International Journal of Electrical, Electronics and Computer Engineering **5**(1): 100-108(2016)

**ISSN No. (Online): 2277-2626**

# Location Marginal Based Transmission Pricing in Restructured Power System

***V.G. Umale*, Dr. S.B. Warkad**, M.R. Shelke*** and A.A. Deosant******

**Priyadarshnini College of Engineering, Nagpur, (Maharashtra), India*

***Pote College of Engineering, Nagpur, (Maharashtra), India*

****P.I.G..C.E, Nagpur, (Maharashtra), India*

*(Corresponding author: MR. Shelke)*

*(Received 27 April, 2016 Accepted 30 May, 2016)*

*(Published by Research Trend, Website: www.researchtrend.net)*

**ABSTRACT: In restructured electricity markets, an effective transmission pricing method is required to address transmission issues and to generate correct economic signals to reduce the generation cost. It is necessary to develop an appropriate pricing scheme that can provide the useful information to market users, such as generation companies, transmission companies and customers. These pricing depends on generator bids, load levels and transmission network constraints. Transmission line constraints can result in variations in energy prices throughout the network. The proposed approach is based on AC optimal power flow model with considering of losses. Resulting optimization problem is solved by linear programming approach. Locational Marginal Pricing methodology is used to determine the energy price for transacted power and to manage the network congestion and marginal losses. Variation of LMP values with transmission constraint conditions also studied. Simulation is carried out on IEEE 30 bus test system and the results are presented.**

**Key Words:** Locational Marginal Pricing, Optimal Power Flow, transmission pricing

## I. INTRODUCTION

By Tradition, power industry is vertically integrated, in which the generation, Transmission and distribution are arranged collectively as a single utility to serve its customers. This will lead to the inefficient operation of power system. So the electric power industry has undergone deregulation around the world, a core tenet of which is to build an open-access, unambiguous and fair electricity markets [6]. Due to central operation of transmission and distribution system it will remain in a monopoly mode. Under the deregulated electricity `market environment, transmission networks play a vital role in supporting the transaction between producers and consumers. One drawback of transmission network is overloading. Federal Energy Regulatory Commission (FERC) willing to create non-profit organizations, called Independent System Operator System (ISO) and Regional

Transmission Organization (RTO), to organize regional power systems to ensure non-discriminatory transmission services to generation companies (GENCO's) and bilateral

transactions. In the restructured power industry open access is provided to the transmission system. Due to Transmission Open Access (TOA) the power flow in the lines reach the power transfer limit and so it will leads to a condition known as congestion [1-2].

The congestion may be caused due to a mixture of reasons, such as transmission line outages, generator outages and change in energy demand. Transmission congestion has impact on the entire system as well as on the individual market participants i.e. sellers and buyers. Without congestion low cost GENCO's are used to meet the load demand but if congestion is present in the transmission network then it prevents the demand to be met by the lowest-priced resources due to mentioned transmission constraints and this leads to the allocation of higher price.

There are two types of pricing methods are available in practice for congestion management [11]. They are uniform and non-uniform pricing structure. In this paper congestion is managed by means of Locational Marginal Pricing (LMP) i.e. non-uniform pricing structure. The LMP at a location is defined as the marginal cost to supply an additional MW increment of power at the location without violating any system security limits [1]. This price reflects not only the marginal cost of energy production, but also its delivery. Because of the effects of both transmission losses and transmission system congestions, LMP can vary significantly from one location to another. If the lowest priced electricity is allocated for all Location LMP values at all nodes will be same.

If congestion present in the system lowest cost energy cannot reach all location, more expensive generators will allocated to reach out the demand. In this situation LMP values will be differ from one location to another. In pool-based electricity market ISO collects hourly supply and demand bids from Generator Serving Traders (GSTs) on behalf of GENCO's and Load Serving Traders (LSTs) on behalf of pool consumers [6]. ISO determines the generation and demand schedule as well as LMPs based on increased social welfare maximization, subject to system operational Mathematically.

