

Transmission Pricing Practices: A Case Study

N.K.Garg

Electrical Engineering
Govt. Engg. College
Jhalawar, India
nk_garg@yahoo.com

D.K.Palwalia

Electrical Engineering
Rajasthan Technical University
Kota, India
dheerajpalwalia@gmail.com

Harish Sharma

Computer Engineering
Rajasthan Technical University
Kota, India
harish.sharma0107@gmail.com

Abstract (This paper presents a case study on transmission pricing practices. Now a days, restructuring of the power system market through deregulation is gaining attention as technical and economical benefits at generator and user. In India, after the Electricity Act 2003, restructuring has been introduced in the Indian power system market. Researchers are continuously working towards improvement of deregulation based on restructuring to improve transmission pricing practices and calculations in a better way. Therefore, this paper presents an overview of MW-Mile and postage stamp methods to estimate the transmission cost. Further, the North Indian practical power system of 37 bus test system has been analyzed by reverse, absolute and dominant Mw-Mile methods. The results obtained to be expected for deregulated power market.)

Index Terms—Deregulation, MW-Mile method, Open access, Restructuring, Transmission Pricing

I. INTRODUCTION

Restructuring of power sector using the method of deregulation has been a keen point of interest for the power system researchers. Deregulation unbundles the electricity business into three components: generation, transmission and distribution. Deregulated electrical utilities provide higher operating efficiency, lower energy cost and competitive market. Restructuring of the transmission system with existing networks has always been a herculean task for power industry people, due to complexity in establishment of the rules for operating transmission system and pricing transmission service in deregulated system [1]. The pricing structure should be so as to recover cost of transmission network, ensure uninterrupted operation, provide investors with good return and provide the same opportunity to all users [2]. Transmission open access refers to a regulatory reform which addresses the obligation, right, operating procedure and economical condition; thus enabling two or more parties to access the transmission facilities (grid) owned by third party (partially or fully) for transmission of electrical power. Countries round the globe, have continuously been making efforts to achieve redefined generator and use friendly transmission system.

The open access transmission concept does not have a uniform model and need to be reviewed and implemented depending upon specific circumstances of different nations. Basically four types of embedded cost methodologies of wheeling cost are used for transmission system viz. Postage stamp, Contract path, MW-Mile and MVA-Mile method. These methods have been tested for allocating the transmission cost to wheeling transactions on standard and practical test system of different nations. Meah et al. [3] discussed MW-Mile method using Malaysian power system in order to assess their impact on the long term transmission planning. Flow based method and the effect of reactive power in embedded cost has been discussed on South African power test system [4]. Park et al. [5] explained a variation of the power flow based MW-Mile methods on standard 5 and 14 bus test system. Ferreira et al. [6] discussed the postage stamp, MW-Mile and some of its variants using a simple 9-bus electrical network. Metering and differentiating between different categories of energy sales, during the wheeling transactions, have been presented on West African interconnected system [7]. Silva et al. [8] explained MW-Mile the modulus and the zero counter flow methods using the Protuges

transmission company network to set tariff. Delshad et al. [9] discussed transmission pricing of Iran electricity market.

In India, with the enactment of the Electricity Act 2003 [10] [11] and implementation of open access, the old single buyer structure market of power sector has been changed to a multi-buyer model. The market structure, taken shape after the Act 2003, has proved promising as it provided the right of choice to the supplier as well as buyer; thus ensuring the quality and reliability of power and competition in the market. The existing transmission pricing practice in India is postage stamp which has discouraged power market [12], as it doesn't considers the circuit loading. Roseline et al. [13] discussed a case study of Tamil Nadu, India and explained different components such as power generation, man power rationalization, renewable energy, and transmission and distribution losses. Warkad et al. [14] applied MW-Mile and MVA-Mile methods to Maharashtra State Electricity Transmission Company Limited (MSETCL) network and worked out optimal cost of tariff for MSETCL system. The effect of reactive power flow caused by the wheeling transaction has been explained using the IEEE-30 bus and Indian utility-62 bus systems. Kumar et al. [15] discussed MW-Mile and MVA-Mile approaches in Indian power system and explained the cost effectiveness of each circuit for various users of the circuit. Researchers have continuously been working in the field of transmission pricing across the world to determine best optimal method. This paper presents transmission cost allocation to power purchasers at multiple transactions and explains the benefits of these transactions on test system. MW-Mile and Postage Stamp methods on Indian utility -37 bus system.

