LOCATIONAL MARGINAL PRICING CALCULATION USING CONCENTRATED AND DISTRIBUTED MODEL BASED ON DCOPF IN POWER MARKET

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Abstract

In restructured electricity markets, one of the significant dispute is the perception of real-time nodal pricing. In this work, the concept of locational marginal pricing (LMP) mechanism is implemented with the Direct Current Optimal Power Flow (DCOPF) and IEEE 39 bus system to develop the simulation test bed of this approach. The nominated LMP employs DCOPF to compute the corresponding nodal prices. Here, two different LMP approaches such as concentrated and distributed model are applied, which has the same objective function with different constraints. It is included in the composition of the two models and is consistent with the dissimilar characteristics of the DC transmission system. The LMP composed of Marginal Energy Cost (MEC), Marginal Congestion Cost (MCC) and Marginal Loss Cost (MLC), can be used to compute LMP nodal pricing for both of the two models. The efficacy and viability of the proposed system using LMP technique is validated with the help of IEEE 39 bus test system.

Keywords: Locational Marginal Pricing (LMP), Marginal Energy Cost (MEC), Marginal Congestion Cost (MCC), Marginal Loss Cost (MLC), Direct Current Optimal Power Flow (DCOPF), concentrated loss model, Distributed loss model.

1. Introduction

In the transmission of the electricity, if there is no transmission losses or less transmission losses, then the low priced power producer will be chosen to function the load at all places and so there is equivalent electricity price across the grid, called as market clearing price (MCP).The proposed scheme increased the transportation capability and reduced the loss by connecting the grid is connected with the loads and the generators in a single line.

If there is any congestion, some of the transmission lines in the system are not proficient to transmit the additional power since it reaches their thermal limit. So that the high priced generation unit is used to assist the load meanwhile the low priced generation could not meet the load due to congestion. Due to such high priced generation, there is an increase in the cost of electricity.

Furthermore with transmission congestion, there is a significant impact of power transmission losses in the electricity prices at various sites. In case of the transmission line having high resistance, in which the load is connected to the grid subjected to higher price due to more losses of electricity in transmission, meanwhile it is opposite in case of the transmission line having low resistance. Consequently, there is a change of electricity price with the change of locations and these features lead to the principle of LMP.

F.C. Schweppe initiated the concept of LMP in 1998 [2], where it is stated that the incremental cost of LMP at particular bus can assist a tiny variation of load, which satisfy all other physical constraints. It is the leading tactic followed in the U.S. power markets for the evaluation of cost of electricity and to accomplish transmission congestion. Presently, LMP has been employed at a number of ISO‟s such as the PJM, New York ISO, ISO-New England, California ISO, and Midwest ISO [4, 14, and 15].It is highly difficult to simulate and forecast the value of LMP based on the point of generation and transmission. So, the traditional production cost optimization techniques are utilized to optimize the cost for the data transmission, generation, and load [2, 3].

Due to the strength and speediness of Linear Programming (LP), it is used in the production cost model for LMP simulation and forecasting. Moreover, the DC Optimal Power Flow (DCOPF) is used for simulating LMP, which is one of the most extensively used techniques due to its expected outcome. In order to shrink the improvement of LMP simulators, various third party LP solvers can use the DCOPF model. So, it is widely used by many software tools for performing the sequential LMP simulation, and forecasting in industrial practice such as ABB‟s Grid View TM, GE‟s MAPSTM, LCG UPLAN, Promod IV®, and Siemens PTI PSSTM LMP [15, 62].

The Financial Transmission Rights (FTRs) have planned to reduce the risk of unpredictable LMPs in the power market, which is highly depends on various congestion component of LMP. A combined optimal spot pricing model [36] is utilized to sort the expense into dissimilar components based on the generation, loss, and supplementary services including voltage control, spinning reserve and security control. A universal decomposition technique is proposed [37] in which the LMP can be divided into independent components related with generators and constraints. In [13], the schemes such as DCOPF-based LMP is developed that contains three components, reliable with industrial observes [4, 14, 13].

