DC-OPF for LMP Calculation in Wholesale Electricity Market

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***Abstract*—Locational Marginal Price (LMP) based Energy Markets are implemented in several countries around the world. In the market environment, LMP based clearance scheme is used to calculate the amount of money earned from ISO by the energy sellers and paid to ISO by the energy consumers. This paper shows that to calculate the LMP in DC OPF in Wholesale Electricity Market. So, the location wise price can be identified on the basis of LMP. The Proposed method is tested in IEEE 6 bus test system.**

Keywords*—Locational Marginal Price (LMP), DC Optimal Power Flow (DC OPF), AC Optimal Power Flow (AC OPF), Generation Shift Factor (GSF)

I. INTRODUCTION

Linearized DC OPF problems are usually applied for the approximation of nonlinear AC optimal power flow problems in order to find real power solutions for restructured wholesale power markets [1]. The complete AC formulation of the problem is too complex to be employed in contemporary production.

The electricity market throughout the world employs LMP as one of the most popular approaches for congestion management. LMP developed into a part of the Standard Market Design (SMD). LMP has either already been implemented or in the process of implementation in every market in the country.

Recent work in the current bid cost minimization suggests two alternative auction objectives. The first auction objective is the minimization of the total consumer payment. The auction formulation depends on the pricing scheme used which can lead to drastically different results. The second auction objective is to maximize the sum of consumer and producer surplus.

II. DC OPF AND AC OPF

A. AC OPF

The AC OPF model involves power system operating constraints as well as real and reactive power flow balance constraints. These constraints comprise a set of non-linear algebraic equations [2].

B. DC OPF

In order to calculate real power LMPs, the DC OPF model is being proposed for the purpose of approximating the AC OPF model.

The reactive power flow equation is ignored in the DC OPF formulation. The real power flow equation is approximated by DC power flow equations under the following assumptions [1].

(1) The resistance of each branch is set to zero because it is negligible as compared to the branch reactance.
(2) The bus voltage magnitude is equal to 1 pu.
(3) Ignoring tap dependence in the transformer reactance.
(4) The DC OPF model itself does not include the effect of the real power loss on the LMP. Hence the line losses are ignored.

C. ADVANTAGES OF DC OPF OVER AC OPF

Solving AC OPF problems for large power systems are often time consuming. The AC OPF model can be up to 60 times slower than the DC OPF model [2]. Also the convergence difficulties can be grave. With the mentioned assumptions the dc power flow reduces the power flow problem to a set of linear equations. Thus the dc power flow simplifies significantly. The DC OPF model has been widely used for LMP calculation for power market operation.

III. LOCATIONAL MARGINAL PRICE

The concept of LMP (also known as spot price or a nodal price) was first developed by Schweppe et al in 1998. The LMP is defined as a change in production cost to optimally deliver an increment of load at the locations while satisfying all the constraints. LMP can be derived using either an AC OPF or a DC OPF model [4].

LMP = marginal cost of Generation + congestion cost of Transmission + marginal Cost of losses

LMP is analogy of a taxi ride for megawatts of electricity. During light traffic we can expect that the predictable fare. That shows there is little or no congestion on the grid. Similarly during heavy traffic the fare is high. That shows the congestion on the transmission network.

A. Generation Shift Factor (GSF)

GSF is demarcated as the "Ratio of the change in line flow to the change in generation of the designated bus". At the reference bus all GSF are equal to zero.

B. Properties of LMP

1. LMP is usually obtained as a result of the OPF.
2. For binding constraints the twin value is non-zero, and for the nonbinding constraints the twin value is zero [5].
3. If losses exist and there is no congestion, the LMP at every bus is the MCP, the marginal system energy price.
4. Marginal units will find the LMP at every bus. LMPs at particular site may be greater/smaller than highest/lowest offered cost. LMPs at particular site may be negative.

C. Electricity Market

1. Freedom of choice: Offer customers with choices on the price and consistency of supply and how they select to use electric energy.
2. Economic efficiency: Inspire customers to adjust their own electric energy usage patterns to match utility marginal costs.
3. Equity: Decrease customers cross subsidies i.e. a customer's charges are based on the utility's cost to serve that customer.
4. Utility control, process and forecasting: consider the engineering requirements for controlling, operating and forecasting an electric power system.