II. INDIAN POWER SECTOR AND MARKET

Indian power sector has changed significantly after enactment of Electricity Laws like Amendments Acts 1998 and Electricity Act 2003. These amendments made Central Transmission Utility (CTU) and State Transmission Utility (STU) responsible for maintaining generation schedule, reviewing project progress, planning

integrated operation among the utilities, coordinating the maintenance schedule, determining the availability of power for inter-state utilities transfer and deciding a suitable tariff for the inter-utility exchange of power. Presently Indian power system is being operated on a regional basis which is divided into five regional grids, i.e. Northern Region (NR), Western Region (WR), Southern Region (SR), Eastern Region (ER) and North Eastern Region (NER). NR, WR, ER and NER regions are being operated in synchronous mode while SR grid is connected in asynchronous link as shown in Fig.1 [16].

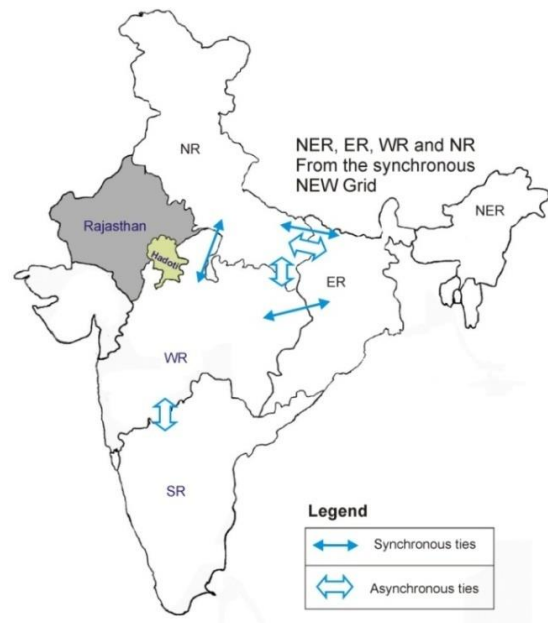


Fig.1 Indian Regional Grids

Each region has a Regional Load Dispatch Center (RLDC), which is under the operation control of CTU. RLDC manages the integrated operation of the connected region and ensure the grid operation [17]. Every state has a State Load Dispatch Center (SLDC) which is top body of state. SLDC has the responsibility to ensure integrated operation of the power system in the state. SLDC has also the responsibility to allocate the total available power to various states through RLDC. The region wise power supply position in the country during the year 2012-13 has been given Table I [18]. It shows that both the energy and peak demand requirement have the deficit. Hence Indian power sector has the challenge to narrow down the gap between demand and supply using existing transmission network.

Transferring power from one place to another point is dependent upon the load and generation of the system; hence transmission cost allocation has significance.

Central Electricity Regulatory Commission (CERC) has improved the efficiency and competition for real time balancing network by allowing Open access, inter-regional electricity transmission and Availability Based Tariff (ABT) [19]. CERC has also setup Indian Energy Exchange (IEX) for providing power trading. IEX manages and provides day-ahead contracts, price discovery and price risk management to the generators, traders, distributors, stakeholders and consumers [20]. Day-ahead contracts timeline management has been in quo with the RLDC. Indian power system is one of the largest growing sectors and hence need to be reformed for optimal utilization of the large and complex transmission network. In this quest, Transmission open access is a key thought and continuous efforts are being made to attain best suitable transmission pricing system.

