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# Assessment Of Market Clearing Price And Social Welfare In A Competitive Electricity Market

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# Assessment Of Market Clearing Price And Social Welfare In A Competitive Electricity Market

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*Abstract*— **In an open-access environment, transmission constraints can result in different energy prices throughout the network. These prices are dependent on a number of factors such as the system load level, generating unit bid, demand unit bid, network topology and security limits imposed on the transmission network due to thermal, voltage and stability considerations. Computing these energy prices at all buses in large networks under given system operating conditions can be time consuming. This paper describes some simple methodology based on the computer programs to calculate saving , worth of transmission transaction, market clearing price, social welfare, transaction cost, locational marginal pricing, transmission capacity cost at selected zones for a given period. These information for energy prices can be used not only to improve the efficient usage of power grid but also to design a reasonable pricing structure of power systems or to provide economic signals for generation or transmission investment.**

*Index Terms* **: Joint dispatch, power pool, worth of transmission transaction, social welfare, market clearing price, bid price of the seller, bid price of the buyer**.

## I. INTRODUCTION

ELECTRIC power industry is under restructuring in response to change in the law, technology, markets and competitive pressures. The industry now includes companies, selling unbundled power of rates set by competitive markets.

In this environment more competition will mean lower rates for customers. With the separate pricing of generation and transmission, it has become necessary to find the capacity usage of different transactions happening at the same time so that a fair use of transmission changes can be given separately to individual customers. Reforms have been under taken by introducing commercial incentives in generation, transmission, distribution and retailing of electricity, with, in many cases, large resultant efficiency gains.

## II. OVERVIEW OF ENERGY PRICING

Power pools came into existence as a reaction to increasing prices of electricity. The objective was to reduce the overall operating cost of utilities by sharing the cheaper sources through multi-area joint dispatch. In multi area joint dispatch all participating utilities co-ordinate to dispatch their generation in a centralized manner. In certain instances, the pool also co-ordinates the system expansion and maintenance planning activities [1].

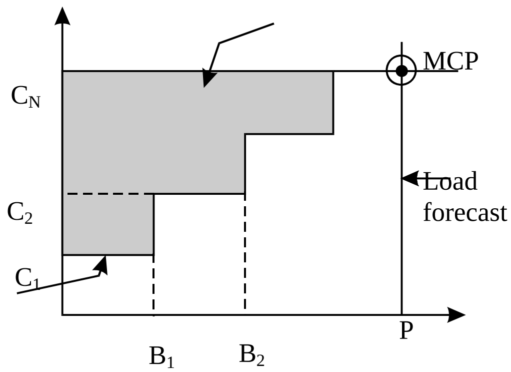
Two types of market settlement have been proposed for adoption by the market operator: Maximization of social

welfare [2] and minimization of consumers payment [3]. In first type the total cost is minimized by assuming that

generation bids correspond to their actual cost. The later objective seeks to minimize the market clearing price and hence the price of the customer would pay for energy. Maximization of social welfare objective function to obtain the optimum dispatch schedules has been the common practice in most centralized power pools. Two cases may arise in the class of problems. One where the market operator receives both supply and demand bids and the system price (MCP) is obtained by matching the highest priced cleared sell bid to the lowest prices cleared buy bid, which is termed as double auction power pool. The other is where only supply bids are received and the system price is obtained by finding the highest priced bid intersecting the system demand forecast. This is known as single auction power pool. Presently there are two pricing methods that are being used in a competitive energy market to account for congestion: the uniform pricing method and the non-uniform pricing method. In the first method, all generators are paid the same price regardless of their individual bids based on the bid of the marginal generating unit that would be dispatched in the absence of congestion. Such a bid is known as market clearing price (MCP). In the second method, each generator is paid a price based on the marginal cost of serving an increment of load at its location Such a price is referred as locational marginal price (LMP). The LMP at a bus is defined as the minimum marginal cost of supplying the next increment of electric energy at the bus without violations of any transmission limits.

## III. Calculation of Market Clearing Price and Social Welfare in Single Auction Power Pool.

This section discusses the market settlement mechanism where only gencos submit their bids that are then arranged in the increasing order of the prices. The highest priced bid to intersect with the system demand forecast determines the market price which is illustrated in Fig. I.




Energy bid in MWh per hour

Fig.I . Market settlement in single auction power pool. Where the market operator receives 'N' supply bid price (BPS) and demand forecast P.

The market operator seeks to minimize the system cost which is effectively maximization of the social welfare [2] denoted by the shaded area in figure I.

