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Locational Marginal Pricing Calculation with Rescheduling of Generation in Deregulation

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Abstract**—** The locational Marginal Pricing (LMP) is very important issue in deregulated environment. This paper provides a method to minimize the locational marginal pricing in the energy market. This market works under locational marginal pricing, i.e., generating units and demand loads are paid and pay, respectively, the locational marginal prices corresponding to the nodes they are connected to. An independent system operator clears the market maximizing the social welfare. As the LMP is also dependent on congestion pricing, here we have reduced the congestion in a particular line by the method of rescheduling of generators. Not all the generators are participating in the congestion initially identified the participating generators based on their sensitivity factors. By the method of rescheduling the generation of the generators congestion can be easily reduced so that congestion cost is reduced. Finally, LMP can be minimized in the deregulated power market. The proposed method is implemented tested on 6-Bus System, IEEE 14-Bus System, IEEE 26-Bus system and IEEE 30-Bus system. It is observed the good result in minimizing the LMP.

Keywords**—** Locational Marginal pricing, Rescheduling of generation, Congestion Pricing, Deregulation, Zonal pricing.

I. INTRODUCTION

LMP was developed by Dr. William Hogan, originally for use by the Pennsylvania-New Jersey-Maryland. Technically speaking, LMP is a voluntary, bid-based, security-constrained, economic dispatch market that determines energy and transmission congestion prices at specific points based on marginal generation costs. More simply stated, LMP is a computational model that determines optimal generation unit dispatch as well as Locational energy and transmission congestion prices [5].

The term "constraint" is used in this presentation to signify an imminent violation of a transmission line's physical or contractual limitations. "Transmission congestion" is created by a constraint, and the term is used to signify any instance where the lowest-bid generator cannot be dispatched in economic merit order to meet load (and thus another higher-bid generator must be re dispatched in out-of-merit order to meet that load) [7]. The term "node" is used to signify generation and/or transmission facilities that reside within a given location and have relatively insignificant impedance. Because the impedance within a node is essentially zero, a generator located in a given node can supply a load at the same node with no impact to the transmission system.

LMP's intended purpose is to determine the delivered energy price at a specific location by calculating and accounting for the relevant energy and transmission congestion prices. Generally, LMP determines an energy price for each electrical node on the grid as well as the transmission congestion price (if any) to serve that node.

For the above reason, LMP is often referred to as "nodal pricing".

The Locational marginal price at a specific location is the sum of the cost of generating the next MW to supply load at a specific location (based on marginal generation cost), the cost of transmission congestion, and the cost of losses

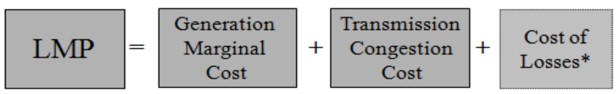

Fig 1: Definition of LMP

Three simple but very important concepts [7]:

- The LMP at a load is usually, but not always, equal to the bid price of the next MW generated to meet that load.
- When the transmission system is unconstrained, the LMPs are equal at all nodes to the bid price of the next MW generated to meet that load.
- Under constrained conditions, LMPs vary by node and can be higher than any generator bid.
-

Note: The load and the generator capabilities and dispatches will vary from example to example, but the generator bid prices remain the same throughout.

LMP prices are based on actual flow of energy and system operating conditions. Nodal LMPs are a direct function of the system's constraints [1].

Various Arguments against LMP

- Lack of pricing transparency: LMP's after-the-fact pricing provides no transparency to buyers.
- High transaction costs: Even relatively small electrical systems such as the PJM or New York ISOs can have thousands of nodes, and the resulting multiple nodal transaction costs can limit market participation and entry.
- Regulated and unregulated services are needlessly bundled: Under LMP, transmission (a regulated service) is effectively bundled with the generation commodity (unregulated market) in order to derive prices.
- LMP improperly allocates risk: The requirement that all successful bidders receive the highest bid price improperly allocates risk and is unnecessarily lucrative to suppliers.
- LMP is subject to market power abuse: LMP becomes subject to market power abuse if a horizontal concentration in generation is capable of manipulating the exchange price.
- LMP does not provide incentive to construct generation or transmission: LMP may in certain instances provide incentive to avoid the construction of generation or transmission in order to maximize congestion revenue.

II. PROBLEM FORMULATION

The Locational Marginal Price usually consists of three components- (i) System Marginal Cost of generator (ii) Network Loss component and (iii) Network constraint element. It can be expressed mathematically as [2]

$$\rho k = \lambda + \lambda . \frac{\partial L(zi)}{\partial dk} + \sum \mu i \frac{\partial zi}{\partial dk}$$

Where, dk is demand at node, k

zi is power flow across line, i

L(zi) is transmission losses as function of line flow

μi, Lagrange multiplier of third term, is the shadow price of transmission line, i, under the Congested and limited transfer capability limit [8].