Buyers in the market pays ISO based on their price for dispatched energy. The ISO pays sellers in the market based on their respective prices. The LMP difference between two adjacent buses is the congestion cost which arises when the energy is transferred from one location to the other location. Marginal losses represent incremental changes in system losses due to incremental demand changes. Incremental losses yield additional costs which are referred to as the cost of marginal losses. Thus LMP is the summation of the costs of marginal energy, marginal loss and congestion. LMP can be stated as follows:

**LMP = generation marginal cost + congestion cost +marginal loss cost**

LMP is obtained from the result of Optimal Power Flow(OPF). Either AC-OPF or DC-OPF is used to determine the LMP [7]. To reduce the complexity in the calculation in this paper DC-OPF is used. In DC-OPF only real power flow is considered [6]. Different types of optimization models are used for LMP calculations like LP and Lagrangian Among these in this paper QP is used to solve the optimization problem.

*A. Day-Ahead and Real-Time Energy Markets*

Restructured power market consists of different types of market. An energy market is a place where the financial trading of electricity takes place. It naturally consists of a day-ahead market and real-time market, while the ancillary service markets are able to provide services such

as synchronized reserve, regulation and reliable operation of transmission system. The day-ahead market is a type of forward market and runs on the day before the functioning day [1-2]. Generation offers, demand bids, and bilateral transactions are accepted by the Day-Ahead market in the regulated market timeline. Virtual offers and bids are also received to increase the market liquidity. Load forecasting tool is used to predict the load in the submitted bids. As a result of running the optimization model the generation dispatch and electricity prices for each hour of the operating day was calculated.

Normally, LMP generated by the day-ahead market is called "ex-ante LMP", because the LMP is calculated before the energy a transaction happens. In the real-time market, "post-LMP" calculation will be performed as like that of "ex-ante LMP". Basically "ex-ante LMP" will be same as that of "post-LMP" if the forecasted load reflects the actual load in the real time market. In this paper Day-ahead market and "ex-ante LMP" is considered. LMP in the deregulated market depends on various factors such as low cost generator outage, transmission line outage, transmission line limits, load changes, demand bids and generation offers of consumers. In this paper we mainly focus on transmission line limit [4] and generation limit [5] as a constraint. The paper is structured as follows: Section 2 provides the existing transmission pricing method. Section 3 provides the problem formation. Section 4 presents the AC-OPF problem formations. Section 5 Section provides the results and analysis. Section 6 describes conclusion.

## II. EXISTING TRANSMISSION PRICING

Transmission pricing offer global access for all participants in the market. To recover the costs of transmission network and encourage market investment in transmission an understandable price structure is necessary. In this section various pricing methods and their calculations are discussed.

*A. Postage-Stamp Rate Method*

Postage-stamp rate scheme is conventionally used by electric utilities to allot the permanent transmission price between the users of firm transmission service. This method does not need power flow calculations and is independent of the transmission distance and system arrangement. This transmission pricing method allocates transmission charges based on the amount of the transacted power. For each transaction the magnitude of power transfer is calculated at the time of system peak.

*B. Contract Path Method*

Contract path method also does not required power flow calculation. In this method contract path is a corporeal transmission pathway among two transmission users that disregards the fact that electrons follow corporeal paths that may differ dramatically from contract paths. Following to the specification of contract paths, transmission prices will then be assigned using a postage- stamp rate, which is determined either individually for each of the transmission systems or on the average for the entire grid.

*C. MW-Mile Method*

The MW-Mile Method is also called as line-by-line method since it considers, in its calculations, changes in MW transmission flows and transmission line lengths in miles. The method calculates charges associated with each wheeling transaction based on the transmission capacity use as a function of the magnitude of transacted power, the path followed by transacted power, and the distance traveled by transacted power. The MW-mile method is also used in identifying transmission paths for a power transaction. This method requires dc power flow calculations. The MW-mile method is the first pricing strategy proposed for the recovery of fixed transmission costs based on the actual use of transmission network.

