Optimal Spot Pricing Evaluation in Restructured Electrical Power System

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ABSTRACT- Electricity markets in both developed and developing countries have been considerably reorganized over the previous two decades. The unbundling of generation and transmission results in restructured electricity market which enhances the competition among the market traders in the regime of open access. Therefore, the transmission pricing methods should be skilled in translating transmission costs into tariffs to allow participation, which leads to profitable effectiveness, allows the grid owner to recover prices, and makes market participants aware of the system's supply defense and consistency maintained. This research intends to *(1)* examine the drivers behind power transmission pricing, *(2)* Create AC-DC OPF-based Nodal Pricing methodology, and *(3)* work out prices for India's real transmission network to enable market participants to compete and make the best decisions. Finally, the study indicated that the planned methodology is more appropriate for rising nations to achieve the goals of building extensive energy markets.

Keywords: Electricity market, Optimal power flow, Spot pricing, Embedded cost, Transmission pricing.

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1. INTRODUCTION

Electricity markets in both developed and developing countries have been considerably reorganized over the previous two decades. This restructuring promoted competition in the electric power industry's wholesale and retail segments. The fundamental rationale for introducing competition in industrialized countries aims to increase technological and financial effectiveness. For rapidly rising countries, the objective is to create competition and draw private investment, releasing the government from the responsibility of financing the essential expansion of the electric industry [1].

The unbundling of generating, and transmission is a frequent feature of energy restructuring, with the latter being made available to all suitable market participants through open access regime. This has significantly increased, and the traditional power business has been revolutionized, introducing numerous new problems into the functioning of the generating, transmission, and system aspects. Due to increased competition in the electric power industry, it is now more viable to use market services to improve power system stability and financial health. Transmission Open Access (TOA) is becoming more popular in developing nations with transmission companies mandated to provide essential transmission services and pricing. Power expenditure in rising countries is predicted to more than twice in the next years, compared to a 35 to 40% increase in developed. In this paper, combine AC-DC OPF-based optimal spot Pricing methodology is proposed to enable market participants to compete and make the best decisions. Simulation is carried out on a 400KV MSETCL system with a DC link with the proposed addition of a 765/1200 KV line to evaluate the optimal spot pricing.

2. ENERGY TRANSMISSION PRICING

As a background for the current inquiry, summaries of the various studies on power transmission pricing have been provided, but fewer conclusions have been drawn. Intending to cover all available work [2] first mentioned embedded capital costs of the marginal cost principle are a notion.[3] calculated wheeling rates. The losses' sensitivities, limitations, load levels, on the power system, revenue reconciliation, and other issues were investigated. [4] analyses the cost of a transmission deal by examining components such as running cost, opportunity cost, transaction cost of the current system, and cost of embedded to make sound economic decisions, considering incremental and marginal costs. [5] Proposed the load flow approach for assigning the transmission capacity cost embedded, progressive, and described are the marginal costs of transmission capacity and [6] estimated the cost of wheeling techniques and recommended computational approaches different techniques are all available with a hidden cost. [7] developed a novel approach based on the transmission capital that has been allocated using the MW-Mile rule. cost. The differences between the embedded cost techniques were examined, along with the economic implications and how such an allocation can affect system expansion planning. [8] proposed a novel analytical method for allocating transaction expenses. Numerous wheelers can use the technique. In a

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deregulated power system setting, methods for allocating the inherent cost of simultaneous two-way transactions were statistically assessed on the power system [9]. A voltage position-based pricing structure for transmission services is suggested [10]. By describing the semantics and numerical characteristics of the slack generating and transmission mechanism, a nodal price model is developed [11]. An OPF has been utilized for a breakdown of locational prices to carry out the operation of the design [12]. The decomposition method was used to obtain the results of the power-related Lagrangian multipliers balance equations into generation, loss, and profit components.