The system Marginal cost at bus, k, is same as marginal cost of swing bus and is derivatives with respect to power generation. In an interconnected Power system, the change in demand and generation will cause change in total system losses.

For accurate modeling of LMP of the actual operating condition the following should be considered [6]:

- Economic dispatch
- Dispatch able transaction
- All external transaction
- Detailed generating resource data
- Generating constraints
- List of binding transmission constraints

Two basic market pricing structures: uniform market pricing (ZMP) (mostly used in Europe) and Locational marginal cost based pricing (LMP) (mostly used in North America). The market models are able to facilitate competitions among generators, calculate total generation costs, market clearing prices, costs of system securities, etc.

Advantage of Using LMP over Uniform Pricing Method [3]:

In LMP model, the price difference between the injection point and withdrawal point is the congestion price

- LMP as a pricing mechanism is an indicator of cost of maintaining the secure operation of the network and it includes the transmission congestion. LMP is the actual cost of energy in that area taking into accounts all the Locational constraints.
- LMP reflects the co-ordination of energy generation in such a way that the total supply of generation can adjust to the constantly changing demand.
- If reserve price is precisely considered, LMP might have strong possibility to provide an economic tool or reserve supply for system security in the energy reserve market.

III. RESCHEDULING OF GENERATORS

Power system congestion is a major problem that the system operator (SO) would face in the post-deregulated era. Therefore, investigation of techniques for congestion-freewheeling of power is of paramount interest. One of the most practiced and an obvious technique of congestion management is rescheduling the power outputs of generators in the system. However, all generators in the system need not take part in congestion management[4]. Therefore optimum selection of participating generators has been introduced using generator sensitivities to the power flow on congested lines.

6 – BUS SYSTEM

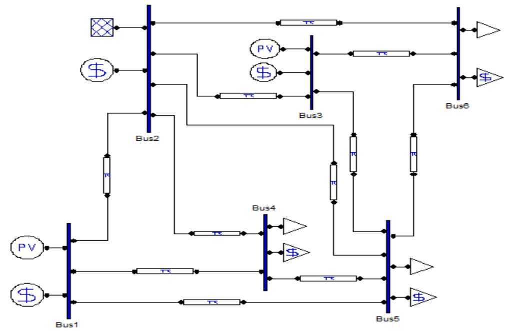

Fig. 2: Block Diagram of 6-Bus System

Table 4.1 RESCHEDULING OF GENERATORS FOR 6-BUS

S.NO.	G 1 in p.u	G 3 in p.u
1	1	0.5
2	1.2	0.3
3	1.3	0.2
4	1.4	0.1
5	**1.5**	**0**
6	0.5	1
7	0.1	1.4

14- BUS SYSTEM

Table 4.2 RESCHEDULING OF GENERATORS FOR 14-BUS

S.NO.	**G 1 in p.u**	**G 2 in p.u**	**G 3 in p.u**	**G 8 in p.u**
1	0	0	0	0.4
2	0.1	0	0.3	0
3	0.2	0	0	0.2
4	**0.2**	**0**	**0.2**	**0**
5	0.3	0	0	0.1
6	0.3	0	0.1	0
7	0	0.1	0	0.3

26 – BUS SYSTEM

Table 4.3 RESCHEDULING OF GENERATORS FOR 26 -BUS

S.NO.	**G 2 in p.u**	**G 3 in p.u**	**G 4 in p.u**	**G 5 in p.u**	**G 26 in p.u**
1	0.79	0.2	1	3	0.6
2	0.59	2.2	1	1	0.6
3	**0.79**	**0.2**	**0**	**0**	**4.6**
4	4.6	0	0	0.2	0.79
5	0	0.99	1	3	0.6

30- BUS SYSTEM

Table 4.4 RESCHEDULING OF GENERATORS FOR 30-BUS

S.NO.	G 2 in p.u	G 3 in p.u	G 8 in p.u	G 11 in p.u	G 13 in p.u
1	**0**	**0**	**1.9**	**0**	**0**
2	0	1.9	0	0	0
3	0.2	0.7	0.4	0.4	0.2
4	0.7	0.4	0.4	0.4	0.2
5	0.8	0.2	0.5	0.2	0.2
6	1.9	0	0	0	0
7	0	0	0	1.9	0

IV. RESULTS

A. 6- BUS RESULTS

Table 4.5: LOCATIONAL MARGINAL PRICE RESULTS FOR 6 -BUS

BUS NUMBER	LMP in ($/MW)	
	BEFORE RESHELDULING	AFTER RESHEDLING
1	**9.0204**	**8.5106**
2	**8.9805**	**8.8113**
3	9.1455	9.216
4	**9.563**	**9.2326**
5	**9.6535**	**9.4516**
6	9.4284	9.4257

