Electricity Transmission Pricing: Marginal Pricing of Transmission Services Using Point of Connection Tariff

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1 Introduction

Transmission pricing has been a very wide and highly disputed issue of power deregulation era because of its diversified approaches and methodologies. Since its commencement from the very beginning, the electric power market models have coincided in a generic view, to centralized dispatch and decentralized dispatch concepts [1]. The transmission pricing mechanisms apparent in the whole range of composition can be divided into two broad frameworks: rolled-in and marginal [2]. Right from establishment, the price of transmission network usage has been estimated by impromptu approaches such as the postage stamp method or the contract path method [3, 4]. In postage stamp method, transmission charges are levied on per MW basis of transaction, either it be a generator or load. Also the distance of the power transmission is not taken into consideration. On the contemporary, the contract path methodology first assigns an arbitrary electrical path between both buyer and customer, and then assigns the wheeling charges for the transaction. Both the abovementioned approaches are simple in nature but they are not capable of estimating the "extent of use" of the lattice by any source/sink or a transaction. Although, after deregulation, the doctrine of cost allotment has reached to allotment in share of the "extent of use," or in simpler words, the recipient pays [5, 6]. It means that a customer should be charged as per the cause. The central doctrine of POC tariff is its settlement at one point giving entrance to entire network arrangement and entire electricity merchandise. This tariff is determined by the connection level of any particular entity. The

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main feature of POC tariff is that it can be applied to bilateral transactions between two parties and also for Power exchange (PX) trades.

In this paper, we propose cost allocation to nodes based on POC principle for a standard IEEE 14-bus system. The real power tracing based on proportional sharing principle [7–10] provides disintegration of transmission line flows into generator and load commodities. We have considered the price estimation of transmission network among source and sink using marginal participation (MP) method [11–17]. This method is best suited for pool market where there is no connection between seller and buyer. It claims the flow share with the portion use in any line or any network. For determining the line consumption price, a price rate is assigned to every line. The most common approach is to take the rate of line price to the line consumption. Generally, it is considered for 1-year time period. Here the line consumption is the power flow in the respective line in MW calculated from power flow investigation. It gives the exact utilization of line by entire entities of the system. Once the price stake of any element present in the network system is calculated, we can easily determine its point of connection tariff (POC tariff). POC tariff is termed in ₹/MW (or $/MW) which an element has to pay for the network utilization either for its injection or withdrawal in a particular duration (e.g., a year).

The MP method along with its variants is used across the globe for cost allocation. One of its variant was implemented by the Central Electricity Regulatory Commission (CERC) in India [17]. Some of the other countries where this method is used are discussed in [18]. In this paper, we propose a hybrid method that calculates the charges based on peak conditions rather than base conditions.

2 Formulation

The proposed formulation involves following steps:

(1) Solution of base case load flow on standard network;
(2) Increment of 1 MW marginal load/generation at desired bus generated/absorbed by responding buses;
(3) Calculation of line utilization factors;
(4) Allocation of cost to nodes;
(5) Calculation of PoC rates/nodal prices.

2.1 Solution of Base Case Load Flow on Standard Network

The standard 14-bus system is considered for the study. The load flow on the system is computed using Newton–Raphson method, which provides us with the nodal power and line power flows. Here the first bus is considered to be reference bus without the loss of generality, i.e., $\delta_1 = 0$. Power injection and withdrawal for this bus is not modeled. The nodal power and the line flows are given in Tables 1 and 2, respectively.

Table 1 Nodal/bus power flows

Node/ bus	P_i (in MW)	Bus type
1	232.6850	0
2	18.30	1
3	94.2	1
4	47.8	2
5	7.6	2
6	11.2	2
7	0	2
8	0	2
9	29.5	2
10	9.0	2
11	3.5	2
12	6.1	2
13	13.8	2
14	14.9	2

Table 2 Line power flows

Line no.	From bus	To bus	Power flow (in MW)
1	1	2	156.4515
2	1	5	76.2335
3	2	3	72.7107
4	2	4	56.1219
5	2	5	41.6452
6	3	4	− 23.7798
7	4	5	− 61.1622
8	4	7	27.7821
9	4	9	15.8603
10	5	6	44.9054
11	6	11	7.6554
12	6	12	7.9190
13	6	13	18.1310
14	7	8	0
15	7	9	27.7821
16	9	10	4.9385
17	9	14	9.2039
18	10	11	− 4.0701
19	12	13	1.7480
20	13	14	5.8570

After running the load flow program, we got with us the nodal data along with line flows and each bus corresponding type. Here the power flow limits got violated for buses 6 and 8 which results as they being load bus from generator bus.