Some of the other works displays the satisfactoriness of the DC model in power flow studies if the R/X ratio is not greater than the value of 0.25, the line flow is not too high and the voltage profile is satisfactorily smooth [5].For a 12965-bus model of the Midwest U.S. transmission grid, a comparison has been made between the DCOPF and ACOPF. As compared to ACOPF, DCOPF performs a good job in detecting congestion pattern and one of the significant advantage of DCOPF is, it has almost 60 times faster than ACOPF, which has the major problem of robustness. A Linear Programming (LP)-based DCOPF algorithm can always give results whereas a Nonlinear Programming (NLP)- based ACOPF algorithm faces convergence problems and it is less robust [16]. Also clears that a deregulated power market carry out some innovative ideas for providing the most suitable solution to the ACOPF problem [16]. To estimate the power flow and loss [13], there are two different factors such as GSF and LF have been utilized.

The GSF factor is also termed as the Power Transfer Distribution Factor (PTDF) that is used to calculate of line flow changes based on a change of injection at a particular bus [1]. These two factors are extensively used in power system analysis, operation, planning, and research. It has been proven that [7], if the topology of the system does not have any transformation and constant bus voltage magnitude with adequate support of reactive power, the PTDF is remains as a constant value. If the above conditions are not gratified, the PTDFs will be updated with respect to the load deviations [8].

Moreover, the PTDF is related with the DC model based on the topology and constraints of the transmission system. This characteristic of the DC PTDF enables sophisticated studies. Based on zonal DC Power Transfer Distribution Factor (PTDF), a new scheme has been proposed [9] to modify the power system to a smaller equivalent one. The incremental loss acquired by the unit net injection at a specific bus is termed as loss factor[1]. The effectiveness of this model is estimated based on the loss penalty factors, because it has the great impact on generation scheduling [10]. A real time solution is taken for estimating the loss sensitivity by using the traditional Energy Management System (EMS) [11].

Over a few number of preceding works [13, 30, 29] have specified the modeling of the LMP, exactly in the marginal loss model and interconnected quarrels. Based on the actual data available at the diverse zones in the New York Control Area,[12] computed the worth of the marginal loss price have a variance of up to 20%.Anew slack-bus-independent methodology [13] has been proposed to calculate the LMP and its congestion component with the inclusion of loss distribution factors to clearly dispute the losses into buses, but it has not mainly discuss about the significance of distribution factors in the computation of LMP. Based on the DC model, marginal loss pricing algorithms [14]has been proposed by familiarizing a delivery factor for the justification of losses in the energy stability calculation.

Even though the LMP and the components of congestion are self-governing based on the optimal of the slack bus, some of the bus dependent parameters are the divided components of energy and loss. Based on the distributed reference bus, the obvious formula for computing the three divided components is stated in [38]. One more decomposition methodology is proposed [39], which realizes the independent loss component of slack bus. The comprehensive framework comprises numerous available decomposition approaches by describing the strategy for marginal nodes.

This paper focuses on the calculation of LMP at all the buses for concentrated and distributed loss model for both fixed bids and linear bids based on DCOPF algorithm. The main objective is to reduce the energy cost. The decomposition of LMP i.e., energy price, congestion price and loss price has also been calculated to ensure the economical pricing.

2. Optimal Power Flow Problem and LMP Calculation

(a) DCOPF with Loss Model

Line losses are ignored in the previous works of LMP calculations with the DCOPF which makes the congestion price and the energy price to track a perfect linear model with a zero loss price. But there is a lot of difficulties get arises if the losses are considered to evaluate the marginal loss in LMP. The main task of the loss model is to characterize a linear network, but it lacks with the limitation of computing the marginal loss price in LMP.

(b) Loss Factor and Delivery Factor

It is very essential to study the marginal loss price with the marginal loss factor or loss factor (L_f) and the marginal delivery factor or delivery factor (D_f) and it is given by

$$D_{fi} = 1 - L_{fi} = 1 - \frac{\partial P_{loss}}{\partial P_i} \qquad (1)$$

$$P_{loss} = \sum_{P=1}^{M} F_p^2 x R_p \qquad (2)$$

$$\frac{\partial P_{loss}}{\partial P_i} = \frac{\partial}{\partial P_i}\left(\sum_{P=1}^{M} F_P^2 x R_P\right) \qquad (3)$$

Where,

D_{fi} is defined as the marginal delivery factor at bus *i*;

L_{fi} denotes the marginal loss factor at bus *i*;

Ploss indicates the total loss of the system;

Pi = *Gi*- *Di* =Net injection at bus *i*.

Fp defines the line flow at line *p*;

Rp is defined as the resistance at line p.