Congestion in the system also showed the sensitivity of the congestion restrictions as a result of generation and losses. [13] brought the nodal price concept into electricity systems and most people's basis and starting point. [15] proposed an integrated nodal system as a result of a subsequent study. Interior created a pricing model by altering an existing Newton OPF. Algorithms for calculating points It includes the development of optimum nodal networks. [16] Described the various components of nodal prices. LMP nodal market forecasting scheme of fuzzy inference, and least-squares estimation, as well as their combination, have recommended increasing the performance of short-term forecasting. [18] presented a DC OPF-based iterative technique to calculate LMPs and examine LMP sensitivity about the restructured load.

3. AIMS AND NECESSITATIES OF NODAL PRICES

A. Financial Effectiveness

Effective transmission pricing the system must provide appropriate incentives and recover. The economic effectiveness of selling players promotes the effective utilization of the current network, stimulates network expansion investments, encourages an effective site for new generation units, and so on. Pricing transparency is critical in a restructured business. Transmission pricing should aim to fully recoup the costs incurred by the transmission owner, assign limited (congested) transmission capacity, allocate the cost of losses in transmission, and adhere to the nodal cost principle.

B. Spot Price Modeling

In the reformed electricity structure, electricity transmission prices have greatly increased in volatility as a result of competition among power producing companies, as well as reductions in supervisory control of the government in price fixing. Participants in the energy market now face greater risk in terms of their ability to produce and sell large amounts of electricity as well as the prices they will be paid for those outputs. Effective modeling of nodal price behavior is necessary to assist market players with the operation, risk assessment, and investment. Regulatory organizations need nodal price models to analyze the market behavior of generators, investors, and consumers.

To assess the likelihood of investing in new or existing power plants, potential investors must take into account estimations of nodal pricing for their investment's profitability (and return on investment). In many cases, these individuals can buy in markets all over the world. contracts for a fixed price of electricity for a set period. The evaluation of financial derivatives is necessary for the evaluation of both volatility pricing and probable nodal values to determine the right set price in addition to a reasonable contract price.

For many transmission grid nodes, market payment prices are determined using the nodal pricing method. Each node on the transmission system represents a physical location, including generators and loads. The locational value of energy price reflects the cost of the energy as well as the expenses incurred for distributing it.

In this mathematical modeling, the active and reactive power costs of bus k stand in for the equality and inequality conditions' Lagrangian multiplier values. These values were acquired from Lagrangian's first-order condition and taking its partial derivatives.

$$
\begin{aligned}
L = & \sum_{k=1}^{NG}(ak\,P_{gk}^{2} + bk\,P_{Gk} + ck) + \sum_{k=1}^{NB}\lambda_{pk}(P_{dk} - P_{gk} + P_{dck} + P_{L}) \\
& + \sum_{k=NV+1}^{NB}\lambda_{qk}(Q_{dk} - Q_{gk} + Q_{dck} + Q_{L}) \\
& + \sum_{k=1}^{NG}\rho\, p_{lk}(P_{gk}^{min} - P_{gk}) + \sum_{k=1}^{NG}\rho\, p_{uk}(P_{gk} - P_{gk}^{max}) \\
& + \sum_{k=1}^{NG}\rho\, q_{lk}(Q_{gk}^{min} - Q_{gk}) + \sum_{k=1}^{NG}k(Q_{gk} - Q_{gk}^{max}) \\
& + \sum_{k=1}^{NB}\rho v_{lk}(|V_{k}^{min}| - |V_{k}|) + \sum_{k=1}^{NB}\rho v_{uk}(|V_{k}| - |V_{k}^{max}|) \\
& + \sum_{k=1}^{NB}\rho\delta_{lk}(\delta_{k}^{min} - \delta_{k}) + \sum_{k=1}^{NB}\rho\delta_{uk}(\delta_{k} - \delta_{k}^{max}) \\
& + \sum_{k=1}^{Noele}\rho\, p_{flk}(P_{fk}^{min} - P_{fk}) + \sum_{i=1}^{Noele}\rho\, p_{fuk}(P_{fk} - P_{fk}^{max})
\end{aligned} \tag{1}
$$

Where, 'l' and 'u' stands for lower and upper bounds; $\lambda = (\lambda_1 \ldots \lambda n)$ is the vector of equality constraints; $\rho\ (\rho_1 \ldots \rho_n)$ is the inequality constraints.