6-bus base

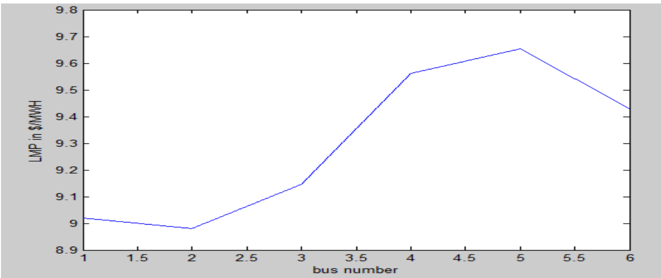

Fig 4.1 graph of 6- Bus LMP base case

6-bus after rescheduling

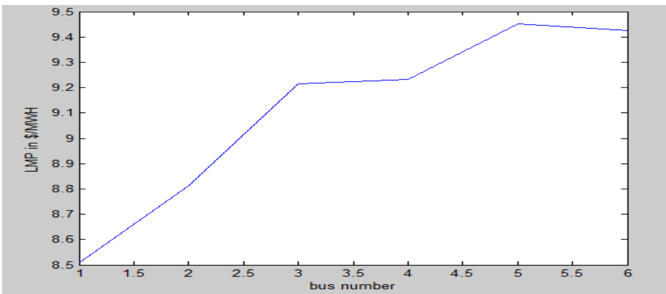

Fig 4.2 graph of 6- Bus LMP reschedule case

B. 14- BUS RESULTS

Table 4.6 LOCATIONAL MARGINAL PRICE RESULTS FOR 14-BUS

BUS NUMBER	LMP in ($/MW)	
	BEFORE RESHELDULING	AFTER RESHEDLING
1	**8.9498**	**8.9858**
2	**9.3438**	**9.4126**
3	**9.9236**	**9.9559**
4	9.8902	9.9191
5	**9.8365**	**9.8719**
6	8.8	8.8
7	9.1501	9.1506
8	8.8	8.8
9	9.4135	9.4141
10	9.4358	9.4362
11	9.1835	9.1837
12	9.1472	9.1472
13	9.2729	9.273
14	9.8147	9.815

14- Bus base

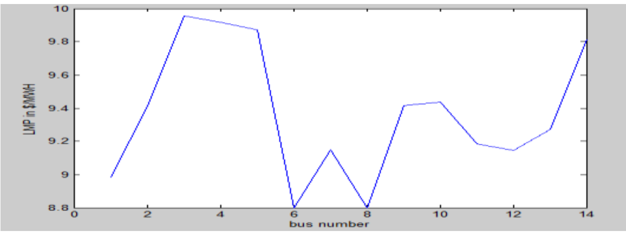

Fig 4.3 graph of 14 -Bus LMP base case

14- Bus after rescheduling

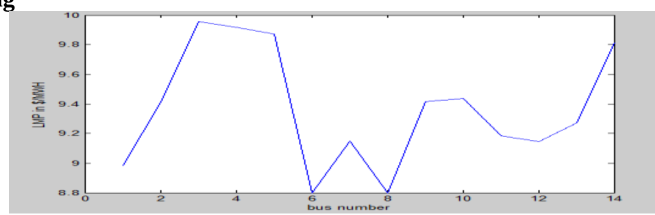

Fig 4.4 graph of 14- Bus LMP reschedule case

C. 26 -BUS RESULTS

BUS NUMBER	LMP in ($/MW)	
	BEFORE RESHELDULING	AFTER RESHEDLING
1	**10.5**	**10.4995**
2	10.4999	10.4994
3	**10.999**	**10.4998**
4	10.4913	10.4993
5	10.4999	10.4999
6	10.5001	10.5
7	**10.5007**	**10.5005**
8	**10.501**	**10.5008**

9	**10.5051**	**10.5048**
10	**10.5042**	**10.5038**
11	**10.501**	**10.5006**
12	**10.5036**	**10.5032**
13	10.5059	10.5062
14	10.5052	10.5052
15	10.5048	10.5048
16	**10.5043**	**10.5042**
17	**10.502**	**10.5018**
18	**10.5002**	**10.4999**
19	**10.5079**	**10.5071**
20	**10.5043**	**10.504**
21	**10.5025**	**10.5023**
22	**10.5046**	**10.5042**
23	**10.5059**	**10.5052**
24	**10.5053**	**10.5048**
25	**10.5054**	**10.5048**
26	**10.4999**	**10.4984**