TABLE I
ENERGY AND PEAK SHORTAGE

Region	Energy			Peak		
	Require- ment (MU)	Availabili- ty (MU)	Deficit (MU)	Deman- d (MW)	Met (MW)	Deficit (MW)
NR	300774	273240	27534	45860	41790	4070
WR	296475	286683	9792	40075	39486	589
SR	281842	238058	43784	38767	31586	7181
ER	107457	102510	4947	16655	15415	1240
NER	11566	10718	848	1998	1864	134
India	998114	911209	86905	135453	123294	12159

III. PROBLEM FORMULATION

Problem is formulated for allocation of transmission cost to customers at multiple transactions. The magnitude of feasible wheeling transactions has been estimated as it does not violate the transmission constraints. In this case, transactions made by power purchasers should be utilized optimally in order to derive maximum benefits. Minimum wheeling charge of the transactions has also been computed in the test system to utilize the buses as industrial promotion and assure consumer benefits. This analysis has been performed by MW-Mile and Postage stamp

techniques. Before the allocation of transmission cost , load flow solution for the network is obtained under steady state condition subjected to certain inequality constraints under which the system is operated and bus voltages, reactive power generations, load magnitude variables are used as the constraints. As the bus voltages and phase angles are determined by load flow solution. Therefore power flow through interconnecting transmission lines and the power injection at all the buses could be estimated easily. Here, the load flow equations are evaluated by Newton Raphson method as its convergence rate is higher.

Consider that there is total N number of buses in a power system network. The nodal active power P_i and reactive power Q_i of each transaction of seller and purchaser at bus i satisfies the following equations and constraints [21].

$$P_i = P_{Gi} - P_{Di} = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j), \forall i = 1, 2, 3, \dots, N \quad (1)$$

$$Q_i = Q_{Gi} - Q_{Di} = -\sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j), \forall i = 1, 2, 3, \dots, N \quad (2)$$

Where P_{Gi} : Active power of Generator, Q_{Gi} : Reactive power of Generator, P_{Di} : Active demand of Load, Q_{Di} : Reactive demand of Load, V : Bus Voltage, Y : Bus Admittance Matrix, δ : Angle of Bus Voltage and θ : Angle of Bus Admittance Matrix

(a) Constraints of real and reactive power generation

$$P_{Gi\min} \leq P_{Gi} \leq P_{Gi\max} \quad (3)$$

$$Q_{Gi\min} \leq Q_{Gi} \leq Q_{Gi\max} \quad (4)$$

(b) Limits of bus voltage magnitude and its angle

$$V_{i\min} \leq V_i \leq V_{i\max} \quad (5)$$

$$\delta_{i\min} \leq \delta_i \leq \delta_{i\max} \quad (6)$$

Initially Power flow solutions are obtained without any transaction, called base value, and the solutions are calculated for multiple transactions by checking the limits of the variables.

Thus transmission cost is computed using MW-Mile method as shown hereunder in flow chart (Fig. 2).

