

# Electricity Transmission Pricing: Tracing Based Point-of-Connection Tariff for Indian Power System

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**Abstract**—Amongst the commonly employed transmission pricing philosophies in the de-centralized markets, i.e., point-to-point and point-of-connection (POC), the later one can be employed for both power exchange (PX) and bilateral trades. POC methodology charges a single rate per MW, depending upon the point of connection. The methodology though apparently simple, easy to implement and understand, entails the difficult task of fixing up the POC rates. Use of grossly aggregated zonal postage stamps as POC rates damps out the locational signals, while the use of LMPs to devise the spatially variate point charges fails to account for the transmission sunk costs. To overcome the above limitations, we propose a methodology to determine POC rates based on real power tracing. We introduce the concept of tracing based *Locational Transmission Price (LTP)* which reflects participation of each node in the transmission line flows and hence the sunk costs of the associated lines. Thus, LTP transforms transmission usage of each node into spatially variate price signals. The proposal is specifically worked out for the Indian power sector where realistic data of 193 bus system of Western regional (WR) grid is used. The POC rates thus calculated would find their practical utility once the PX activity starts in India.

**Index Terms**—Power Flow Tracing, Transmission Pricing, Point-of-Connection Tariff

## NOMENCLATURE

$\bar{c}_{lm}$	Rate of transmission line/ element in $Rs/MW$
$LTP^q$	Aggregate rate for $q^{th}$ state
$LTP_G^q$	Generation weighted aggregated locational transmission price for $q^{th}$ state
$LTP_L^q$	Load weighted aggregated locational transmission price for $q^{th}$ state
$LTP_i$	Locational transmission price of $i^{th}$ load
$LTP_k$	Locational transmission price of $k^{th}$ generation
$P_{lm}^i$	Contribution of $i^{th}$ load in MW flow of line/ element $lm$
$P_{lm}^k$	Contribution of $k^{th}$ generator in MW flow of line/ element $lm$
$P_G^q$	Generation of $q^{th}$ state
$P_L^q$	Load of $q^{th}$ state
$P_{Gk}$	$k^{th}$ generation in MW
$P_{Li}$	$i^{th}$ load in MW
$P_{lm}$	Receiving end real power flow on line $lm$
$Rate_G^q$	Point-of-connection charge in $Rs/MW$ for generators in $q^{th}$ state

$Rate_L^q$	Point-of-connection charge in $Rs/MW$ for loads in $q^{th}$ state
$y_k^i$	Real power fraction of load $i$ contributed by generator $k$
$y_{lm}^i$	Receiving end real power fraction of load $i$ on line $lm$

## I. INTRODUCTION

THE transmission pricing schemes appearing in the entire gamut of literature can be classified into two basic paradigms: Rolled-in and Marginal [1]. An in depth analysis on inability of marginal methods to recover sunk costs of transmission is done in [2]. The composite pricing schemes proposing toping up of marginal prices with the *complementary charge* are suggested in [3], which combine the bests of both the paradigms.

Two commonly employed philosophies for transmission pricing in the de-centralized markets are: Point-to-point tariff and the point-of-connection (POC) tariff [4]. The point-to-point tariff is also called transaction based tariff which is specific to a particular sale of power from named seller to a named buyer. Various versions of MW-Mile [5], postage stamp and contract path methods essentially represent the class of point-to-point *ex-ante* transmission pricing schemes. There is not much literature available on calculation of POC tariff.

POC tariff is employed in the Nordic pool [6]. The basic principle of POC tariff is that payment at one point, the point of connection, gives access to the whole network system, and thus the whole electricity market place. Those entities who take part in power market activity (generators, loads), pay a single charge in  $\$/MW$  towards network usage. This charge is decided by the connection level of that particular entity. The POC tariff depends on the characteristics of the individual seller or buyer. The distinguishing feature of POC tariff is that it can be applied to power exchange (PX) trades as well as bilateral transactions between two parties.

POC scheme is simple to understand and easy to implement. However, the condition of satisfying certain objectives by any transmission pricing scheme makes the calculation of POC rates an involved task. According to [7], one of the important tasks that a transmission pricing scheme has to accomplish is that of providing appropriate price signals. To promote economic efficiency, social welfare and least-cost operation, the pricing scheme should follow the marginal costs. However, due to economies of scale, transmission networks consists of long term investments. Hence, the short run marginal costs are unable reflect these investments while, the long run marginal

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costs are difficult to determine. Moreover, another important principle laid down in [7] mandates recovery of fixed costs of transmission network. It is difficult to accommodate the conflicting principles of transmission pricing in a single pricing scheme [8]. However, according to [4], the transmission prices must compromise between signalling short run marginal costs and offering reasonable assurance of cost recovery over the long run.

