TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 14, No. 1, April 2015, pp. 42 ~ 48
DOI: 10.11591/telkomnika.v14i1.7713

Forecasting of Utility Cost in a Deregulated Electricity Market by Using Locational Marginal Pricing

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Abstract

In the deregulated electricity market bidding contest is the major operation. Prices obtained from the result of bidding strategy is essential, since all market participants do not be familiar with the accurate assessment of future prices in their decision-making process. Locational Marginal Pricing (LMP) obtains from the Optimal Power Flow problem gives the economic value of electrical energy at each location. Proposed method is based on lossless DC Optimal Power Flow. To solve this LMP problem optimization based Linear Programming (LP) approach has been implemented. In this paper LMP values with transmission, line outage and generator outage constraints are studied. IEEE 14 and IEEE 30 bus systems are used as a test system in this paper.

***Keywords**: locational marginal pricing, congestion management, generator outage, line outage, linear programming.*

1. Introduction

By tradition the delivery of electrical energy has been seen as a communal facility provided by regulated utilities. In a lot of countries, a single state-owned utility was accountable for the generation, transmission and deliver of power. We simply call this utility as Vertically Integrated Utilities (VIUs). The electrical supply industry all over the world has practiced a stage of quick and permanent change in terms of structure, rights, process and administration. To improve the operation efficiency of VIUs huge changes are taking position in the power industry whereby competitive markets are replaced by VIUs as to initiate a competition between power producers and buyers [1]. These changes are commonly referred as deregulation or restructuring. The main objectives of restructured market are secure and economic operation of a power system without violating any system security limit. Security is the most significant feature of the power system operation and could be facilitated by utilizing the assorted services offered to the market. The economical operation of the power market would decrease the cost of electricity [1].

Major types of market structure are pool, bilateral and hybrid models [2]. Pool is a centralized market for buyers and sellers where electric power sellers and buyers submit bids and prices into the pool for the amount that they are willing to sell or buy. The Independent System Operator (ISO) is a centralized authority to sellers and buyers. The main objective of the ISO is maintaining reliable and secure operation of power industry. ISO will forecast the demand for the day and receive bids that will satisfy the demand at the lowest cost and prices for the electricity on the basis of the most expensive generator in operation. Bilateral models also referred to as Direct Access Model. As the name implies, customers are free to contract directly with power generating companies. By establishing an appropriate access and pricing standards, customers transfer purchased power as restricted to the power transmission and distribution over utility wires. Bilateral market does not require ISO as in the case of pool markets. Generator unit commitment and economic dispatch decisions are dependent on individual market participants. Due to this self commitment need of independent operator is minimized [2]. Still there is a need of an ISO for the Independent operation of transmission system. This kind of ISO is normally referred to as Minimal ISO due it minimal central operation.

Received January 6, 2015; Revised March 6, 2015; Accepted March 24, 2015

Transmission Pricing is a major issue in the deregulated electricity market [3]. Federal Energy Regulatory Commission (FERC) recognized that transmission grid is the key issue to competition, and issued guidelines to price the transmission system. Even though transmission costs are small as compared to power production expenses and represents a small percent of major investor owned utilities operating expenses, a transmission system is the most important key to competition because it can create efficiencies in the power generation market. The condition where overloads in transmission lines or transformers occur is called congestion [4-6]. Congestion could prevent system operators from dispatching additional power from a specific generator. Congestion could be caused for various reasons, such as transmission line outages, generator outages, change in energy demand and uncoordinated transactions. Congestion may result in preventing new contracts, infeasibility in existing and new contracts, additional outages, and monopoly of prices in some regions of power systems and damage to system components [4-6]. Congestion may be prevented to some extent by means of reservations, rights and congestion pricing. There are two types of pricing methods are available in practice for congestion management [7]. They are uniform and non-uniform pricing structure. In this paper congestion is managed by means of Locational Marginal Pricing (LMP) i.e. non-uniform pricing structure. In this paper day-ahead market and Ex-Anti is considered [7]. The LMP at a location is defined as the marginal cost to supply an additional MW increment of power at the location without violating any system security limits [8]. This charge reflects not simply the marginal charge of power production, other than that delivery charge also considered. If the lowest priced electricity is allocated for all Location LMP values at all nodes will be same. If congestion present in the system lowest cost energy cannot reach all location, more expensive generators will allocated to reach out the demand. In this situation LMP values will be differ from one location to another location. Mathematically, LMP at a bus is Lagrange multiplier incorporated with the equality constraint [8]. LMP at a bus is decomposed into three components.