$$C_K = \sum_{i=1}^N \frac{L_i \cdot F_i \cdot P_i^K}{P_i} \quad (7)$$

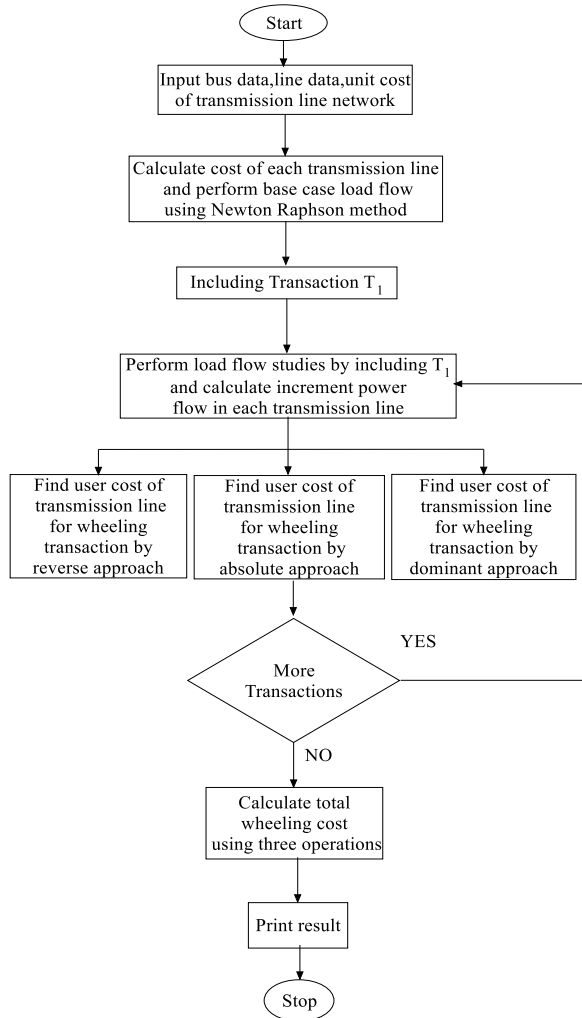


Fig.2 Flow Chart for MW-Mile Method

IV. MW-MILE METHOD

This method deals with change in the magnitude of power flow for the system by wheeling transaction in order to allocate the wheeling costs of each wheeling transaction [22] [23]. One of the distinct features of this method includes the determination of wheeling cost for the length of transmission lines used in the transaction. This attempt helps in solving the flaws in the rolled-in-embedded method, where the distance between the point of supply and the point of the recipient has no effect in determining the usage of the transmission system by the wheeling transaction. This method is also known as Line-by-Line method and the cost is calculated by the equation (7)

Where L_i is length of circuit i , F_i is pre-determined unit cost reflecting the cost/mile of circuit i , N is total number of circuits in the circuit, P_i^k is power flow imposed on the circuit i by user k , P_i is capacity rating of circuit i .

There are three different approaches, used in MW-Mile method considering the direction of power flows [15], [24].

A. Reverse MW-Mile Approach

This approach calculates the charge for each line based on power flows. It considers the positive and negative power flows. Power flow imposed on the circuit i by the user k , P_{ik} is treated based on the following condition,

$$P_i^k = \begin{cases} +ve & \text{for direct power flows, or} \\ -ve & \text{for reverse power flows} \end{cases}$$

B. Absolute MW-Mile Approach

In this approach, charge is calculated by the absolute value of the power flow whether it is positive or negative power flow. Power flow imposed on the circuit i by the user k , P_{ik} is considered based on the following condition,

$$P_i^k = |P_i^k| \text{ for direct and reverse power flows}$$

C. Dominant MW-Mile Approach

In the dominant MW-Mile approach, network users are only charged on the basis of direct power flow impose on each line and power flow imposed on the circuit i by the user k , P_{ik} is calculated based on the following condition,

$$P_i^k = \begin{cases} |P_i^k| & \text{for direct power flows, or} \\ 0 & \text{for reverse power flows} \end{cases}$$

Total cost of transmission is calculated using the postage stamp method [3]. This method allocates the wheeling charges based on the magnitude of the wheeled or transacted power. It assumes the whole transmission system is involved in wheeling transaction. This approach is applied to each bus and residual cost will be appointed to each user based on its load level using the equation.

$$R_K = \Delta TC \cdot \frac{P_{LK}}{P_{LT}} \quad (8)$$

The total cost allocated to each individual user, TC_k is calculated by the equation

