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Artificial Bee Colony Algorithm to Generator Maintenance Scheduling in Competitive Market

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ABSTRACT

This paper proposes an Artificial Bee Colony (ABC) algorithm to Generator Maintenance Scheduling (GMS) in competitive market. In the regulated market the problem of generating optimal maintenance schedules of generating units for the purpose of maximizing economic benefits and improving reliable operation of a power system, subject to satisfying system constraints. In case of deregulated market, the self-governing generation company GENCO prepares GMS aims to maximize their revenue with less consideration on reliability. The Independent System Operator (ISO) receives the maintenance schedules from GENCO and compares with ISO schedules for sanction. This paper proposes an ABC algorithm to solve the GMS in GENCO to maximize their revenue without considering expected renewal cost. Numerical examples on 4 and 32 unit power producers are utilized to demonstrate the effectiveness of the proposed ABC algorithm.

Keywords

Deregulation, generator maintenance scheduling, artificial bee colony algorithm, generation scheduling, market clearing price.

1. INTRODUCTION

The thermal generator maintenance scheduling of generating units plays a vital role in power system operation and planning activities of the electric power utility. Essential maintenance must be performed on a number of thermal generators inside a fixed planning horizon while ensuring high system reliability, reducing production cost, prolonging generator life time subject to some unit and system constraints. An appropriate maintenance schedule either decreases the operation cost or increases the system reliability. GMS should minimize the total operation cost and meanwhile satisfy various unit and system constraints and the problem can be mathematically formulated as a constrained nonlinear, mixed integer optimization one [1]. Modern power systems have witnessed increased demand for electrical energy with a related expansion in system size, which leads to higher number of generators and lower reserve margins making the GMS more complicated. The resultant effect is the increased complexity of the constrained GMS optimization problem for such large power system. In a regulated power industry the primary objective of the GMS is the effective allocation of generating units for maintenance while ensuring high system reliability, reducing production cost and prolonging generator life time subject to some unit and system constraints [2]. In the regulated market the GMS problem are classified depends upon the economic cost and reliability criterion [3]. The many kinds of artificial intelligence computational methods, such as Simulated Annealing (SA), expert system, Genetic Algorithm (GA), Tabu Search (TS), Evolutionary Programming (EP) and bio-inspired techniques have been applied successfully to solve the unit maintenance scheduling problem in regulated market [4 – 7].

Due to the deregulation the power system attains the considerable modification and the motivation of the deregulation is to allow the consumers to choose the electric power supply depends upon the electric price and decrease the overall cost by bidding strategy. In a competitive electricity markets, the self – governing generation company GENCO is responsible for its own risk – based maintenance outage scheduling. The privatized GENCO aims to achieve maximum revenue irrespective of the reliability during maintenance scheduling of generating units and always prepare the maintenance schedule at low electricity price. The long – term scheduler has been designed for GENCO with local transmission lines and system constraints [8]. The benders decomposition technique is used to include network, fuel and emission constraints.

Short-term generating unit maintenance scheduling in a deregulated power system using a probabilistic approach have been presented [9]. The maintenance coordination technique has been proposed [10] to coordinate composite system maintenance scheduling in a deregulated utility system. A new game-theoretic framework for the generating unit maintenance scheduling under competitive electricity markets has been discussed [11]. In the framework, GMS problem is cast into a dynamic non – cooperative game with complete information. The market equilibrium solution is characterized by the Nash equilibrium and can be obtained by the backward induction scheme based on the subgame perfect equilibrium concept.

The optimal risk-based generation maintenance outage scheduling based on hourly price – based unit commitment in a generation company GENCO has been proposed [12]. This approach considers market price uncertainties, including energy and ancillary services price, as well as fuel price. The price uncertainties are simulated by Monte Carlo method and Lagrangian relaxation is applied to decompose the original stochastic problem into several tractable scenarios. In each scenario sub problem, the midterm maintenance outage schedule is coordinated with unit commitment while fuel allocation and emission allowance are regarded as constraints. The unit maintenance scheduling coordination mechanism in deregulated electricity market environment has been presented [13]. The proposed model consider the transmission capacity constraint and the random line outage in order to make the analysis about the impact of unit maintenance scheduling on the system security more reasonable.

The security coordinated maintenance scheduling in deregulation based on genco contribution to unserved energy has been discussed [14]. The final solution obtained by the proposed method is the set of genco maintenance cum production schedules that maximize their respective profits while meeting system security constraints. The generation maintenance scheduling in power market based on Genetic Algorithm (GA) have been presented [15]. The combination of Linear Programming (LP) and Genetic Algorithm (GA) to solve GMS of power producer to maximize their potential benefit with and without considering unexpected unit failure has been proposed [16]. The producer benefits including the expected profit of selling energy, expected renewal cost of damaged components and maintenance cost. A competitive mechanism of unit maintenance scheduling in a deregulated environment have been presented [17]. The proposed scheme aims to achieve a tradeoff between ensuring the producer's benefit and maintaining system reliability, providing satisfactory maintenance windows and cost-reflective reward/charge to individual producer.

