DEVELOPMENT OF REAL TIME ENERGY MARKET IN DEREGULATED POWER SYSTEM

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Abstract: This paper focuses on the need of electricity market in deregulated power system and represents an auction based alternative day-ahead electricity market which focuses on minimizing customer's payment and increasing the social benefit. This is for pool based electricity market in which the different participating generators bids to sell their power at a particular price and distributors bid to buy the power, the bids are collected by ISO (Independent System Operator). The double auction model is based on determination of marginal price or it can be said as market clearing price on the basis of which it is decided whether the transaction is feasible or not. The market clearing price is the result of optimization process. In this paper IEEE 30 bus system is taken to implement the mechanism and numerical results obtained are used to calculate the profit obtained by an ISO (Independent System operator)

Keywords: Deregulation, Bidding, Auction, Marginal Price, ISO (Independent System Operator), Transactions

I. INTRODUCTION

In different processes of deregulation the market structure may be different but the ideas behind the processes were same. These ideas include separating of competitive function of the retail from the natural monopoly function of transmission and distribution and based on this wholesale electricity market and retail electricity market were established. Wholesale electricity market allows transactions between generators, retailers and other financial intermediaries both for the short term delivery of electricity and for future delivery periods. The existence of wholesale electricity market is governed by the competitive generators which offer electricity produced by them to retailers. The retailers again reset it prices and take it to the market. There are many drawbacks in buying wholesale electricity such as organization cost, setup fees, market uncertainty, collateral investment as electricity would be bought on daily basis. For an economically significant wholesale market to flourish, it is obligatory to consider no of criteria. A market that has "bid-constrained, security constrained, economic dispatch nodal prices".

The market price in a day-ahead market, is determined by matching offers from generator side and bids from loads or consumers at each point, so as to setup a marginal price usually on an hourly intervals. This marginal price is also called as market clearing price. These market clearing procedures are an essential requirement for the restructured power system. Within the structure of pool based electricity market the offers from the generator side and bids from consumers side are collected by an ISO for a particular time period. On the basis of marginal price it is made clear that which offers and bids are accepted for transactions.

The current electricity market solves the problem of unit commitment with the objective of not only minimizing generation cost but also focusing more on maximizing social benefit [1],

[2]. The total social benefit is a measure of social benefit which depends on the bids and offers are submitted by market participants. It is significant to note that if the demand is inelastic maximizing of social benefit is related to minimizing the cost of generation, and thereby leads to the problem of unit commitment which was present in the non-competitive market structure.

Efficiency of electricity market depends on how competitive is the market environment. as the present electricity market fails to be competitive under certain circumstances and as a consequence the actual cost may not be reflected by the generation offers and the social benefit may not be maximized by optimization or it may not be able to accurately model the bidding behavior of market. In addition, the generation scheduling is characterized by irregularities associated with the gen attempts generating units operation [1], [3] such as ramping rates, minimum generation limits and no loads and start-up offers. In [4] the computational challenge brought up by deregulation and attempts to address them through the introduction of OPF formulations and algorithms. A new optimization based algorithm has been proposed in [5] for assessment of feasibility of simultaneous bilateral and multilateral wheeling transactions. Several works have been done for customer payment minimization and to maximize the profit out of transactions. In [6] a comprehensive optimal model that dispatches the pool in arrangement with privately transferred bilateral and multilateral agreements while maximizing social benefit.

In several electricity market in US [7]-[9] unique strategies are currently implemented to reduce the effects of dishonest offering and market power abuse. For an instance, California ISO[8] and PJM [9] addresses market power linked up with transmission constraints depending on two measures which relates to the structure of electricity market; which are three pivotal supplier test and residual supply index.

The practical efforts which does not takes into account, non-existence of ideal market conditions, specific features of generation rescheduling plus the impact of maximizing social benefit; still leaves a question mark about the economic significance of current auction designs, as a consequence of which debate occurred [10], [11] and there are also some proposals to change the current electricity market structure, as proposed in [12]. These requirements for restructuring of that resulted in discovery of other market clearing procedures [11], and these can be categorized as specific instance of cost based market clearing [13], of these new procedures of market clearing minimization is studied broadly [11]. The market clearing prices act as decision variables in solving the problem.

This paper takes into account the transmission network for maximizing the social benefit. The market clearing prices are calculated by optimization method and adding the wheeling and transmission charges in the result of OPF. A new method of determining wheeling prices under a deregulated environment is proposed in [14], the proposed hybrid model is capable of handling generating plants with any type of cost characteristics without any approximation and can also analyze reactive power wheeling cost in addition to real power wheeling cost.

II. UNIFORM PRICE AUCTIONS

Basically auctions are divided into two types which are single sided auctions and double sided auctions.

