ANALYSING EQUILIBRIA IN AN ELECTRICITY MARKET

[1]Arvind.R B.E. (M.E),
PG Scholar,
Department of EEE,
St. Joseph's college of Engineering,
OMR, Chennai-600 119.
(IEEE MEMBER)

[2] R. Sreekanth. M.E.(Ph.D.),
Assistant Professor,
Department of EEE,
St. Joseph's college of Engineering,
OMR, Chennai-600 119.
(IEEE professional member)

[3]Dr.M. Ramesh Babu Ph.D.,
Professor,
Department of EEE,
St. Joseph's college of Engineering,
OMR, Chennai-600 119.

Abstract — **In a deregulated electricity market, the market participant will be able to choose the supplier or consumer to buy or sell the power in a competitive manner based on the price and service provided. In such competitive market generating companies offer a much broader array of services than monopolies or as in a regulated generating market. The generating companies are very much concerned about a better method for reducing cost and a faster way of dealing problems at competitive edge. The major problem faced by the generating companies is to obtain greater profits and satisfy the consumer demand at competitive prices. In this paper, the main objective is to maximize the profit of the generating companies by finding the Market clearing price. MCP mechanism is one of the key tools for market settlements in deregulated power system environment. The optimization of profits is done by using Whale optimization algorithm (WAO) in a modified IEEE 30 bus test system.**

Keywords— Deregulated power market, Maximize Profit, Market Clearing Price (MCP), MATLAB, Whale Optimization Algorithm (WAO).

I. INTRODUCTION

As the demand for power requirement increasing nowadays, the capacity of power generation needs to be increased. Which results in increasing in number of generating units which in turn makes the monopolies market into a competitive market. While compared to monopolies market in competitive power market the participants are separated as the generating companies (GENCO), the transmission companies (TRANSCO), the distribution companies (DISCO) and the customers (load or demand). This partition influenced the rise of competitiveness and incoming of Independent Power Producers (IPP) in the market. The whole market is governed and control by the Independent system operator (ISO) in order to maintain the equilibrium between the demand and supply. An equilibrium is defined to be the price-quantity pair where the quantity demanded is equal to the quantity supplied. It is represented by the intersection of the demand and supply curves [1].

As day fly by the generating companies started to plan for their profits increments to lead a social life which can able disturb the equilibrium in a market structure. So, to increase the profit there by not disturb the market equilibrium GENCO has to make use market clearing price method (MCP) [2] or locational marginal pricing (LMP) [3] method. In this paper, the MCP is consider for calculations.In the market the power is traded between the supplier and costumer through the bids via the ISO.

The various bidding strategy are followed by various player across the power market to maximize their profits [7]. The profit maximization can be done by converting the objective into an optimization problem. Those optimization problems are evaluated by using various optimization technique. The traditional approach like Linear Programing, Minimum Maximum approach. The modern heuristics approach like Particle Swarm Optimization (PSO) [4], Genetic Algorithm (GA), Whale Optimization Algorithm (WAO). Here we consider WAO as the latest and best suited for the work.

II. PROBLEM FORMULATION

The main objective is to maximize the generators profits so, the profit formulation is given below: -

$$\text{Frim's profit} = \text{Total Revenue} - \text{Fuel Cost}$$

$$\pi = R - C \quad (1)$$

Total revenue of the firm: -

$$R = MCP * P_i \quad (2)$$

Fuel cost incurred by the firm: -

$$C = C_i(P_i) \quad (3)$$

The fuel cost of the generators is given by the equation below,

$$C_i(P_i) = a_i(P_i)^2 + b_i(P_i) + c_i \quad \text{for } i = 1,2,3, \dots n, \quad (4)$$

Market clearing price can be formulated as,

$$Q(R) = D - K * (MCP) \quad (5)$$

$$\sum_{i=1}^{n} P_i - Q(R) \quad (6)$$

$$MCP = \frac{(D + \sum_{i=1}^{n} \frac{\alpha_i}{\beta_i})}{(K + \sum_{i=1}^{n} \frac{1}{\alpha_i})} \quad (7)$$

$$p_i = \frac{MCP - (x_i * \beta_i)}{x_i * \alpha_i} \quad (8)$$

A. Constraints

1) <u>Generation Limits:</u> The power generation must always be in between the maximum and minimum power generation capacity.

$$p_{i\,min} \le p_i \le p_{i\,max} \quad (9)$$

Where

$p_{i\,min}$ represents the minimum value of the generation of the i^th unit .