$$TC_k = C_K + R_K \quad (9)$$

V. RESULT ANALYSIS AND DISCUSSION

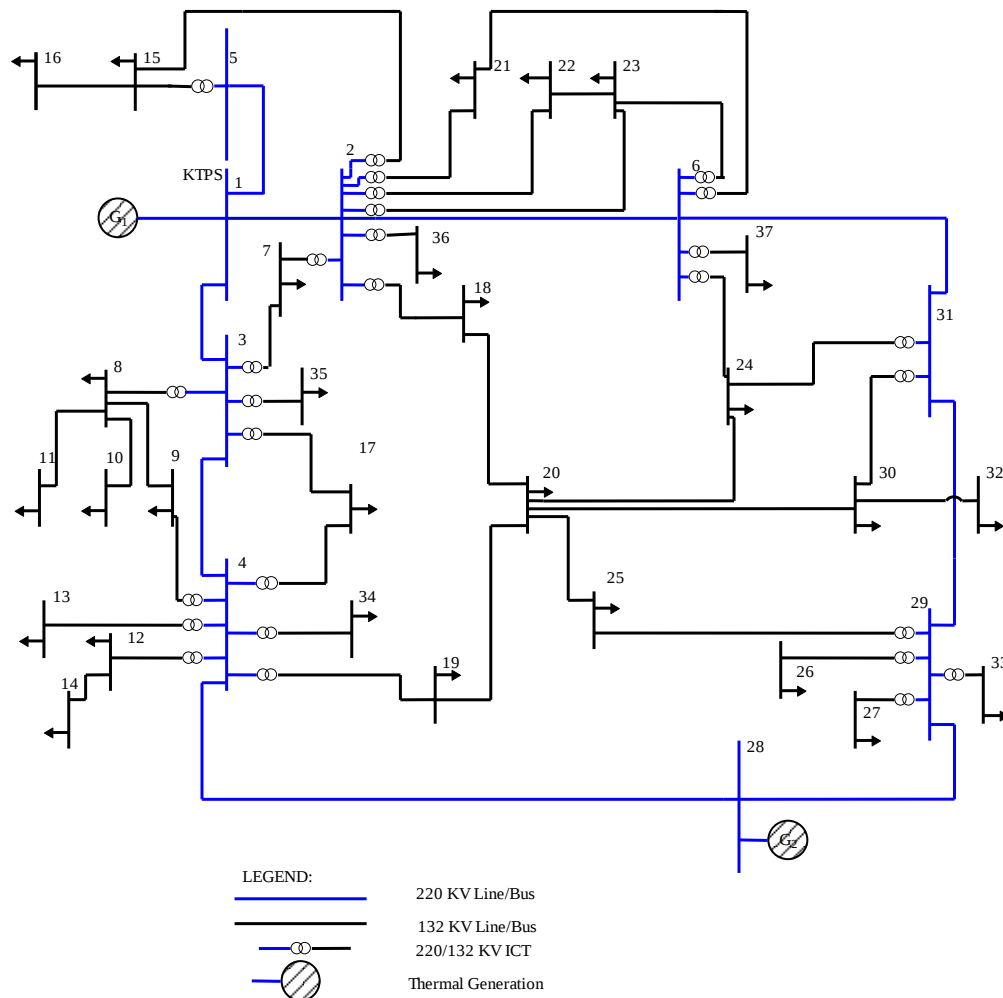


Fig.3 37 -Bus Test Network

Rajasthan state is one among few states to begin power sector reforms in India. Rajasthan State Electricity Board (RSEB) has now been unbundled as one Generation, one Transmission and three Distribution companies. Rajasthan Rajya Vidyut Utpadan Nigam Ltd. (RVUNL) Company has installed capacity of 5057.35 MW. RVUNL is also managing and operating inter-states operation projects of 271 MW. Peak demand of the state is 8940 MW and EHV lines of around 29604 Ckm. Open access is being allowed in phased mode of 1 MVA and above, from April 2008. The study has been conducted on Indian utility -37 bus system of Rajasthan state. The one line diagram is shown in Figure 3. The names of the buses are given in Appendix AI. It consists of 37 buses, 2 generators and 49

transmission lines at 220 kV and 132 kV voltage level.