Single sided auction: when we consider single sided auction for an inelastic demand. In this type of auction offers are ranked in an increasing order the beginning is done with the least expensive and it is continued till the demand is satisfied. Two limits are set in this type of auction these are First Rejected Offer (FRO) and Last Accepted Offer (LAO). The uniform price is set either as FRO or LAO. For a uninterrupted quantity product with block offers, excluding the exceptional case where the quantity dispels on a block margin, there is a marginal block which is somewhat accepted, as shown in Figure. This block is occupied as the last accepted block and its charge, the marginal price, resembles to the incremental cost of supplementary demand. In this case, the first rejected rate is occupied to be the price of the first fully rejected block. The price will always be

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greater than or it may be equal to all offers which are accepted and transaction is feasible and therefore accepted by all the selected suppliers, whether the uniform price is set by the LAO or the FRO.

Likewise, in a single-sided auction with bids to acquire an inelastic supply, bids are graded in falling order and accepted beginning with the highest and enduring until the supply is bushed. Again there are two pricing choices, last accepted bid (LAB) and first rejected bid (FRB), as shown in figure. In this method, the marginal cost will be equivalent to the last accepted bid. Both LAB and FAB results in a uniform price that is equal to or less than all accepted bids and therefore accepted by all selected buyers.

Two sided auctions: In this type of auctions, offers and bids are ranked as single sided auction. An equal quantity of each is accepted and the ranking begins with the lowest offer and highest bid and the process continues till either the supply or demand is exhausted or it can be said when offer price surpasses the bid price. Again, excluding for the exceptional case where the amount clears on a block borderline, there will be a partly accepted block and this is called as marginal block. This marginal block could be either an offer or a bid. The last accepted bid is greater than last accepted offer and the difference between two is called as bid offer gap.

A uniform price is set between this bid offer gap and it satisfies all buyers and sellers. The uniform price will be always greater than or equal to all accepted offers and it will be less than or equal to all accepted bids. FRO and FRB are not suitable for double sided auction as they do not yield prices, other than LAO and LAB there are many other valid pricing approach. For instance, the marginal or first price rule selects LAO or LAB, contingent which one is the marginal element. A split-the-difference rule employs the mid-point of the bid-offer difference by captivating the average of LAO and LAB. And, slightly similar to the first forbidden single-sided auctions, a second price rule could be intended as follows. If the marginal unit is a bid, set the price to the extreme of the LAO or FRB. Set the price to the minimum of the FRO or LAB.

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III. PROBLEM FORMULATION

This suppleness in the choice of uniform cost can be simplified to auctions that are resolved by \smart markets" that take into consideration externalities, such as an optimal power flow (OPF) used up to resolve a power market issue to network constraints.

When DC OPF is used to elucidate the problem of bilateral pool market, a set of nodal prices are developed λ_p^k for real power. These prices narrate to the incremental price (benefit) of supplementary demand (supply) at each node. In an uncongested communication network, these prices will be unvarying for DC and they will be equivalent to the value of the marginal or last accepted unit but for AC these nodal prices are non-uniform because of losses. If the marketplace is a single-sided auction with inflexible demand, the λ_p^k can be used unswervingly as the uniform price, resulting in LAO pricing. The value of the first disallowed block could also be used unswervingly to set a uniform price, as in a standard auction. Likewise, for two-sided markets, expending the λ_p^k unswervingly as the uniform price resembles to the first-price auction defined above, where the cost is defined by the marginal unit. Otherwise, the uniform price can be set equivalent to LAO, LAB or something else in between.

When congestion exists the nodal prices are no longer unvarying but change with location. The nodal prices signify the marginal worth of power at a site and can be used to calculate exchange rates for standardizing location precise charges, offers or bids to a reference position r. Meanwhile the marginal price of a single component of real power at bus k is λ_p^k and the similar component has a value of λ_p^r at bus r, some charge, offer or bid at bus k can be transformed to the correspondent at bus r by proliferating by an exchange rate of $\lambda_p^r / \lambda_p^k$.

Given the OPF description which stipulates the nodal prices laterally with which offers and bids are acknowledged and which are forbidden, these offers and bids can be standardized to a reference location r, then grade ordered as in a typical auction and the standardized uniform price can be elected directly conferring to the anticipated pricing rule (first-price, LAO, LAB, FRO, FRB, split-the-difference, second-price). Conversely, this uniform price only smears at the reference bus r. The corresponding price at bus k is bring into being by multiplying by the suitable exchange rate.