The optimal solution (X,λ,ρ) for a set of (P,Q), Nodal prices of reactive and real power for the bus is expressed for $k=1,\ldots,n$,

$$\pi_{p,k} = \frac{\partial L(X,\lambda,\rho,P,Q)}{\partial_{pk}} = \frac{\partial f}{\partial_{pk}} + \lambda\frac{\partial S}{\partial_{pk}} + \rho\frac{\partial T}{\partial_{pk}} \tag{2}$$

$$\pi_{q,k} = \frac{\partial L(X,\lambda,\rho,P,Q)}{\partial_{qk}} = \frac{\partial f}{\partial_{qk}} + \lambda\frac{\partial S}{\partial_{qk}} + \rho\frac{\partial T}{\partial_{qk}} \tag{3}$$

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The difference ($\pi_{p,k}$ -$\pi_{q,k}$) represents actual transmission costs between the j and k buses. The LMP caused due to an increment in power demand at bus k, is represented by *equations (2) and (3)* respectively.

The MATLAB function 'fmincon' was used to simulate the fore mentioned formulae. Programming complexity can be reduced by explicitly evaluating the restrictions as functions of the state variables.

4. INDIAN ELECTRICITY MARKET

For the years 2021–2022, a 1356-billion-unit target for energy generation from thermal, hydro, nuclear, and Bhutan import sources has been established (BU) *i.e.* an increase of about 9.83% above the 1234.608 BU that was generated the prior year (2020-21). In comparison to the 1250.784 BU generated in 2019–20, the generation from the a fore mentioned categories for 2020–21 was 1234.608 BU, suggesting a negative growth of approximately 1.29%. The supply and demand in this market are out of balance. The Government of India has been reorganizing the power sector since 1991 to boost productivity. The EA 2003 was passed to promote private investment in the electrical sector, safeguard consumer interests, and ensure universal access to electricity. Day-ahead contracts are currently available through IEX with time frames. For the scheduling of traded contracts, IEX works with State, regional, and national dispatch centers.

4.1 Indian Transmission Network

As of March 31, 2022, MSETCL had 706 EHV substations with a transformation capacity of more than 133583 MVA and EHV lines measuring around 49813 Ckm, making it the largest state transmission utility in India. ABT meters have also been installed by MSETCL for the proper analysis of the energy and the assessment of transmission loss. The only MSETCL, is responsible for the operation and maintenance of the +/- 500 KV, 1500 MW HVDC bipolar line existing between Chandrapur to Padghe. Through this connection, a load center in western Maharashtra receives substantial amounts of electricity from Maharashtra's Eastern side.

The peak load condition is determined by looking at the maximum load carried by multiple buses for 24 hours on a real network with peak demand. The assignment of the top and lower constraints for generators is shown in the tables. The bus voltage ranges from 0.96 to 1.04. The cost of fuel for intrastate generation and interstate power purchases from generators is displayed in tables in (Rs. /KWh). The actual power needs on the network at various buses are shown in a table. In contrast to interstate transmission lines, which have active power flow constraints between -1.0 and 1.0, intrastate transmission lines have active power flow limitations between -0.5 and 0.5. The values are all displayed.

4.2 Impact of Transmission Expansion on Spot Prices

For the existing network under consideration, spot prices at peak load are high. Furthermore, given the rate of expanding command in Maharashtra, the existing transportation network will be unable to take in the additional demand in the future, and hence determination not foster the necessary contest. As a result, the current intra-state transmission capacity must be enhanced.