In this paper, we propose determination of transmission usage charges based on POC principle for the power exchange (PX) trades in India. Recent reforms initiatives in the vertically integrated Indian power sector have mandated evolution of PX in the near future. While de-centralized market model is being suggested for PX trades, the POC tariff is evolving as the most favored candidate for transmission pricing scheme. Even though the POC scheme will be introduced for PX trades initially, in the later stages, it is expected to replace the current point-to-point tariff scheme for short term bilateral trades.

It is clear that for bilateral transactions, the actual power flowing through the network need not follow the contractual path. Also, for PX trades, the suppliers and consumers put in or take away their commodity from a marketplace located at a *virtual* location, while the associated power flows still obey the physical laws. However, for any real life power system, the pattern of system usage for both type of trades can be found out based on the past data or by statistical means [9]. The real power tracing based on proportionate sharing principle [10], [11], [8], [12] provides decomposition of transmission line flows into generator and load commodities. Based on these results, *notional* usage of the transmission network by various entities is known. In this paper, we employ this technique for determination of POC rates in Indian system. The method finds out the pattern of power flows and network usage by various entities and hence decides the spatially variate transmission usage charges. An added advantage of the scheme is that the usage of the overall interconnected network is taken into account.

The paper is organized as follows: Section II is devoted to enlighten the reader about some facts of Indian power system. It throws light on the current transmission pricing practices in India. Also, proposed PX model is discussed in brief. Section III gives the concept behind POC tariff. Section IV introduces concept of LTP and explains use of real power tracing to calculate LTP. In section V, the methodology involved in calculation of POC charges in Indian grid is elaborated. System description and results are presented in section VI. Section VII concludes the paper.

## II. OVERVIEW OF INDIAN POWER SECTOR AND CURRENT PRACTICE OF TRANSMISSION PRICING

Indian power system is divided into five regional grids, viz., Northern, Western, Eastern, North-Eastern & Southern. A region consists of number of state owned utilities, which are also separate control areas within that region. The power plants set up by central government enterprises have allocations to the state utilities in a region. The backbone of transmission network in the country is provided by POWERGRID (Central

Transmission Utility) which is primarily built to evacuate the power of central sector power plants and to inter-connect the state utility grids as well as regional grids. The interstate transmission system (ISTS) connects all central sector and inter-regional injection points with drawl points of the states similar to a LAN system with multiple computer nodes. The owner of state utility grid, i.e., State Electricity Board of each state acts as a State Transmission Utility (STU). More information about the hierarchical structure and facts and figures about the Indian power sector can be found in [13].

Amongst various regional inter-connections, Western, Eastern and North-Eastern grids are coupled with synchronous AC tie lines. The Northern and Southern regional grids are coupled to the other neighboring regional grids through HVDC back-to-back links. More details about the regional inter-connections can be obtained from [14].

### A. Various Power Transactions

The power transaction practices among the power utilities can be classified into three categories viz., long term transactions arising out of central sector allocations, short term transactions which are traded among the utilities under open access through forward contracts and UI power (Unscheduled Interchange) which is essentially the balancing power [15]. In the near future with the setting up of the PX at the national level, some of the day-ahead transactions would be dealt through the PX.

1) *Long Term Transactions*: The central sector power plant allocations to the state utilities are termed as long term transactions irrespective of duration of the transactions. In case of other transactions, those exceeding 25 years are termed as long term transactions. The transmission network was built by CTU mainly for catering to the long term power requirements. Similarly, the transmission network owned by STUs caters to the power evacuation of state owned generating stations and IPPs in the state.

2) *Short Term Transactions*: Surpluses and deficits on seasonal basis, daily variation of load, weather effects, diversity etc., necessitate trading of power between the power utilities on a short term basis. The short term transactions include those covering up to next three months which are approved in the current month, transactions approved on first cum first served basis, day-ahead transactions and same day transactions. As per the regulations in force, the short term open access transactions are approved by Regional Load Dispatch Center (RLDC) of the region in which the buyer is situated. The inherent design margins in the network, margins available due to network redundancies, margins available due to outage of some generating units, low demand etc., are utilized by RLDCs by granting access for short term open access users.

### B. Current Transmission Pricing Scheme

The network operators like CTU, STU recover annual transmission costs through tariff regulated by the respective regulatory commissions. The transmission licensee is allowed to recover full transmission charges from *long term* customers. The regulatory commissions decide upon the tariff norms such

as interest on loan, return on equity, debt-equity ratio, O&M charges, interest on working capital, depreciation etc. The transmission licensees earn revenue from the short term open access customers out of which 75% is passed on as credit to the long term customers.

