

Locational Marginal Pricing of GENCOs in a Deregulated Energy Market

S. Padmini, V.S. Rajesh, N. Chandrakanth and V. Rajesh

Department of Electrical and Electronics Engineering, SRM University, SRM Nagar,
Kattankulathur – 603 203, Kancheepuram, Chennai, Tamil Nadu, India;
padmini.s@ktr.srmuniv.ac.in, rajeshvedam5@gmail.com,
chandun246@gmail.com,
rajeshkrishna.vrk@gmail.com

Abstract

Background/Objectives: In this paper a clear focus on pricing of the GENERation Companies (GENCO) has been dealt with. GENCO participate in day-ahead power pool trading to maximize their profit in the energy market. **Methods/Statistical Analysis:** Since the self-scheduling problem is a highly non-linear, non-convex mixed-integer optimization problem, conventional methods for optimizing may suffer excessive computational burden. This paper incorporates the method for determining the Locational Marginal Pricing with and without congestion due to over load and gives an observation of the ways to overcome this critical situation in the deregulated energy market using Power World Simulator (PWS) software for 3-bus system and IEEE 9-bus system **Findings:** In the case of Locational Marginal Pricing (LMP) forecasting, the main challenge is to forecast the volatile prices accurately in a day-ahead market. The PWS software used for test cases considered indicates that the output information is obtained at the short time frame which ultimately reduces the computation burden existed earlier in the conventional method **Applications:** The proposed methodology will be helpful for the generating company to forecast the Locational Marginal Pricing for both with and without congestion due to over load and rescheduling of generators will be carried out accordingly in the deregulated energy market within a very short time frame.

Keywords: Congestion, Deregulated Market, GENERation Companies (GENCO), Locational Marginal Pricing (LMP)

1. Introduction

Locational Marginal Pricing (LMP) is the method of providing a small incremental power demand at the respective places on the power system network in the deregulated market^{1,6}. In the competitive market, generation, transmission and distribution are not distinct entities. Here the market participants participate in the power-pool trading to maximize their profit. In the power pool trading, restrictions will be applied to transmission systems for power-pool traders for maximizing its profit in a deregulated power system².

Due to the restructuring of the power system, it leads to many problems such as incremental increase in line loss and overloading which might results in congestion of the power system³. Congestion can cause instability and increases the cost of power. Hence, congestion should be either removed or avoided from the power system to reduce the cost of power⁴. Congestion can be alleviated by the rescheduling of generators or by limiting the load. Among the various methods of congestion alleviation, rescheduling of active powers of generators are utilized mainly due to the limitation of load or load shedding⁵. Thus, rescheduling of

*Author for correspondence

generators is used which is beneficial technically as well as economically.

LMP is given by the following expression:

$$LMP = LMP_{energy} + LMP_{congestion} + LMP_{loss} \quad (1)$$

Thus, LMP includes the marginal energy cost, congestion cost, and cost incurred due to losses. Congestion management and generation rescheduling has been discussed using Differential Evolution (DE) algorithm in paper⁷. This paper proposed a mathematical Economic Load Dispatch (ELD) of a power system⁸. The method for generation re-scheduling to alleviate line overloads and load shedding has been proposed using local optimization technique⁹. A new approach for optimal operation of the generators is found out using Particle Swarm Optimization (PSO)¹⁰. The Congestion in transmission networks and its alleviation by generators rescheduling has been carried out in paper¹¹. Congestion management has been successfully handled as a multi-objective problem¹². Different risk management strategies have been carried out for a wind power producer in electricity markets¹³. An insight into the general capabilities and formulation of LMP formulation has been proposed which forms the basis for market design in deregulated energy market¹⁴. Zonal Congestion management has been discussed in paper¹⁵ for relieving for the congestion.

