© 2017 IJSRSET | Volume 3 | Issue 8 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology

Comparison of Locational Marginal Transmission Pricing

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ABSTRACT

Locational marginal price is required in restructured power system.It is require creating an effective pricing scheme that to provide the useful information to generation, transmission section and customers. These transmission pricing depends on generator, load levels and transmission line constraints. Transmission line constraints result is 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 220kV, 400Kv & 765kV MSETCL system of Maharashtra transmission line for real data bus system and the results are presented.

Keywords: 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. 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. 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 GENCOs 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 [10]. 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. ISO determines the generation and demand schedule as well as LMPs based on increased social welfare maximization, subject to system operational.

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 quadrating programming is used to solve the optimization problem.

To reduce the gap between transmission capacity and electricity demand, trend is now to incorporate HVDC transmission in the existing AC networks to gain techno-economical advantages of the investment.

II. 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.
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 [12].

III. OPTIMAL SOLUTION

(A) AC System Equations
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 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-
(1) Vector of equality constraint i.e. power flow balance is,

$$P_g=P_d+P_{dc}+P_L$$
$$Q_g=Q_d+Q_{dc}+Q_L$$

Here suffix 'd' represents the demand, 'g' is the generation, 'dc' represents dc terminal and 'L' istransmission loss.

(2) Vector of inequality constraint as

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

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

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

$$V_i^{\min}\le V_i\le V_i^{\max} \qquad (i=NV+1,\ NV+2,\dots,NB)\ (8)$$

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

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

(B) Electricity Spot Price Equations
The real and reactive power cost at bus 'i' is the Lagrange multiplier function of the equality and inequality constraints calculated by solving first order condition of the Lagrangian, partial derivatives of the

Lagrangian with respect to every variable concerned. So the Lagrange function of equations are defined as a cost,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 derivative of the Lagrangian with respect to every variable concered. So the Lagrange function of equation is defined as a cost function

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

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

Then at an optimal solution (X, λ, ρ) for a set of given (P, Q), Spot price of real and reactive power for bus is expressed for $i = 1, \ldots, n$ are,

$$\pi_{p,i} = \frac{\partial L(X, \lambda, \rho, P, Q)}{\partial pi} = \frac{\partial f}{\partial pi} + \lambda \frac{\partial S}{\partial pi} + \rho \frac{\partial T}{\partial pi} \quad (21)$$

$$\pi_{q,i} = \frac{\partial L(X, \lambda, \rho, P, Q)}{\partial qi} = \frac{\partial f}{\partial qi} + \lambda \frac{\partial S}{\partial qi} + \rho \frac{\partial T}{\partial qi}$$

The difference ($\pi_{p,i}$ - $\pi_{p,j}$) represents real transmission charges from bus-j to bus-*i*. The system marginal cost created by an increment of real and reactive power load at bus *i* respectively. This methodology has been simulated in MATLAB software and results are obtained for several conditions and constraints tested over software 220kV, 400kV& 765kV MSETCL network.

IV. RESULTS FOR MSETCL SYSTEM

This paper considered for 220kV, 400kV & 765kV of Maharashtra transmission line bus system Locational Marginal Pricing is computed by implementing AC-DC OPF based methodology. The electricity LMPs are computed is shown in Table-I, Table-II & Table-III here we calculated locational marginal prices on each node, the prices are change according to load variation.

Table 1. Locational Marginal Prices for 200kV

Bus No.	Voltage (Volts)	Real Power (p.u.)	Reactive Power (p.u.)	Angle	Spot Price (Rs./kWh)
1	1.08	0.05	1.60	0.59	3.36
2	1.07	0.03	0.45	0.62	3.24
3	1.06	0.00	0.00	0.00	3.14
4	1.06	0.01	0.00	0.00	3.13
5	1.07	0.01	0.00	0.00	3.21
6	1.08	0.01	0.00	0.00	3.21
7	1.06	0.01	0.00	0.00	3.18
8	1.08	0.02	0.00	0.00	3.18
9	1.06	0.01	0.00	0.00	3.28
10	1.06	0.01	0.00	0.00	3.27
11	1.05	0.02	0.00	0.00	3.28
12	1.07	0.01	0.07	0.30	3.27
13	1.05	0.01	0.00	0.00	3.27
14	1.05	0.01	1.12	0.80	3.28
15	1.06	0.02	0.00	0.00	3.29
16	1.07	0.01	0.00	0.00	3.34
17	1.07	0.01	0.00	0.00	3.27
18	1.05	0.01	0.00	0.00	3.31
19	1.00	0.01	0.00	0.00	3.32
20	0.99	0.06	0.35	0.11	3.33
21	1.01	0.02	0.57	0.33	3.30
22	1.01	0.01	0.01	0.35	3.31
23	1.01	0.01	0.12	0.09	3.28
24	1.01	0.02	0.00	0.00	3.27
25	0.96	0.05	1.58	0.04	3.26