2.2 Increment of 1 MW Marginal Load/generation at Desired Bus Absorbed/generated by Responding Buses

As we know the marginal participation method allocates charges to every entity on the extent of its use, for that we need to increase the marginal data by 1 MW and note down the change it causes to the remaining system with the calculation of various parameters. Here we consecutively increase each node power injection/withdrawal by 1 MW and note down the modified nodal powers and line flows. By doing this we can trace the contribution of each node or line on any particular node. Further, we will calculate the indices required for the cost allocation.

2.3 Calculation of Line Utilization Factors

Marginal participation examines the variations in the system when inferior changes are developed in the generation or withdrawal of any agent. The output of this approach comes as the utilization factor of each line by various nodes. The cost of each line is assigned to each node on the basis of their utilization factor. The process develops as follows:

i. Marginal participation sensitivity A_{ij} gives the alteration in the power flow of any line j when the withdrawal/injection in any node i is risen by 1 MW. The rise of 1 MW is compensated by analogous rise in load or generation at some other bus or buses known as slack bus(es) that is achieved through average participation method. Also this factor is always considered to be positive since its negation neither gives any capital nor charges for the use of the system.

$$A_{ij} = \left|F_1^i\right| - |F_1| \quad (1)$$

A_{ij} = marginal participation in line j due to increased injection/withdrawal on node i.

$F^i{}_1$ = power flow in line 1 due to increased injection/withdrawal of 1 MW at a node.

F_1 = power flow in line 1 under base case.

ii. Seasonal index gives the total participation for each entity. For each entity, it is calculated as the product of its net injection with its marginal participation sensitivity.

$$U_{e,i,1} = \left(\left| F_1^i \right| - \left| F_1 \right| \right) \cdot P_i \tag{2}$$

$U_{e,i,1}$ = seasonal index in line 1 due to injection/withdrawal at node i.
P_i = net base case power injection at bus I.

iii. Marginal participation factor (MPF) provides the extent of use of any line for a particular node. The MPF of node i in line 1 can be defined as

$$MPF_{i,1} = U_{e,i,1} \Big/ \sum_i U_{e,i,1} \tag{3}$$

2.4 Allocation of Cost to Nodes

For allocation of cost to nodes/buses, firstly the total allocation cost is derived via the line cost information. The line cost is considered as ₹ 1 Crore/Km for indicative purposes only (Table 3).

Table 3 Line cost information

Line no.	From bus	To bus	Length (in Kms)	Cost (in Crores)
1	1	2	160	160
2	1	5	112	112
3	2	3	200	200
4	2	4	80	80
5	2	5	152	152
6	3	4	99	99
7	4	5	143	143
8	4	7	120	120
9	4	9	83	83
10	5	6	97	97
11	6	11	137	137
12	6	12	149	149
13	6	13	193	193
14	7	8	67	67
15	7	9	89	89
16	9	10	79	79
17	9	14	104	104
18	10	11	139	139
19	12	13	175	175
20	13	14	122	122
Total			2500	2500

2.5 Calculation of PoC Rates/Nodal Prices

Calculation of Uniform Charges

The uniform charging method generalizes the entire entity on the basis of their net injection/withdrawal. The formula for the computation of uniform rate is given by

$$\text{Uniform Rate} = \frac{\text{Total Transmission charges}}{\text{Approved injection} + \text{Approved withdrawal}} \tag{4}$$

For the calculation of PoC charges, we have considered 50% contribution from uniform method and 50% from MP method. This will ensure steady transition to new transmission pricing mechanism. Here the uniform charge is calculated and it comes out to be 5.1168 ₹ Cr/MW (Table 4).

Calculation of MP charges

The marginal participation method cost is estimated by using the line utilization factors we have calculated in section C. The formula deployed is as follows:

$$MP\,\text{Cost allocated} = \frac{U_{e,i,1}}{\sum i\, U_{e,i,1}} * C_A \tag{5}$$

C_A = cost allocated to the entire network in a specified time (for ex. yearly transmission).