2. Mathematical Formulation

LMP is the method of reallocating an extra one MW at the specific buses as per the necessity which adopts two formulation of Optimal Power Flow (OPF). These formulations are given as below:

Problem Formulation 1:

$$\min c^T \cdot P - b^T \cdot P_D \quad (2)$$

S.t.

$$P_{Dmin} \leq P_D \leq P_{Dmax} \quad (3)$$

$$K \cdot PL_v - x \cdot P + y \cdot P_D = 0 \quad (4)$$

$$PL_R = \frac{\omega_a - \omega_b}{x_{ab}} \quad (5)$$

$$P_{gmin} \leq P_g \leq P_{gmax} \quad (6)$$

$$|P_l| \leq PL_{max} \quad (7)$$

Problem Formulation 2:

If Shift Factor (SF) is used then the LMP can be calculated using the following:

$$\min c^T \cdot P - b^T \cdot P_D \quad (8)$$

S.t.

$$\sum_m P_{D,m} - \sum_n P_n = 0 \quad (9)$$

$$P_{Dmin} \leq P_D \leq P_{Dmax} \quad (10)$$

$$P_{min} \leq P \leq P_{max} \quad (11)$$

$$-PL_v = -SF \cdot (x \cdot P - y \cdot P_D) \leq PL_{max} \quad (12)$$

$$PL_v = SF \cdot (x \cdot P - y \cdot P_D) \leq PL_{max} \quad (13)$$

$$LMP = \lambda - SF^T \cdot (\pi^+ - \pi^-), \quad \text{provided } LMP_{energy} = \lambda \quad (14)$$

$$LMP_{congestion} = -SF^T \cdot (\pi^+ - \pi^-) \quad (15)$$

3. Solution Methodology

PWS is interactable power system software which can handle up to 250000 buses. The test system considered for analysis is 3-bus system and IEEE 9-bus system each of which is considered as a separate GENCO.

4. Result and Discussions

4.1 Test System-1

For calculation of LMP, here a 3 bus system is taken into consideration. By applying the same concept of calculation of LMP, we can obtain LMP for higher bus systems. The sample 3-bus system is shown in Figure 1. Consider all lines have a reactance of 0.5pu and supplying a load of 300 MW. The calculation of LMP involves four different cases.

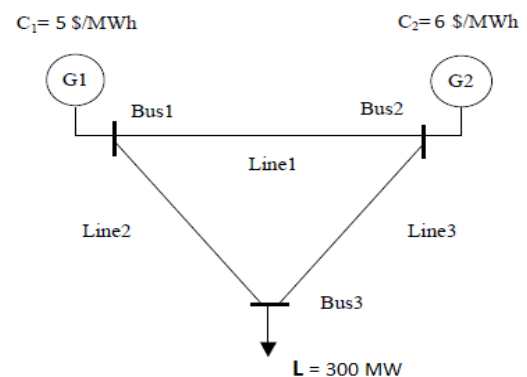


Figure 1. 3-bus system with a load of 300 MW.

Case 1: Without considering line limits.

Case 2: With the inclusion of line limits.

Case 3: LMP of all other buses are less than LMP of bus 3.

Case 4: LMP of all other buses are greater than LMP of bus 3.

Case 1: Without considering line limits, the load of 300 MW is entirely supplied by the generator G1 and sets its price at 5 \$/MWh. The total cost is \$1500. Therefore, an increase of load of 1MW at every bus amounts to \$5. Since, the line limits are neglected there is no congestion in the system as shown in Figure 2.

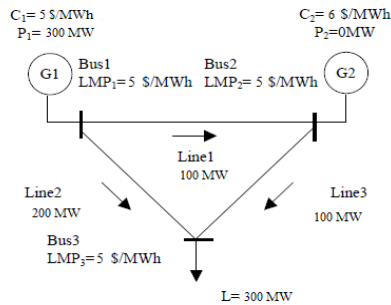


Figure 2. 3-bus system without congestion.

Case 2: For example, capacity of transmission line 1 is considered to be 60 MW whereas for lines 2 and 3 it is considered as 300 MW. Therefore, generator G1 supplies a power of 240 MW while the other 60MW will be contributed by generator G2 as shown in Figure 3. The total cost is \$1560. For example, if there is an increase in demand of 1 MW at bus 3, it leads to overloading of first transmission line resulting in congestion. Now the generating unit G2 supplies the load demand at bus-3. Hence, congestion leads to rescheduling of generators that providing a LMP of 5.5 \$/MWh at bus-3 which differs from the cost of bidding of generators G1 & G2 respectively.

$$\Delta P_1 + \Delta P_2 = 1 \text{ MW} \quad (16)$$

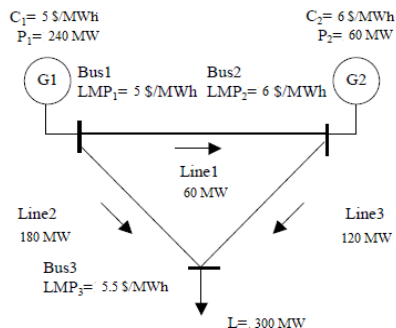


Figure 3. 3-bus system with congestion in line-1.