Here, the Generation Shift Factor (GSF) is defined as the sensitivity of contribution to a line flow from a bus, which is represented as follows:

$$F_P = \sum_{j=1}^{N} GSF_{p-j} x P_j \qquad (4)$$

The above equation can be applied further to enlarge L_f, which is represented as follows:

$$\frac{\partial P_{loss}}{\partial P_i} = \sum_{P=1}^{M} \frac{\partial}{\partial P_i}\left(F_P^2 x R_p\right) = \sum_{p=1}^{M} R_p x 2 F_p x \frac{\partial F_P}{\partial P_i}$$

……………………. (5)

$$\frac{\partial P_{loss}}{\partial P_i} = \sum_{P=1}^{M} \frac{\partial}{\partial P_i} 2 x R_p x GSF_{p-j} x \left(\sum_{j=1}^{N}\left(GSF_{p-j} x P_j\right)\right)$$

…………………………... (6)

The marginal loss factor at a bus could be positive or negative. If the loss factor is positive, the total system loss can occurred at the particular bus. If the loss factor is negative, it denotes that the total system loss may reduce with the rise of injection at the particular bus.

(c) Marginal Loss Estimation using DCOPF Algorithm

As mentioned above, the marginal loss factor fully depends on the net injection, *Pj*, (i.e.,) actual dispatch minus the load at Bus *j*. Due to the marginal loss factor, the generation dispatch can be affected at the meantime of various generators, which may be subject to penalized in a different way, which depends on their loss factors.

Since *Pj*is unidentified earlier to carrying out any dispatch, a valuation of the dispatch is addressed to gain an estimated L_f at each bus. After that the estimated loss factors is used to find the new dispatch results. The iterative process is carried out until to meet the convergence stop criteria and so the LMP can be simply computed from the concluding iteration. Undoubtedly, the very first iteration is a lossless DCOPF where the estimated loss is zero.

$$Min \sum_{i=1}^{N} C_i x G_i \qquad (7)$$

$$s.t \sum_{t=1}^{N} D_{f_i}^{est} x G_i - \sum_{i=1}^{N} D_{f_i}^{est} x D_i + P_{loss}^{est} = 0$$

……. (8)

$$\left\lfloor \sum_{i=1}^{N} GSF_{p-i} x\left(G_i - D_i\right) \right\rfloor \leq limit_p, forp \notin alllines$$

…… (9)

$$G_i^{min} \leq G_i \leq G_i^{max} \; fori \in al\,lg\,eneratorss$$

…… (10)

Where,

$D_{f\,i}^{est}$ indicates the delivery factor at Bus *i* from the previous iteration;

P_{loss}^{est} = *Ploss* is the loss from the previous iteration;

Here, the optimal solution is identified for performing the generation scheduling, and the LMP of bus B is computed based on the langrangian function. It is computed as below:

$$\psi = \left(\sum_{i=1}^{N} C_i x G_i\right) - \lambda\left(\sum_{i=1}^{N} D_{f_i}.G_i - \sum_{i=1}^{N} D_{f_i}.D_i + P_{loss}\right) - \sum_{p=1}^{M} \mu_p \left(\sum_{i=1}^{N} GSF_{p-i} x\left(G_i - D_i\right) - Limit_p\right) \quad \ldots \quad (11)$$

$$LMP_B = \frac{\partial \psi}{\partial D_B} = \lambda.DF_B + \left(\sum_{p=1}^{M} \mu_p x GSF_{p-B}\right) \quad \ldots\ldots \quad (12)$$

Where

LMP_B defines the factor of LMP at Bus B

λ is the lagrangian multiplier for energy price of the system, i.e., price at the reference bus;

μk is the lagrangian multiplier for sensitivity of the *kth* transmission constraint.

The LMP is split into three different constituents, which includes the marginal congestion price, loss price and energy price.

$$LMP_B = LMP^{energy} + LMP_B^{Congestion} + LMP_B^{loss} \quad \ldots. \quad (13)$$

$$LMP^{energy} = \lambda \quad (14)$$

$$LMP_B^{Congestion} = \sum_{P=1}^{M} \mu_p x GSF_{p-B} \quad (15)$$

$$LMP_B^{Loss} = \lambda x\left(D_{fb} - 1\right) \quad (16)$$

3. Results and Discussion

To evaluate the effectiveness of concentrated and distributed loss model for both fixed and linear bids developed in this paper, IEEE 39 bus test system is considered, which is shown in Fig 1.