## III. PROBLEM FORMATION

The main objective of this problem is minimization of total cost subjected to energy balance constraint and transmission constraint. Power flow is obtained by ACOPF model with considering of losses. In this OPF reactive power is ignored and the voltage magnitudes are assumed to be unity [7].

$$\begin{aligned} &\min_{p} \boldsymbol{C}^{\mathrm{T}}\boldsymbol{P} \\ \text{s.t. } &\boldsymbol{e}^{\mathrm{T}}(\boldsymbol{P}-\boldsymbol{D}) - \mathrm{Loss} = 0, \quad (\boldsymbol{\lambda} > 0) \\ &\boldsymbol{T}(\boldsymbol{P}-\boldsymbol{D}) \le \boldsymbol{F}^{\max}, \quad (\boldsymbol{\mu} \le 0) \\ &\boldsymbol{P}^{\min} \le \boldsymbol{P} \le \boldsymbol{P}^{\max}, \quad (\boldsymbol{\eta}^{\min}, \boldsymbol{\eta}^{\max} > 0) \end{aligned}$$

k -index of a transmission constraint
N -number of generators in the system
C -N-vector of generator offer prices
P -N-vector of generator output levels
D -vector of nodal loads
e -unit vector (all components equal to 1)
Loss- physical system losses
λ- balance constraint
μ- K-vector of the transmission constraints
i -generator/load index
T-(K * N) matrix of generator shift factors (GSF)
$F^{max}$ – K-vector of transmission limits
$P^{min}$- N-vector of minimum generator capacity limits

<u>AC system equations</u>

For $n$ bus system, let $P=(p_1,\dots,p_n)$ and $Q=(q_1,\dots,q_n)$, where $p_i$ and $q_i$ be active and reactive power demands of bus-$i$ respectively. The variables in power system operation are defined as $X=(x_1,\dots,x_m)$ i.e. real and imaginary parts of each bus voltage. Then the problem of a power system for given load $(P,Q)$ can be formulated as OPF problem.

Minimize $f=(X, P, Q)$ *for X* (Objective function)

subject to $S(X, P, Q) = 0$ (Equality constraints)

$T(X, P, Q) \le 0$ (Inequality constraints)

where $S(X) = (s_1(X,P,Q),\dots,s_{n1}(X,P,Q))^T$ and

$T(X) = (t_1(X,P,Q),\dots,t_{n2}(X,P,Q))^T$ have $n1$ and $n2$ equations, and are column vectors. $A^T$ is the transpose of vector A.

$f=(X, P, Q)$ is a scalar, generator cost function $f_i(P_{gi})$ having cost characteristics represented by, $F = \sum_{i=1}^{NG} F_i = \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{gi} - c_i)$

Power system constraints i.e. $T(X, P, Q) \le 0$ to be satisfied are-

(2) Vector of inequality constraint as

(i) minimum and maximum limits on real and reactive power generations is

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (i = 1, 2, \ldots, NG)$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad (i = 1, 2, \ldots, NG)$$

(ii) minimum and maximum limits on bus voltage magnitudes is,

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad (i = NV+1,\ NV+2, \ldots, NB)$$

(iii) limits on transmission line power flow (MVA) limits is,

$$P_f^{\min} \le P_f \le P_f^{\max} \qquad (f = 1, 2, \ldots, Noele)$$

In general, for buses $n$ and $i$ connected by a controllable transformer with tap ratio $1 : t_{ki}$, the expressions for real and reactive power injection at these buses into the ac network are as follows

$$P_n = V_n \sum_{\substack{i=1 \\ j \ne n \\ j \ne i}}^{N} V_j \left( G_{nj} \cos\delta_{nj} + B_{nj} \sin\delta_{nj} \right) - V_n V_i t_{ni} \left( g_{ni} \cos\delta_{ni} + b_{ni} \sin\delta_{ni} \right) + V_n^2 \left( G_{nn} + t_{ni}^2 g_{ni} \right)$$

