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Analysis of Locational Marginal Pricing Based DCOPF

Jenita Shanthini .D[1]

[1]SRM University, Master of Technology in Power Systems, Department of Electrical and Electronics Engineering, Kattankulathur campus, Potheri-603203

Abstract: ***In this paper , the analysis of locational marginal pricing based on DCOPF for concentrated and distributed model is explained with fixed bids and linear bids. LMP is an effective transmission pricing method and it is required to address transmission issues, generate correct economic pricing and to reduce the generation cost. Transmission line constraints can result in variations in energy prices throughout the network. These prices depend on generator bids, load levels and transmission network limitations. Locational marginal pricing (LMP) has become popular method in restructured power markets to address the congestion price. Both fixed and linear bids are considered for generators. Here we are using DCOPF in MATPOWER software to calculate LMP's at all buses considering concentrated loss model and a distributed loss model for fixed bids and linear bids in MATLAB software. LMP decomposition is also given, which can be decomposed into energy price, congestion price and loss price. IEEE 14 bus system is used here. The total production cost will be reduced. Decomposition of LMP is carried out to ensure economic operation. Distributed loss model considering linear bids shows reduced generation fuel cost compared to concentrated loss model.***

Keywords: Locational Marginal Pricing(LMP), DCOPF, Concentrated loss model, Distributed loss model.

1. Introduction

When you submit your paper print it in two-column format, including figures and tables [1]. In addition, designate one author as the "corresponding author". This is the author to whom proofs of the paper will be sent. Proofs are sent to the corresponding author only [2]. In April 2003 White Paper notice [1] the U.S. Federal Energy Regulatory Commission (FERC) proposed a market design for common adoption by U.S. wholesale power markets. 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. Proper and fair pricing of real power is an important issue in this competitive market. Core features of a market design include; a two settlement system consisting of a day-ahead market supported by a real-time market to ensure continual balancing of supply and demand for power; and grid congestion management by means of Locational Marginal Pricing (LMP).

One drawback of transmission constraint is congestion. Congestion occurs when transmission lines or transformers operate at or above its thermal limits and this prevents the system operators from dispatching additional power from a specific generator. Congestion can result in an overall increase in the cost of power delivery. Presently there are two pricing structures [2] that are being used in a competitive energy market to account for congestion: the uniform pricing method market clearing price (MCP) and the non-uniform pricing method (LMP). In the first method, all generators are paid the same price (MCP) based on the bid of the marginal generator that would be dispatched in the absence of congestion. The second method (LMP) has been the basic approach in power markets to calculate nodal prices and to manage transmission congestion. The theory of spot price, which was first proposed by Schweppe et al. [3], is increasingly being employed in the form of (LMP) within an OPF frame work. The LMP at a location is defined as the marginal cost to supply an additional increment of power to the location without violating any system security limits. Because of the effects of both transmission losses and transmission system congestion, LMP can vary significantly from one location to another. Or, LMP is the additional cost for providing one additional MW at certain node.

Buyers pay ISO based on their LMP for dispatched energy. The ISO pays sellers based on their respective LMP's. The LMP difference between two adjacent buses is the congestion cost which arises when the energy is transferred from one location (injection) to the other location (withdrawal). 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 [4]. Thus LMP is the summation of the costs of marginal energy, marginal loss and congestion. Therefore LMP is stated as follows:

LMP = generation marginal cost+ congestion cost+ loss cost

The ACOPF model is more accurate than the DCOPF model, but it is prone to divergence. Also, the ACOPF model can be up to 60 times slower than the DCOPF model [6]. The objective function of OPF is meeting the load in the power system while maximizing social surplus and respecting operational constraints. LMP is calculated with distributed loss using genetic algorithm based dcopf [5]. Concentrated and Distributed model for fixed bids and linear bids has been explained and compared. A systematic description on how the LMP's are produced both the modeling and implementation challenges and solution [7]. An iterative DCOPF based algorithm with lossless model, considering marginal losses, and with fictitious nodal demand model to calculate LMP. All these 3 models are solved with linear programming[8].

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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 ie., energy price, congestion price and loss price has also been calculated to ensure the economical pricing.

Therefore, codes have to be written for computation of Locational marginal Pricing. Comparison of concentrated and distributed loss model has been carried out to find out the most economical pricing. Further a Matlab code is developed for the proposed approach and applied to IEEE-14 bus system and the results are tabulated.

In section 2 this paper carries the LMP calculation of concentrated loss model and distributed loss model. The results and different cases are presented in section 3. Finally, conclusion is discussed in section 4.