IV. PROBLEM FORMULATION

DC model doesn't contain system losses. So the Marginal loss component has not been considered in the LMP [3]. LMPs are being divided into three components.

$$\lambda_i = \lambda_m + \lambda_l + \lambda_c$$

λ_i = LMP of Bus i

λ_m = Marginal Price Component

λ_l = Loss Component

λ_c = Congestion component

$$\lambda_l = \left(1 - \frac{\partial Loss}{\partial Pi}\right)\lambda$$

$$\lambda_c = \sum_{i}^{K} GSF_{ik}\mu_k$$

GSF_{ik}= Generation Shift factor for bus i on line k

μ_k = Line k constraints cost

λ = Lagrangian Multiplier

A. Equility Constraints

Real (Active) Power balance equation

$$P_i = P_{Gi} - P_{Di}$$

Reactive Power balance equation

$$Q_i = Q_{Gi} - Q_{Di}$$

B. Inequility Constraints

(1) Real Power Constraints:

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}$$

(2) Reactive Power Constraints:

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}$$

(3) Thermal Limit of Line Flow:

The maximum amount of power that can flow through a line is restricted by thermal limit of the line. The thermal limit restriction of the line put a constraint on the amount of power flow between two nodes can be stated as

$$S_{ij} \le S_{ij}^{max}$$

$$S_{ji} \le S_{ji}^{max}$$

(4) Bus Voltage Limit:

The bus voltage limit within a suitable small range space

$$V_i^{min} \le V_i \le V_i^{max}$$

Algorithm of LMP Calculation

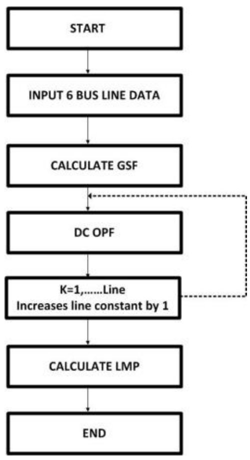

Fig. 1 LMP Calculation

V. RESULTS

LMP at every node is calculated by using DCOPF. IEEE 6 Bus test system consists of 3 Generators and 3 Load bus shown in fig. 2. In first stage the marginal generation price based on DCOPF is determined and in next stage the LMP congestion price is formulated. For simplicity only the active power is considered for all the three generators. This method is tested on IEEE 6 bus using MATLAB shown in fig. 3.

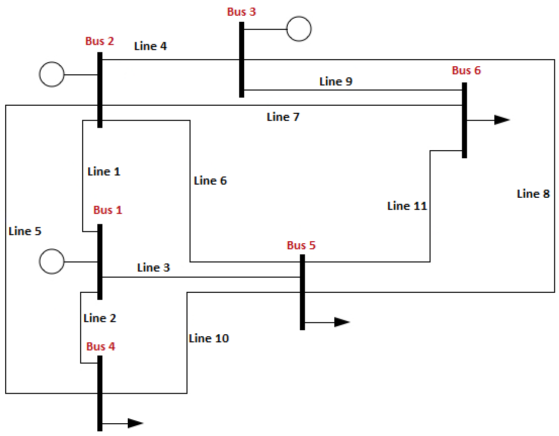

Fig. 2 IEEE 6 BUS SYSTEM

Bus No.	LMP ($/MWh)
1	15.000
2	19.033
3	26.349
4	32.074
5	26.901
6	31.377

Table 1 LMP of 6 bus test system

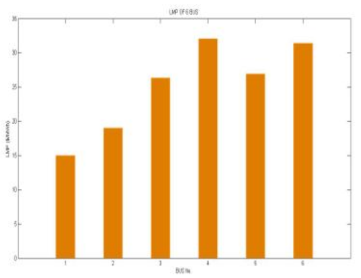

Fig. 3 LMP of IEEE 6 BUS TEST SYSTEM

VI. CONCLUSION

With the help of LMP we can calculate the price at all the locations. In the considered IEEE 6 bus test system, the LMP was found to be highest at Bus 6 and the lowest at Bus 1 is shown in Table 1. These data are of immense help for the wholesale electricity market in bidding strategy. As the electricity market throughout the world employs LMP as one of the most popular approaches, more research is required in methods of economic, mathematical and engineering foundation. The LMP implementation approaches can be made more efficient.

VII. FUTURE SCOPE

This topic needs more attention. The use of AC based OPF demands extensive research. The further development of this work could be its implementation using the optimization technique.

APPENDIX

Line No.	From	To	R	X	B_{sh}
1	1	2	0.10	0.20	0.02
2	1	4	0.05	0.20	0.02
3	1	5	0.08	0.30	0.03
4	2	3	0.05	0.25	0.03
5	2	4	0.05	0.10	0.01
6	2	5	0.10	0.30	0.02
7	2	6	0.07	0.20	0.025
8	3	5	0.12	0.26	0.025
9	3	6	0.02	0.10	0.01
10	4	5	0.20	0.40	0.04
11	5	6	0.10	0.30	0.03

Table 2 IEEE 6 Bus Line data (in p.u)

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