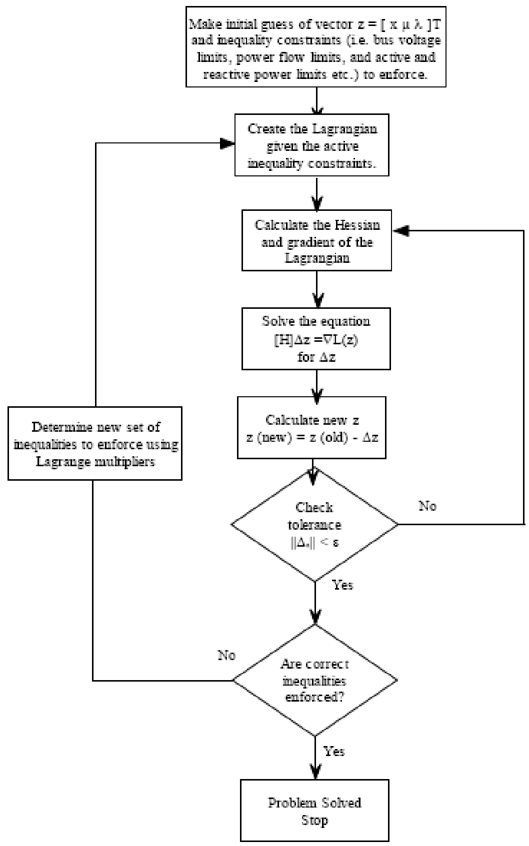
$$Q_n = V_n \sum_{\substack{i=1 \\ j \ne n \\ j \ne i}}^{N} V_j \left( G_{nj} \sin\delta_{nj} - B_{nj} \cos\delta_{nj} \right)$$

**The optimal solution:** The real and reactive cost at bus '$i$' is the Lagrange multiplier function of the equality and inequality constraints calculated by solving the first order condition of the Lagrangian, partial derivatives of the Lagrangian with respect to every variable concerned. So the Lagrange function of equations is defined as a cost function

$$
\begin{aligned}
L(P_g, V, \delta) = & \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{Gi} + c_i) + \sum_{i=1}^{NB} \lambda_{pi} [P_{di} - P_{gi} + P_L] \\
& + \sum_{i=NV+1}^{NB} \lambda_{qi} [Q_{di} - Q_{gi} + Q_L] \\
& + \sum_{i=1}^{NG} \rho p_{li} (P_{gi}^{\min} - P_{gi}) + \sum_{i=1}^{NG} \rho p_{ui} (P_{gi} - P_{gi}^{\max}) \\
& + \sum_{i=1}^{NG} \rho q_{li} (Q_{gi}^{\min} - Q_{gi}) + \sum_{i=1}^{NG} \rho q_{ui} (Q_{gi} - Q_{gi}^{\max}) \\
& + \sum_{i=1}^{NB} \rho v_{li} \left( \left| V_i^{\min} \right| - \left| V_i \right| \right) + \sum_{i=1}^{NB} \rho v_{ui} \left( \left| V_i \right| - \left| V_i^{\max} \right| \right) \\
& + \sum_{i=1}^{NB} \rho \delta_{li} (\delta_i^{\min} - \delta_i) + \sum_{i=1}^{NB} \rho \delta_{ui} (\delta_i - \delta_i^{\max}) \\
& + \sum_{i=1}^{Ncele} \rho p_{fli} (P_{fi}^{\min} - P_{fi}) + \sum_{i=1}^{Ncele} \rho p_{fui} (P_{fi} - P_{fi}^{\max})
\end{aligned}
$$