In this paper, LMP can be calculated for four different cases: (1) Concentrated loss model with fixed bids (2) Concentrated loss model with linear bids (3) Distributed loss model with fixed bids and (4) Distributed loss model with linear bids. The energy cost for IEEE-39bus system is calculated from DCOPF.Table-1 gives the LMP calculation for IEEE 39 bus system for concentrated loss model with fixed bids and linear bids and distributed loss model with fixed bids and linear bids.

4. Conclusion

This research work in this paper implemented the approach of LMP mechanism by utilizing Direct Current Optimal Power Flow (DCOPF). LMP is calculated on IEEE 39 bus system for concentrated and distributed model, which has the same objective functions with different constraints that are included in the construction of models, Also, it is consistent with the different characteristics of DC transmission system for both fixed and linear bids of generators, considering transmission constraints. Fuel cost minimization is taken as the objective function for this work. Comparison is made between concentrated loss model and distributed loss model for both fixed bids and linear bids. From the result, it is shown that the proposed approach has significant savings in total cost of fuel generators can be accomplished with distributed loss tactic with linear bids.

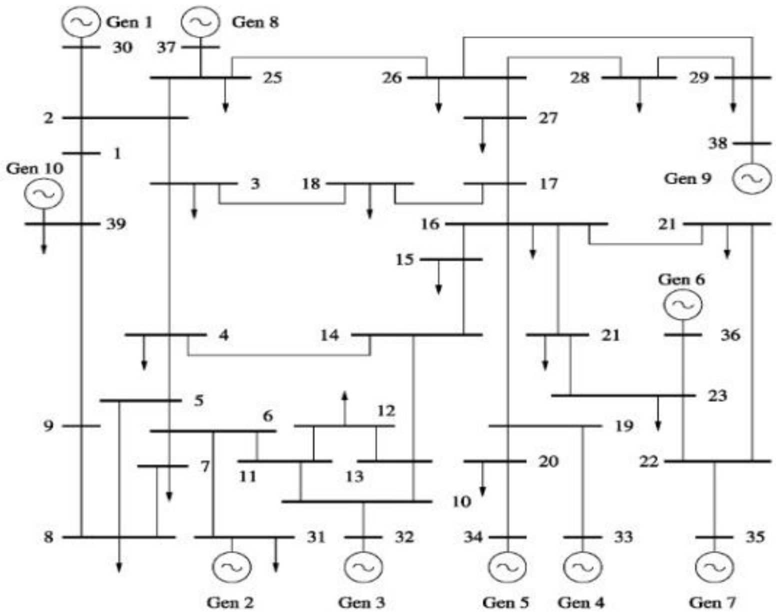

Fig. 1 IEEE 39 Bus Test System

Bus No.	**Gen No.**	**P_{gi_min} (MW)**	**P_{gi_max} (MW)**	**Generation cost ($/hr)**
30	G1	0	1040	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
31	G2	0	646	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
32	G3	0	725	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
33	G4	0	652	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
34	G5	0	508	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
35	G7	0	687	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
36	G6	0	580	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
37	G8	0	564	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
38	G9	0	865	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$
39	G10	0	1100	$0.01P_{gi}^2+0.3\ P_{gi}+0.2$