2. LMP Calculation

2.1 Mathematical Formulation for Concentrated loss Model

The location of reference bus or slack bus will not impact LMP values, when ignoring system losses. But the individual components of LMP depend on the location of reference bus. If transmission losses are balanced at reference bus, i.e., in concentrated loss model the bus LMP's definitely depends on the location of reference bus. In distributed loss model the bus LMP's will not change with respect to reference bus and are independent of the choice of reference bus. It should also be noted that actual GSF values depend on the choice of slack bus, although the line flow based on GSF is the same with different references buses.

$$Minimize\ J = \sum_{i=1}^{N} MC_i \times P_{Gi} \quad (1)$$

$$\sum_{i=1}^{N} DF_i \times (P_i) + P_{loss} = 0 \quad (2)$$

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

for i=1,2,.....N

where, N=number of buses
M=number of lines
P_{Gi}=output power of generator at bus i (Mwh)
$MC_i = b_i + c_i P_{Gi}$ ($/Mwh), marginal cost at bus i
DF_i=delivery factor at bus i
P_{loss}=system loss

The main objective is to reduce the energy cost an it can be calculated by (1) where (2) and (3) are the equality constraints.

There are two types of generator bids ie., Fixed Bids and Linear Bids. When the heat rate curve is converted to an approximate fixed incremental heat rate for each unit through Linear regression method, the cost changes in steps with respect to generation. The non-smooth nature of the fixed bid may result in step changes in prices at certain load levels. One way to mitigate this is to use linear bids for the generating units. In this concentrated loss model it is assumed that total system loss is supplied by slack bus generator.

$$LMP^{energy} = \lambda \quad (4)$$

For Fixed Bids, $Energy\ cost = a_i + b_i P_{Gi} + c_i P_{Gi}^2$ (5)

For Linear Bids, $Energy\ cost = b_i P_{Gi} + c_i P_{Gi}$ (6)

where, $LMP^{energy} = \lambda$ = energy cost
P_{Gi}= output power of generator at bus i
a_i, b_i, c_i= cost coefficients

$$LMP_B^{congestion} = -\sum_{k=1}^{M} GSF_k \times \mu_k \quad (7)$$

$$GSF_{k-i} = \frac{B_a^{-1} - B_b^{-1}}{X_k} \quad (8)$$

where, $LMP_B^{congestion}$ is congestion cost at bus B
GSF_{k-i}=generation shift factor of line k from bus i
B^{-1}=inverse of B ; X_k=reactance of line k
a=sending end bus; b=receiving end bus

$$LMP_B^{loss} = lambda \times (DF_B - 1) \quad (9)$$

$$F_k = \sum_{i=1}^{N} GSF_{k-i} \times P_i \quad (10)$$

$$P_{loss} = \sum_{k=1}^{M} F_k^2 \times R_k \quad (11)$$

$$DF_i = 1 - LF_i = 1 - \frac{\partial P_{loss}}{\partial P_i} \quad (12)$$

where, LMP_B^{loss} = Loss cost at bus B
F_k=line flow of line k; R_k=resistance of line k
Therefore, LMP formulation at bus B can be written as,

$$LMP_B = LMP^{energy} + LMP_B^{congestion} + LMP_B^{loss} \quad (13)$$

The calculation of LMP for concentrated loss model can be carried out using the above equations. The decomposition of LMP can be carried out using (4), (7) and (9).

2.2 Mathematical Formulation for Distributed loss Model

Previous model addresses the marginal loss price through the delivery factors. But the equality constraint in (2) gives total generation is greater than the total demand by the average system loss. This causes a mismatch at slack bus and this mismatch is absorbed by the system slack bus. If system demand is huge like a few GW, then the system loss may be in the order of hundreds of MW and this is not feasible to add that much amount of loss to slack bus. So to address this mismatch issue at slack bus, it is necessary that the line losses are represented in the transmission lines. This paper employs the concept of distributed loss to represent the losses of the lines connected to a bus. In this method system losses are distributed among all buses and eliminate the large mismatch at the reference bus. By this approach, loss in each transmission line is divided into two equal halves, and each half is added to the each bus end of the line as an extra load. So for each bus the total extra load is the sum of halves of line losses which are connected to that bus. Due to the distribution of loss to all buses loss price of LMP is reduced for the same loading level. The extra load at bus 'i' is assumed as Ei, and it is defined as follows:

$$E_i = \sum_{k=1}^{M_i} \frac{1}{2} \times F_k^2 \times R_k \quad (14)$$

M_i=number of lines connected to bus i
The line flow F_k for this model is calculated as follows

$$F_k = \sum_{i=1}^{N} GSF_{k-i} \times (G_i - D_i - E_i) \quad (15)$$

The algorithm for this problem is same as in section 2.1. After getting power outputs of generators, Extra load is calculated for distributed loss model using (14) and LMP's at all buses are calculated using (4), (7), (9), and (13). With this approach the fuel cost is reduced than the concentrated loss model and the burden on the slack bus is eliminated.