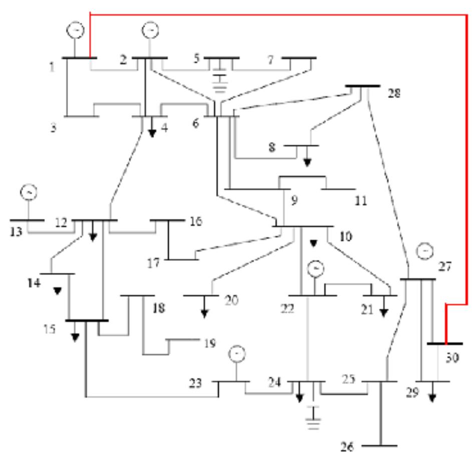
where, '$l$' and '$u$' are lower and upper limits; $\lambda = (\lambda_1, \ldots, \lambda_n)$ are the vector of Lagrange multipliers concerning equality constraints; $\rho = (\rho_1, \ldots, \rho_L)$ are the Lagrange multipliers concerning inequality constraints.

**C-1: Flowchart for optimal power flow**




## IV. PROBLEM SIMULATION AND NUMERICAL RESULTS

The configuration of IEEE-30 Bus system is shown in Fig. (Appendix B-4). It consists of 6 generators and 41 transmission lines. The generator and demand data is shown in Table B-4.1.1. The upper and lower bounds (reactive power) for all generators i.e. G1, G2, G13, G22, G23 and G27 are. The voltages for all buses are bounded between 0.95 and 1.05. Also to study the effect of HVDC link, a dc link is assumed and connected between Bus 1 and Bus 30. The converter rating at buses is assumed to be 1.0 p.u.



IEEE 30-bus test system.

Table A1: Real Power and Fuel cost of generator

| Bus No. (Generator) | Lower Limit (Real Power) | Upper Limit (Real Power) | Generation cost | | |
|---|---|---|---|---|---|
| | | | $a_i$ | $b_i$ | $c_i$ |
| 1 | 0.1 | 1.5 | 0.14 | 20.4 | 5.0 |
| 2 | 0.1 | 1.5 | 0.20 | 19.3 | 5.0 |
| 13 | 0.1 | 1.0 | 0.14 | 20.4 | 5.0 |
| 22 | 0.1 | 1.5 | 0.20 | 19.3 | 5.0 |
| 23 | 0.1 | 1.0 | 0.14 | 20.4 | 5.0 |
| 27 | 0.1 | 1.5 | 0.20 | 19.3 | 5.0 |

Table A2: Demand $(p_i + jq_i)$ for IEEE 30-Bus System

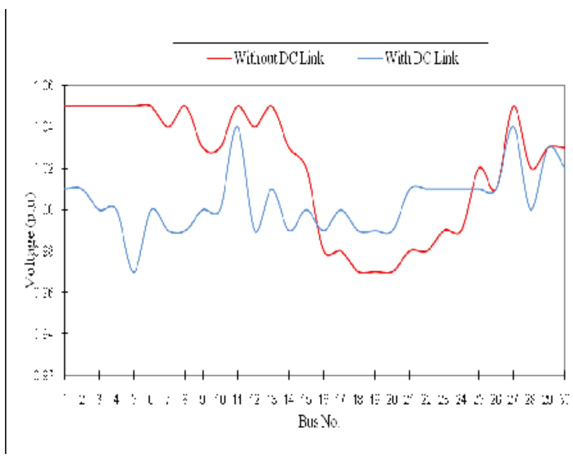
| Bus | Demand | Bus | Demand | Bus | Demand |
|---|---|---|---|---|---|
| 1 | 0.0+j0.0 | 11 | 0.0-j0.177 | 21 | 0.175+j0.112 |
| 2 | 0.217+j0.13 | 12 | 0.112+j0.0 | 22 | 0.00+j0.00 |
| 3 | 0.024+j0.012 | 13 | 0.00-j0.155 | 23 | 0.032+j0.016 |
| 4 | 0.076+j0.016 | 14 | 0.062+j0.016 | 24 | 0.087+j0.067 |
| 5 | 0.942+j0.019 | 15 | 0.082+j0.025 | 25 | 0.0+j0.0 |
| 6 | 0.0+j0.0 | 16 | 0.035+j0.018 | 26 | 0.035+j0.023 |
| 7 | 0.228+j0.109 | 17 | 0.090+j0.058 | 27 | 0.0-j0.10 |
| 8 | 0.30-j0.30 | 18 | 0.032-j0.009 | 28 | 0.0+j0.0 |
| 9 | 0.0+j0.0 | 19 | 0.095+j0.034 | 29 | 0.024+j0.009 |
| 10 | 0.058+j0.0 | 20 | 0.022+j0.007 | 30 | 0.106+j0.0 |

