₹ 200 ISSN - 2249-555X

Volume : 1 Issue : 6 March 2012

Journal for All Subjects

www.ijar.in

Listed in International ISSN Directory, Paris.

ISSN - 2249-555X

Indian Journal of Applied Research

Journal for All Subjects

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Volume : 1 | Issue : 6 | March 2012 ISSN - 2249-555X

Research Paper Engineering

Uniform Price Electricity Market Model in Deregulated Power System

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ABSTRACT

The main objective of the power sector deregulation process is more choices available to the customers and to reduce electricity costs to the customers. The market models are able to facilitate competitions among generators, calculate total generation costs, market clearing prices, costs of system securities, etc. Nodal pricing is a pricing system for purchasing and selling electric energy in deregulated power systems. It takes into account bid prices for generation, the flow of power within the transmission system and power transfer constraints. In order to maximize the social welfare in pool market, the elasticity of the demand is assumed. The customer benefit here can be defined as the benefit that customer receive from consuming the electricity and supplier benefit from selling the electricity in the pool market. The benefits can be calculated from the supply and demand curve and Market Clearing Price (MCP). Here MCP is the considered single price for all the market participants. The proposed work is tested on four areas, 48-bus System.

Keywords : Electricity Market, Locational marginal Pricing, Market Clearing Price (MCP), Uniform Price Market, End User Price, Electricity Market Model

I. INTRODUCTION

The first step in deregulation process is separating the generation, transmission and distribution. Then, competitiveness is introduced in generation and distribution activities. Transmission congestion is a restriction on the flow of power across a transmission system; this power flow, if not restricted, would cause one or more branches within the system to exceed certain technical limits (thermal, voltage, stability or short circuit) under certain conditions.

A nodal price in an LMP system is the incremental increase in total system cost associated with supplying the next increment of load at a specific location or bus. In a constrained system, the next increment of load at a given bus is typically supplied by adjusting the output of more than one generator, each contributing to the load in a ratio dictated by the physical attributes of each system and the location of the bus relative to other elements in the system. Typically, the output of some generators must be decreased when the output of other generators is increased, to prevent the flow on constrained lines from exceeding the constraint. When there is no transmission congestion on an electric system, the cost of serving the next increment of load at any location within the system is the bid price of the next unit in the order of economic dispatch. If there is congestion, the next least-cost generator in the system cannot serve incremental loads at certain locations. As a result, system generation cannot follow economic merit order, and prices at various locations within the system diverge. Generators pay the nodal price and loads pay the nodal price, with the difference being the congestion charge. Owners of firm transmission rights or congestion revenue rights, get a credit equal to the congestion charge which can be used as a financial hedge. Load-serving entities that do not have firm transmission rights must either purchase firm transmission rights or pay the congestion charge. Transactions that cause the most congestion pay the highest price. Therefore, there are incentives to make the most efficient use of the system. The components of LMP[10] are

LMP = Generation Marginal Cost + Transmission

Congestion Cost + Cost of Marginal Losses.

There are three main forms of Deregulated electric power industry differs in each country and among various regions in the United States. The forms are the Optimal Power flow model, the price area based model and the transaction based model. Here Optimal Power Flow model is considered.

II. INDIAN ELECTRICITY MARKET MODEL

The restructuring was started by inviting IPPs in its limited competitive market. In 1992, the generation and transmission were separated and Power Grid Corporation of India Limited (PGCIL) was entrusted with transmission network for its better co-ordination. The unbundling of generation, transmission and distribution at state level saw privatization of distribution in some states. In 1998, Central Transmission utility (CTU) at national level and State Transmission utilities (STUs) were formed. Private sector can now invest in all the three areas of generation, transmission and distribution [1], [2], [3].

TSO (Transmission System Operator) as prevalent in Europe and other Asian countries is found suitable for India. It is because the main transmission company is government owned and will be effective in providing non-discriminatory open access and is solely responsible for planning and developing the transmission system which was found operationally and financially effective. ABT adopted by system operator for load dispatch function was found effective in maintaining nominal system voltage profile and frequency [2], [3].

