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Modelling and Analysis of Deregulated Electricity Market Operations

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Abstract*: Deregulation in power industry is restructuring of the rules and economic incentives that government set up to control and drive the electrical power industry. Restructuring in electricity industry will create new business opportunities where new firms selling new products and services will appear, consumers will have alternatives in buying electricity services, and new technologies such as metering and telecommunication devices will develop. Bidding by participants is one of the major challenges. To overcome this issue, strategic bidding models are being developed based on market structure, auction rules and bidding protocols. This paper proposes to formulate an optimal bidding strategy algorithm for DisCos and analyze its impact in the market operations. The bidding optimization is aimed at developing bids that get selected in the market operations and simultaneously maximizing the total profit of DisCos and minimizing power imbalances. Power Exchange market, which is simple yet enables competition, will be considered. This is proposed to be done using MATLAB coding and Genetic Algorithm tool box. Multiple simple bids are modeled. Power imbalance for each of the possible cases is computed. Decision variables (L_1,L_2,L_3) and (C_1,C_2,C_3) are used in order to compute objective functions i.e. Minimization of Power imbalances and maximization of profit, using MATLAB coding and GA tool box.

Index Terms*: Distribution company, Market Clearing Price, Power Exchange, Genetic Algorithm.

I. INTRODUCTION

During the nineties, many electric utilities and power network companies world-wide have been forced to change their way of operation and business, from vertically integrated mechanisms to open market systems. For many decades, the integrated Electric power utilities have their own policy in selling, controlling and distributing Electric power to their customers. Each utility manage the main components of power system Genco, Transco and Disco

The reason for change in structure of power system and electricity utility are high demand growth coupled with inefficient system management and irrational tariff policies.[3]

To implement competition, vertically integrated utilities are required to unbundle their retail services into generation, transmission and distribution, generation utilities will no longer have a monopoly, small businesses will be free to sign contract for buying power from cheaper sources, and utilities will be obligated to deliver or wheel power over existing lines for a fee that is the same as the cost (non-discriminatory) of delivering the utility's own power without power production costs. The restructuring of electric power will significantly reduce the cost of power charged to small businesses and consumers. The cost of electricity generation will be reduced by driving prices through market forces and more competition. Deregulation in power industry is restructuring of the rules and economic incentives that government set up to control and drive the electrical power industry. Restructuring in electricity industry will give an opportunity for new start ups to sell new products and new technologies such as metering and telecommunication devices.[2]

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II. MARKET MODELS

Three major Power Market Model available in Electricity Power Market are:

- PoolCo Model
- Bilateral Contracts Model
- Power Exchange Model

Elements of a certain electric power industry define the nature of competition and models or institutions that support the competition process. Modeling of Deregulated Electricity Market varies based on Power Market Model. Even though the three market models seem different in approach to guarantee competition, several features are common to all three. Some of these features are competition among generation providers, continued regulation of monopoly in transmission and distribution functions, and establishment of a vertically integrated entity responsible for operating the transmission grid and maintaining the security of power system. The role of this vertically integrated entity could differ from model to model.

A. Poolco Model

This model is centralized where buyers and sellers can exchange the bids and prices for the electric power. They submit the bids and prices into this centralized market pool for the amounts of energy they wish to sell or buy. The International standard societies will anticipate the demand for the forthcoming days. They receive bids at the lowest cost based on the demand. The important feature of the PoolCo model is the founding of power pools served with interconnected transmission systems.

This pool serves as a centralized place for trading electricity instead of going with generation companies. The company sell power at a market clearing price (MCP) defined by the PoolCo, instead of a price based on the generation cost.

B. Bilateral Contracts (Direct Access) Model

The Bilateral Contracts model differ from two main characteristics when compared to PoolCo model. The two characteristics are limitations in the ISO's role and negotiations can be done directly in the marketplace. In this model, small customers' aggregation is essential to ensure that they would benefit from competition.

In this model transparency is there between customers and generators without entering into the pooling arrangements, so it is called as Direct Access Model. As the name implies, the customers are free to contract directly (bilaterally) with power generating companies. By fixing an appropriate access and pricing standards, the utility wires are not used for power transmission and distribution from the customer side. Under this model, a single centrally dispatched regional power pool is not obligatory as under the PoolCo Model.

C. Power Exchange (Px) Market

Power Exchange market combines the various features of the above two models. The PX model Suits where decentralized markets exist, with deregulated environment. PX Market is being used in India. In Power Exchange Market generation companies put their bids and pricing in the power market. Similarly, distribution companies also put their buying bids along with price. Based on Market Clearing Price (MCP), ISO will select the selling bids given by GenCos and buying bids proposed by DisCos. There will be no discrimination in the Power Exchange Market. Here Power Exchange Market is considered for the modelling and analysis of bids proposed by DisCos.