System cost $J = \sum_{i=1}^{N} BPS \times P_i = \sum_{i=1}^{N} f_i(P_i)$ …………..(I)

The above objective function is minimized subject to the demand supply balance constraint, neglecting losses

$$\sum_{i=1}^{N} P_i - P_D = 0 \quad \text{…………………………………… (2)}$$

We can formulate the Lagrangian as follows

$$F = \sum_{i=1}^{N} f_i(P_i) - \lambda\left(\sum_{i=1}^{N} P_i - P_D\right) \quad \text{……………………(3)}$$

and the Kuhn-Tuckers condition of optimality is

$$\frac{dC_i(P_i)}{dP_i} = \lambda \quad \text{……………………………………..(4)}$$

Incorporating unit commitment decisions the gencos are required to submit a start up price bid in addition to the variable component. Accordingly, the unit commitment decisions are incorporated in the social welfare objective function as follows;

$$J = \sum_{K=1}^{T}\sum_{i=1}^{N} PBS_{i,K} P_{i,K} + ST_i \times UST_{i,k} \quad \text{……………….(5)}$$

In (9) the index K denotes the bid time period i.e. half an hour or one hour and T stands for the entire market scheduling horizon. UST is a binary variable denoting the unit start up decision, while ST represents start up price offer. .

The algorithm of the program used for market settlement in single auction power pool is illustrated in Fig .2.