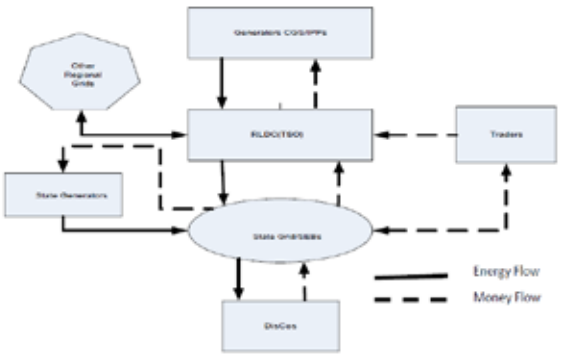

Figure 1: Current Indian Power Market Structures

It is felt gainful experience from wholesale market should be used to form competitive market at retail level which they find bit immature for Indian Power industry at present [2], [3].

The Power system is divided into four areas at least including one generating unit in each area from the major existing generation plants in the country. Each area is assumed to be interconnected to each other. Each area has its own demand and supply.

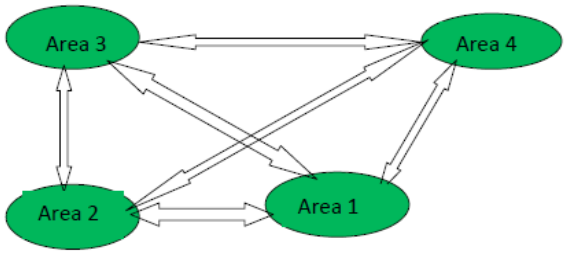

Figure 2: Power Market Areas

III. CALCULATION OF END USER PRICE

A. Determination of generation price

The Total cost of supply includes Operating and Maintenance (O&M) Cost, Depreciation, Return on Fixed Asset, Power Purchase and fuel cost for electric generation, cost f losses and non-payment of electricity bills, cost of working capital and regulatory fees, duties or levies that the licensee is liable to pay. The total cost of Licensee in any year as determined by is determined by Authority as:

$$TC = OM + DEP + RoA + RoWc$$

Where,

$$RoA = WACC \times NA$$

$$RoWC = WACC \times \left[REV \times \frac{ARREARS}{365} + INVENTORIES\right]$$

$$WACC = CoE \times \left(\frac{1-Gearing}{1-Tax}\right) + CoD \times Gearing$$

$$REV = OM + DEP + RoA$$

B. Determination of Average Cost of Supply

The Average Cost of supply is taken as the ratio of discounted annual cost of supply to the discounted energy volumes, with discounting applied over the Tariff Period using the WACC as given below,

$$AC = \frac{\sum_{n=1}^{TP} \frac{TC_n}{((1+WACC)^n)}}{\sum_{n=1}^{TP} \frac{ENERGY_n}{(1+WACC)^n}}$$

$$ENERGY = \sum_i ENERGY_i \times (1 - Aux_i) \times AVAIL_i$$

C. Determination of Royalty Price

The Royalty Price is the average cost of supply lesser than the ratio of discounted subsidy amounts to the discounted royalty energy, with discounting applied over the tariff period using the WACC and is as below:

$$RP = AC - \frac{\sum_{n=1}^{TP} SUB_n / (1+WACC)^n}{\sum_{n=1}^{TP} ROYALTY_n / (1+WACC)^n}$$

Any energy delivered by the Generation Licensee to a Distribution Licensee above the Royalty Energy is termed Additional Energy and the price of additional energy is equal to Average Cost.

D. Determination of End User Price

Average price for each customer group that is determined by the authority in its price reviews according to the provision of regulation,

$$\mathbf{AP_c} = \frac{\sum_{n=1}^{TP} \mathbf{COST_{c,n}} / \mathbf{(1+WACC)^n}}{\sum_{n=1}^{TP} \left(\mathbf{SALES_{c,n}} \times \mathbf{COLL}\right) / \mathbf{(1+WACC)^n}}$$

Where, Cost of supply for a customer group can be calculated as:

$$\mathrm{COST_c} = (1 + \mathrm{LOSS_c}) \times \mathrm{PPP} \times \mathrm{SALES_c} + \mathrm{IP} \times \mathrm{IMPORT} \times \mathrm{IMALLOC_c}\ (\mathrm{NETWORK_c}) + \mathrm{WC_c} - \mathrm{REV_c} - \mathrm{SUB_c}$$