The optimal real electricity nodal prices without and with HVDC link are computed and compared. The simulated results are obtained and shown in Table.

The result obtained by proposed methodology shows that the electricity nodal prices are considerably reduced at several buses with the incorporation of DC link in existing AC transmission system. Nodal prices at Bus No. 29 and Bus No. 30 are increased because these buses might be served by costly generators due to transmission congestion. Also with incorporation of DC link, the voltage profiles at few buses are within narrow range compared to without DC link due to decrease in power flow and voltage drop across few transmission lines.

Electricity nodal price: IEEE 30-Bus test system

| Bus No. | Real Nodal Price ($/MWh) | | Bus No. | Real Nodal Price ($/MWh) | |
|---|---|---|---|---|---|
| | Without DC link | With DC Link | | Without DC link | With DC Link |
| 1 | 19.54 | 15.61 | 16 | 19.70 | 15.78 |
| 2 | 19.62 | 15.63 | 17 | 20.03 | 16.17 |
| 3 | 19.52 | 15.70 | 18 | 19.94 | 16.29 |
| 4 | 19.51 | 15.71 | 19 | 20.16 | 16.43 |
| 5 | 20.95 | 15.30 | 20 | 20.16 | 16.39 |
| 6 | 19.72 | 15.85 | 21 | 19.67 | 16.50 |
| 7 | 20.30 | 15.76 | 22 | 19.47 | 16.53 |
| 8 | 19.84 | 15.91 | 23 | 18.88 | 16.59 |
| 9 | 19.92 | 16.08 | 24 | 18.57 | 17.31 |
| 10 | 20.02 | 16.22 | 25 | 16.09 | 19.16 |
| 11 | 19.91 | 16.08 | 26 | 15.29 | 19.99 |
| 12 | 19.15 | 15.24 | 27 | 15.10 | 19.93 |
| 13 | 15.20 | 15.20 | 28 | 19.74 | 15.86 |
| 14 | 19.43 | 15.60 | 29 | 15.49 | 20.58 |
| 15 | 19.38 | 15.95 | 30 | 15.75 | 21.02 |




Voltage behaviour at buses

## V. CONCLUSION

In a lot of restructured energy markets, the Locational Marginal Pricing acts as an important position in recent times. To understand the determination of LMP Loss AC Optimal power Flow is carefully analyzed which is the proposed technique in this paper. LMP also used to maintain the stable operation of transmission system without affect the buyers and sellers in the market. LMP act as a true price signals for adding transmission capacity, generation capacity and future loads. It achieves its unique ambition of better effectiveness of power system operations in the short-term operational time frames by openly addressing the effects related with power transmission above the interconnected grid. We can extend our work with higher bus system and adding more constraints to our problem.

**REFERENCES**

[1]. V. Sarkar, S.A. Khaparde, "Optimal LMP decomposition for the ACOPF calculation" *IEEE Trans. Power Syst.*, vol. **26**, no. 3, pp. 1714–1723, Aug. 2011.