$p_{i\,max}$represents the maximum value of the generation of the i^th unit .

B. Objective Function

The Expected profits (π) of power generation for a given generator is the objective function to be maximized. The optimization problem can be modelled as shown below:

$$\pi = \max\left((MCP * P_i) - C_i(P_i)\right) \qquad (10)$$

The expanded form of the objective function in the equation (10) is given below:

$$\pi = \max\left[\left(MCP * \frac{MCP-(x_i*\beta_i)}{x_i*\alpha_i}\right)-((a_i * (\frac{MCP-(x_i*\beta_i)}{x_i*\alpha_i})\text{^}2) + (b_i(\frac{MCP-(x_i*\beta_i)}{x_i*\alpha_i})))\right] \qquad (11)$$

where

n is the total number of suppliers participating in electricity market.
p_i is the active power output of the firm.
a_i, b_i, c_i is the fuel cost coefficient of the generators used in the firms.
$c_i(p_i)$ is the fuel cost function of the generator.
α_i, β_i is the bidding coefficient of the firms.
D is the total demand considered in the system.
K is the load price elasticity assumed in the system.
Q(R) is the quantity of power.
x_i is the bidding value based on strategy.
π is the profits obtained by the companies.

III. WHALE OPTIMIZATION ALGORITHM

The Whale Optimization Algorithm (WOA) is a novel meta-heuristics algorithm proposed by S.Mirjalili at.et in 2016.WOA is a population-based method which works on bubble net attacking method of the humpback whales when they hunting their preys. The basic concept of WAO is that hump back whales know the location of prey and encircle them. They consider the current best candidate solution is best obtained solution and near the optimal solution. After assigning the best candidate solution the other agents try to update their position toward the best search agents [9]. The flowchart for the WAO is show in the Fig1.

The proposed methodology is implemented as follows:

- Step 1: Initialize number of populations
- Step 2: Get the generator data, demand data generation limits, iteration limits.
- Step 3: Calculate the MCP value using equation (7)
- Step 4: From the value of MCP in step 3 evaluate the fitness function (11)
- Step 5: Compute for the profit value till the max_iteration.
- Step 6: Repeat (4) and (5) till the best value is achieved.
- Step 7: Save Results

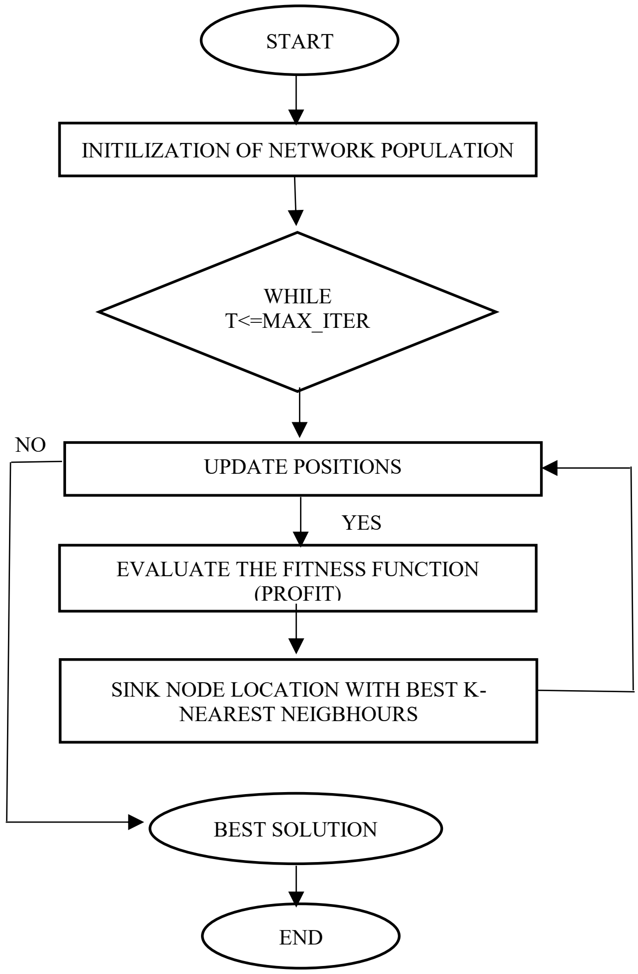

Fig 1 Flowchart for WAO

IV. CASE STUDY AND ANALYSIS

The proposed approach was applied to amodified IEEE 30 bus test system. This system consist of six generation units and twenty load demand side.Transmission line constraints are not included in the analysis.In this paper we assume the load elasticity factor as 1. The cost coefficient of the system is given in table I.