5. SIMULATION AND RESULTS OF THE REAL MSETCL SYSTEM

This study considered a real network of a 400 KV Maharashtra State Electricity Transmission with additional lines of 765 / 1200 KV. The MSETCL consists of several intrastate and interstate buses from where the power is purchased to satisfy intrastate demand. The generator and demand data are shown in the *table 1* and *2*. The HVDC link is connected between CHDPUR to PADGE buses. AC-DC OPF-based electricity nodal pricing methodology is simulated for this system and results are obtained for different conditions.

An electricity nodal pricing scheme is implemented for this system considering the HVDC line between CHDPUR-PADGE. The resulting nodal prices at several buses are high as shown in *table 2*. It is due to congestion in several transmission lines i.e. CHDPUR, KORDY, KORDY BHSWL, ARGBD, PARLY, SOLPR, CHDPUR, PARLY and KARAD, SOLPR as there is limited flow of low-cost power from BDRVT, CHDPUR, and KORDY generators.

The demand has been fulfilled by the high cost power available at DABHOL and other interstate generators. Heavy power must be directed towards intrastate plants to increase competition in the wholesale electricity market. Likewise, additional funding for transmission lines is required where the nodal prices are high. The system is simulated for the addition of 765 KV/ 1200 KV transmission lines in the existing 400 KV AC transmission system. The 765 KV lines are available from bus no 20 to 21, 21 to 22, and 22 to 4. At several other buses, the electricity nodal prices are low.

Here we have added the proposed 1200 KV transmission line from Wardha to Aurangabad, a double line with a 696 km distance. The proposed 1200 KV transmission lines are available from bus no 5 to 6 (Wardha to Aurangabad). The real electricity nodal prices are lower at above mentioned buses. The results of 400 KV with the addition of 765 KV and 1200 KV transmission lines are shown in *Table 2*.

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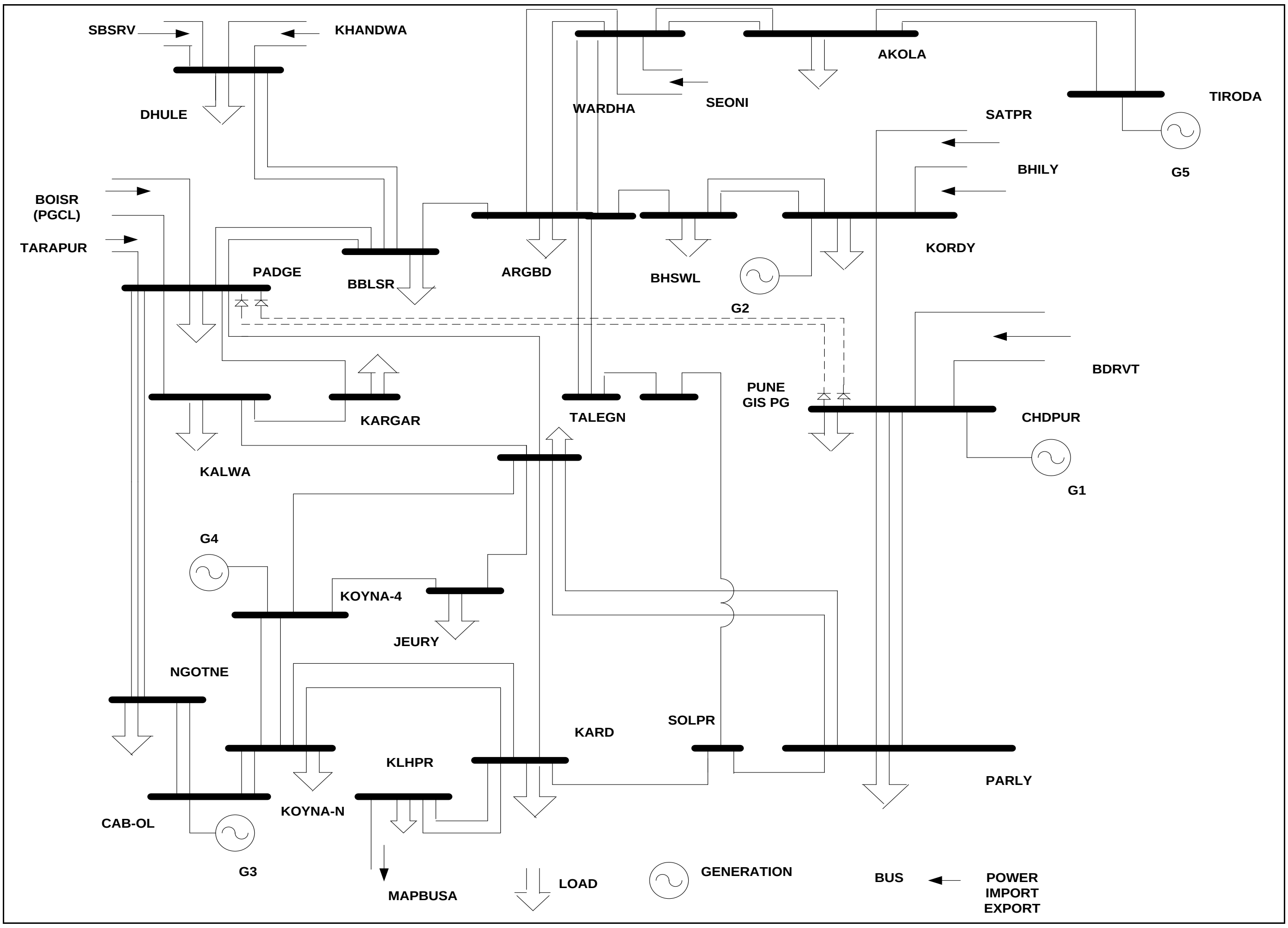