LMP = Marginal Generating unit price + Congestion price+ Marginal loss Price

LMP is obtained from the result of Optimal Power Flow (OPF). Either AC-OPF or DC-OPF is used to determine the LMP. To reduce the complexity in the calculation in this paper DC-OPF is used [9]. In DC-OPF only real power flow is considered [10]. Different types of optimization models are used for LMP calculations like LP and Lagrangian relaxation using karush–kuhn-Tucker conditions [11]. Evolutionary algorithm like genetic algorithm [12] and constrained bat algorithm [12] is also used. Among these in this paper LP is used to solve the optimization problem.

The paper is structured as follows: Section 2 provides the existing transmission pricing method. Section 3 provides the problem formation. Section 4 presents the lossless DC-OPF problem formations. Section 5 provides the linear programming method. Section 6 provides the results and analysis. Section 7 describes conclusion.

2. Existing Transmission Pricing Method

Transmission pricing offer global access for all participants in the market. To recover the costs of transmission network and encourage market investment in transmission an understandable price structure is necessary. In this section various pricing methods and their calculations are discussed.

2.1. Postage-Stamp Rate Method

Postage-stamp rate scheme is conventionally used by electric utilities to allot the permanent transmission price between the users of firm transmission service. This method does not need power flow calculations and is independent of the transmission distance and system arrangement. This transmission pricing method allocates transmission charges based on the amount of the transacted power. For each transaction the magnitude of power transfer is calculated at the time of system peak.

2.2. Contract Path Method

Contract path method also does not required power flow calculation. In this method contract path is a corporeal transmission pathway among two transmission users that disregards the fact that electrons follow corporeal paths that may differ dramatically from contract paths. Following to the specification of contract paths, transmission prices will then be assigned using a postage-stamp rate, which is determined either individually for each of the transmission systems or on the average for the entire grid.

2.3. MW-Mile Method

The MW-Mile Method is also called as line-by-line method since it considers, in its calculations, changes in MW transmission flows and transmission line lengths in miles. The method calculates charges associated with each wheeling transaction based on the transmission capacity use as a function of the magnitude of transacted power, the path followed by transacted power, and the distance traveled by transacted power. The MW-mile method is also used in identifying transmission paths for a power transaction. This method requires dc power flow calculations. The MW-mile method is the first pricing strategy proposed for the recovery of fixed transmission costs based on the actual use of transmission network.

Total transmission capacity cost is calculated as follows:

$$TC_t = TC \times \frac{\sum_{k \in K} c_k L_k MW_{t,k}}{\sum_{t \in T} \sum_{k \in K} c_k L_k MW_{t,k}} \tag{1}$$

TC_t - cost allocated to transaction t
TC - total cost of all lines in $
L_k - length of line k in mile
c_k - cost per MW per unit length of line k
$MW_{t,k}$ - flow in line k, due to transaction t
T - set of transactions
K - set of lines

3. Problem Formation

The main objective of this problem is minimization of total cost subjected to energy balance constraint and transmission constraint [13-16]. Power flow is obtained by lossless DC-OPF model. In this OPF reactive power is ignored and the voltage magnitudes are assumed to be unity [9]. Objective function is given by the Equation (2).

$$min \sum_{i=1}^{ng} s_i pg_i \tag{2}$$

Subject to demand constraint as shown in the Equation (3).

$$\sum_{i=1}^{n} pg_i = \sum_{i=1}^{n} pd_i \tag{3}$$

Generation limit constraint is given by the Equation (4).

$$pg_i^{min} \leq pg_i \leq pg_i^{max} \tag{4}$$

Transmission line limit is given by the Equation (5).

$$lf_j^{min} \leq lf_j \leq lf_j^{max} \tag{5}$$

Where,
i - Generator index.
ng - Number of generators.
J - Line index.

n - Number of buses.
s_i - Cost of i^{th} generator unit.
pg_i - generation of i^{th} generator unit
pg_i^{min} - Minimum limit of generating unit.
pg_i^{max} - Maximum limit of generating unit.
pd_i - Demand of i^{th} unit.
lf_j^{min} - Minimum limit of line flow.
lf_j^{max} Maximum limit of line flow.

4. Lossless DC-OPF Problem Formation

In AC network real and reactive power transmitted from the generating unit to load centre. Direct Current Optimal Power Flow gives active Power Flow in AC network. This DC-OPF is does not have convergence problem i.e. non iterative. From the accuracy level AC-OPF is better than DC-OPF. In DC-OPF some assumptions are made as [9-10].