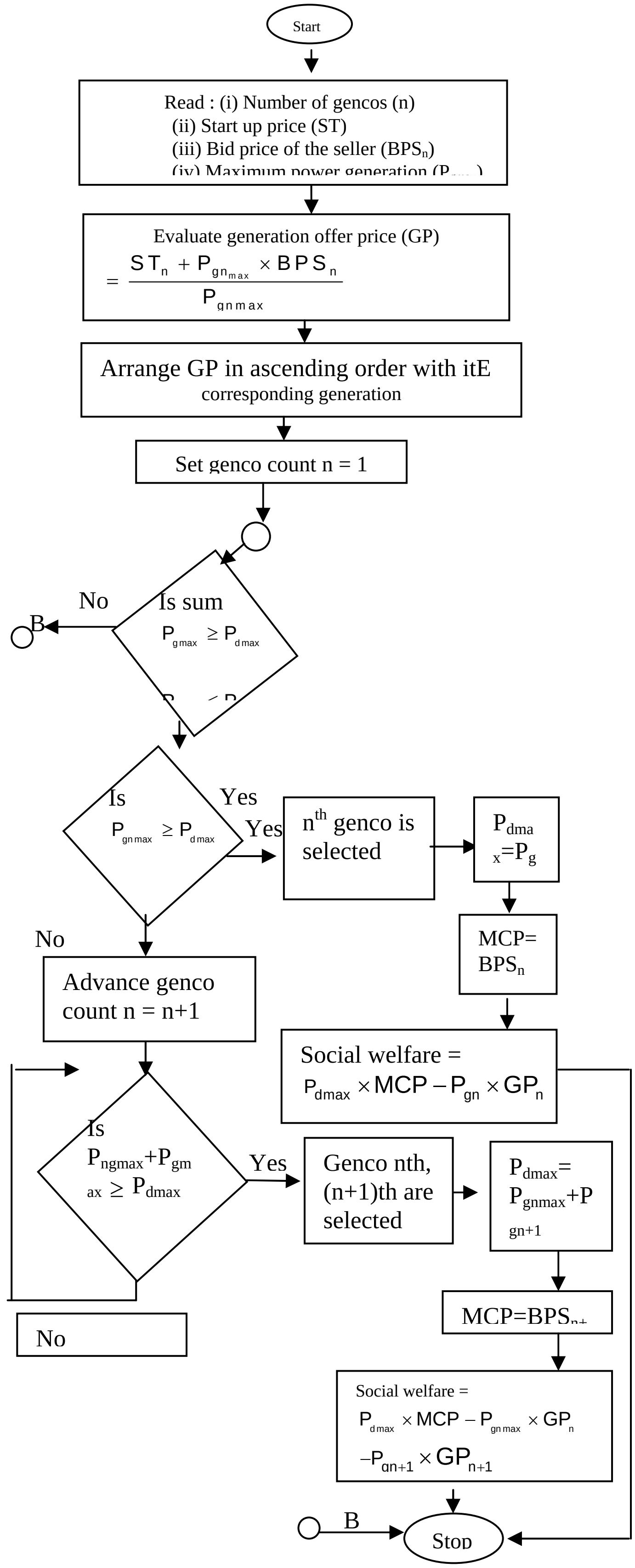

Start
Read : (i) Number of gencos (n)
(ii) Start up price (ST)
(iii) Bid price of the seller (BPS$_n$)
Evaluate generation offer price (GP)
$= \frac{ST_n + P_{gn_{max}} \times BPS_n}{P_{gnmax}}$
Arrange GP in ascending order with itE
corresponding generation
Set genco count n = 1
No
B
Is sum
$P_{gmax} \geq P_{dmax}$
Is
$P_{gnmax} \geq P_{dmax}$
Yes
Yes
$n^{th}$ genco is selected
$P_{dmax} = P_g$
MCP= BPS$_n$
No
Advance genco count n = n+1
Social welfare =
$P_{dmax} \times MCP - P_{gn} \times GP_n$
Is
$P_{ngmax} + P_{gmax} \geq P_{dmax}$
Yes
Genco nth, (n+1)th are selected
$P_{dmax} = P_{gnmax} + P_{gn+1}$
No
Social welfare =
$P_{dmax} \times MCP - P_{gnmax} \times GP_n$
$-P_{gn+1} \times GP_{n+1}$
B
Stop

**Fig.2. Flow chart for market settlement in single auction power pool.**

## IV. CALCULATION OF MARKET CLEARING PRICE AND SOCIAL WELFARE IN DOUBLE AUCTION POWER POOL

This section discusses the market settlement mechanism where gencos as well as discos submit their bids. The gencos bids are arranged in increasing order of the prices where as the discos bids are arranged in decreasing order of the prices. The system price and the amount of energy clearing for trading is obtained from the intersecting point of these curves as shown in Fig. 3.

The market operator seeks to minimize the system cost which is effectively maximization of social welfare [2] denoted by the shaded area in fig. 3.

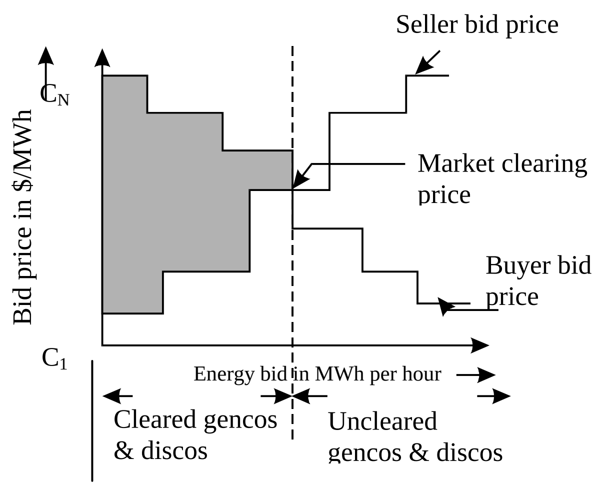



Fig.3 Market settlement in double auction power pools, where the market operator receives 'N' supply bids with bid price (BPS) from the participating genco and 'M' demand sides from the customers with bid price (BPB)

We can assume that BPS represents a genco's true marginal cost while BPB represents a customer's true benefit or utility function.

We can thus write ;

$$C_i = f_i\left(P_i\right),\ B_j = g_j\left(P_{Dj}\right);\ \forall i \in N\ \ \&\ \forall j \in M \ \ldots\ldots\ldots(6)$$

In (10) $C_i$ is the cost function of genco 'i' expressed as function power supplied $P_i$, while $B_j$ is the benefit function of customer 'j' as a function of the power demand $P_{Dj}$.

The social welfare function 'J' can be defined as the difference of total customer benefit and total cost of genco.

Social welfare = $J = \sum_{j=1}^{m} P_{Dj} BPB_j - \sum_{i=1}^{N} P_i.BPS_i$

$$\Rightarrow J = \sum_{j=1}^{M} B_j - \sum_{i=1}^{N} C_i$$

$$= \sum_{j=1}^{M} g_j\left(P_{Dj}\right) - \sum_{i=1}^{N} f_i\left(P_i\right) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

A demand supply balance constraints, neglecting losses, need to be included as follows,

$$\sum_{i=1}^{N} P_i = \sum_{j=1}^{M} P_{Dj} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

Formulating the Lagrangian for the maximization problem described by (11) and (12), we have