Annual Network cost allocated to each customer group can be calculated as:

$$\mathrm{NETWORK_c} = \mathrm{WACC} \times \sum_i [\mathrm{ASSET_i} \times \mathrm{AALLOC_{i,c}}] + \sum_i [\mathrm{DEP_i} \times \mathrm{AALLOC_{i,c}}] + \sum_i [\mathrm{OM_i} \times \mathrm{OMALLOC_{i,c}}] + \mathrm{FEES} \times \mathrm{FALLOC_c}$$

Cost of working capital allocated to each customer group,

$$\mathrm{WC_c} = \mathrm{WACC} \times \mathrm{INV} \times \mathrm{IALLOC_c}$$

Power Purchase Price,

$$PPP = \frac{\sum_i [AP_i \times DOMESTIC_i]}{\sum_i DOMESTIC_i}$$

IV. UNIFORM PRICE MARKET

A. Single Auction Market

It is adopted in country like Australia and UK where the load forecast every five minutes is used to clear the quantity of supply bids in pool market [4]. As increasing power demands, in this proposal, complete market models for competitive generators are developed and tested using Power World Simulator [12].

Here only the Generation Companies submit their offers and it is stacked in increasing order of their bidding price. The demand is just a total aggregate load forecast. The market clearing price is obtained at the intersection point of demand forecast and the supply bid curve. The objective function to maximize social welfare in this case would be concerned with

lowering of cost of generation. As such it can be written as [5], [9], [11]:

$$Minimize, J = \sum_{i=1}^{n} BPS_i \times P_i = \sum_{i=1}^{N} f_i\ (P_i)$$

$$\text{S.t.} \quad \sum_{i=1}^{n} P_i - PD = 0,$$

This is demand-supply balance.

Where, BPSi is the Generation Companies true marginal cost or bid cost of Generation Company i.

B. Double Auction Market

In double Auction market both suppliers and buyers bid to sell and buy from the market pool. The supply bid is stacked in increasing order of its bid prices and buyers price in decreasing order of its bid prices. The system price or the market clearing price is obtained from the intersection of supply and demand curve. In this kind of market the demand cleared is variable [6],[7]. The double auction market in Fig. 3 is constructed assuming marginal price at load bus as demand bid price.

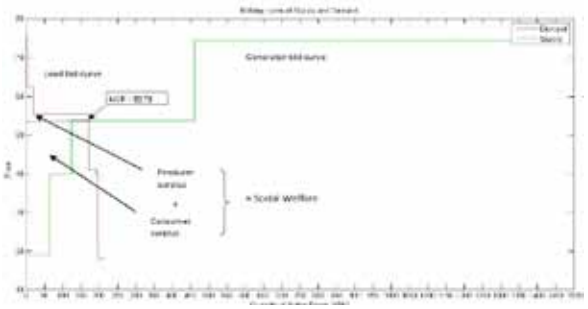

Figure 3: Demand-Supply curve and MCP in Double Auction Market.

The objective function of social welfare maximization based on Nodal price can be written as follow [8]:

C. Day-Ahead Market simulation for Uniform Price Market

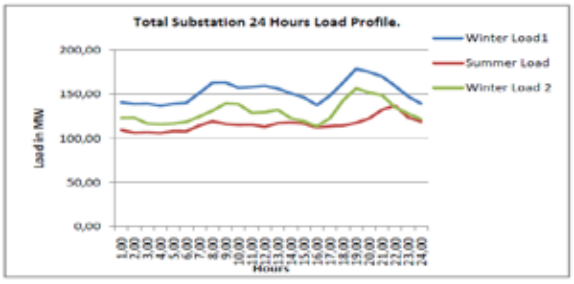

Figure 4: Twenty four Hours Load duration for Total Substation

The peak load is taken as base load to normalize the 24 hours load profile. The result is a normalized profile as given in below.

Figure 5: normalized load profile.

The hourly market is simulated using the load profile in Fig. 4 & Fig. 5.The Market Clearing Price (MCP) is obtained for d peak and minimum load of 136.84 MW and 81.539 MW respectively as shown in Fig. 7.

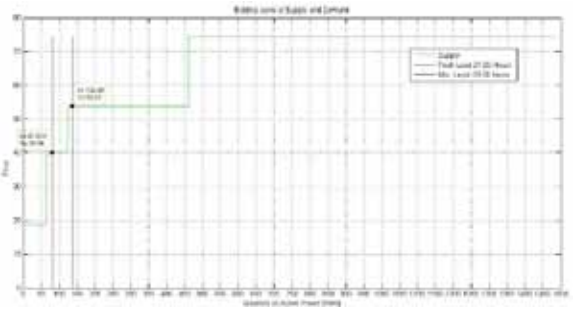

Figure 6: MCP for one hour (uniform market pricing)

Similarly clearing for all other hourly load, we get the hourly price profile as shown in Fig. 7.