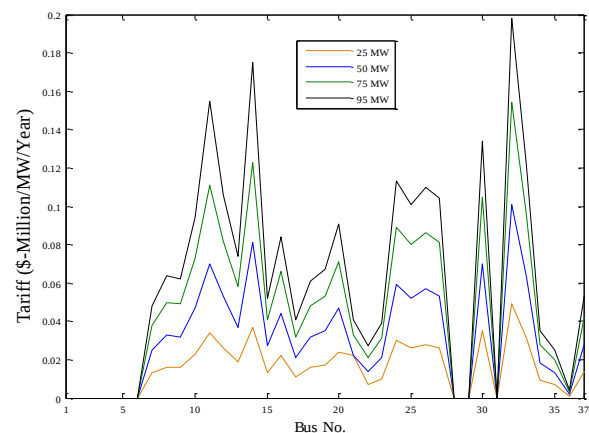


Fig.4. Tariff for Reverse Approach

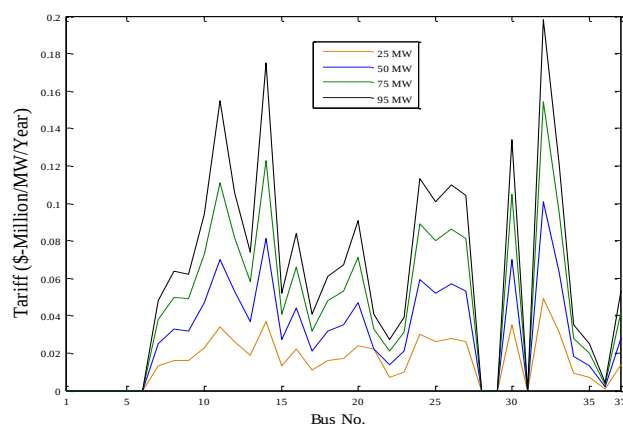


Fig. 5. Tariff for Dominant Approach

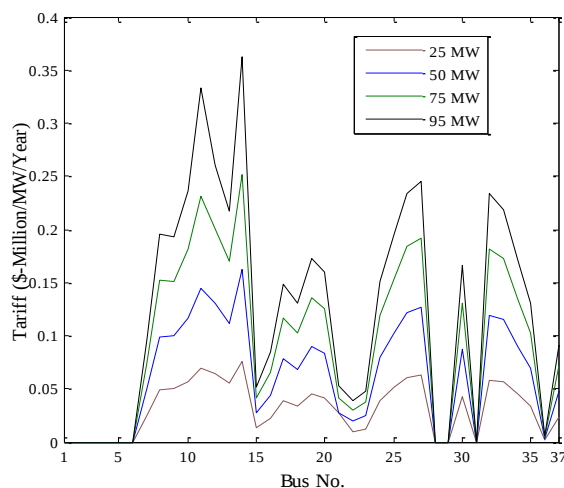


Fig.6. Tariff for Absolute Approach

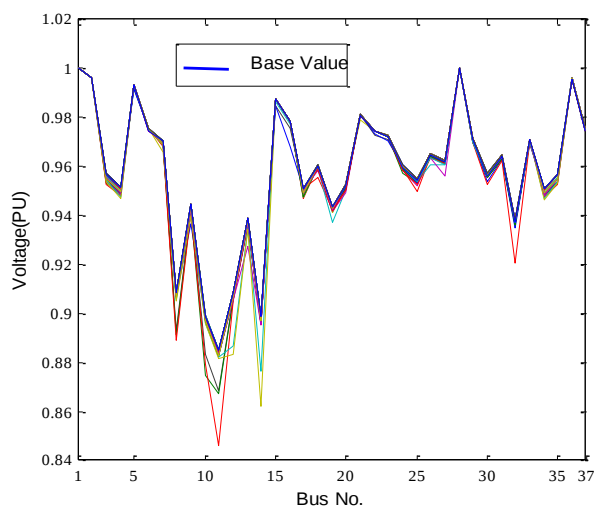


Fig.7 Voltage Variation

The generation capacity 1300 MW is assumed as base load condition and total load connected on the system is 911 MW. The simulation studies are carried out on Intel core i3 2.53 GHz system in MATLAB environment. It is assumed in this analysis load customer would pay 100% of the transmission cost of services to the transmission utility. The annual revenue requirement of transmission facility is 140.59 \$-Million.

The MW-Mile method is applied to Indian utility system with four feasible wheeling transactions. Table II shows the values of feasible transactions. Tariff costs are calculated using MW-Mile approaches and results obtained for the test system. Fig. 4 shows the tariff for reverse approach. The tariffs for the bus no. 1,2,3,4,5,6,28,29 and 31 are found zero as load is not connected to these buses and no charges are being paid. The wheeling charges are also varying evenly for all feasible transactions. Fig. 5 and Fig. 6 presents tariff for dominant and absolute approach. Absolute approach gives the maximum value of tariff as shown in Fig.6. It is observed that the results obtained from the reverse, dominant and absolute approaches are fairly accurate. The minimum wheeling charges are obtained for the bus no.36. It is near to generator that favors the system in all three approaches. It could be used for customer and industry promotion. The values of minimum charges are tabulated in Table III.

The result obtained shows that the tariff is raised by increasing the value of transaction. Table IV presents the total transmission cost for the test system using MW-Mile approaches and postage stamp methods. It indicates that MW-Mile method does not recover the total payment. The postage stamp method is being applied to allocate the total cost. Absolute approach recovers the highest cost and recovery of total cost by MW-Mile method is also improved by the transaction. It increases as the transaction moved up. Fig. 7 shows that voltage variation for computing the cost of these transactions. Results found reasonable and vary within permissible range. Voltage varies to close to reference base value with and without transaction.