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3. Results and Discussion

IEEE 14bus test system is used to assess the effectiveness of concentrated and distributed loss model developed in this paper. Two cases are considered, concentrated loss model with fixed bids and linear bids and distributed loss model with fixed bids and linear bids. The energy cost for IEEE-14 bus system is calculated from DCOPF.

Table-1 gives the LMP calculation for IEEE 14 bus system for concentrated loss model with fixed bids and linear bids and distributed loss model with fixed bids and linear bids.

Table-1: LMP calculation for IEEE-14 bus system

Bus No.	*Concentrated loss Model*		*Distributed loss Model*	
	Fixed Bids	*Linear Bids*	*Fixed Bids*	*Linear Bids*
1	39.016	38.69	39.016	38.69
2	45.979	45.643	45.969	45.633
3	49.8045	49.4585	49.7845	48.2485
4	53.0518	51.9947	53.0307	52.1837
5	54.5789	53.2459	54.5568	53.0382
6	56.9667	54.6847	56.9554	54.4755
7	57.0468	55.3813	57.0246	55.7705
8	59.1201	58.3829	59.107	58.2737
9	60.3769	60.0353	60.3534	59.6162
10	60.8313	61.2941	60.8196	60.4868
11	63.0962	61.7618	63.0572	62.0416
12	66.8643	64.6295	66.7943	63.4819
13	67.4265	65.0706	67.4125	63.8524
14	78.2173	72.8791	78.1963	71.8581

Table-2 gives the decomposition of LMP for IEEE-14 bus system for concentrated and distributed model for fixed bids. Table-2 gives the decomposition of LMP for IEEE-14 bus system for concentrated and distributed model for linear bids.

Table 2: LMP Decomposition for IEEE 14 bus system for both models-Fixed Bids

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	39.016	0	0	39.016	39.016	0	0	39.016
2	39.016	6.843	0.12	45.979	39.016	6.843	0.11	45.969
3	39.016	10.6285	0.16	49.8045	39.016	10.6285	0.14	49.7845
4	39.016	13.8145	0.2213	53.0518	39.016	13.8145	0.2002	53.0307
5	39.016	15.3384	0.2245	54.5789	39.016	15.3384	0.2024	54.5568
6	39.016	17.6746	0.2761	56.9667	39.016	17.6746	0.2648	56.9554
7	39.016	17.7428	0.288	57.0468	39.016	17.7428	0.2658	57.0246
8	39.016	19.8145	0.2896	59.1201	39.016	19.8145	0.2765	59.107
9	39.016	21.0397	0.3212	60.3769	39.016	21.0397	0.2977	60.3534
10	39.016	21.4909	0.3244	60.8313	39.016	21.4909	0.3127	60.8196
11	39.016	23.7428	0.3374	63.0962	39.016	23.7428	0.2984	63.0572
12	39.016	27.4909	0.3574	66.8643	39.016	27.4909	0.2874	66.7943
13	39.016	28.0397	0.3708	67.4265	39.016	28.0397	0.3568	67.4125
14	39.016	38.8145	0.3868	78.2173	39.016	38.8145	0.3658	78.1963

Table-3 : LMP Decomposition for IEEE 14 bus system for both models-Linear Bids

Bus no.	*Decomposition of LMP with Concentrated loss Model with Linear bids*				*Decomposition of LMP with Distributed loss Model with Linear bids*			
	Energy Price	*Congestion Price*	*Loss Price*	*LMP ($/MWh)*	*Energy Price*	*Congestion Price*	*Loss Price*	*LMP ($/MWh)*
1	38.69	0	0	38.69	38.69	0	0	38.69
2	38.69	6.843	0.11	45.643	38.69	6.843	0.1	45.633
3	38.69	10.6285	0.14	49.4585	38.69	9.4285	0.13	48.248
4	38.69	13.1145	0.1902	51.9947	38.69	13.3145	0.1792	52.183
5	38.69	14.3384	0.2175	53.2459	38.69	14.1384	0.2098	53.038
6	38.69	15.7746	0.2201	54.6847	38.69	15.5746	0.2109	54.475
7	38.69	16.4428	0.2485	55.3813	38.69	16.8428	0.2377	55.770
8	38.69	19.4145	0.2784	58.3829	38.69	19.3145	0.2692	58.273
9	38.69	21.0397	0.3056	60.0353	38.69	20.6397	0.2865	59.616
10	38.69	22.2909	0.3132	61.2941	38.69	21.4909	0.3059	60.486
11	38.69	22.7428	0.329	61.7618	38.69	23.0428	0.3088	62.0416
12	38.69	25.5909	0.3486	64.6295	38.69	24.4909	0.301	63.4819
13	38.69	26.0397	0.3409	65.0706	38.69	24.8397	0.3227	63.8524
14	38.69	33.8145	0.3746	72.8791	38.69	32.8145	0.3536	71.8581

Figure.1 gives the comparison of concentrated and distributed model for IEEE-14 bus system for fixed bids. Figure.2 gives the comparison of concentrated and distributed model for IEEE-14 bus system for linear bids. Figure.3 gives the comparison of concentrated and distributed loss model for both fixed bids and linear bids.