The methodology adopted for transmission pricing for short term open access customers entails determination of injection point, drawl point and inter-regional path. The methodology essentially is similar to postage stamp method, wherein, usage of a particular network is charged a stamp of that network. It is presumed that the seller utility injects power at its control area boundary by increasing generation at one or more plants. The power injected has to pass through various transmission systems owned by STUs or CTU (in each region) for which a postage stamp of each of the systems is charged. The inter-connection between two regions is treated as a separate system with a postage stamp of its own.

The short term rate for each of these transmission systems is determined as 25% of the long term rate and the long term rate in turn is determined based on the annual transmission costs to be recovered by the transmission licensees and the average power demand catered by the network during the year. The short term open access rate is given as  $Rs/MW/day$  and is charged on six hourly time blocks.

Table I shows the postage stamp rates of CTU networks in various regions for long term as well as short term bilateral contracts. The charges for short term transactions are less because these transactions are curtailable in the case of congestion.

TABLE I  
TRANSMISSION CHARGES FOR REGIONS

Region	Long Term Rate Rs/MW/Day	Short Term Rate Rs/MW/Day
Southern	2456.60	614.15
Western	1438.73	359.68
Eastern	1737.68	434.42
Northern	2064.11	516.03

1 USD  $\equiv$  45 Rs. approximately

Table II shows the transmission charges for usage of inter-regional links, in case of a short term transaction across the regions.

TABLE II  
TRANSMISSION CHARGES FOR INTER-REGIONAL LINKS

Link	Long Term Rate Rs/MW/Day	Short Term Rate Rs/MW/Day
Southern-Western	2256.78	1128.39
Eastern-Southern	4866.77	2433.39
Eastern-Western	866.18	433.09
Northern-Western	895.47	447.73
Eastern-Northern	3590.22	1795.11
Eastern-North Eastern	1718.09	859.05

1 USD  $\equiv$  45 Rs. approximately

One disadvantage of the present pricing methodology for short term transactions is *pancaking* of transmission charges of various transmission systems along the path between injection point and drawl point. The losses are paid in kind through increasing generation at the injection point.

### C. Proposed Model for PX in India

Impetus for discussion on new transmission tariff scheme in India is derived from the proposal for PX in India. Hence, it is worthwhile to have brief idea about the suggested model.

1) *Need for Power Exchange in India:* The Electricity Act 2003 along with the recently announced electricity policy [16] mandates the provision of choice to consumers above 1 MW demand by January 2009. Hence, a common marketplace is required to facilitate the provisions of the act. A national level, day ahead PX is expected to provide well known benefits like reduction in transaction costs, efficiency in price discovery, optimization of generation capacity utilization, standardization of contracts, etc. While proposing a model for PX and its activities, the major concern kept in mind is that there should be least deviation from the current practice. Hence, the prevailing concept of de-centralized dispatch is further extended to the proposed PX.

2) *Modalities:* There will be one National power exchange. As a day ahead activity, the Regional Load Dispatch Centers (RLDCs) of all 5 regions would allot the remaining network capacities to the PX after accounting for the long term and short term bilateral transactions. The participants of the PX could be the state utilities, central power stations with surplus capacity, IPPs, CPPs, brokers and traders. The bids would be portfolio based.

The PX would carry out unconstrained market clearing. The day ahead congestion management would be done on the same lines with that of Nordic pool, i.e., price area congestion management technique. In this case, the system would generally split into various price areas which would be nothing but the regional grids. Respective RLDCs in their regions would do the job of TSOs, as in the Nordic pool.

In the next section, we will discuss the features of the POC tariff.

### III. POINT-OF-CONNECTION TARIFF

The basic principle of POC tariff is that payment at one point, the point of connection, gives access to the whole network system, and thus the whole electricity market place. It is commonly used in the Nordic pool where, the charges are devised so as to recover the costs for managing the transmission network and are controlled by country specific regulatory offices [17]. The consumers or producers connected to a local network pay only to the owner of that network. This payment allows them to trade electricity with any other player within the entire national network system.

In Nordic pool, three levels of grids exist: Local grid, Regional grid and Main grid. The charge at a local grid also embeds the charges of its next upstream grid i.e., the regional grid. The regional grid in turn embeds charges of next upstream grid, i.e., the main grid. The advantage of the scheme is that free trade across the region is possible and the transmission tariff does not become a hurdle in the way of trade.

There are other advantages associated with this type of pricing scheme. First and the most important from the market participants' point of view is that they know the transmission

cost to be paid towards a particular sale or purchase of energy, *a priori*. Secondly, since the market participant pays just one charge proportional to MW injected or drawn, the contract path for a particular transaction is not required to be determined and hence *pancaking* of charges is avoided. Another important aspect of this pricing scheme is that it can be employed for both PX and bilateral trades.