Recently, inspired by the foraging behavior of honeybees, researchers have developed Artificial Bee Colony (ABC) algorithm for solving various optimization problems [18-21]. ABC is a relatively new population-based bio-inspired approach with the desirable characteristics such as robust and easy to implement. Some recent researches illustrate that ABC algorithm outperforms Particle Swarm Optimization (PSO) algorithm in terms of quality of solution [18-21]. Though the PSO and ABC algorithms are population based optimization algorithms, the later avoids trapping of solution in local minima. Further, ABC does not use any gradient – based information and it incorporates a flexible and well balanced mechanism to adapt to the global and local exploration abilities within a short computation time. This makes the algorithm efficient in handling large and complex search spaces. In this paper, an ABC algorithm is proposed to determine the optimal solution for GMS in a deregulated environment.

2. PROBLEM FORMULATION

The Generation Maintenance Scheduling (GMS) problem of an individual generation producer can be formulated as

$$Max\ V_{Benefit} = \sum_{t=1}^{T} E_{\Pr ofit}(t) - \sum_{t=1}^{T} E_{\mathrm{Re}newal}(t) - \sum_{t=1}^{T} E_M(t) \tag{1}$$

The objective function (1) represents the producer's potential benefit over the entire scheduling horizon, which is calculated as the difference between revenues and costs, including three parts: the expected energy-selling profit, the expected renewal cost of the damaged components and the maintenance cost.

For the sake of simplicity, the unexpected unit failures (expected renewal cost) are ignored, then (1) becomes

$$Max\ V_{Benefit} = \sum_{t=1}^{T} E_{\Pr ofit}(t) - \sum_{t=1}^{T} E_M(t) \tag{2}$$

$$MaxV_{Benefit} = \sum_{t=1}^{T} \left\{ \sum_{j \in G} \left[\rho(t) \times P(j,t) - C_j^p \times P(j,t) \right] \right\} \times HW - \sum_{t=1}^{T} \sum_{j \in G} \left[C_j^{MFX} \times P_j^{\max} \times x_j(t) + C_j^{MV} \times P_j^{\max} \times x_j(t) \right] \times HW \tag{3}$$

From the above equations, producers may always prefer to plan the maintenance outage at those periods with low prices of energy and spinning reserve in order to mitigate the risk from market. Therefore on one hand, it may provoke more-than-necessary maintenance that could increase the probability of maintenance-induced failures and lead to the investment loss in the previous maintenance. On the other hand, it may result in less-than-necessary maintenance and thereby expose generating units to higher probability of forced outages. However, compared with traditional methods, it still demonstrates its applicability and predominance under the deregulated electric power environment.

For the sake of simplicity, only some critical constraints are considered in the following

Capacity and minimum power output:

The total power output of each online unit must be within a certain range determined by its minimum power output and its capacity

$$(1 - x_j(t)) \times z_m(j,t) \times P_j^{\min} \le P_m(j,t) \le (1 - x_j(t)) \times z_m(j,t) \times P_j^{\max}\ \forall j \in G, \forall t \tag{4}$$

Obviously, when one unit is on maintenance or unexpected failure, its total power output should be zero.

Maintenance outage duration:

This constraint ensures that each unit should be maintained in the required number of periods.

$$\sum_{t=1}^{T} x_j(t) = D_j\ \forall j \in G \tag{5}$$

Continuous maintenance:

The following constraint ensures that the maintenance of each unit should not be interrupted once it begins

$$x_j(t) - x_j(t-1) \le x_j(t + D_j - 1) \forall j \in G, \forall t \tag{6}$$

Maintenance resource:

Owing to limitations of facilities or crew, several units should not be scheduled to be on maintenance simultaneously

$$\sum_{j=1}^{N} f_{Rj} \times x_j(t) \le H_R(t) \forall t \tag{7}$$

Where f_{Rj} is the resource needed by unit j and $H_R(t)$ is the producer's total available resource at period t.

3. ARTIFICIAL BEE COLONY ALGORITHM (ABC)

Swarm intelligence is a research branch that models the population of interacting agents or swarms that are able to self-organize. An ant colony, a flock of birds or an immune system is a typical example of a swarm system. Bees' swarming around their hive is another example of swarm intelligence. Interaction between insects contributes to the collective intelligence of the social insect colonies. These communication systems between insects have been adapted to scientific problems for optimization. One of the examples of such interactive behavior is the waggle dance of bees during the food procuring. By performing this dance, successful foragers share the information about the direction and distance to patches of flower and the amount of nectar within this flower with their hive mates. So this is a successful mechanism which foragers can recruit other bees in their colony to productive locations to collect various resources. Bee colony can quickly and precisely adjust its searching pattern in time and space according to changing nectar sources.