InPX market there is tough and healthy competition among different power operating bodies.

PX, as sometimes called, spot price pool permits different participants to sell and buy energy and other services in a competitive way based on quantity bids and prices. Power Exchange (PX) is a new independent, non-government and non-profit entity which accepts schedules for loads and generation resources. It provides a competitive marketplace by running an electronic auction where market participants buy and sell electricity and can do business quickly and easily. Through an electronic auction, PX establishes an MCP for each hour of the following day for trades between buyers (demands) and sellers (supplies). As a main objective in its work, PX guarantees an equal and non-discriminatory access and competitive opportunity to all participants.

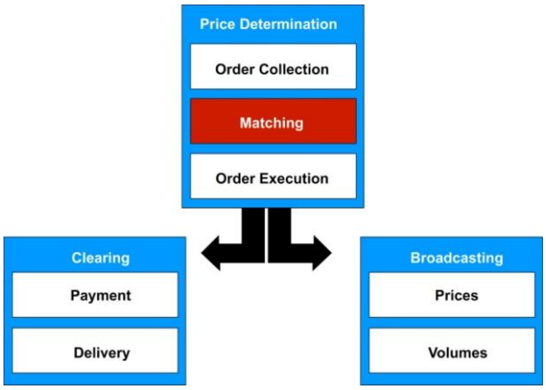

Fig A Functions of PX Market

III. BIDDING STRATEGIES

Ideally, in electric power markets the bidding should be very close to the marginal cost to gain profit. However, the competition in the electric power market is not good due to the lack of producers, so suppliers bid higher than the marginal cost. [4]If a supplier bids more than the production cost to gain more profit the behavior is called strategic bidding. [6]

The challenges faced due to strategic bidding by the individual supplier are demand variation, generator cost characteristic, rivals bidding behavior, operating and regulatory constraints. So they develop bidding strategy to increase the profit, accounting production costs and constraints, rivals' bidding behavior and market policy. In this project minimization of power imbalances along with maximum possible profit is proposed. In a common market clearing price system the revenue collected from the consumer is high compared to the price paid to the generators. This is due to the selection of expensive bid to avoid transmission overloading.

IV. MODELLING OF BIDDING STRATEGIES

Deficit power is submitted as bids in competitive market. Bidding problem formulation depends upon the market model, type of bidding protocol, and auction mechanism and estimation technique of rivals' bidding behavior.[5] Aim of Strategic biddings to construct best optimal bid knowing their own costs, technical constraints and their expectation of rival and market behavior.

In this project optimal bidding strategies involves the following two major objectives:

- ➢ Minimization of power imbalance
- ➢ Maximization of profit for DisCo

Minimum power imbalances can be achieved when there is selection of most of the multiple simple bids proposed by DisCo in the Power Exchange Market.[1] For selection of most number of bids in PX market the bidding price should be given higher than that of Market Clearing Price (MCP). However, selection of costly bids of DisCo leads to low profit. Zero Power Imbalance can be achieved at the cost of minimum possible profit for DisCo. To achieve an optimal compromise between the two contradicting objectives, bidding optimization is performed.

Decision and Control variables of optimal strategic bids formed for DisCo are Quantity of electric power in the form of bids (L_1, L_2, L_3) Price of multiple simple bids (C_1, C_2, C_3). This is proposed to be solved using Genetic Algorithm (GA).

V. ANALYSIS OF DEREGULATED MARKET OPERATIONS

In the day-ahead market and for each hour of the 24-hour scheduling day, sellers i.e. GenCos bid a schedule of supply at various prices, buyers i.e. DisCos bid a schedule of demand at various prices, and MCP is determined for each hour. Then, sellers specify the resources for the sold power, and buyers specify the delivery points for the purchased power. PX schedules supply and demand with the ISO for delivery.

Supply and demand are adjusted to account for congestion and ancillary services and then PX finalizes the schedules.[7]

The hour-ahead market is similar to day-ahead, except trades are for 1 hour, and the available transfer capability (ATC) is reduced to include day-ahead trades, and bids are not iterative in this market. Once the MCP is determined in the PX, market participants submit additional data to the PX. The data would include individual schedules by generating unit; take out point for demand, adjustment bids for congestion management and ancillary service bids. After this stage, the ISO and the PX know the injection points of individual generating units to the transmission system.

VI. MARKET CLEARING PRICE (MCP)

To determine the MCP in a trading day the PX receives the supply and demand bids for each 24 periods. The cumulative supply and demand bids are validated through the energy supply curve and energy demand curve.[8] The intersection of the two curves determines the MCP in all trades. The design of the generator is determined by the operating cost since bidding lower will lead to financial loss. If MCP is less than the operating cost and bidding high will lead to the units run less frequently or to stop. For GenCo MCP≥ bid selected and for DisCo MCP≤ bid selected.