Fixing POC rates for a system is a challenging task. The simplest version consisting of charging flat fee for all customers towards transmission usage makes it unfair to small customers or sellers. Application of postage stamp, i.e., a single charge throughout the zone is the most simplified form of POC tariff. However, grossly aggregated zonal postage stamp damps out the locational signals associated with the network usage costs. Moreover, this scheme may not correctly accommodate the usage costs of the other inter-connected grids in its own stamp. The most efficient way of satisfying desired features is to fix the POC rates that follow the *Locational marginal Price* (LMP) pattern. However, the sunk costs of transmission network are not included in the formulation of the short run marginal costs and hence, the cost component associated with the sunk costs of transmission is not directly accounted for.

Keeping in view the above discussion, we propose the use of real power tracing for calculation of POC rates in the next section. The POC tariff being suggested for Indian power system should satisfy some features which are described as follows:

- 1) The POC tariff should reflect the possible network usage if power is injected or drawn on a particular node.
- 2) Both, generators and loads should share the costs of transaction.
- 3) The pricing scheme should create locational signals so as to provide incentives for generation investments in deficit areas and incentives for load growth in surplus areas.
- 4) The price signals should not be oversensitive so that they create hurdle for free trade across the regions; rather, these should be in tune with the degree of deficiency or adequacy of power in that region.
- 5) It is expected that in the Indian model, the PX and short term bilateral trades would co-exist and compete with each other. However, the PX would be mainly used for balancing the net position in a day ahead market. The price reference for bilateral trades, however, would be derived from the PX price. Hence, the POC tariff should be comparable with the current practice of pricing short term bilateral transactions.

#### IV. POINT-OF-CONNECTION CHARGES BASED ON REAL POWER TRACING

In this section, we float the concept of *Locational Transmission Price* (LTP) based on real power tracing, which takes into account the transmission sunk cost and represents the spatial distribution of network usage prices. The basic concept aims at finding the participation of each generator and load in each transmission element flows and thereby decide its locational

*weight* towards network usage. A concept on similar lines to that of LTP, but for energy charges was proposed in [18] where, load pricing scheme was developed to eliminate the merchandizing surplus.

##### A. Concept of Locational Transmission Price (LTP)

The *Locational Transmission Price* (LTP) for each node is decided by the results of real power tracing. In simple words, LTP of a node reflects usage of various transmission lines and elements by load or generator on that node. In the discussion to follow, we develop the concept of LTP for loads. Same discussion holds true for generators.

Let the cost of line  $lm$  per MW per unit length be given by  $c_{lm}$  and let  $L_{lm}$  denote the length of the transmission line. Then,

$$\bar{c}_{lm} = c_{lm}L_{lm}$$

is usage price per MW associated with the line. The usage cost of the transmission line is known from the power flow solution. Consequently, total transmission system usage cost

$$TC = \sum_{\forall lm} \bar{c}_{lm}P_{lm}$$

is also known. Real power tracing makes it possible to distribute this cost accurately among all the constituents of the system including utility's native loads and generators. Since,

$$P_{lm} = \sum_{i=1}^{nL} y_{lm}^i P_{L_i}$$

the transmission usage cost for load  $P_{L_i}$  of the line  $lm$  is given by  $(\bar{c}_{lm}y_{lm}^i P_{L_i})$ . Thus, the total transmission system usage cost for a load  $i$  is given by

$$TC_{P_{L_i}} = P_{L_i} \sum_{\forall lm} y_{lm}^i \bar{c}_{lm} \quad (1)$$

The locational transmission price (LTP) is obtained by dividing the above by  $P_{L_i}$ .

$$LTP^i = \sum_{\forall lm} y_{lm}^i \bar{c}_{lm} \quad \text{Rs/MW} \quad (2)$$

Spatial variation of LTP over all nodes for IEEE 30 bus system is shown in Fig. 1. For  $\bar{c}_{lm}$ , absolute difference of nodal marginal prices across the nodes connected by a line is taken. It is expected that for those load buses which are far away from the generators (e.g. bus no. 17 onwards), the network usage for them becomes more. The bars representing LTPs quantify this usage. Thus, Fig. 1 signals the usage of the network by a node directly in terms of  $Rs/MW$ . The information rendered by this spatial variation can be used to fix up the transmission usage prices.

*Remark 1:* In the above discussion, it is assumed that only loads make payment towards transmission. However, same formulation can be developed if generators share the payment in some ratio.

*Remark 2:* The LTP at all buses represent the spatially variate POC charges. The practical constraints for actual implementation may lead to aggregation of nodal POC charges to zonal POC charges.