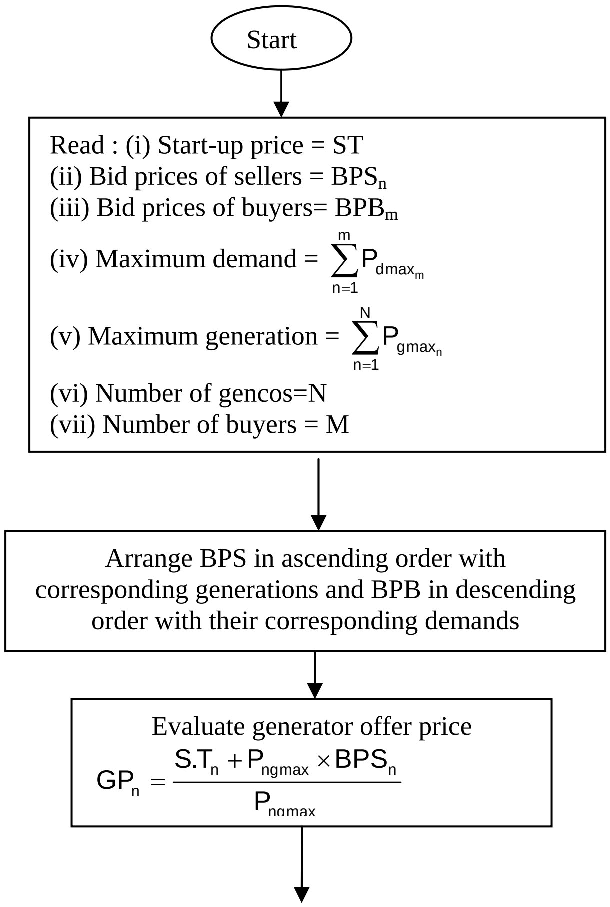
$$F = \sum_{j=1}^{M} g_j\left(P_{Dj}\right) - \sum_{i=1}^{N} f_i\left(P_i\right) - \lambda\left(\sum_{j=1}^{M} P_{Dj} - \sum_{i=1}^{N} P_i\right) \ldots\ldots\ldots..(9)$$

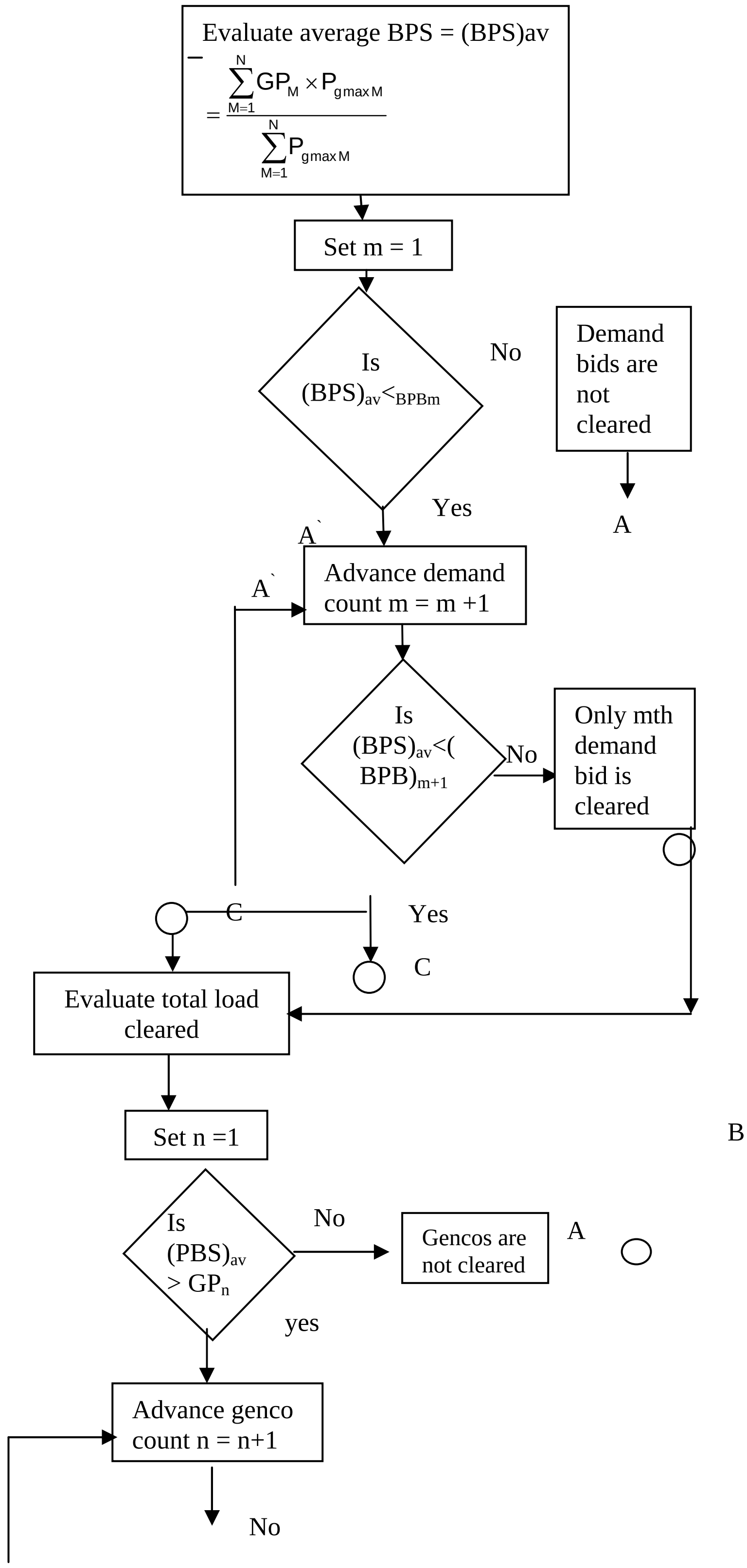
Applying the Kuhn-Tuckers condition of optimality, we can write