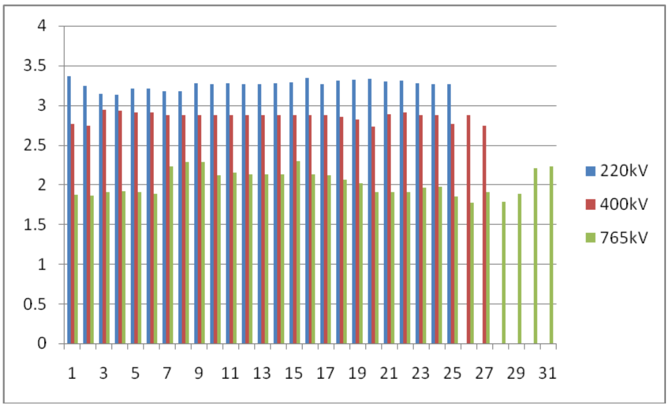
Table 1. Locational Marginal Prices for 400kV

Bus No.	Voltage (Volts)	Real Power (p.u.)	Reactive Power (p.u.)	Angle	Spot Price (Rs./kWh)
1	1.08	0.04	1.49	0.59	2.76
2	1.07	0.04	0.40	0.62	2.74
3	1.06	0.00	0.00	0.00	2.94
4	1.06	0.01	0.00	0.00	2.93
5	1.07	0.01	0.00	0.00	2.91
6	1.08	0.01	0.00	0.00	2.91
7	1.06	0.02	0.00	0.00	2.88
8	1.08	0.02	0.00	0.00	2.88
9	1.06	0.02	0.00	0.00	2.88
10	1.06	0.01	0.00	0.00	2.87
11	1.05	0.02	0.00	0.00	2.88
12	1.07	0.01	0.05	0.30	2.87
13	1.05	0.01	0.00	0.00	2.87
14	1.05	0.01	1.12	0.80	2.87
15	1.06	0.02	0.00	0.00	2.87
16	1.07	0.01	0.00	0.00	2.87
17	1.07	0.01	0.00	0.00	2.87
18	1.05	0.01	0.00	0.00	2.85
19	1.00	0.01	0.00	0.00	2.82
20	0.99	0.06	0.39	0.11	2.73
21	1.01	0.02	0.54	0.33	2.89
22	1.01	0.01	0.01	0.35	2.91

23	1.01	0.01	0.10	0.09	2.88
24	1.01	0.02	0.00	0.00	2.87
25	0.96	0.05	1.50	0.04	2.76
26	0.97	0.01	0.13	0.46	2.88
27	1.02	0.04	0.08	0.06	2.74

Table 3. Locational Marginal Prices for 765kV

Bus No.	Voltage (Volts)	Real Power (p.u.)	Reactive Power (p.u.)	Angle	Spot Price (Rs./kWh)
1	1.08	2.58	1.97	0.14	1.87
2	1.07	2.65	0.54	0.26	1.86
3	1.06	2.53	0.00	0.00	1.90
4	1.06	2.49	0.00	0.00	1.92
5	1.07	2.54	0.00	0.00	1.91
6	1.08	2.65	0.00	0.00	1.88
7	1.06	1.84	0.00	0.00	2.23
8	1.08	1.83	0.00	0.00	2.28
9	1.06	1.82	0.00	0.00	2.28
10	1.06	1.87	0.00	0.00	2.12
11	1.05	1.85	0.00	0.00	2.15
12	1.07	1.93	0.80	0.12	2.13
13	1.05	1.92	0.00	0.00	2.13
14	1.05	1.92	0.10	0.17	2.13
15	1.06	1.88	0.00	0.00	2.30
16	1.07	1.81	0.00	0.00	2.13
17	1.07	1.93	0.00	0.00	2.12
18	1.05	2.08	0.00	0.00	2.06
19	1.00	2.18	0.00	0.00	2.02
20	0.99	2.59	0.40	0.41	1.91
21	1.01	2.56	0.00	0.00	1.91
22	1.01	2.53	0.00	0.00	1.91
23	1.01	2.37	0.00	0.00	1.96
24	1.01	2.33	0.00	0.00	1.97
25	0.96	2.59	0.39	0.11	1.85
26	0.97	2.91	0.50	0.02	1.77
27	1.02	2.54	0.12	0.50	1.91
28	1.08	3.00	0.84	0.13	1.78
29	1.07	2.68	0.10	0.24	1.88
30	1.06	1.90	0.19	0.15	2.21
31	1.06	1.86	0.19	0.01	2.23



Graph 1. Comparison of 200kV/400kV/765kV MSETCL Network

V. CONCLUSION

This paper also presented and implemented the relative electrical distance based allocation methodology of transmission tariff for a real 220kV, 400kV & 765kV of Maharashtra transmission line system. The method's inherent advantages, it has fairly allocated power transactions based on relative electrical distance between injection node and drawal node. The numerical results are shown in Table I, Table II & Table III indicate the locational marginal prices at different buses. Transmission investments are needed to reduce electricity prices as well as to relieve congestion in an important transmission lines. In this context, AC-DC OPF based electricity nodal prices are evaluated for MSETCL system. The prices are variation in Graph I This paper is evaluated with reference to hourly variations in bus voltage behavior, electricity nodal prices, generation behavior and their payments and transmission utility's revenues in terms of transmission congestion charges.

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