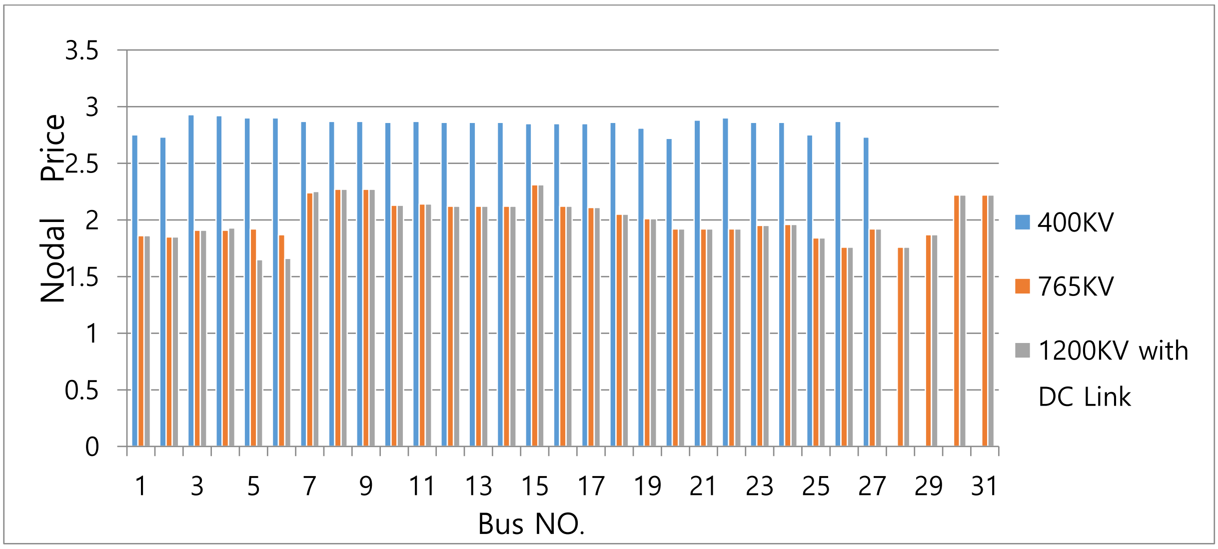
Figure 1: Single Line Diagram of 400/765 / 1200 kV MSETCL System with DC link

Table 1: Input data- Generator and Real Demand data (A 400/765kV MSETCL system)