$$\left.\begin{aligned} \frac{d\left[g_j\left(P_{Dj}\right)\right]}{dP_{Dj}} &= \lambda \\ \text{and}\ \ \frac{d\left[f_i\left(P_i\right)\right]}{dP_i} &= \lambda \end{aligned}\right\} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(10)$$

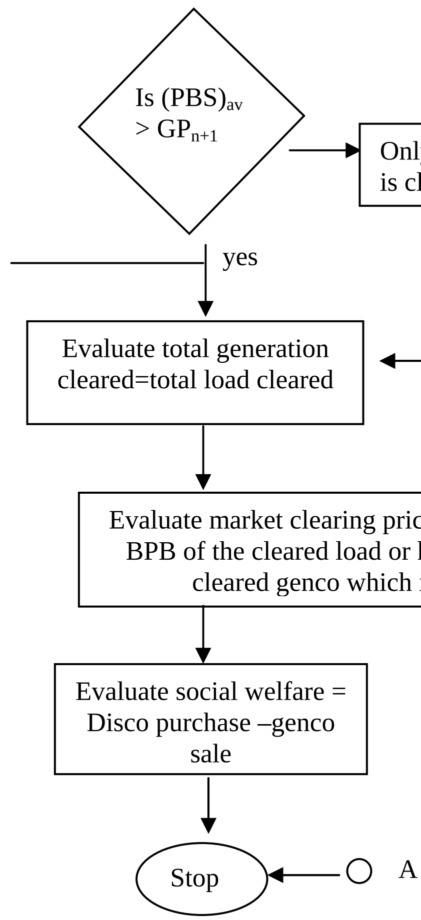
The Lagrange multiplier '$\lambda$' denotes the system marginal price.

The algorithm of the program used for the market settlement in double auction power pool is illustrated in Fig.4.


Start
Read : (i) Start-up price = ST
(ii) Bid prices of sellers = $BPS_n$
(iii) Bid prices of buyers= $BPB_m$
(iv) Maximum demand = $\sum_{n=1}^{m} P_{dmax_m}$
(v) Maximum generation = $\sum_{n=1}^{N} P_{gmax_n}$
(vi) Number of gencos=N
(vii) Number of buyers = M
Arrange BPS in ascending order with corresponding generations and BPB in descending order with their corresponding demands
Evaluate generator offer price
$GP_n = \frac{S.T_n + P_{ngmax} \times BPS_n}{P_{ngmax}}$


Evaluate average BPS = (BPS)av
$$=\frac{\sum_{M=1}^{N} GP_M \times P_{gmax M}}{\sum_{M=1}^{N} P_{gmax M}}$$
Set m = 1
Is (BPS)av<BPBm
No
Demand bids are not cleared
A
Yes
A`
Advance demand count m = m +1
A`
Is (BPS)av<( BPB)m+1
No
Only mth demand bid is cleared
C
Yes
C
Evaluate total load cleared
Set n =1
B
Is (PBS)av > GPn
No
Gencos are not cleared
A
yes
Advance genco count n = n+1
No

-


Is (PBS)av > GPn+1
Only nth genco is cleared
yes
Evaluate total generation cleared=total load cleared
Evaluate market clearing price =either lowest BPB of the cleared load or highest BPS of cleared genco which is higher
Evaluate social welfare = Disco purchase –genco sale
Stop
A

CASE STUDIES

To illustrate the validity of the proposed methodology based on the computer program,6 gencos and seven discos power pool has been studied.