Case 3: In this case, line-2 limit is set as 160 MW whereas line limit of lines 1 and 3 as set as 200MW. Here line-2 between bus-and bus-3 are constrained as depicted in Figure 4. The total cost is \$1620. Therefore, congestion occurs in line-2. To increase an additional one MW demand at bus-3 the below mentioned equations are to be adhered with and LMP value obtained is 7 \$/MWh.

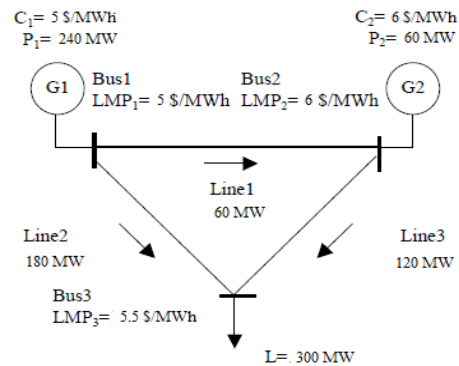


Figure 4. 3-bus system with congestion in line-2.

$$\frac{2}{3} \cdot \Delta P_1 + \frac{1}{3} \cdot \Delta P_2 = 0 \quad (17)$$

$$\Delta P_1 + \Delta P_2 = 1 \text{ MW} \quad (18)$$

Case 4: Here, bus-3 loading capability of 300 MW will be transferred to bus-2. The line limit of line-3 will be set as 60MW whereas 200 MW are set at line-1 and line-2. Here, constraint in line-3 is as depicted in Figure 5 which will make the total cost of generation as \$1620. To increase a one MW demand at bus 3 by 1MW, the below mentioned equations are to be adhered with and LMP value obtained is 4 \$/MWh.

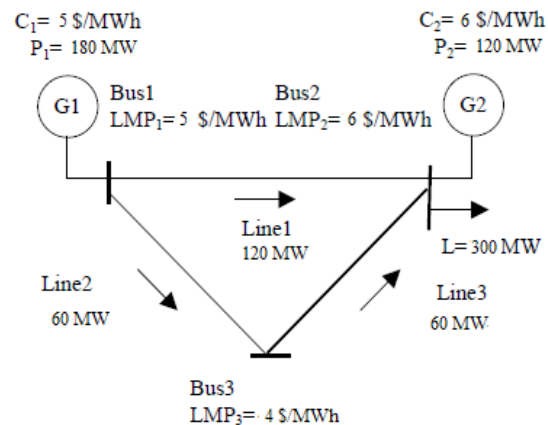


Figure 5. 3-bus system with congestion in line-3.

$$\frac{1}{3} \cdot \Delta P_1 + \frac{2}{3} \cdot \Delta P_2 = 0 \quad (19)$$

$$\Delta P_1 + \Delta P_2 = 1 \text{ MW} \quad (20)$$

4.2 Test System -II

In this case, an IEEE 9-bus system is taken into consideration. The test case is shown in Figure 6. It supplies a load of 350MW. The calculation of LMP for 9-bus system involves two different cases and the results are provided as follows:

Case 1: LMP calculation without inclusion of congestion.

Case 2: LMP calculation with congestion.

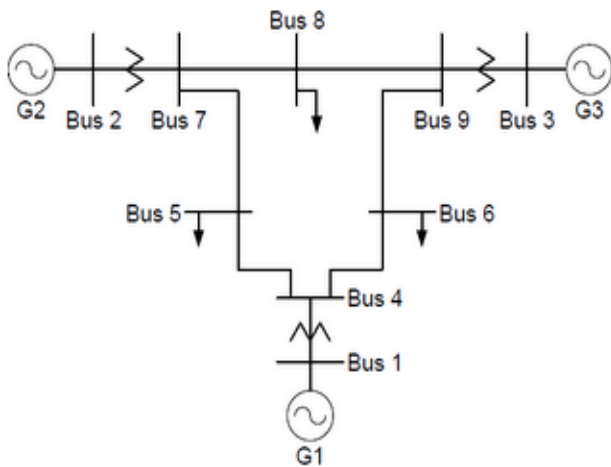


Figure 6. IEEE9-bus system.