Table 4 Bus/node uniform charge allocation

Node no.	Cost (in Crores)
1	1190.6000
2	93.6378
3	482.0042
4	244.5839
5	38.8878
6	57.3084
7	0
8	0
9	150.9461
10	46.0514
11	17.9089
12	31.2126
13	70.6121
14	76.2406
Total	2500.0000

Calculation of PoC charges

In this paper, the PoC rates are calculated for uniform method, marginal participation method, and the hybrid.

(50% UC + 50% MP) method.

$$PoC\text{ charges } = \frac{\text{Cost assigned to a node}}{\text{Base case injection}/\text{withdrawal at that node} * 12} Cr/MW/\text{Month} \tag{6}$$

Here we have computed the PoC rates for the above methods and made a comparison among them (Table 5).

Issues

At present, there is not any globally adopted best common approach for allocation of transmission costs. All methods have their own pros and cons. In the entire world, a combination of different approaches is applied for the estimation of cost such as postage stamp, marginal/nodal pricing, marginal participation, average participation, MW-Mile, game theory, etc.

Since postage stamp method is the easiest one to understand, it neither considers transmission distance nor the real power flow through the line, or we can say it ignores the actual system operation. Coming to the marginal participation method,

Table 5 Cost allocation to nodes based on uniform, marginal participation, and hybrid method with PoC rates

Nodes	UC case	MP case	Hybrid case	PoC rates (₹ Cr./MW/Month)
1	1190.6000	0	595.3032	0 (0)
2	93.6378	13.6442	53.6410	0.2443 (0.0621)
3	482.0042	33.9932	257.9987	0.2282 (0.0301)
4	244.5839	343.7575	294.1707	0.5128 (0.5993)
5	38.8878	36.2914	37.5896	0.4122 (0.3979)
6	57.3084	206.1197	131.7140	0.9800 (1.5336)
7	0	0	0	0.8313 (1.2363)
8	0	116.0561	58.0280	0 (0)
9	150.9461	548.9008	349.9235	0.9885 (1.5506)
10	46.0514	238.2679	142.1596	1.3163 (2.2062)
11	17.9089	80.5300	49.2195	1.1719 (1.9174)
12	31.2126	143.8532	87.5329	1.1958 (1.9652)
13	70.6121	331.9978	201.3049	1.2156 (2.0048)
14	76.2406	406.5882	241.4144	1.3502 (2.2740)
Total	2500.0000	2500.0000	2500.0000	

* PoC rates in bracket are under MP trace only

it lacks the fair selection of slack bus and network usage reliability. The average participation method simply traces the path of power from the origin to the sink(s) or vice versa, which doesn't capture the network utilization in an efficient manner. On the other hand, the MW-Mile method doesn't recover embedded cost of transmission expansion, i.e., it only charges for base case not for transmission reserve. In the transmission cost loss allocation using game theory, we have the monotonic shape value while it may or may not set inside the core. Also it follows additive property which represents linearity while the loss allocation is quadratic in its expression. Hence, we come to a point where we not only need an approach that includes extent of use by any entity but also is easy to implement or carry out. Here we come to conclude that the transmission charges should be estimated on the basis of peak scenario rather than base case.

3 PoC Charges Under Peak Conditions

For estimation of PoC charges under peak condition, we have increased the load at bus 4 by 50% (Table 6).

Now we will perform the entire process of PoC calculation on peak load. At first, we will calculate the line power flow under peak loaded case following which we will have the required data for the calculation of cost allocated to each node. Since the line lengths are not changed the line cost remains same. Only the cost distribution among all will change not the total cost of the system. We will calculate the uniform charges for peak load condition.

Table 6 Nodal/bus power flow

Node/bus	P_i (in MW)
1	259.433
2	18.30
3	94.2
4	71.7
5	7.6
6	11.2
7	0
8	0
9	29.5
10	9.0
11	3.5
12	6.1
13	13.8
14	14.9