**Results for Single Auction**

gencos = 6
discos = 7
st =
Columns 1 through 6
1000 1500 750 500 100 1000
Column 7
900
bps = 20.5000 21.5000 25.5500 22.0000 27.5000 22.0000 24.5000
pgmax = 350 600 200 200 150 900 200 300
pdmax = 250 350 500 450 200 350 400 500

MaximumDemand_MaximumGeneration = 2500 2400
avbps = 24.3167
TOTAL_DISCO_load( should be < SumPDmax )= 2000
ALL_GENCO_bps =
23.3571
24.0000
29.3000
24.5000
28.1667
23.1111

market_clearing_price_mcp_from_GENCO_side_only =
24.5000

sumDISCOloadMW = 2000
gencoofferingBPS = 23.1111 23.3571 24.0000 24.5000
genco_numbers_loadsharing = 6 1 2 4

gencoGENERATIONclearedMW = 900 350 600 150
gencoTOTALgenerationMW = 2000
SOCIAL_WELFARE = 47050
gencosale1 = 20800
gencosale2 = 8175
gencosale3 = 14400
gencosale4 = 3675
gencosale5 = 0

-----------------------------------------------------------------

**Results for Double Auction**

gencos = 6
discos = 7
stgeneral = Columns 1 through 6
1000 1500 750 500 100 1000
Column 7 900
bpsgeneral = 20.5000 21.5000 25.5500 22.0000 27.5000 22.0000 24.5000
pgmaxgeneral = 350 600 200 200 150 900 200 300
bpbgeneral = Columns 1 through 7

23.3500 30.5900 28.2500 27.7500 23.5000 22.6000 20.3000
Columns 8 through 9 33.0000 27.2000
pdmaxgeneral = 250 350 500 450 200 350 400 500
MaximumDemand_MaximumGeneration = 2500 2400
averageBidPrice_Genco = 24.3167

All_DISCO_bid_prices =

23.3500
30.5900
28.2500
27.7500
23.5000
22.6000
20.3000
Market_clearing_price_from_DISCOside = 27.7500
discoNUMBERScleared = 2 3 4
discoBPBcleared = 30.5900 28.2500 27.7500
discoNUMBERS_NOTcleared = 1 5 6 7
discoBPB_NOTcleared = 23.3500 23.5000 22.6000 20.3000
discoloadclearedMW = 350 500 450
sumDISCOloadMWcleared = 1300
ALL_GENCO_bps =
23.3571
24.0000
29.3000
24.5000
28.1667
23.1111
gencoofferingBPS = 23.1111 23.3571 24.0000
genco_numbers_loadsharing = 6 1 2
gencoGENERATIONclearedMW = 900 350 50
gencoTOTALgenerationMW = 1300
SOCIAL_WELFARE = 7144

## VII. CONCLUDING REMARKS

The electricity power industry is undergoing vast changes in many parts of the world. Restructuring of the industry involves a transition from natural monopolies, with centralized planning to markets that are subjected to competition. The method of assessment will be a valuable tool to power system operators in determining saving cost, worth of transaction, market clearing price, transaction cost, locational marginal pricing, transmission capacity cost in a competitive energy market under different operating conditions.

## REFERENCE

*[1] B.W. Beately. "Integrating non-utility generation into the NEPOOL resource Planning process". IEEE Transaction on Power Systems. Nov., 1988. pp. 1754-1756.*

*[2] X.Ma.D. Sun and K.Cheung. "Energy and reserve dispatch in a multizone electricity market". IEEE Transaction on Power Systems, Aug. 1999. pp.913-919.*

*[3] S.Hao, G.A. Angelidis, H. Sing and A.D. Papalexopolous, "Consumers payment minimization in power pool auctions", IEEE Transaction on Power System. Vol. 13,. No. 3,. Aug 1998. pp. 986-991.*

*[4] R.D. Christie, .F. Wollenberg and I. Wangensteen, "Transmission management in the deregulated environment". Proceedings of the IEEE, Feb. 2000, pp. 170-195*