TABLE I:
COST COEFFICIENTS OF MODIFIED IEEE 30 BUS SYSTEM

BUS NO.	COEFFICIENTS			$p_{i\,max}$
	a_i	b_i	c_i	
1	0.00375	2	0	80
2	0.0175	1.75	0	80
13	0.0625	1	0	40

23	0.025	3	0	50
22	0.00834	3.25	0	30
27	0.025	3	0	55

V. RESULT

The generation result of 6 generators considering power limit constraints are described below:Assuming the total demand as 100MW,the calculated MCP value is 24.93$/MW.

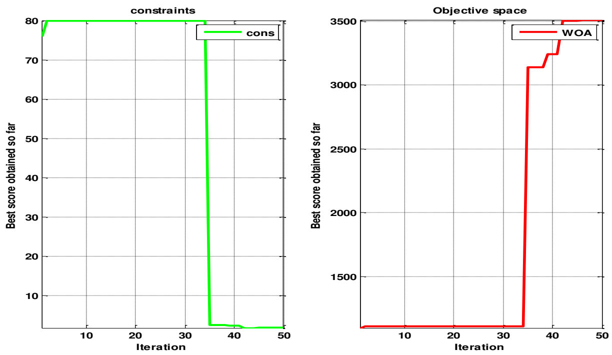

Fig 2 (a): Generator 1

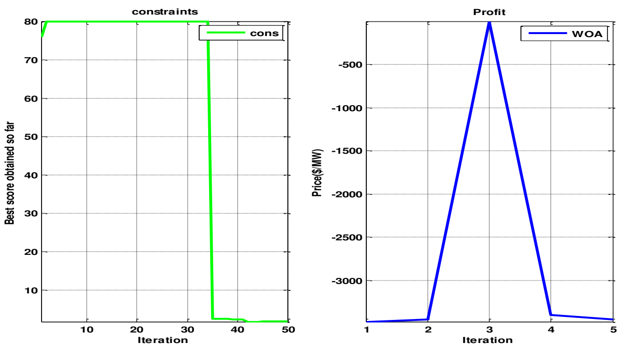

Fig 2 (b): Profits of Generator 1

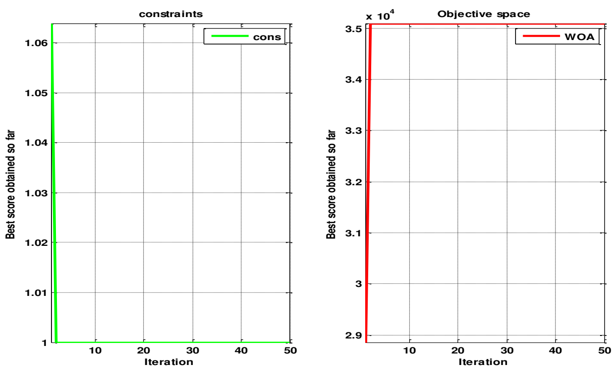

Fig 3 (a): Generator 2

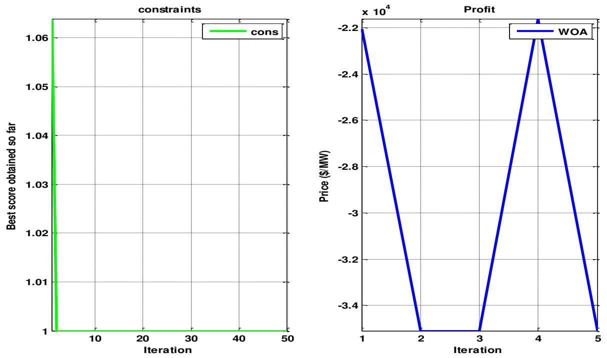

Fig 3 (b): profits of Generator 2

The fig 2a),3a) shows the convergence of the constraints and the maximized output for generator 1,2.