Table 1.Generator Data

Bus No.	Decomposition of LMP with Concentrated loss Model with Fixed bids			Decomposition of LMP with Distributed loss Model with Fixed bids		
	Energy Price	Congestion price	Loss Price LMP ($/MWh)	Energy Price	Congestion price	Loss Price LMP ($/MWh)
1	865608.61	30148.23	23624.13	865608.61	30148.23	0.00
2	865608.61	60296.46	0.00	865608.61	60296.46	804.82
3	865608.61	45222.34	77940.28	865608.61	45222.34	78129.08
4	865608.61	45222.34	121025.28	865608.61	45222.34	121156.95
5	865608.61	45222.34	0.00	865608.61	45222.34	219.66
6	865608.61	60296.46	0.00	865608.61	60296.46	309.58
7	865608.61	30148.23	56591.42	865608.61	30148.23	56767.27
8	865608.61	45222.34	126350.39	865608.61	45222.34	126525.76
9	865608.61	30148.23	1573.33	865608.61	30148.23	1614.72
10	865608.61	45222.34	0.00	865608.61	45222.34	102.27
11	865608.61	45222.34	0.00	865608.61	45222.34	144.14
12	865608.61	30148.23	2064.69	865608.61	30148.23	2072.32
13	865608.61	45222.34	0.00	865608.61	45222.34	159.75
14	865608.61	45222.34	0.00	865608.61	45222.34	181.90
15	865608.61	30148.23	77456.18	865608.61	30148.23	77562.44
16	865608.61	75370.57	79634.63	865608.61	75370.57	80250.89
17	865608.61	45222.34	0.00	865608.61	45222.34	74.43
18	865608.61	30148.23	38243.99	865608.61	30148.23	38277.63
19	865608.61	45222.34	0.00	865608.61	45222.34	749.15
20	865608.61	30148.23	164594.38	865608.61	30148.23	164924.66
21	865608.61	30148.23	66321.85	865608.61	30148.23	66758.03
22	865608.61	45222.34	0.00	865608.61	45222.34	339.84
23	865608.61	45222.34	59907.51	865608.61	45222.34	60389.68
24	865608.61	30148.23	74696.80	865608.61	30148.23	75006.51
25	865608.61	45222.34	54219.32	865608.61	45222.34	54960.00
26	865608.61	60296.46	33645.03	865608.61	60296.46	34098.63
27	865608.61	30148.23	68016.21	865608.61	30148.23	68129.49
28	865608.61	30148.23	49862.41	865608.61	30148.23	50146.10
29	865608.61	45222.34	68621.33	865608.61	45222.34	69674.74
30	865608.61	15074.11	60512.64	865608.61	15074.11	60512.64
31	865608.61	15074.11	161851.95	865608.61	15074.11	161851.95
32	865608.61	15074.11	157332.86	865608.61	15074.11	157332.86
33	865608.61	15074.11	152975.95	865608.61	15074.11	152625.70
34	865608.61	15074.11	122961.68	865608.61	15074.11	122657.79
35	865608.61	15074.11	157332.86	865608.61	15074.11	157332.86
36	865608.61	15074.11	135548.31	865608.61	15074.11	135375.25
37	865608.61	15074.11	130707.30	865608.61	15074.11	130506.76
38	865608.61	15074.11	200901.96	865608.61	15074.11	200268.52
39	865608.61	30148.23	25173.26	865608.61	30148.23	25183.42

Table 2.LMP Decomposition for IEEE 39 Bus System

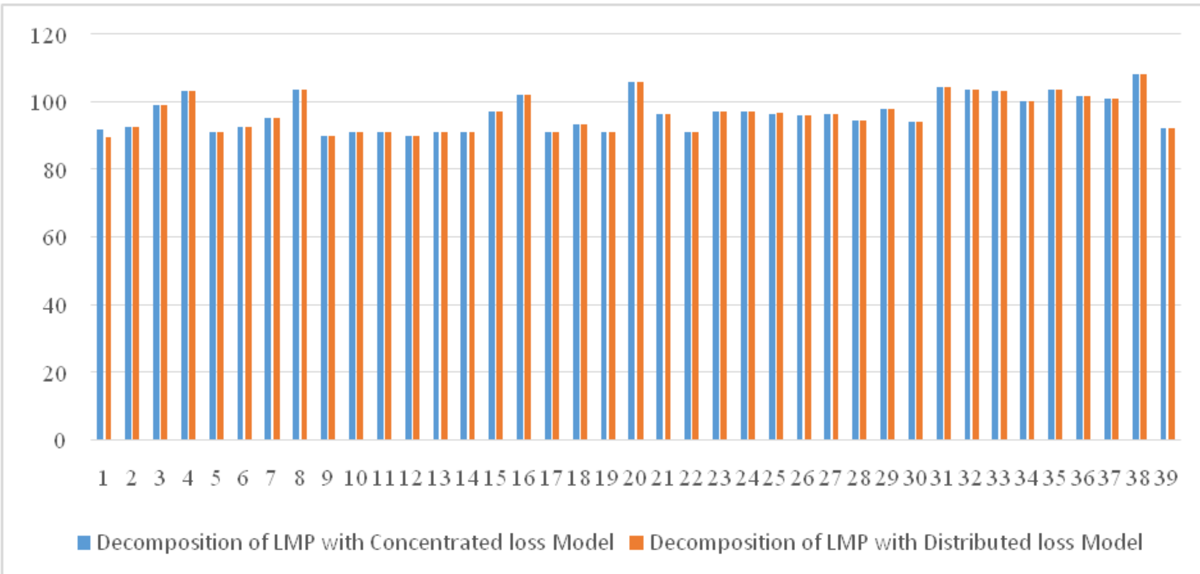

Fig. 2 Comparison of LMP with Concentrated & Distributed Loss Model

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