Power injection at a node and voltage angles are the important variables for DC-OPF. Active power injection at a bus P_i is given by the Equation (6).

$$P_i = \sum_{j=1}^{N} B_{ij}(\theta_i - \theta_j) \tag{6}$$

B_{ij} – Reactance between bus i and bus j.

Power flow on the transmission line is given by the Equation (7).

$$P_{Li} = \frac{1}{X_{Li}}(\theta_s - \theta_r) \tag{7}$$

X_{Li} - Reactance of line i.

DC-OPF equations and power flow in the branch relationship is represented by the Equation (8) & (9).

$$\theta = [B]^{-1}P \tag{8}$$

$$P_L = (b \times A)\theta \tag{9}$$

Where,
P - N×1 vector of bus active power injection for buses 1,...., N.
B - N×N admittance matrix with R=0.
θ - N×1 vector of bus voltage angle for buses 1,.....,N.
P_L - M×1 vector of branch flows.
M - Number of branches.
b - M×M vector diagonal susceptance matrix.
A - M×N bus – branch incidence matrix. Starting and ending bus elements are 1 and -1 respectively. Otherwise 0.

5. Linear Programming

Linear programming is a mathematical model to accomplish the finest outcome [12]. This is one of the optimization techniques. It consists of linear objective function, subject to equality and inequality conditions. In the lossless DCOPF optimization problem is formed as a linear programming problem. In this paper, optimization problem is solved by linearized approach. Figure 1 explains the Solving procedure for optimal power flow with Linear Programming approach using LP solver.

6. Results and Analysis

The proposed LP method simulation were developed using MATLAB 7.10 software package and the system configuration is Intel Core i3-2328M Processor with 2.20 GHz speed and 2 GB RAM. For simulation work two test systems IEEE 14 and IEEE 30 bus systems are considered. The computational results obtained from the test systems are analyzed for line outage, generation outage, transmission and generator congestion. Generator offer price is calculated by the linear bid function. Linear bid function is given by the Equation (10).

$$C_i(PG_i) = a_i + b_iPG_i + c_iPG_i^2 \ (\$/hr) \qquad (10)$$

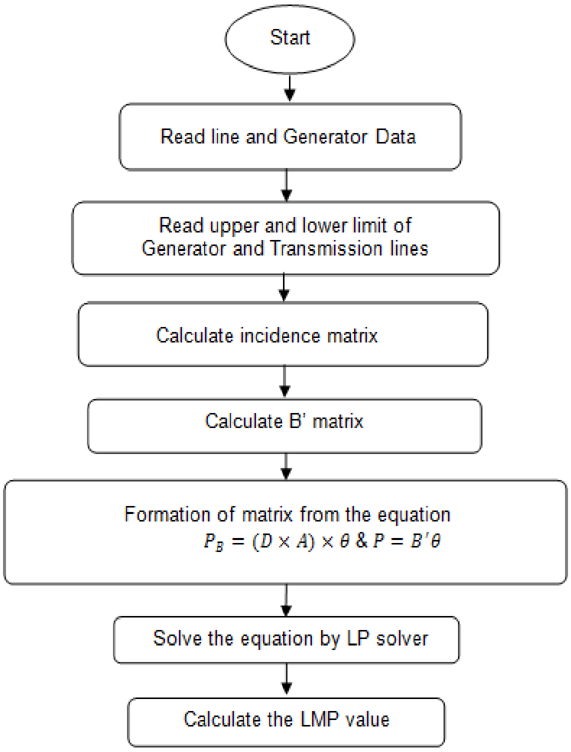

Figure 1. Flow chart for LMP calculation using linear programming

6.1. Case study – IEEE 14 Bus System

IEEE 14 bus system consists of 20 lines and 14 buses. Line and generator data's are used for the simulation work. Line data consist of sending and receiving end bus, line resistance, Line reactance, half susceptance and transformer tap ratio. Two test cases LMP values under normal system condition and LMP values under transmission congestion condition are analyzed in this model.

Table 1. LMP values under normal Condition in IEEE 14 bus system

Bus. No	LMP ($/MWhr)	Bus. No	LMP ($/MWhr)
1	107.45	8	107.45
2	107.45	9	107.45
3	107.45	10	107.45
4	107.45	11	107.45
5	107.45	12	107.45
6	107.45	13	107.45
7	107.45	14	107.45

Table 2. LMP values under transmission congestion in IEEE 14 bus system

Bus. No	LMP ($/MWhr)	Bus. No	LMP ($/MWhr)
1	107.455	8	272.99
2	47.615	9	279.859
3	161.532	10	281.827
4	259.948	11	293.707
5	330.756	12	303.943
6	306.010	13	302.329
7	272.99	14	289.683

LMP under normal system condition is calculated using Lossless DCOPF. In this case, simulations are carried out under normal test system data's and the obtained LMP values are given in the Table 1. Congestion is created in the 5th transmission line by reducing the power flow upper limit from 45 MW to 0.772 MW.LMP values under congestion condition is presented in the Table 2.