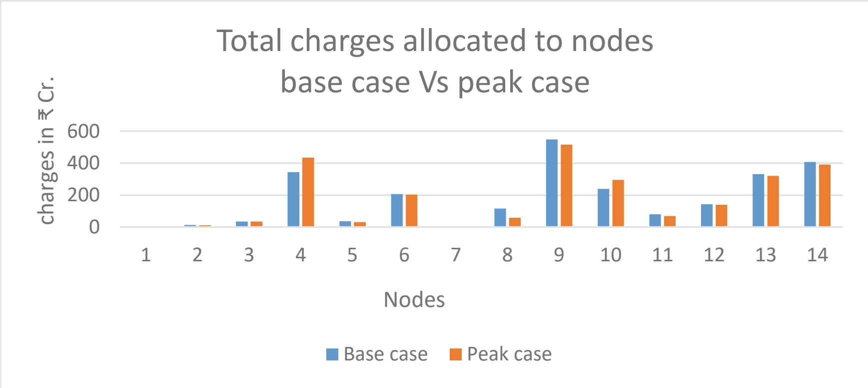

Fig. 1 Charge allocated to IEEE 14-bus system

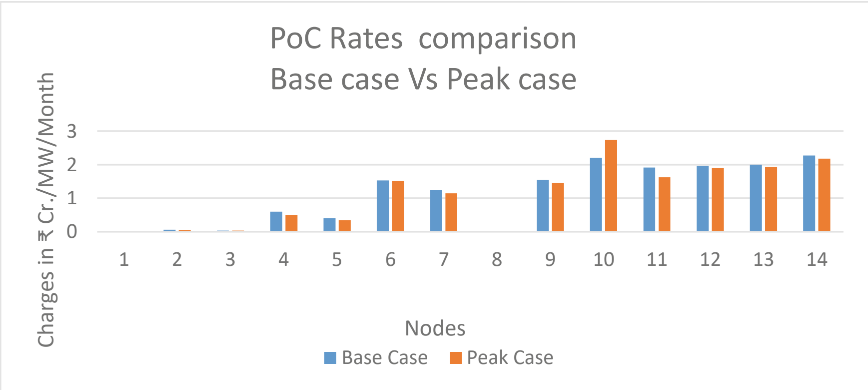

Fig. 2 PoC rate comparison for base case and peak case

$$\text{Uniform charges} = \frac{\text{Total Transmission charges}}{\text{Approved injection} + \text{Approved withdrawal}} = 5.1168\, Cr/MW.$$

Now as we have with us the uniform charges, we go for calculation of MP charges and then the hybrid method charge on peak withdrawal condition (Figs. 1, 2 and Table 7).

4 Conclusion

Here we see that even when the load at bus 4 increased by 1.5 times, the total cost allocated to the node has increased only 1.26 times. Also we can see that the cost/MW/month will go down as the MW increases, i.e., the more the system will

Table 7 Tabulated data for base case and peak case

Node	Base case cost (MP)	Peak scenario cost (MP)	% change	PoC rate for base case (MP)	PoC rate for base case (UC + MP)	PoC rate for peak case (MP)
1	0	0	0	0	0	0
2	13.6442	11.7320	14.0145	0.0621	0.2443	0.0534
3	33.9932	33.7844	0.6141	0.0301	0.2282	0.0299
4	343.7575	433.6677	26.1551	0.5993	0.5128	0.5040
5	36.2914	31.2376	13.9257	0.3979	0.4122	0.3425
6	206.1197	203.5138	1.2642	1.5336	0.9800	1.5142
7	0	0	0	1.2363	0.8313	1.1420
8	116.0561	57.1034	50.7967	0	0	0
9	548.9008	515.7000	6.0486	1.5506	0.9885	1.4568
10	238.2679	295.8356	24.1609	2.2062	1.3163	2.7392
11	80.5300	68.1618	15.3586	1.9174	1.1719	1.6229
12	143.8532	138.7313	3.5605	1.9652	1.1958	1.8952
13	331.9978	319.9159	3.6391	2.0048	1.2156	1.9319
14	406.5882	390.6165	3.9282	2.2740	1.3502	2.1847

operate at peak condition the less the PoC tariff will be for that respective node/bus. When any node/bus in a system starts operating on peak load then the charges allocated to other nodes will change only when the power flows in that respective node/bus change. Otherwise, the charges will remain same or may reduce (as in the above case).

Hence, we arrived at a method that is not only easy to implement but also reliable as it charges on the basis of "extent of use." In the future, we can observe the impact of selection of slack bus for the entire process. Also, we can take into context how the reactive power varies with changes implemented above so that we can add one more feather to the crown of this hybrid technology.

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