26- Bus base case

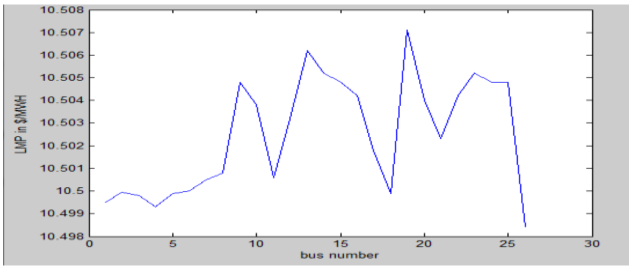

Fig 4.5 graph of 26- Bus LMP base case

26 -Bus after rescheduling

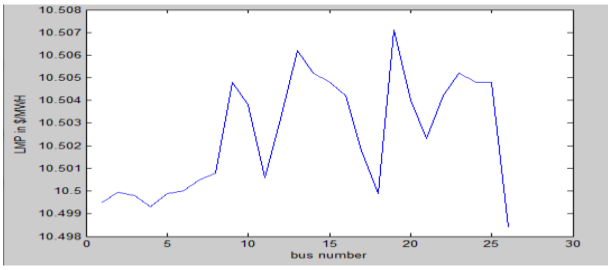

Fig 4.6 graph of 26- Bus LMP reschedule case

D. 30 -BUS RESULTS

TABLE4.8 LOCATIONAL MARGINAL PRICE RESULTS FOR 30-BUS

BUS NUMBE R	LMP in ($/MW)	
	BEFORE RESHELDULING	AFTER RESHEDLING
1	10.4998	10.3949

2	10.4998	10.3934
3	10.5	10.3917
4	10.5	10.3884
5	10.4999	10.395
6	10.4999	10.3829
7	10.5	10.3905
8	10.4999	10.3755
9	**10.4998**	**9.3607**
10	**10.4998**	**9.5182**
11	**10.4998**	**8.8**
12	**10.4998**	**9.6466**
13	**10.4998**	**9.5678**
14	**10.5**	**9.6536**
15	**10.5**	**9.6515**
16	**10.4999**	**9.6004**
17	**10.4999**	**9.5476**
18	**10.5001**	**9.6429**
19	**10.5001**	**9.635**
20	**10.5**	**9.5492**
21	**10.4999**	**9.5497**
22	**10.4999**	**9.5567**
23	**10.5001**	**9.6536**
24	**10.5001**	**9.6537**
25	**10.5004**	**9.8032**
26	**10.5005**	**9.8117**
27	**10.5004**	**9.8878**
28	**10.5**	**10.3805**
29	**10.5006**	**9.9029**
30	**10.5007**	**9.9126**

30 -Bus base case

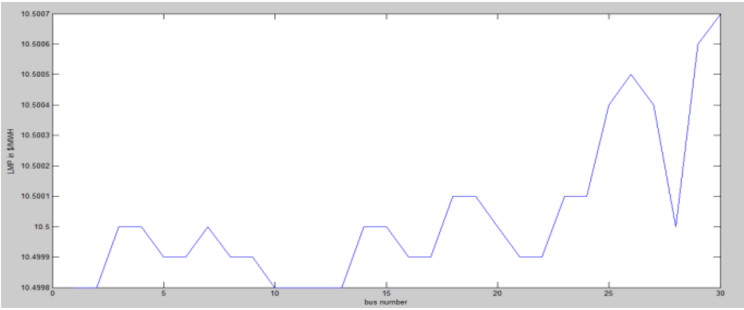

Fig 4.7 graph of 30- Bus LMP base case

30 -Bus after rescheduling

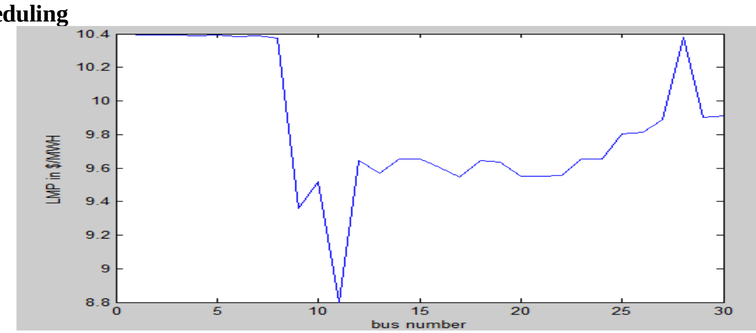

Fig 4.8 graph of 30- Bus LMP reschedule case

V. CONCLUSION

LMP plays the major role in deregulated power market. We have to take necessary steps to keep the LMP values as minimum as possible. One of the methods to reduce the LMP values is rescheduling the generators in the existing power system. Based on the rescheduling of generation we can reduce the congestion and then automatically congestion cost will decrease and then finally LMP values can be reduced.

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