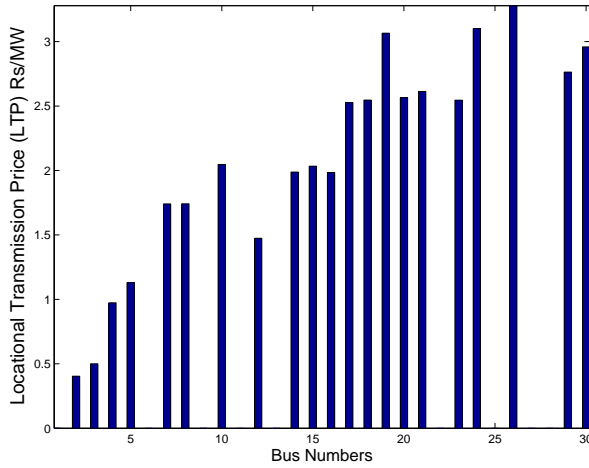


Fig. 1. LTP for IEEE 30 bus system

## V. APPLICATION ON INDIAN SYSTEM

In Indian power system, transmission systems can be categorized into three classes: Class A, class B and class C. These are shown in Fig. 2. Class A represents an inter-regional link, class B represents regional grid owned by CTU, while class C represents state utility owned (STU) grid.

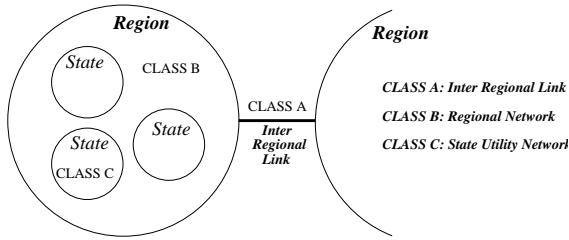


Fig. 2. Different classes of networks in Indian system

The short term transmission usage rates for each class of network are predefined. From this, depending upon its voltage class and line length, the short term rate for each line in that class of network is calculated. Later on after carrying out real power tracing, the load and generator entities using these lines are charged in proportion to their participation in the line flows. Thus, the POC tariff rate at a node reflects the extent of use of all classes of network by a load or generator entity. This act of transformation of network usage into prices is facilitated by virtue of real power tracing.

In this paper, out of five regional grids in India, the POC tariffs are found out for various states in Western Regional grid of India. However, similar exercise can be carried out for states in all five regions in India. Step by step procedure to arrive at a POC tariff rate is given as follows:

### A. Calculation of Rate of a Line in particular Class of network

Total fixed charges to be recovered from a particular class of network are known *a priori*. These are denoted as  $TSC_{long}^A$ ,  $TSC_{long}^B$  and  $TSC_{long}^C$ . These costs are supposed to be recovered from the customers of long term contracts. Our main

interest is in the short term rates, as the POC tariff has to be made comparable with the same. Hence, the short term TSC for various classes of networks is calculated as follows: Let these be  $TSC^A$ ,  $TSC^B$  and  $TSC^C$  for class A, B and C networks respectively. Then,

$$TSC^A = 0.5 \times TSC_{long}^A \quad (3)$$

$$TSC^B = 0.25 \times TSC_{long}^B \quad (4)$$

$$TSC^C = 0.25 \times TSC_{long}^C \quad (5)$$

More details on rates can be obtained from [19].

To apportion these  $TSC$  into respective lines owned by each class of network, the lines are differentiated by their lengths and voltage classes. Let  $l_{lm}^A$  be length and  $Q_{lm}^A$  be a factor reflecting voltage class for a particular line  $lm$  in class A network. Similar definitions hold for other classes of networks. Lines can be divided into 3 voltage classes, i.e., 400 KV, 220 KV and 132 KV. Their weights are made proportional to their voltage levels. Since, we wish to give same weight to both the attributes, normalized values of  $l_{lm}^A$  and  $Q_{lm}^A$  are used.

Then, participation of line  $lm$  in  $TSC^A$  is calculated by:

$$TSC_{lm}^A = \frac{l_{lm}^A Q_{lm}^A}{\sum_{\forall lm \in A} l_{lm}^A Q_{lm}^A} TSC^A \quad (6)$$

Similarly,  $TSC_{lm}^B$  and  $TSC_{lm}^C$  are calculated. In general, both loads and generators should share 50% of the TSC.

### B. Calculation of Locational Transmission Price

As a subsequent step, real power tracing is carried out on the system data. Real power tracing finds out the participation of each node's load or generator in the transmission line real power flows.