[2]. Q. Zhou, L. Tesfatsion, C.C. Liu, "Short term congestion forecasting in wholesale power" *IEEE Trans. Power Syst.*, vol. **26**, no. 4, pp. 2185–2196, Nov. 2011.

[3]. E. Litvinov, Design and operation of the locational marginal prices-based electricity markets" *IET Gener. Transm. Distrib.*, 2010, Vol. **4**, Iss. 2, pp. 315–323.

[4]. J.C. Peng, H. Jiaang, G, Xu, A. Luo & C. Huang "Independent marginal losses with application to localtional marginal price calculaton *IET Gener. Transm. Distrib.*, 2009, Vol. **3**, Iss. 7, pp. 679–689.

[5]. M.S. Kumari, M. Murali "LMP based electricity market simulation using genetic algorithm" *7th IEEE conference on Industrial Electronics and Applications (ICIEA)2012*.

[6]. F. Li, R. Bo, DCOPF based LMP simulation :Algorithm comparison with ACOPF and sensitivity", *IEEE Trans. Power Syst.*, vol. **22**, no. 4, pp. 14751485–2196, Nov. 2007.

[7]. Dan Yang, Variation Index to measure transmission congestion impact in LMP based electricity market", *IEEE-2009.*

[8]. V. Sarkar, S.A. Khaparde, "Reactive power constrained OPF scheduling with two dimensional locational marginal price", *IEEE Trans. Power Syst.*, pp. 1-10, May. 2012.

[9]. Fangxing Li., Continuous locational margin (CLMP)" *IEEE Trans. Power Syst.*, vol. **22**, no. 4, pp. 16381646, Nov. 2007.

[10]. V. Sarkar, S.A. Khaparde, "DCOPF-based marginal loss pricing with enhanced power flow accuracy by using Matrix loss distribution" *IEEE Trans. Power Syst.*, vol. **26**, no. 3, pp. 1435–1445,Aug. 2009.

[11] K. Kalsi, S. Elbert, M. Vlachopoulou, N. Zhou & Z. Huang, "Advacned computational Methods for security constrained financial transmission rights" Anlaysis program at P.N.N.L, U.S., *IEEE 2012.*

[12] V. Sarkar, S.A. Khaparde, "Introduction to loss hedging financial transmission rights", *IEEE Trans. Power Syst.*, vol. **24**, no. 2, pp. 621–630, May. 2009.

[13] Shmuel Oren & Kory Hedman "Revenue adequacy, shortfall allocation & transmission performance in FTR" Bulk power system dynamics and control-VIII(IREP), 1-6,2010 Buzios, RJ, Brazil, *IEEE 2010.*

[14] S.N. Pandey, S. Tapaswi and L. Srivastava," Nodal congestion price estimation in spot power market using artificial neural network *" IET Gener. Transm. Distrib.*, 2008, **2**, pp. 280–290.

[15] Feng Zhao, Peter B. Luh, *Fellow*, Joseph H. Yan, Gary A. Stern, and Shi-Chung Chang "Payment Cost Minimization Auction for Deregulated Electricity Markets With Transmission Capacity Constraints" *IEEE Trans. Power Syst.*, VOL. **23**, NO. 2, pp.532-544 MAY 2008.

[16] Tina Orfanogianni and George Gross, *Fellow,"* A General Formulation for LMP Evaluation", *IEEE Trans. Power Syst.*, VOL. **22**, NO. 3 pp-1163-1173, Aug- 2007.

[17] S. Vani, R. Kopperundevi**,** T. Thilagavathi, R. Kabeel Arun Presath & R. Rajathy "OPF- based market clearing procedure using Bacterial foraging algorithm & auction – based market clearing procedure in a pool based electricity market- A comparison" 2012 *IEEE, Conference on CEEEC*-12.

[18] Litvinove: 'Power flow and LMP fundamentals", http://www.isone.com/suppor/training/courses/wem301 /lmp. pdf, accessed January 2009.