The fig 2b),3b) shows the convergence of the constraints and point of maximization of output for generator 1,2 and the best solution and the best optimal value is obtained.

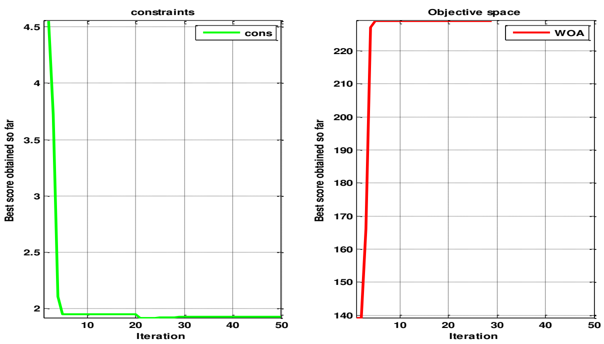

Fig.4 (a): Generator 3

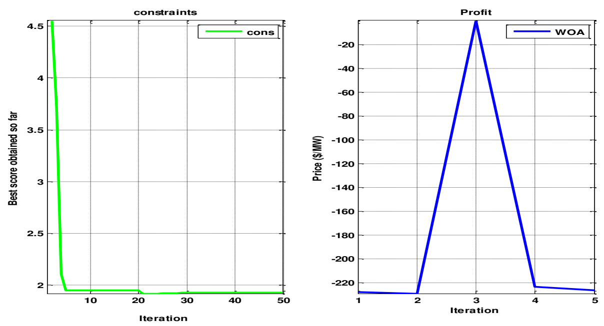

Fig.4 (b): Profit of Generator 3

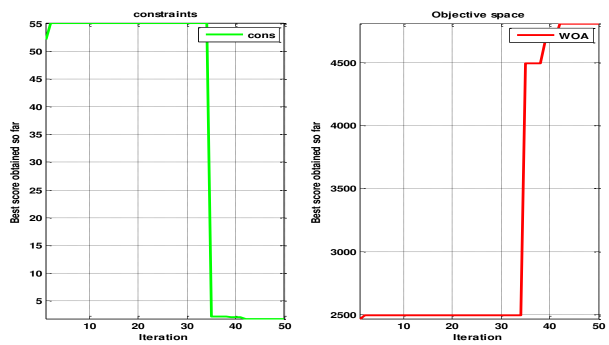

Fig.5(a): Generator 4

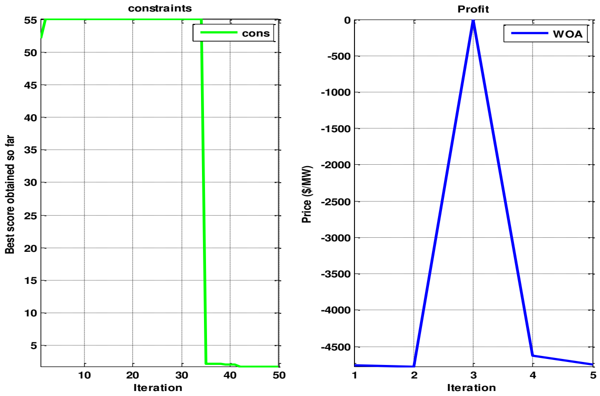

Fig.5 (b): Profit of Generator 4

The fig 4a),5a) shows the convergence of the constraints and the maximized output for generator 3,4.

The fig 4b),5b) shows the convergence of the constraints and point of maximization of output for generator 3,4 and the best solution and the best optimal value is obtained.