Likewise, an AC OPF can be used to resolve a smart market for real power. In the nonexistence of dispatchable loads with persistent power factor limitations, the exchange rates for a number of pricing rules can be considered in just the identical way as for the DC OPF. Without congestion, the AC OPF characteristically produces varying nodal prices due to presence of losses. Congestion in the form of obligatory line flow or voltage limits only upsurges the nodal price differences.

Though, as quickly as constant power factor dispatchable loads are involved, new difficulties are familiarized due to the combination of the real and reactive power. Even if the main purpose deals merely with real power, the AC OPF yields a set of nodal prices for both reactive power λ_q^k as well as real power λ_p^k.

IV. SOLUTION APPROACH

The main objective of this paper is developing a model of electricity market which may be able to provide the complete information of transmission and transaction of electricity. Bidding model of electricity is developed where generators set offers to sell electricity and loads bids to buy power at a particular rate in a particular interval of time. Now in AC both real and reactive power is present, as only objective function deals with real power, solution is to bundle real and reactive power and convert reactive power in terms of real power.

If a dispatchable load i is formed with a constant power factor, consequently the proportion of reactive to real power demand is a constant

$$k_i = \frac{q_D^i}{p_D^i}$$

then the real and reactive power intake of this load can be supposed of as a sole bundled product. The value of this product can be articulated on a per MW (or per MVAr) base. If this load is positioned at bus k and λ_p^k and λ_q^k are the values of real and reactive power, correspondingly, then the worth v of the bundled power is

$$\begin{aligned} v &= \lambda_p^k . p_D^i + \lambda_q^k . q_D^i \\ &= \lambda_p^k . p_D^i + \lambda_q^k k_i p_D^i \\ &= (\lambda_p^k + \lambda_q^k k_i)\, p_D^i \end{aligned}$$

In other words the price per MW of the bundled product is $(\lambda_p^k + \lambda_q^k k_i)$.). Likewise, the price per MVAr is $(\lambda_p^k / k_i) + \lambda_q^k$.

If α specifies a inclination to pay up to the similar amount for a assumed measure of the bundled product then α should lie in the middle of

$$\lambda_p^k < \alpha < \lambda_p^k + \lambda_q^k k_i$$

According to the above equation the bid will be accepted if the bundled bid exceeds the bundled price and it will be rejected if it is less than the bundled price. Therefore the exchange rates for bundled bid and bundled nodal prices are given as

$$X^{LAB} = min_i \frac{b_{pq}^{i,LA}}{\lambda_{pq}^{k(i)}}$$

$$X^{FRB} = max_i \frac{b_{pq}^{i,FR}}{\lambda_{pq}^{k(i)}}$$

If $p_D^{i,FR}$ and $q_D^{i,FR}$ are used to represent the amounts of real and reactive power at which the individual first rejected bid block instigates, then the last accepted and first rejected bundled bid charges used in above can be well-defined as

$$b_{pq}^{i,LA} = b_p^{i,LA} + k_i b_p^{i,LA}$$

$$b_{pq}^{i,FR} = b_p^{i,FR} + k_i b_q^{i,FR} \text{ if } k_i p_D^{i,FR} <= q_D^{i,FR}$$

$$= b_p^{i,LA} + k_i b_q^{i,FR} \text{ if } k_i p_D^{i,FR} = q_D^{i,FR}$$

$$= b_p^{i,LA} + k_i b_q^{i,FR} \text{ if } k_i p_D^{i,FR} => q_D^{i,FR}$$

Merging all of these factors yields the subsequent generalized formulations for the exchange rates are specified as:

$$X^{LAO} = \max\left(max_i \frac{o_p^{i,LA}}{\lambda_p^{k(i)}}, max_i \frac{o_q^{i,LA}}{\lambda_q^{k(i)}}\right)$$

$$X^{LAB} = \min\left(min_i \frac{b_p^{i,LA}}{\lambda_p^{k(i)}}, min_i \frac{b_q^{i,LA}}{\lambda_q^{k(i)}}\right)$$

V. NUMERICAL DATA

Market model have been developed by taking the example of IEEE 30 bus system. There are 6 generating units, 20 loads of which 17 are dispatchable and 3 loads are fixed and 41 branches. The load dispatched duration is considered to be one hour.

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VI. RESULTS

As the generators set offers to sell the power and loads set bids to buy the power. after the bidding process is stopped, by the OPF method market price at each bus is at that bus, than the transaction is considered feasible and is allowed. Similarly if the bid set by loads is less than the market price determined than the bid is accepted. After this the social benefit is calculated as a difference of total revenue and total cost. And that is ISO profit.

VII. CONCLUSION

This paper represents an efficient market model in deregulated power system which keeps the track of all transmission and transaction taking place in the network. This electricity model represents real time energy markets which not only provide profit for the ISO but also focuses on consumer payment minimization by providing the choice of suppliers and an efficient market price. It is a significant computational approach for present network-constrained day-ahead pool market. These approaches explicitly characterize the importance of marginal prices in the market development.