Generator	Generation Capacity (MW)	Generation				Generation cost (`/kWh)		
		P (MW)		Q (MVAR)				
		Max	Min	Max	Min	ai	bi	ci
Intra-State Generators								
CHDPUR (G1)	2340	2000	1000	1000	-1000	0.0001	1.05	0.0226
KORDY (G2)	1040	900	300	500	-500	0.0002	1.10	0.03
DABHOL (G3)	0	0	0	0	0	0	0	0
KOYNA-4 (G4)	0	0	0	0	0	0	0	0
TIRODA(G5)	660/2313	563/1900	300	191	99	0.0002	1.30	0.03
Inter-State Generators								
BHILY (G26)		600		400	-400	0.0003	3.00	0.05
KHANDWA(G29)		600		400	-400	0.0003	3.00	0.05
SDSRV (G30)		200		400	-400	0.0003	3.00	0.05
BOISR (G31)		200		400	-400	0.0003	3.00	0.05
BDRVT (G25)		1700		1000	-1000	0.0002	1.10	0.03
TARAPUR (G32)		250		400	-400	0.0003	3.00	0.05
SEONI(G28)		1076		800	-500	0.0002	1.10	0.03

Table 2: OPF result and electricity nodal prices with the addition of 765/1200kV Transmission line in 400KV MSETCL system with DC link

Bus No.	Voltages (Volts)	Real Power (inp.u.)	Reactive Power (inp.u.)	Angle	Nodal Price (Rs./kWh)
1	1.07	2.57	1.96	0.13	1.86
2	1.06	2.64	0.53	0.25	1.85
3	1.05	2.52	0.01	0.01	1.91
4	1.05	2.50	0.00	0.00	1.93
5	1.06	2.53	0.00	0.00	1.65
6	1.07	2.64	0.01	0.01	1.66
7	1.05	1.83	0.00	0.00	2.25
8	1.07	1.82	0.00	0.00	2.27
9	1.05	1.81	0.01	0.01	2.27
10	1.05	1.85	0.00	0.00	2.13
11	1.04	1.84	0.00	0.00	2.14
12	1.06	1.92	0.81	0.11	2.12
13	1.04	1.91	0.00	0.00	2.12
14	1.04	1.91	0.11	0.15	2.12
15	1.05	1.85	0.00	0.01	2.31
16	1.06	1.80	0.01	0.00	2.12
17	1.06	1.92	0.00	0.00	2.11
18	1.04	2.09	0.00	0.00	2.05
19	1.01	2.16	0.00	0.00	2.01
20	0.98	2.58	0.41	0.42	1.92
21	1.01	2.58	0.00	0.00	1.92
22	1.01	2.54	0.00	0.00	1.92
23	1.02	2.36	0.01	0.00	1.95
24	1.00	2.31	0.00	0.00	1.96
25	0.95	2.58	0.38	0.12	1.84
26	0.96	2.92	0.51	0.01	1.76
27	1.01	2.52	0.11	0.51	1.92
28	1.07	3.01	0.83	0.12	1.76
29	1.07	2.67	0.11	0.23	1.87
30	1.05	1.91	0.18	0.14	2.22
31	1.05	1.85	0.18	0.02	2.22



Graph1: Variation in Nodal Price with the transmission voltage and with DC Link

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6. CONCLUSION

This paper presents a fixed integrated and dynamic nodal pricing approach using AC-DC OPF-based methodology. Simulation results show a drastic improvement in nodal prices with the addition of higher voltage transmission lines and DC link between the buses having high LMPs. It is found suitable for actual transmission networks in India and other developing nations. These pricing models can help to enable market participants to compete and make the best decisions to build wholesale energy markets while achieving several transmission pricing objectives, including cost coverage, economic efficiency, and non-discrimination.

REFERENCES

[1] F.F Wu, F.L. Zheng, F.S. Wen, “Transmission investment and expansion planning in a restructured electricity market”, Energy 31, 2006, pp. 954–966.

