVA-MILE METHD

MVA-mile component of TCA along with postage stamp component of TCA are used to finalize TCA to users of the transmission network. TCA by composite MVA-mile method to user k is calculated by using following equation.

$TC_k = C_k + R_k$. (3)

Composite MVA-mile method is used in TCA to users for use of system charge of the transmission network is discussed in this section. TCA to user by flow chart is discussed in Fig.1. Four main steps are involved in evaluation of TCA to users with three different approaches of MVA flow in MVA-mile component and concurrent postage stamp component. MVA-mile component of TCA has shown its inability to recover the entire revenue defined as ARR. This paper seeks to prove that the revenue reconciliation also depends on the utilization of the network. Maximum utilization of the network decreases the postage stamp TCA component.

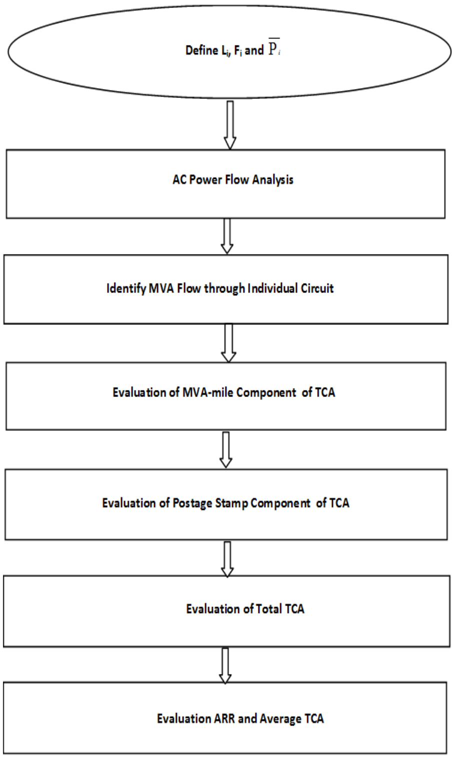

Fig.1. Block Diagram of Composite MVA-mile Method

Main steps involved in evaluation of TCA to users in composite MVA-mile method are discussed below with its MVA-mile component and concurrent postage stamp component.

(i) Determine cost per km of each circuit

- ARR allocated to individual circuit of the network is fixed.
- Cost per km length of circuit is calculated.

(ii) AC Power flow analysis

- AC power flow analysis is carried out by considering the system with peak load demand. The MVA flow obtained is treated as the base case MVA flow.
- The impact of each demand by user on circuit is evaluated by setting zero value for the other demands at any bus. The MVA flow obtained is treated as the new case MVA flow.
- The MVA flow imposed by each demand on a specific circuit is calculated by the difference between the base case and the new case.

(iii) Evaluation of TCA to User

- MVA-mile component of TCA to user is determined using simulation.
- Unremunerated revenue is determined. The component of TCA is evaluated by using simulation to reconcile this with postage stamp method.
- TCA to users per unit demand for utilization of the transmission network is evaluated by simulation.
- ARR is finally evaluated by each user.

4. SIMULATIONS RESULTS

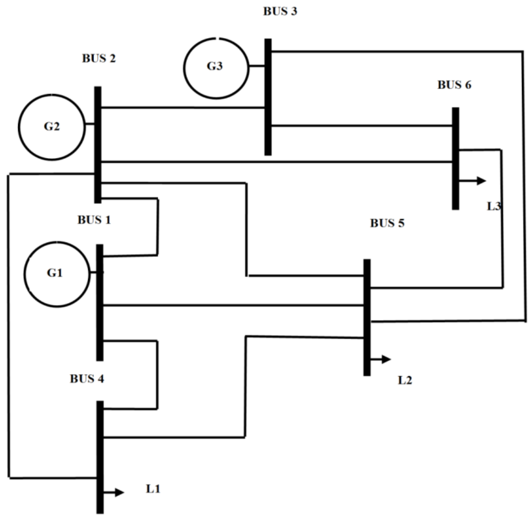

Fig. 2. Six Bus System

A six bus transmission system used for simulation [7], [16] is shown in Fig.2. The embedded cost of a circuit is 435750 $ /km with Annual Revenue Reconciliation (ARR) of 41804363.64 $ for a span 15 years at an annual interest rate of 6.9%. Buses 1, 2 and 3 are generator buses showing power injected in MVA and power in MVA is being extracted at load buses 4, 5, and 6 by user's k_1, k_2, k_3 respectively. The generation installed capacity is 610 MW and at peak load transmission network carries maximum 479 MVA. Six cases of demand variation are simulated.

The simulation results are displayed for network utilization charges in each case of demand. Users at buses 1, 2 and 3 has no TCA applied as it is assumed only load users pays the 100% cost of transmission use.