The research is currently underway to extend the work for development of website which can be accessed by the consumer/load as well as utility side which consist of information about all the transaction that are approved or failed. The proposed work will also extend to the information about ancillary services in auction and information about the available transfer capability (ATC) of generators.

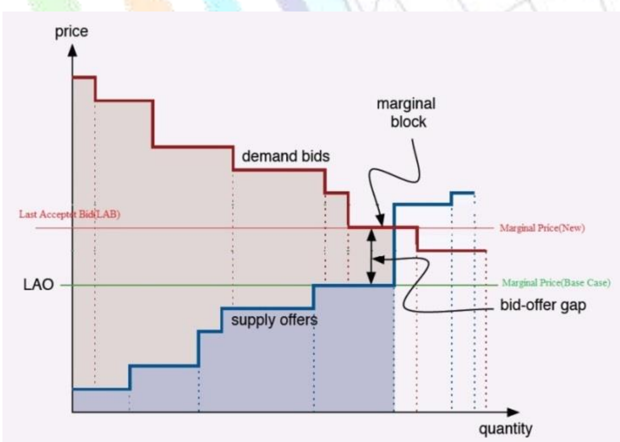

Figure: Double Sided Auction

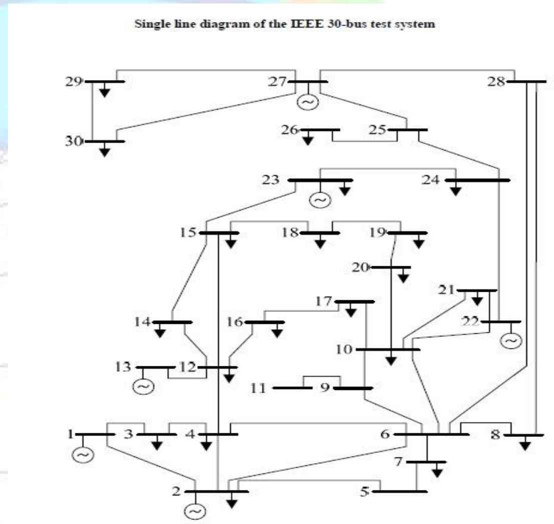

Figure: Single line diagram of ieee-30 bus system

Table I: Auction Data for Generators

Generator Offers	MW@Rs/MWh
1	36@20
2	48@25
3	50@35
4	40@30
5	55@40
6	60@50

TABLE II: Auction Data for 17 Dispatchable Loads

Load Offers	MW@Rs/MWh
1	26@70
2	15@41
3	16@42
4	17@43
5	18@44
6	19@45
7	20@46
8	21@47

9	21@55
10	22@60
11	23@65
12	24@70
13	25@35
14	26@40
15	27@80
16	30@50
17	30@56

Table III: Generation Results

No	Bus	P_g (MW)	Market Price (Rs/MWh)	Revenue (Rs)	Total Cost (Rs)	Profit (Rs)
1	1	36	43.207	1555.46	720	835.46
2	2	48	43.304	2083.41	1200	883.41
3	13	50	42.953	2147.65	1750	397.75
4	22	40	44.416	1776.67	1200	576.67
5	23	55	40.000	2200	2200	0.00
6	27	12	50.000	600	600	0.00
					Total	2693.29

TABLE IV: Load Results

No	Bus	P_g (MW)	Market Price (Rs/MWh)	Revenue (Rs)	Total Cost (Rs)	Profit (Rs)
1	7	26.00	44.925	1168.05	1820	668.05.
2	8	0.00	44.624	0.00	0.00	0.00
3	10	0.00	44.780	0.00	0.00	0.00
4	12	0.00	43.953	0.00	0.00	0.00
5	14	4.39	43.910	192.77	193.16	0.39
6	15	1.28	44.908	57.48	57.60	0.12
7	16	20.00	45.817	916.34	920	3.66
8	17	12.79	46.904	599.90	601.13	1.23
9	18	5.50	54.888	301.88	302.50	0.62
10	19	0.00	60.673	0	0.00	0.00
11	20	23.00	63.807	1467.56	1495.00	27.44
12	21	24.00	44.668	1072.03	1680.00	607.97
13	24	0.00	44.632	0.00	0.00	0.00
14	26	0.00	45.901	0.00	0.00	0.00
15	28	27.00	45.179	1219.83	2160	940.17
16	29	1.05	49.898	52.39	52.50	0.11
17	30	30.00	43.593	1307.79	1680	372.21
					Total	2621.97

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