TABLE II
.DETAILS OF FEASIBLE TRANSACTIONS

Transaction	From Bus No.	To Bus No.	Value of Transaction (MW)
T ₁	2	37	25
T ₂	2	37	50
T ₃	2	37	75
T ₄	2	37	95

TABLE III
. WHEELING CHARGE (\$-Million/MW/Year)

Transaction	Transaction (MW)	Bus No.	Reverse	Dominant	Absolute
T ₁	25	36	0.0011	0.0014	0.0016
T ₂	50		0.0022	0.0027	0.0033
T ₃	75		0.0033	0.0041	0.0049
T ₄	95		0.0042	0.0052	0.0062

TABLE IV
PAYMENT (MW-MILE AND POSTAGE STAMP METHOD) \$-MILLION

S.No.	Total Load (MW)	Transaction(MW)	Reverse	Postage	Dominant	Postage	Absolute	Postage
1	911	25	16.553	123.726	24.757	115.836	32.641	107.953
2		50	16.781	123.726	49.005	91.589	64.832	75.761
3		75	17.011	123.532	74.323	66.271	98.337	42.256

VI. CONCLUSION

In this paper, a case study is presented to estimate the transmission pricing of deregulated North Indian power system. MW-Mile method and simultaneously feasible wheeling transactions have been carried out at 37-bus real test system. Obtained wheeling charges do not have significant variations among the four wheeling transactions. MW-Mile does not recover the total transmission cost, postage stamp method is applied at the system to share the costs associated with unused capacity. From the analysis, it is very much clear that if MW-Mile and postage stamp methods are applied strategically then the

transmission pricing could be calculated with more accuracy. Both the methods also fulfill the objective of transmission pricing i.e. cost coverage, transparency, return to investors, efficiency and reliability in developing deregulated power market. The methodology produced and results obtained are of practical use for optimal operation of the power market and also ensure the economic advantages for the transmission companies.

APPENDIX

Table A
NAMES OF BUSES-INDIAN UTILITY-37 BUS
SYSTEM

Bus No.	Bus Name	Bus No.	Bus Name
1	KTPS (Generator)	20	Sangod
2	Sakatpura (220 kV)	21	Gopal Mill
3	Morak (220 kV)	22	Mahveer Nagar
4	Jhalawar (220 kV)	23	Industrial Area
5	Bundi (220 kV)	24	Anta
6	Dahra (220 kV)	25	Bapawar
7	MadanaTown	26	Atru
8	BhawaniMandi	27	ChhipaBarod
9	Kanwari	28	Chhabra(Generator)
10	Hemda	29	Kawai (220 kV)
11	Dug	30	Baran (132 kV)
12	Akelera	31	Baran (220 kV)
13	Bakani	32	Kelwara
14	Manoharthane	33	Kawai (132 kV)
15	Bundi (132 kV)	34	Jhalawar (132 kV)
16	Hindoli	35	Morak (132 kV)
	Mayla Ramganj		
17	Mandi	36	Sakatpura (132 kV)
18	Deoli Manji	37	Dahara (132 kV)

REFERENCES

[1] J.W.Marangon Lima, E. J. de Oliverira, “The long-term impact of transmission pricing”, *IEEE Transactions on Power Systems*, vol. 13, no. 4, 1998, pp. 1514-1520.

[2] P.S.Kulkarni, O. P. Yadav, “SRMC based Transmission Pricing for Wheeling Transactions under Deregulated Environment of Power Sector.”, *IE (I) Journal-EL*, 2008.

[3] M.M, Meah, Azah Mohamed, and Salleh Serwan, “Comparative analysis of using MW-Mile methods in transmission cost allocation for the Malaysia power system”, *Proc. of IEEE National. Conf. on Power Engineering*, *PECon 2003*, 15-16 Dec. 2003, pp. 379-382.

[4] Y.R.Sood, Narayana Prasad Padhy, and H. O. Gupta, “A new method for allocating embedded cost of transmission under deregulated environment of power system”, *Proc. of IEEE Int. Conf. on Electric Utility*

Deregulation and Restructuring and Power Technologies, DRPT 2000, 4-7 April 2000, pp. 528-531.