Based on results of real power tracing, the locational transmission price for  $i^{th}$  load is calculated by,

$$\begin{aligned} LTP^i &= \left( \frac{\sum_{\forall lm \in A} \frac{P_{lm}^i}{P_{L_i}} TSC_{lm}^A}{P_{L_i}} \right) \times 0.5 \\ &+ \left( \frac{\sum_{\forall lm \in B} \frac{P_{lm}^i}{P_{L_i}} TSC_{lm}^B}{P_{L_i}} \right) \times 0.5 \\ &+ \left( \frac{\sum_{\forall lm \in C} \frac{P_{lm}^i}{P_{L_i}} TSC_{lm}^C}{P_{L_i}} \right) \times 0.5 \end{aligned} \quad (7)$$

where,  $P_{lm}^i$  is obtained by upstream tracing. Similarly, the LTP for  $k^{th}$  generator is calculated by,

$$\begin{aligned} LTP^k &= \left( \frac{\sum_{\forall lm \in A} \frac{P_{lm}^k}{P_{G_k}} TSC_{lm}^A}{P_{G_k}} \right) \times 0.5 \\ &+ \left( \frac{\sum_{\forall lm \in B} \frac{P_{lm}^k}{P_{G_k}} TSC_{lm}^B}{P_{G_k}} \right) \times 0.5 \\ &+ \left( \frac{\sum_{\forall lm \in C} \frac{P_{lm}^k}{P_{G_k}} TSC_{lm}^C}{P_{G_k}} \right) \times 0.5 \end{aligned} \quad (8)$$

where,  $P_{lm}^k$  is obtained by downstream tracing.

### C. Aggregation of Locational Transmission Prices to form Zones

Results of equations (7) and (8) can directly be used as POC tariffs for all nodes in the system. However, from the point of view of implementation practicability, the locational transmission prices in a *Discom* or a *State* need to be aggregated to form one single price for that area. We aggregate the prices for a *State* rather than for a *Discom* because the *Discom* boundaries are yet to be decided. The aggregation is done by load and generation weighted averaging for each state. For  $q^{th}$  state, load weighted aggregated locational transmission price for all loads,

$$LTP_L^q = \frac{\sum_{i \in q} P_{L_i} LTP_i}{\sum_{i \in q} P_{L_i}} \quad (9)$$

Similarly, for  $q^{th}$  state, generation weighted aggregated locational price for all generators,

$$LTP_G^q = \frac{\sum_{k \in q} P_{G_k} LTP_k}{\sum_{k \in q} P_{G_k}} \quad (10)$$

To calculate the aggregated rate for a particular state  $q$ ,

$$LTP^q = \frac{P_G^q LTP_G^q + P_L^q LTP_L^q}{P_G^q + P_L^q} \text{ Rs/MW} \quad (11)$$

### D. Point-of-Connection Tariff Rates for a State

One of the desired features of the pricing scheme should be that the generators and the loads should pay different rates depending upon the surplus or deficit status of a state. This is desired because it gives rise to appropriate signals for load and generation investments in corresponding areas. Let  $Rate_G^q$  and  $Rate_L^q$  denote the generation and load charges in *Rs/MW* respectively, for state  $q$ . The pricing scheme should be such that for power deficit state,  $(Rate_G^q) < (Rate_L^q)$ , while for power surplus state,  $(Rate_G^q) > (Rate_L^q)$ .

Hence, POC tariff or charge for loads in  $q^{th}$  state:

$$Rate_L^q = LTP^q \frac{P_L^q}{P_G^q + P_L^q} \text{ Rs/MW} \quad (12)$$

POC tariff or charge for generators in  $q^{th}$  state:

$$Rate_G^q = LTP^q \frac{P_G^q}{P_G^q + P_L^q} \text{ Rs/MW} \quad (13)$$

Equations (12) and (13) provide us the POC tariff rates for generators and loads respectively, for state  $q$ . On similar lines, rates are calculated for all states.

## VI. IMPLEMENTATION AND RESULTS

### A. System Description

For the simulation purpose, the real life 193 bus system of Western regional (WR) grid is considered. It consists of 49 generators and 452 lines. The system models all CTU lines and STU lines up to 110 KV level. The base case corresponds to peak load condition. Power flow solution is obtained for this data and downstream as well as upstream tracing is carried out so as to obtain various decompositions. Western Region has 7 constituent states out of which the states of Gujarat (GU), Madhya Pradesh (MP), Maharashtra (MH) and Chhattisgarh (CH) together hold the large share of load and generation in WR. Hence, results are obtained for these 4 states.