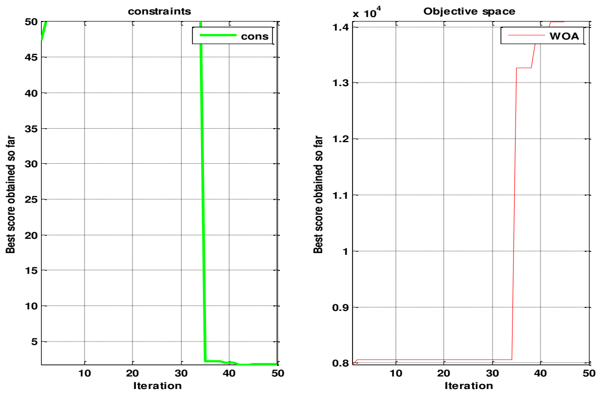

Fig 6(a): Generator 5

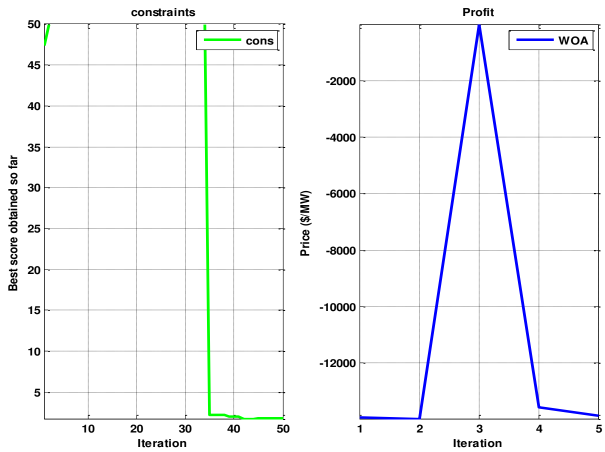

Fig 6 (b): Profit of Generator 5

The fig 6a), shows the convergence of the constraints and the maximized output for generator 5.

The fig 6b), shows the convergence of the constraints and point of maximization of output for generator 5 and the best solution and the best optimal value is obtained.

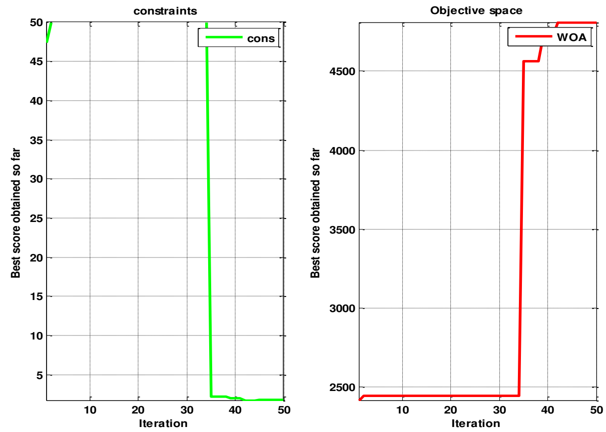

Fig 7(a): Generator 6

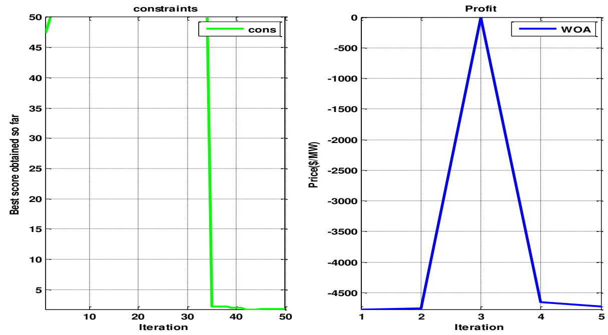

Fig 7(b): Profit Generator 6

The Fig 7a), shows the convergence of the constraints and the maximized output for generator 6.

The Fig 7b), shows the convergence of the constraints and point of maximization of output for generator 6 and the best solution and the best optimal value is obtained.

TABLE II:
PROFITS OBTAINED

Generator	x_i	**Profits($/MW)**
1	1.8479	3481.4435
2	1	3754.58.27
3	1.9229	227.7838
4	1.7760	4770.235
5	1.7752	1394.33
6	1.7768	4770.235

The table II shows the maximum profits obtained by all generator in the taken IEEE 30 bus test case with the corresponding bidding value.

VI. CONCLUSION

In this paper a modified IEEE-30 bus test system is taken and simulated in order to get the Market Clearing Price (MCP) using MATLAB programming. The MCP (Market clearing price) is calculated with help of the known value of total demand and the cost coefficients. With the result the of MCP the profits of each of the generator has been calculated. Whale Optimization algorithm has been used to optimize the profits gained by the generator.

In future by following the same procedure the profit of the firm can be enhanced with the integration of renewable energy sources and energy storage devices. By Random selection of generator, profit of the selected generators can be calculated. With the help of this profits the GENCOs may able to bid their supply nearly to the marginal cost in order to get maximum profits.

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