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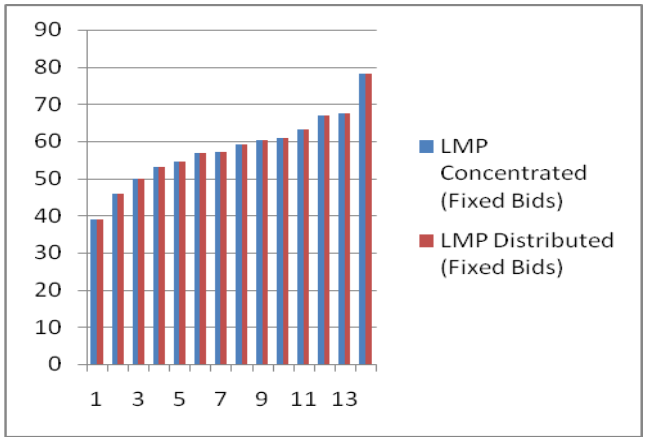


Figure 1: LMP for IEEE-14 bus system for concentrated and distributed model-Fixed Bids

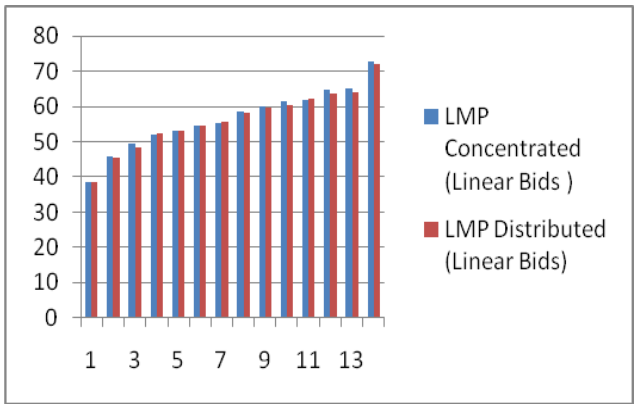


Figure 2: LMP for IEEE-14 bus system for concentrated and distributed model-Linear Bids

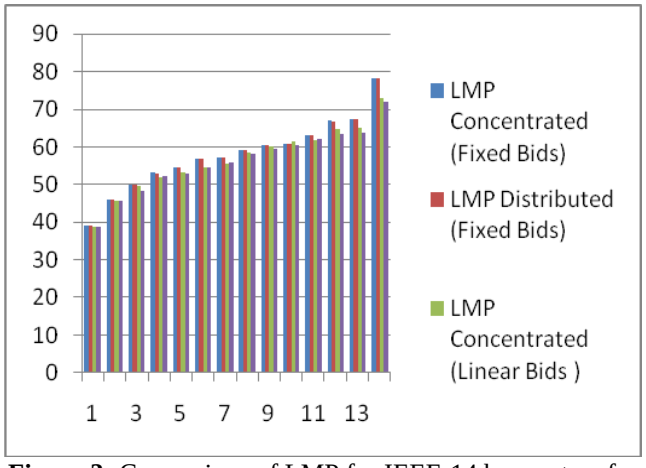


Figure 3: Comparison of LMP for IEEE-14 bus system for concentrated and distributed model for Fixed bids and Linear bids

4. Conclusion

This paper work presented Concentrated Loss Model and Distributed loss Model for LMP calculation, considering transmission constraints. Fuel cost minimization is taken as the objective function for this work. This is attempted with two types of bids i.e., fixed bids and linear bids for the generators. The proposed models are calculated based on dcopf and the distributed loss approach is compared with the concentrated loss approach for IEEE 14 bus system. LMP Decomposition ie., Energy price , Congestion price and Loss price are calculated. Comparison is made between Concentrated loss model and distributed loss model for both fixed bids and linear bids. It is observed that considerable savings in total fuel cost of generators can be achieved with distributed loss approach with linear bids.

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Author Profile



Jenita Shanthini.D Received B-tech in Electrical and Electronics Engineering from Karunya University, Coimbatore in 2013, currently pursuing M-tech with specialization in Power System Engineering in SRM University, Kattankulathur campus, Chennai (2013-2015).

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