### B. Results

Figure 3 shows the locational transmission price (Rs/MW) of all load buses in the system, calculated as discussed in section V. It can be seen that highest locational transmission price corresponds to that of bus no. 130 (*Barsoor*) which is situated in CH state. This is because of the fact that the *Barsoor* bus is connected radially by 220 KV line with large physical length and hence the  $TSC_{lm}^C$  of this line is attributed solely to *Barsoor* bus. Also, it is observed that those buses connected only to the CTU lines, have lesser locational transmission prices. For example, bus no. 83 (*Bhadravati*) has locational price Rs. 16.75/MW. In contrast, those buses which are devoid of direct connection to CTU lines and are connected to STU lines have greater locational transmission price. For example, bus no. 182 (*Jamnagar*) has locational price Rs. 1080.3/MW. These observations however, are case specific and the results largely depend upon the topology of the lines and buses in the area of concern, as the tracing results are topology dependent.

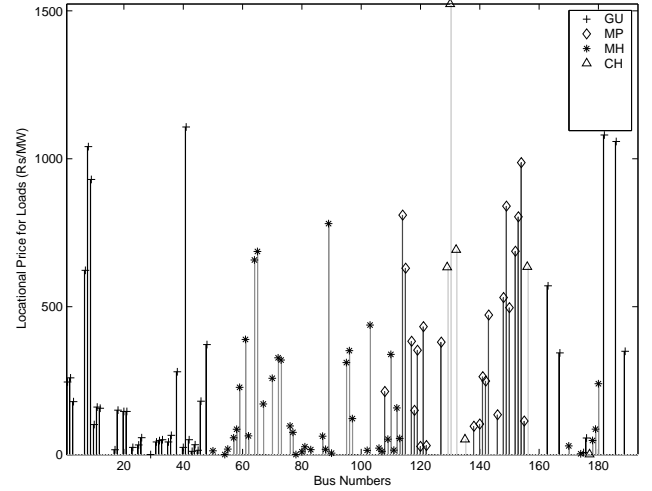


Fig. 3. Locational Transmission Price for load buses

Figure 4 shows the locational transmission price (Rs/MW) of all generator buses in the system. The locational transmission price sky scrappers are dominated by the giant thermal generators that are directly connected to the CTU network. For example, bus no. 133 (*Korba E*), 134 (*Korba W*), 159 (*Vindhyachal*) have locational transmission prices of Rs. 978.25, 827.60 and 881.06 per MW, respectively. The line flow decomposition of 400 KV lines emanating from these plants shows large contribution of these plants' power in their flows and hence large share of TSC is allocated to the buses representing these plants.

The POC rates for each of the four states are compared in Fig. 5. Same information is demonstrated in table III.

### C. Discussion

The results obtained in table III need to be verified so as to see to what degree they satisfy the desired features of pricing scheme. Amongst the four states, the area confined

TABLE IV  
TRANSMISSION COSTS FOR 1 MW POWER TRADE ACROSS STATES

	GU		MP		MH		CH	
	gen	load	gen	load	gen	load	gen	load
GU gen	—	201.06	—	322.43	—	180.209	—	239.24
GU load	201.06	—	381.46	—	212.92	—	399.33	—
MP gen	—	381.46	—	502.82	—	360.61	—	419.64
MP load	322.43	—	502.82	—	334.29	—	520.70	—
MH gen	—	212.92	—	334.29	—	192.07	—	251.1
MH load	180.21	—	360.61	—	192.07	—	378.48	—
CH gen	—	399.33	—	520.70	—	378.48	—	437.515
CH load	239.23	—	419.64	—	251.1	—	437.51	—