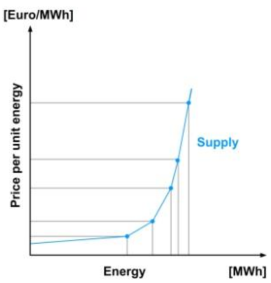

Fig B Supply Curve

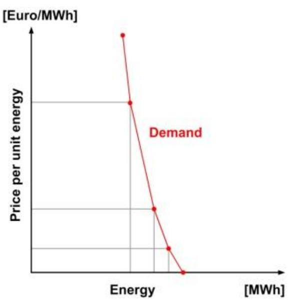

Fig C Demand Curve

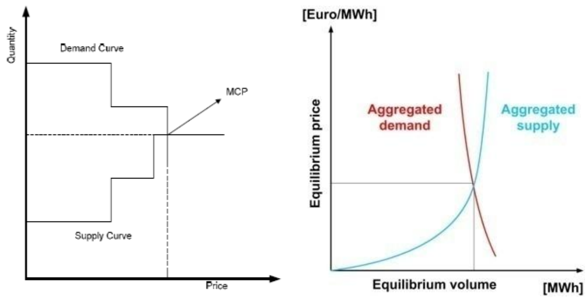

Fig D MCP Curve

VII. SELECTION OF PROPOSED BID(S) IN THE MARKET

A. Bids Proposed

In power Exchange Market, GenCos i.e. sellers bid a schedule of supply at various prices, DisCos i.e. buyers bid a schedule of demand at various prices, and MCP is determined for each hour. In this project three simple bids are proposed for DisCos.

Table A Proposed Bids in the PX market

GenCos		DisCos
1Quality of Power 2Price of Bids 3Load Scheduling time	PX Market	Bids Proposed by other buyers
		Proposed bids of Our DisCo 1.Amount of Power imbalance 2.Price of each Bids formed

For any DisCo,
Total Load Demand (TL) = 100 MW
Total Load Met (TLM) = 70 MW
Power Imbalance = TL-TLM -- 1
= 100-70 MW
= 30 MW

Now, this Power Imbalance (P_{imb}) will be proposed in form of multiple simple bids in the Power Exchange Market. Power Imbalance will be proposed in three bids as follows:

Bid = [L_1, C_1; L_2, C_2; L_3, C_3]
L_1=Load demand of Bid 1
L_2=Load demand of Bid 2
L_3=Load demand of Bid 3
C_1= Price of Bid 1
C_2=Price of Bid 2
C_3= Price of Bid 3

Power Imbalance = sum of loads of all multiple simple bids

$$P_{imb} = \sum_{i=1}^{3} L_i \qquad \text{-- 2}$$

When there will be minimum power imbalance, profit of DisCo will be minimum. It means in order to form multiple simple bids in such a way that most of them get selected by PX market, Price of Bids should be higher than the MCP. In such case profit will be less. This project aims to form strategic bids for Disco in order to achieve minimum power imbalances along with maximum profit.

B. Cases of Bids Selection

There are mainly three cases of bid selection:

1. ***Selection of single Bid:***

Out of proposed three bids any one bid may get selected. Selection of only one bid in the PX market produces maximum power imbalances. Selected bid may be first bid, second bid or third bid.

Power imbalance $_{New}$ = Power imbalance $_{old}$ – selected bid's power.

2. *Selection of double Bids:*

Selection of any two bids out of three proposed simple bids produces low or minimum power imbalances. Selected bids may be first and second bids, second and third bids or first and third bids.

Power imbalance $_{New}$ = Power imbalance $_{old}$ – selected any two bids' power

3. *Selection of all three proposed simple Bids:*

Selection of all three proposed simple bids produces zero power imbalances. It means all the required loads are met for DisCo.

Power imbalance $_{New}$ = Power imbalance $_{old}$ – sum of power of all three bids

Power imbalance $_{New}$ = 0 MW.

Total Load Demand = Total load Met

Selection of all the three simple bids may give rise to least profit for DisCo.

VIII. OPTIMIZATION OF BIDS PROPOSED

After calculating Market Clearing Price (MCP), we formed DisCos Bids in such a way that at least one of the multiple simple bids gets selected in the electricity market operation. In case of optimization some parameters are set between predefined limits. Typically, we look for the minimum or the maximum of the objective function(s). In this project we have two objective functions; we call it Multiple Objective Optimization- MOO. In the competitive electricity market, we face mainly the MOO, e.g. the optimization of bids proposed by DisCo.