In the ABC algorithm, each cycle of the search consists of three steps:

At the initialization stage, a set of food source positions are randomly selected by the bees and their nectar amounts are determined. Then, these bees come into the hive and share the nectar information of the sources with the bees waiting on the dance area within the hive.

At the second stage, after sharing the information, every employed bee goes to the food source area visited by her at the previous cycle since that food source exists in her memory, and then chooses a new food source by means of visual information in the neighborhood of the present one.

At the third stage, an onlooker prefers a food source area depending on the nectar information distributed by the employed bees on the dance area. As the nectar amount of a food source increases, the probability with which that food source is chosen by an onlooker increases, too. Hence, the dance of employed bees carrying higher nectar recruits the onlookers for the food source areas with higher nectar amount. After arriving at the selected area, she chooses a new food source in the neighborhood of the one in the memory depending on visual information. Visual information is based on the comparison of food source positions. When the nectar of a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaced with the abandoned one.

The position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the fitness of the associated solution, calculated by

$$fit_i = \frac{1}{1+f_i} \qquad (8)$$

In the algorithm, the first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. The number of employed bees or the onlooker bees is equal to the number of solutions in the population. At the first step, the ABC generates a randomly distributed initial population P(C=0) of N solutions (food source positions), where N denotes the size of population.

Each solution x_i where i = 1,2,….,N is a D-dimensional vector. Here, D is the number of product of input size for each data set, i.e. the number of optimization parameters. After initialization, the population of the positions (solutions) is subjected to repeated cycles, C = 1,2….MCN, of the search processes of the employed bee produces a modification on the position (solution) in her memory depending on the local information (visual information) and tests the nectar amount (fitness value) of the new source (new solution). Provided that the nectar amount of the new one is higher than that of the previous one, the bee memorizes the new position and forgets the old one. Otherwise she keeps the position of the previous one in her memory. After all employed bees complete the search process; they share the nectar information of the food sources and their position information with the onlooker bees on the dance area. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. As in the case of the employed bee, she produces a modification on the position in her memory and checks the nectar amount of the candidate source. Providing that its nectar is higher than that of the previous one, the bee memorizes the new position and forgets old one.

An artificial onlooker bee chooses a food source depending on the probability value associated with that food source, p_i, calculated by the following expression:

$$p_i = \frac{fit_i}{\sum_{n=1}^{N} fit_n} \qquad (9)$$

Where N the number of food sources is equal to the number of employed bees, and fit_i is the fitness of the solution given in Eq. (8) which is inversely proportional to the objective function given in Eq. (2).

In order to produce a candidate food position from the old one in memory, the ABC uses the following expression:

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) \qquad (10)$$

Where k ϵ {1,2,….N}and j ϵ {1,2….D} are randomly chosen indexes. Although k is determined randomly, it has to be different from i. ϕ_{ij} is a random number between [-1, 1]. It controls the comparison of two food positions visible to a bee. As can be seen from Eq. (10), as the difference between the parameters of the $x_{i,j}$ and $x_{k,j}$ decreases, the perturbation on the position $x_{i,j}$ decreases too. Thus, as the search approaches to the optimum solution in the search space, the step length is adaptively reduced.

If a parameter produced by this operation exceeds its predetermined limit, the parameter can be set to an acceptable value. The food source whose nectar is abandoned by the bees is replaced with a new food source by the scouts. In the ABC algorithm this is simulated by randomly producing a position and replacing it with the abandoned one. In the ABC algorithm, if a position cannot be improved further through a predetermined number of cycles called limit then that food source is assumed to be abandoned. After each candidate source position $v_{i,j}$ is produced and then evaluated by the artificial bee, its performance is compared with that of $x_{i,j}$. If the new food has equal or better nectar than the old source, it is replaced with the old one in the memory. Otherwise, the old one is retained.

4. IMPLEMENTATION OF ABC ALGORITHM FOR GMS IN COMPETITIVE MARKET

The proposed algorithm for solving GMS problem is summarized as follows.

Step 1: Read the system data.

Step 2: Initialize the control parameters of the algorithm.