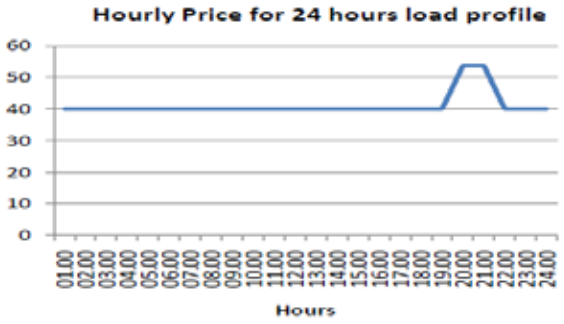

Figure 7: MCP profile for 24 hours (Uniform market price)

APPENDIX

- TC is the total cost of supply
- OM is the allowance for operating and maintenance costs including any regulatory and other fees.
- DEP is allowance for depreciation of assets.
- RoA is return on fixed assets.
- WACC is the weighted average cost of capital
- NA is the net value of all the fixed assets at the start of the year.
- RoWC is the return on working capital
- ARREARS is the allowed days receivables, in days
- An INVENTORIES is the allowance for the inventories.
- COE is the cost of equity in % determined by BEA.
- Gearing ratio is the standard ratio of debt to total fixed assets, as determined by the Authority
- CoD is the cost of debt, as percentage, being the weighted average interest of Licensee's Loan.
- Tax is the prevailing rate of company taxation, as a percentage.
- AC is the average cost of supply for the Licensee
- TP is the number of years in the Tariff period.
- TC_n is the total cost of supply in year "n"
- $ENERGY_n$ is the energy volume in year "n".
- ENERGY is the annual energy volume in any year, in GWh
- $ENERGY_i$ is the design energy, in the case of hydropower, or expected energy production, in the case of thermal plant, for plant "i"
- AUX_i is the allowance for auxiliary consumption at plant "i", as percentage
- $AVAIL_i$ is the station availability allowance for plant "i", as percentage
- RP is the Royalty Price per kWh.
- SUB_n is the subsidy amount in year "n".
- $ROYALTY_n$ is the amount of Royalty Energy in year "n".

- $ASSET_i$ is the net historical value of assets in asset category "i"
- DEP_i is the depreciation allowance for assets in asset category "i"
- OM_i is operating and maintenance allowance for cost category "I"
- FEES is the allowance for fees and levies.
- $AALLOC_{i,c}$ is the allocation factor to Consumer category "C" for asset-related costs in asset category "i", as percentage, where $\sum_c AALLPC_{i,c} = 1$
- $OMALLOC_{i,c}$ is the allocation factor to customer "C" for O&M in cost category "i", as percentage, where $OMALLOC_{i,c} = 1$
- FALLOCC is the allocation factor for fees, as a percentage, where $\sum_c FALLOCC_{i,c} = 1$
- $IALLOC_c$ is the allocation factor to customer category "C" for inventories, as percentage $\sum IALLOC_c = 1$.
- INV is the allowance for the value of inventories.
- AP_i is the additional price for generator "i".
- $DOMESTIC_i$ is the volume of electricity supplied to the Licensee by generator "i" in GWh.
- IP is the average import price per kWh.
- REV_c is the estimated Non-Tariff revenue for the year arising from customer group "C".
- $SALES_c$ is the sales for the year attributed to customer group "C" in kWh.
- $LOSS_c$ is sum of technical and commercial loss allocated to customer group "C" , as a percentage.
- SUB_c is amount of subsidy allocated to customer group "C".
- COLL is the target collection rate set by the Authority for the Licensee, as percentage.
- $COST_{c,n}$ is the cost if supply allocated to customer group "C" in year "n".
- $SALES_{c,n}$ is the volume of electricity sales expected from customer group "C" in year "n" in GWh.

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Printed at Unique Offset, Novatsing Rupam Estate, Opp. Abhay Estate, Tavdipura, Shahibaug, Ahmedabad