Nowadays dozens of tools stay at disposal to solve the large optimization tasks by computer. In this project, we look for min power imbalance and max of a profit function taking into account constraints.

Power imbalance was minimized using MATLAB[9] coding and Genetic Algorithm tool box.[11][12] We have considered three simple bids. Power imbalance was computed as follows:

a) Compute P_{imb} for all possible cases. Here there are total seven cases.

b) Objective function for GA is minimum Sum of P_{imb}. Decision Variables are L_1, L2, and L3.

c) Maximization of total profit of DisCo. Decision Variables are C_1, C_2, and C3.

IX. OPTIMIZATION PARAMETERS

A. Objectives

1. Optimization of Minimum sum of Power imbalance and
2. Optimization of Maximum profit for DisCos.

B. Decision Variables

1. Total load demands in form of bids (L_1. L_2, L_3)
2. Cost price of loads in form of bids (C_1, C_2, C_3)

C. Constraints

Here we are not considering nonlinear constraints, transmission losses, service charges, penalty factor etc.[13] However linear constraint is considered as follows:

Sum of Power Imbalances = Sum of total demands of bids

Bids should be formed in such a way that at least one of the bids gets selected in the power market.

For GenCos MCP>= bid selected

For DisCos MCP<=bid selected

So DisCos should form their bids at price greater than the market clearing price (MCP). However high price bids may result in loss or low profit for DisCos.

X. RESULTS AND DISCUSSION

Strategic bidding optimization is performed using Genetic Algorithm toolbox. Market Clearing Price (MCP) is calculated using bidding data of generation companies (GenCos) and distribution companies (DisCos). Bids of DisCo are formed and proposed in power exchange (PX) market. Volume and price of each strategic bid is considered as decision variable.A set of bid data of the GenCos and DisCos participating in the market is initialized, to which the proposed DisCo bids are included.

Initially the power imbalance was aimed to be minimized using GA solver. The results obtained are shown.

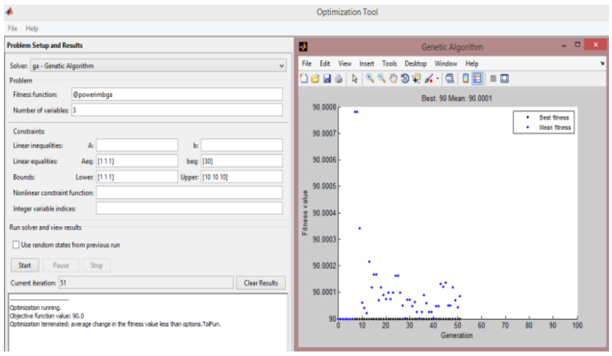

Fig E Best Fitness curve of minimization of power imbalance

The total cost incurred in the market is then simultaneously minimized along with the minimization of power imbalance using multi-objective GA solver.[10] The output obtained in this case is shown.

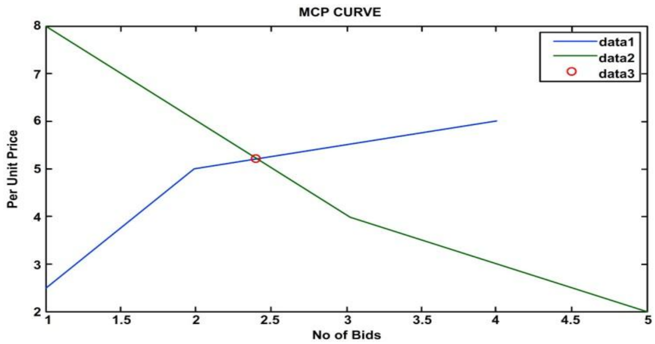

Fig F Pareto diagram of optimized output

XI. CONCLUSION AND FUTURE SCOPE

In this paper, strategic bidding optimization is performed using Genetic Algorithm toolbox in MATLAB working environment. Multiple simple bids are modeled and its impacts in the market operations are analyzed. Bids are formed for DisCo in such a way that at least one of the bids gets selected by Power Exchange (PX) Market. The volume and price of each bid is considered as a decision variable, to be varied by GA solver. Strategic bidding models are being developed based on market structure, auction rules and bidding protocols. Market Clearing Price (MCP) is determined by finding the intersection of GenCo and DisCo bid curve. The bidding optimization is aimed at simultaneously minimizing the total cost incurred in market operations and power imbalances. This is done using MATLAB coding and Genetic Algorithm tool box. The objectives were effectively minimized.

The work can further be extended by considering the volume of each bid in the computation of MCP, to improve the accuracy in bid analysis. The code can also be analyzed for real-time bid data from IEX website or any other power exchange.

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