[5] Y.M. Park, J.B.Park, J.U.Lim, and J.R. Won, “An analytical approach for transaction costs allocation in transmission system”, *IEEE Transactions on Power Systems*, vol. 13, no. No. 4, 1998, pp. 1407-1412.

[6] J.Ferreira, Zita Vale, A. Almeida Vale and Ricardo Puga., “Cost of Transmission Transactions: Comparison and Discussion of used Methods”, *International Conference on Renewable Energy and Power Quality (ICREPQ'2003)*, *Vigo, Espanha*, 2003.

[7] T.Sackey, S. Z. Zakhary, “Power wheeling through the West African interconnected system”, *Sixth International Conference on AC and DC Power Transmission*, 29 Apr-3 May 1996, pp. 13-18.

[8] J.P. Da Silva, J. T. Saraiva, and M. T. P. de Leao, “Use of power flow based embedded methods to set tariffs for use of networks-a case study using the Portuguese transmission company”, *IEEE Power Tech Proceedings, 2001 Porto.*, 2001.

[9] M.M.Delshad, I. Rahmati, and M. S. Ghazizadeh, “Transmission pricing in Iran electricity market”, *IEEE International Conference on Power and Energy (PECon)*, 2010, 29 Nov-1 Dec 2010, pp. 824-825.

[10] Government of India, The Electricity Act, 2003, The Gazette of India, Extraordinary, 2003, New Delhi, June 2003, http://powermin.nic.in/JSP_SERVLETS/internal.jsp.

[11] Central Electricity Authority of India, www.cea.nic.in/reports/electricity_act2003.pdf

[12] N.Kumar, Y. V. R Reddy, D. Das, and N.P.Padhy, “Existing transmission charging practices in India: Discouraging for power market”, *Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES*, 20-23 March 2011, pp. 1-7.

[13] J. Roseline, Anitha, and B. L. Mathur, “Tamil Nadu power sector reform and restructuring—a case study”, *4th IEEE*

- International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*, 2011.
- [14]S. B.Warkad, M. K. Khedkar, and G. M. Dhole, "Optimal Electricity Transmission Pricing in a Restructured Electricity Market", *International Journal of Computer and Electrical Engineering*, vol. 1, no. No.4, 2009.
- [15]N. Kumar, Y. R. V.Reddy, D. Das, and N. P Padhy, "Transmission cost allocation by using MW-Mile approaches in a restructured Indian power system", *IEEE Power and Energy Society General Meeting*, 25-29 July 2010, pp. 1-8.
- [16]S. K. Soonee, S.R Narasimhan, R.K. Porwal, S.Kumar, R. Kumar and V. Pandey, "Application of phase angle measurement for real time security monitoring of Indian Electric Power System—an experience", *International Water and Energy*, 2008, pp. 19-25.
- [17]V.Pandey, "Electricity Grid Management in India-An Overview", *Electrical India*, 2007.
- [18]Load Generation Balance Report 2013-14, Central Electricity Authority of India, http://www.cea.nic.in/reports/yearly/lgbr_report.pdf.
- [19]S. N.Singh, and S. C. Srivastava, "Electric power industry restructuring in India: present scenario and future prospect", *IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, (DRPT 2004)*, 2004.
- [20]P.Bajpai, and S. N. Singh, "An electric power trading model for Indian electricity market", *IEEE Engineering Society General Meeting*, 2006.
- [21]Hadi Saadat, "Power system analysis", WCB/McGraw-Hill Singapore, 1999.
- [22]W.J. Lee, , C. H. Lin, and K. D. Swift, "Wheeling charge under a deregulated environment", *IEEE Transactions on Industry Applications*, vol. 37, no. No.1, 2001, pp. 178-183.
- [23]H.H.App, "Cost of wheeling methodologies", *IEEE Transactions on Power Systems*, vol. 9, no. No.1, 1994, pp. 147-156.
- [24]J.W.Marangon Lima, "Allocation of transmission fixed charges: an overview", *IEEE Transactions on Power Systems*, vol. 11, no. No.3, 1996, pp. 1409-1418