From the Table 1 & 2 it can be inferred that LMP values under normal condition is same as that of all buses. But in case of congestion occurred LMP values vary from location to location.

6.2. Case Study – IEEE 30 Bus System

IEEE 30 bus system consists of 41 lines and 30 bus system. It has 9 generating unit. In this test system four test cases like LMP values under normal system condition, Transmission congestion, generator and line outage conditions are studied.

Table 3. LMP values under normal condition in IEEE 30 bus system

Bus. No	LMP ($/MWhr)	Bus. No	LMP ($/MWhr)
1	236.71	16	236.71
2	236.71	17	236.71
3	236.71	18	236.71
4	236.71	19	236.71
5	236.71	20	236.71
6	236.71	21	236.71
7	236.71	22	236.71
8	236.71	23	236.71
9	236.71	24	236.71
10	236.71	25	236.71
11	236.71	26	236.71
12	236.71	27	236.71
13	236.71	28	236.71
14	236.71	29	236.71
15	236.71	30	236.71

Table 4. LMP values under transmission congestion condition in IEEE 30 bus system

Bus. No	LMP ($/MWhr)	Bus. No	LMP ($/MWhr)
1	236.71	16	236.22
2	236.44	17	235.82
3	237.59	18	236.12
4	237.77	19	235.97
5	235.67	20	235.89
6	234.91	21	235.67
7	235.23	22	235.68
8	234.92	23	236.11
9	235.40	24	235.76
10	235.65	25	235.48
11	235.40	26	235.48
12	236.62	27	235.30
13	236.63	28	234.96
14	236.49	29	235.30
15	236.38	30	235.30

Table 5. LMP values under Generator outage condition in IEEE 30 bus system

Bus. No	LMP ($/MWhr)	Bus. No	LMP ($/MWhr)
1	248.31	16	248.31
2	248.31	17	248.31
3	248.31	18	248.31
4	248.31	19	248.31
5	248.31	20	248.31
6	248.31	21	248.31
7	248.31	22	248.31
8	248.31	23	248.31
9	248.31	24	248.31
10	248.31	25	248.31
11	248.31	26	248.31
12	248.31	27	248.31
13	248.31	28	248.31
14	248.31	29	248.31
15	248.31	30	248.31

Table 6. LMP values under line outage condition in IEEE 30 bus system

Bus. No	LMP ($/MWhr)	Bus. No	LMP ($/MWhr)
1	236.72	16	233.95
2	236.75	17	233.7
3	236.61	18	233.46
4	236.59	19	233.50
5	236.83	20	233.52
6	236.92	21	232.80
7	236.88	22	232.55
8	94.6	23	231.69
9	234.74	24	229.43
10	233.59	25	220.93
11	234.74	26	220.93
12	234.2	27	215.55
13	234.20	28	205.32
14	233.74	29	215.55
15	233.39	30	215.55

Simulation is carried out on IEEE 30 bus system under normal system condition and the test results are tabulated in the Table 3. Congestion is created in the 7th transmission line that connecting bus 2 and 6 by reducing the upper limit of transmission line from 30 MW to 0.2 MW and the results are given in the Table 4. In addition to transmission constraint generator outage and line outage constraints also analyzed. For generator outage condition 9th generator placed in 30th bus is taken as a outage generator and test results are tabulated in the Table 5. For transmission line outage condition 10th line that connects the bus 6 and 8 is considered as a outage line and simulation results are given in the Table 6.

5. Conclusion

In a lot of restructured energy markets, the Locational Marginal Pricing acts as an important position in recent times. LMP is looks set to be the most popular congestion management technique adopted by electricity markets around the world. To understand the determination of LMP Lossless DC Optimal power Flow is carefully analysed which is the proposed technique in this paper. Constraints like transmission, generation and transmission line outages are used to analyze the market participants about the location value of electricity. LMP also used to maintain the stable operation of transmission system without affect the buyers and sellers in the market. LMP act as a true price signals for adding transmission capacity, generation capacity and future loads. It achieves its unique ambition of better effectiveness of power system operations in the short-term operational time frames by openly addressing the effects related with power transmission above the interconnected grid. We can extend our work with higher bus system and adding more constraints to our problem. Instead of DC-OPF, AC-OPF can be used to solve the power flow problem.

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