[2] F. C. Schweppe, M.C. Caramanis, and R.E. Bohn, “The cost of Wheeling and optimal Wheeling Rates” IEEE Trans. on PWRS Vol.1, No. 1, Feb 1986.

[3] Hyde M. Merrill, Bruce W. Erickson, “Wheeling Rates Based on Marginal cost Theory”, IEEE Trans. on Power System, Vol.4, No. 4, Oct 1989.

[4] D. Shirmohammmadi, C. Rajgopalan, E.R. Alward and C. L. Thomas “Cost of Transmission Transaction: Introduction”, IEEE Trans. On Power System, Vol.6 No.4, Nov 1991, pp. 1546-1560.

[5] Ross Kovacs, Allen Leverett, “ A Load Flow Based Method for calculating Embedded, Incremental and Marginal cost of Transmission capacity”, IEEE Trans. on Power System, Vol.9, No. 1, Feb 1994, pp. 272-278.

[6] Happ, “Cost of Wheeling Methodologies”, IEEE Trans. on Power System, Vol.9, No. 1, Feb 1994.

[7] J.W. Marangon Lima, “Allocation of transmission Fixed Charges: An Overview” IEEE Trans. on Power Systems, Vol.11, No. 3, August 1996, pp. 1409-1415.

[8] Young-Moon Park; Jong-Bae Park; Jung-Uk Lim; Jong-Ryul Won “An analytical approach for transaction costs allocation in transmission system”, IEEE Trans. on Power Systems, Volume: 13 Issue 4, Nov. 1998, pp. 1407 –1412.

[9] Yog Raj Sood, N. Padhy, H.O. Gupta, “ Allocating Embedded Cost of transmission to Simultaneous Bilateral Transactions- An Applications to South African System” Journal of the International Associations on Electricity Generation Transmission and Distribution (Afro AsianRegion), Vol 8-10, No 1, March-June 2002, pp. 1-11.

[10] M. Oloomi-Buygi, and M. Reza Salehizadeh, “Transmission Pricing based on Voltage Angle Decomposition”, Proceedings of World Academy of Science, Engineering and Technology Volume 17, December 2006, pp. 151-156.

[11] M. Rivier and I. J. Perez-Ariaga, "Computation and decomposition of nodal price for transmission pricing," in 11th PSCC conference, 1991.

[12] D. Finney, H. A. Othman, and W. L. Rutz, "Evaluating transmission congestion constraints in system planning," IEEE Trans. on Power Systems, vol. 12, no. 3, Aug. 1997.

[13] F.C. Schweppe, M.C. Caramanis, R.D. Tabors, and R.E. Bohn, Nodal Pricing of Electricity, Norwell, MA: Kluwer, 1988.

[14] C. N. Lu, S. S. Chen, C. M. Ong, “The Incorporation of HVDC Equations in Optimal Power Flow Methods using Sequential Quadratic Programming Techniques”, IEEE Trans. on Power Systems, Vol. 3, No.3, August 1988, pp 1005-1011.

[15] Kai Xie, Yong-Hua Song, John Stonham, Erkeng Yu, and Guangyi Liu, “Decomposition Model and Interior Point Methods for Optimal Nodal Pricing of Electricity in Deregulation Environments”, IEEE Trans. On Power Systems, vol. I, No. 1, February 2000, pp. 39-50.

[16] Luonan Chen, Hideki Suzuki, TsunehisaWachi, and Yukihiro Shimura, “Components of Nodal Prices for Electric Power Systems”, IEEE Trans. on Power Systems, Vol. 17, No. 1, 2002, pp. 41-49.

[17] Tong Wu, Ziad Alaywan, and Alex D. Papalexopoulos, “Locational Marginal Price Calculations Using the Distributed-Slack Power-Flow Formulation”, IEEE Trans. on Power Systems, Vol. 20, No. 2, May 2005, pp. 1188-1190.

[18] S.B.Warkad, V.G.Umale “Locational Marginal Pricing based Financial Transmission Rights”, IEEE Explore2017