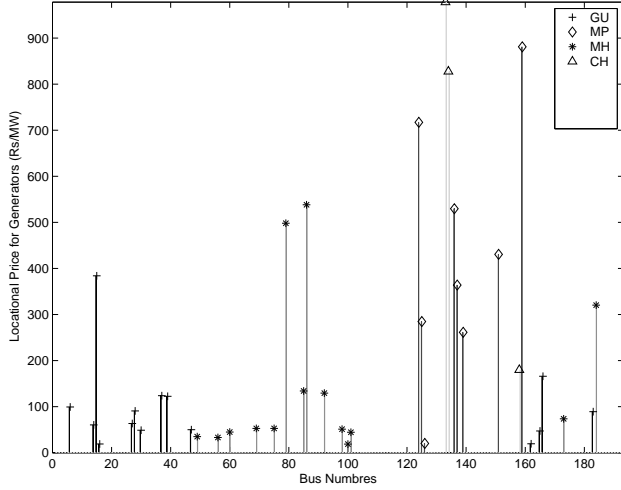


Fig. 4. Locational Transmission Price for generator buses

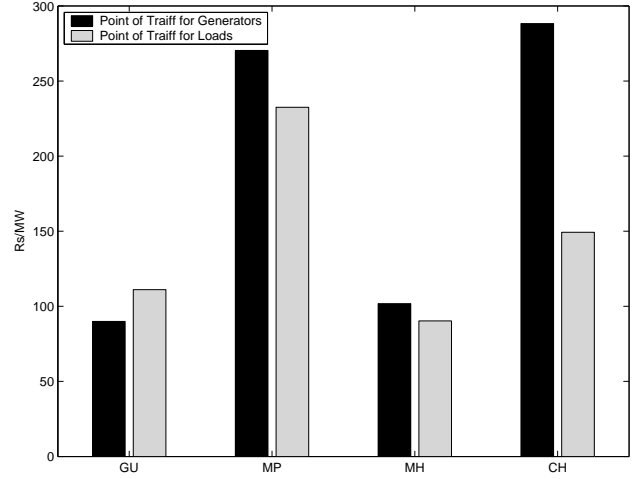


Fig. 5. Point-of-Connection Tariff Rates for Various States

TABLE III

DETAILS ABOUT GENERATION AND LOADS AND CORRESPONDING POC RATES

	GU	MP	MH	CH
POC Tariff Generation (Rs/MW)	89.9527	270.352	101.815	288.229
POC Tariff Load (Rs/MW)	111.109	232.476	90.2563	149.286

by geographical boundary of GU has less generation than the load in it. For the rest of the states, generation is more than the load in the area confined by their geographical boundaries. Hence, as per desired feature 4, discussed in section III, the POC tariff for generators in all the states except GU has to be greater than that for loads. However, GU being a deficit state, POC tariff for generators in this state has to be greater than that for loads. This is evident from table III.

To check the performance of the proposed scheme so far as signalling of locational advantage is concerned, a small exercise is carried out and the results are demonstrated in table IV. In this, it is assumed that a trader buys 1 MW of power in one state and sells it at the other, through the PX. Only one pair of drawl and injection points in two different states is considered at a time. Transmission price paid by a trader is calculated according to the POC tariff mentioned in table III. Following points are worth noting:

- If a load is situated in any of the states, while the injection

point in GU, that makes the cheapest deal for the trader for transmission pricing. The 'load' column entry for each state shows minimum price for row corresponding to GU 'gen'. Hence, generating companies are motivated to bring up new generation in GU, which itself is a deficit state.

- Similarly, maximum transaction price has to be paid if injection point is in CH state, which is more surplus than any other states.

As desired, the POC rates are comparable with that of the short term rates. The short term rate of WR is  $Rs.359/MW/day$ . The smallest entry in table IV is  $Rs.180.209$  that corresponds to 1 MW load in MH and 1 MW generation in GU., while the highest entry is  $Rs.520.70$ , that corresponds to 1 MW generation in CH and 1 MW load in MP. Hence, the prices vary around the rate that corresponds to short term rate of the WR, while deviation from that creates appropriate price signals.

Another characteristic of POC tariff pricing based on real power tracing is that the pancaking that arises in case of point-to-point scheme, is avoided. This feature can also be observed from the results presented in table III. Suppose a short term bilateral transaction of 1 MW takes place between a state in WR and a state in ER. In this case, postage stamp rates of both the regions need to be paid, i.e.  $(Rs.359+Rs.434=Rs.793)$ . For simplicity, postage stamp of inter-regional link is not considered. If similar transaction takes place through PX, then

from table III, it can be found that the maximum transmission cost paid by any state in WR is Rs.288.229. Similar rate would be paid by the ER constituent, but which would always be lesser than Rs.434. Hence, the transmission price paid by this type of contract would be lesser than  $(288.229 + 434.42 = 722.649)$ .

## VII. CONCLUSIONS

This paper provides a methodology to determine the point-of-connection (POC) rates based on the real power tracing. The paper floats a concept of *Locational Transmission Price* (LTP). The LTP is calculated based on the participation of each node in each transmission line power flow. Thus, depending on the sunk costs of that line, the LTP provides spatial variation of the network usage charges across the system. Hence, the LTP at a bus represents the POC charge at that bus.

The study is carried out to calculate POC rates for four states in Western regional system of India where, real life data is employed. This study bears a practical importance, as a national level power exchange is expected to come into reality in the near future in India. It is expected that simple to adopt and implement POC tariff would be employed to charge the PX trades as well as the short term bilateral transactions towards transmission network usage.

It is found that the POC rates thus calculated satisfy the desired features of transmission pricing schemes like reflection of network usage, creation of moderate price signals, removal of pancaking phenomena, etc. Even though the rates have been calculated at the state level, same methodology can be used to calculate the rates down to *Discom* level. Similar exercise can be carried out for rest of the regional grids in India to find out POC rates.

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