Case 1: In this case, there are no constraints applied on the transmission system. Hence, Congestion will not occur in this case.

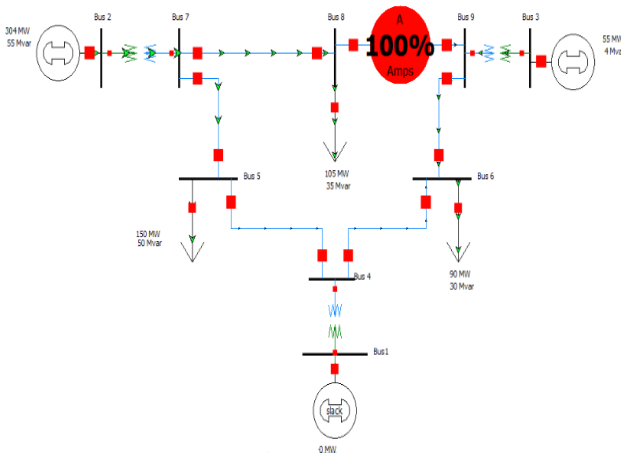


Figure 7. Calculation of LMP without congestion.

Table 1. LMP values at each bus without congestion.

Number	Name	Area Name	MW Marginal cost	Mvar Marginal Cost
1	Bus 1	1	12.26	Slack bus
2	Bus 2	1	12	PV bus
3	Bus 3	1	15	PV bus
4	Bus 4	1	12.26	-0.2
5	Bus 5	1	10.71	-3.55
6	Bus 6	1	14.05	2.95
7	Bus 7	1	10.6	-9.32
8	Bus 8	1	5.93	-22.1
9	Bus9	1	15.53	8.64

The LMP values at each bus are obtained as shown in Table 1 and the total cost without congestion is obtained as 4473\$/MWh and the simulation output is shown in Figure 7.

Case 2: In this case, the capacity of line between bus-8 and bus-9 is limited as 30MW. Due to this, the transmission line gets overloaded and leads to congestion.

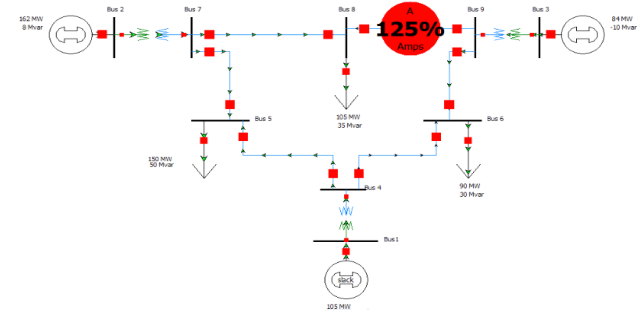


Figure 8. Calculation of LMP with congestion.

Table 2. LMP values at each bus during congestion.

No.	Name	Area Name	MW Marginal cost	Mvar Marginal Cost
1	Bus 1	1	13.64	Slack bus
2	Bus 2	1	12	PV bus
3	Bus 3	1	15	PV bus
4	Bus 4	1	13.64	0.05
5	Bus 5	1	13.22	0.4
6	Bus 6	1	14.08	-0.27
7	Bus 7	1	12.15	0.78
8	Bus 8	1	12.08	1.67
9	Bus 9	1	14.98	-0.73

The LMP values at each bus are obtained as shown in Table 2 and the total cost with congestion is obtained as 5304 \$/MWh and the simulation output is shown in Figure 8.

5. Conclusion

Thus, the above observations on LMP calculations has been successfully carried out for the 2 test systems considering various cases using Power World Simulator software. This LMP methodology is based on PWS which helps to determine the marginal cost for the power transmission and manages the congestion in the network. This method achieves the calculation of LMP in a very short time frame which will be useful when applied for test system. This work can be extended further for higher bus systems and by incorporating additional constraints.

6. References

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