TABLE 1: TCA TO USERS WITH CHANGED DEMAND & ARR (FOR ABSOLUTE MVA FLOW)

Users at Bus	TCA ($/MVA) to User			ARR Obtained from each User & Total ARR($)
	MVA-mile Component	POS Component	Total TCA	
50% Network Usage				
4	98867.27	72834.55	171701.8	16393094.55
5	105136.4	72834.55	177970.9	11625854.55
6	98627.27	72834.55	171461.8	13785416.36
Total ARR ($)				41804363.64
60% Network Usage				
4	96718.18	47869.09	144587.3	15983945.45
5	98270.91	47869.09	146140	11308845.45
6	96525.45	47869.09	144396.4	14511572.73
Total ARR ($)				41804363.64
70% Network Usage				
4	87180	33176.36	120354.5	16328943.64
5	90189.09	33176.36	123365.5	13017981.82
6	97305.45	33176.36	130480	12457438.18
Total ARR ($)				41804363.64
80% Network Usage				
4	86140	19294.55	105434.5	14834405
5	92378.18	19294.55	111672.7	11671849
6	91010.91	19294.55	110305.5	15298109
Total ARR ($)				41804363.64
90% Network Usage				
4	86996.36	6829.091	93825.45	14615535
5	91945.45	6829.091	98774.55	11911978
6	91241.82	6829.091	98070.91	15276853
Total ARR ($)				41804363.64
100% Network Usage				
4	83716.36	-876.364	82840	14486115
5	89750.91	-876.364	88874.55	11611502
6	91214.55	-876.364	90338.18	15706744
Total ARR ($)				41804363.64

Table 1 is shows the results obtained for MVA-mile, Postage Stamp (POS) components of TCA to users for absolute variant of MVA flow for incremental percentage of circuit utilization. Each circuit has its scheduled load growth from 50 to 100% for the system considered. The MVA-mile component of TCA along with POS component and total TCA decreases with increase in circuit utilization. The TCA to users may negative for the reverse MVA flow. Similar results obtained for dominant and reverse variant of MVA flow are shown in table 2 and table 3 respectively.

TABLE 2: TCA TO USERS WITH CHANGED DEMAND & ARR(FOR DOMINANT MVA FLOW)

Users at Bus	TCA ($/MVA) to User			ARR Obtained from each User & Total ARR($)
	MVA-mile Component	POS Component	Total TCA	
50% Network Usage				
4	98867.27	80621.82	179489.1	17136572.73
5	94712.73	80621.82	175336.4	11453663.64
6	83734.55	80621.82	164356.4	13214125.45
Total ARR ($)				41804363.64
60% Network Usage				
4	96718.18	56976.36	153694.5	16990689.09
5	86834.55	56976.36	143810.9	11128596.36
6	79196.36	56976.36	136170.9	13685080
Total ARR ($)				41804363.64
70% Network Usage				
4	87180	44716.36	131894.5	17894609.09
5	68474.55	44716.36	113189.1	11944205.45
6	80612.73	44716.36	125327.3	11965550.91
Total ARR ($)				41804363.64
80% Network Usage				
4	86140	31220	117360	16512294.55
5	78480	31220	109700	11465716.36
6	68474.55	31220	99694.55	13826352.73
Total ARR ($)				41804363.64
90% Network Usage				
4	86996.36	20654.55	107650.9	16769170.91
5	72894.55	20654.55	93549.09	11281872.73
6	67636.36	20654.55	88290.91	13753320
Total ARR ($)				41804363.64
100% Network Usage				
4	83716.36	14367.27	98083.64	17151649.09
5	69658.18	14367.27	84025.45	10977745.45
6	64285.45	14367.27	78652.73	13674969.09
Total ARR ($)				41804363.64

TCA to users decreases with increase in circuit utilization of the transmission network. The unremunerated POS component of TCA of transmission network usage by postage stamp method is less as compared to MW-Mile method. The results shows continue reduction TCA to user with increase in demand. At maximum (more than 90 %) utilization of circuit it is observed that there is no need of postage stamp TCA component.

Variation in TCA to users (load consumers) for absolute, dominant and reverse variants of MVA flow along with increase in line utilization is shown in fig. 3, fig. 4 and fig. 5. The analysis seeks to prove that the TCA to load users is highest for absolute variant of MVA flow and lowest for reverse in any case of network utilization. The relationship of TCA to users with percentage network utilization of the transmission network is shown in figures. TCA to users for combinations of MVA-mile component and concurrent postage stamp component is highest for absolute variant of MVA flow and lowest for reverse variant. The concurrent postage stamp component is used to cover the unremunerated revenue from the users. The component of TCA is designed in order to get total ARR in each case of line utilization.

TABLE 3: TCA TO USERS WITH CHANGED DEMAND & ARR (FOR REVERSE MVA FLOW)

Users at Bus	TCA ($/MVA) to User			ARR Obtained from each User & Total ARR($)
	MVA-mile Component	POS Component	Total TCA	
50% Network Usage				
4	98867.27	88409.09	187276.4	17880052.73
5	84290.91	88409.09	172700	11281474.55
6	68841.82	88409.09	157250.9	12642836.36
Total ARR ($)				41804363.64
60% Network Usage				
4	96718.18	66083.64	162801.8	17997432.73
5	75398.18	66083.64	141480	10948345.45
6	61865.45	66083.64	127947.3	12858585.45
Total ARR ($)				41804363.64
70% Network Usage				
4	87180	56256.36	143434.5	19460274.55
5	46758.18	56256.36	103014.5	10870427.27
6	63920	56256.36	120176.4	11473661.82
Total ARR ($)				41804363.64
80% Network Usage				
4	86140	43145.45	129285.5	18190181.82
5	64581.82	43145.45	107727.3	11259587.27
6	45936.36	43145.45	89081.82	12354594.55
Total ARR ($)				41804363.64
90% Network Usage				
4	86996.36	34480	121476.4	18922809.09
5	53843.64	34480	88323.64	10651769.09
6	44030.91	34480	78510.91	12229789.09
Total ARR ($)				41804363.64
100% Network Usage				
4	83716.36	29610.91	113327.3	19817181.82
5	49563.64	29610.91	79174.55	10343989.09
6	37356.36	29610.91	66967.27	11643183.64
Total ARR ($)				41804363.64

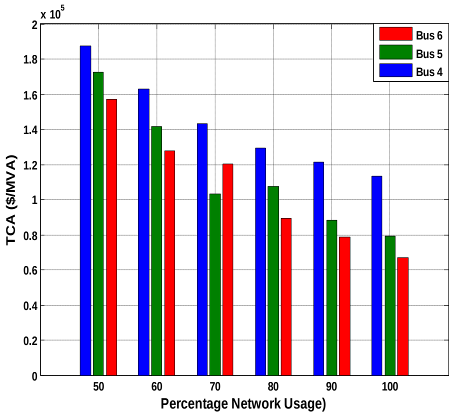

Fig.3. TCA to Users at Load Buses with Absolute Variant of MVA flow

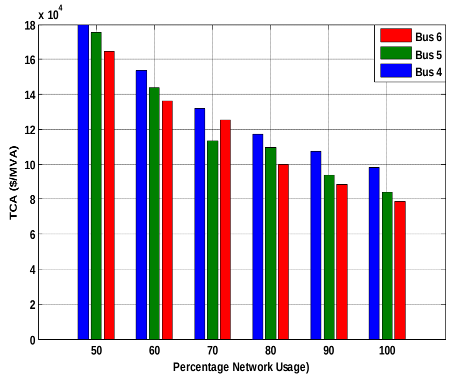

Fig.4. TCA to Users at Load Buses with Dominant Variant of MVA flow

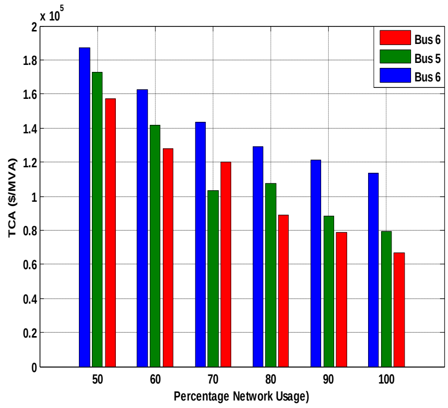

Fig.5. TCA to Users at Load Buses with Reverse Variant of MVA flow

5. CONCLUSIONS

Composite MVA-mile method is fair and transparent way TCA to users because it includes the cost of reactive power flow through transmission network. In combinations of three variants of MVA flow, absolute approach is most popular. This approach provides highest revenue reconciliation to the transmission owner. The result analysis reveals that MVA-mile component of TCA to users fails to recover the expected ARR with all three variants of MVA flow if network is lightly loaded. To cover the total transmission system cost 100% is necessary. Hence the cost associated with unused capacity is considered and shared among the users in TCA in the combined MVA-mile approach. In this case concurrent postage stamp component of TCA is used to cover the unremunerated cost from the users. The unremunerated cost translated into TCA component is found lower. This analysis seeks to prove that the proposed transmission tariff allocation using combined approach is simple and practicable. It is very easy to implement for different loading levels of the networks along with the different transmission facility users. The approach with reverse MVA flow gives strong economic signal as far as fair and transparent transmission tariff is concern compared to MW-mile method.

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