Step 3: An initial population of N solution is generated randomly, each solution Xi (i=1, 2,…, N) is represented by a D-dimensional vector.
Step 4: Evaluate the fitness value of each individual in the colony.
Step 5: Produce neighbor solutions for the employed bees and evaluate them.
Step 6: Apply the selection process.
Step 7: If all onlooker bees are distributed, go to step 10. Otherwise, go to the next step.
Step 8: Calculate the probability values p_i for the solutions X_i.
Step 9: Produce neighbor solutions for the selected onlooker bee, depending on the p_i value and evaluate them.
Step 10: Determine the abandoned solution for the scout bees, if it exists and replace it with a completely new randomly generated solution and evaluate them.
Step 11: Memorize the best solution attained so far.
Step 12: Stop the process if the termination criteria is satisfied. Otherwise, go to step 3.
The detailed flowchart for the proposed ABC algorithm is shown in Figure 1.

5. NUMERICAL SIMULATION RESULTS AND DISCUSSIONS

This paper considers a test problem of scheduling maintenance of 4 and 32 generating units over the 52 weeks planning period. This test problem is loosely derived from the example presented in the literature [15-16]. The proposed algorithm is developed in Matlab environment and is implemented using Intel(R) Core(TM)^2 Duo CPU, 2.10 GHz processor. The control parameters of ABC algorithm for both cases are chosen as colony size (N) 100, maximum cycle/generation number (MCN) 100, and limit value 30.

5.1 Case I: Four unit system [16]

The proposed algorithm is applied to GMS problem, with 4 generating units. The system particulars are available in the literature [16] and also presented in Table 1. The weekly load demand and forecasted spot prizes are taken from Federal Energy Regulatory Commission (FERC) in the year 2010 (www.ferc.gov/oversight), and are presented in Figure 2 & 3.

The complete unit maintenance schedule and power output of the committed units obtained by the proposed ABC algorithm is given in Table 2. The generating unit 1 starts the maintenance in the week 35 and all the remaining units are starts maintenance in the week 26. From the Table 2 it is clear that the proposed ABC algorithm satisfies the system constraints. The economic benefit values for different cases and maintenance cost is presented in Table 3. The proposed algorithm obtain the best economic producer benefit of 61 248 329$ and maintenance cost of 423 212$.

The producer benefit and maintenance schedule obtained by the proposed ABC algorithm is not compared with GA [16] because the load demand and energy prizes of New England power market in 2002 and 2003 years (http://www.iso-ne.com) which is not available. Figure 4 shows the typical convergence of the objective function (fitness) given in Eq. (3) for the 4-unit test system using ABC algorithm, obtained over 100 trials. The figure shows that the minimization of the objective function converged to 3.24E+09 to 3.14E+09. A lower value of the objective function is preferable for better economic benefit. The converged results clearly present minimization of the objective function and it is also a guarantee for more effective maintenance schedules produced by the ABC algorithm.

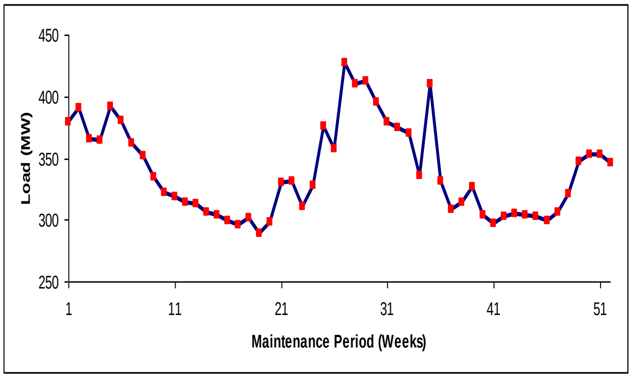

Fig 2: Load details of 4 unit test system

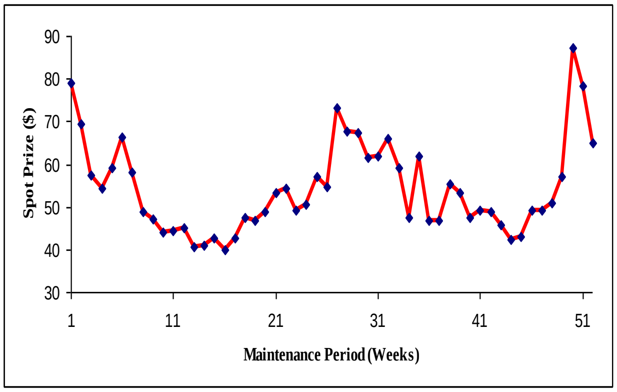

Fig 3: Forecasted Spot prize of 4 unit test system

Table 1. Generating Unit Data and Operating Cost data of 4 unit test system

Unit	P^{max}, MW	P^{min}, MW	C^{P}, $/MWh	D, week	C^{MFX}, $/MWh	C^{MV}, $/MWh
1	76	15.2	28.8	3	1.14	0.9
2	100	25	46	3	0.97	0.8
3	100	25	46	3	0.97	0.8
4	155	54.25	23.28	4	0.8	0.8

Fig 1: flow chart for the proposed ABC algorithm

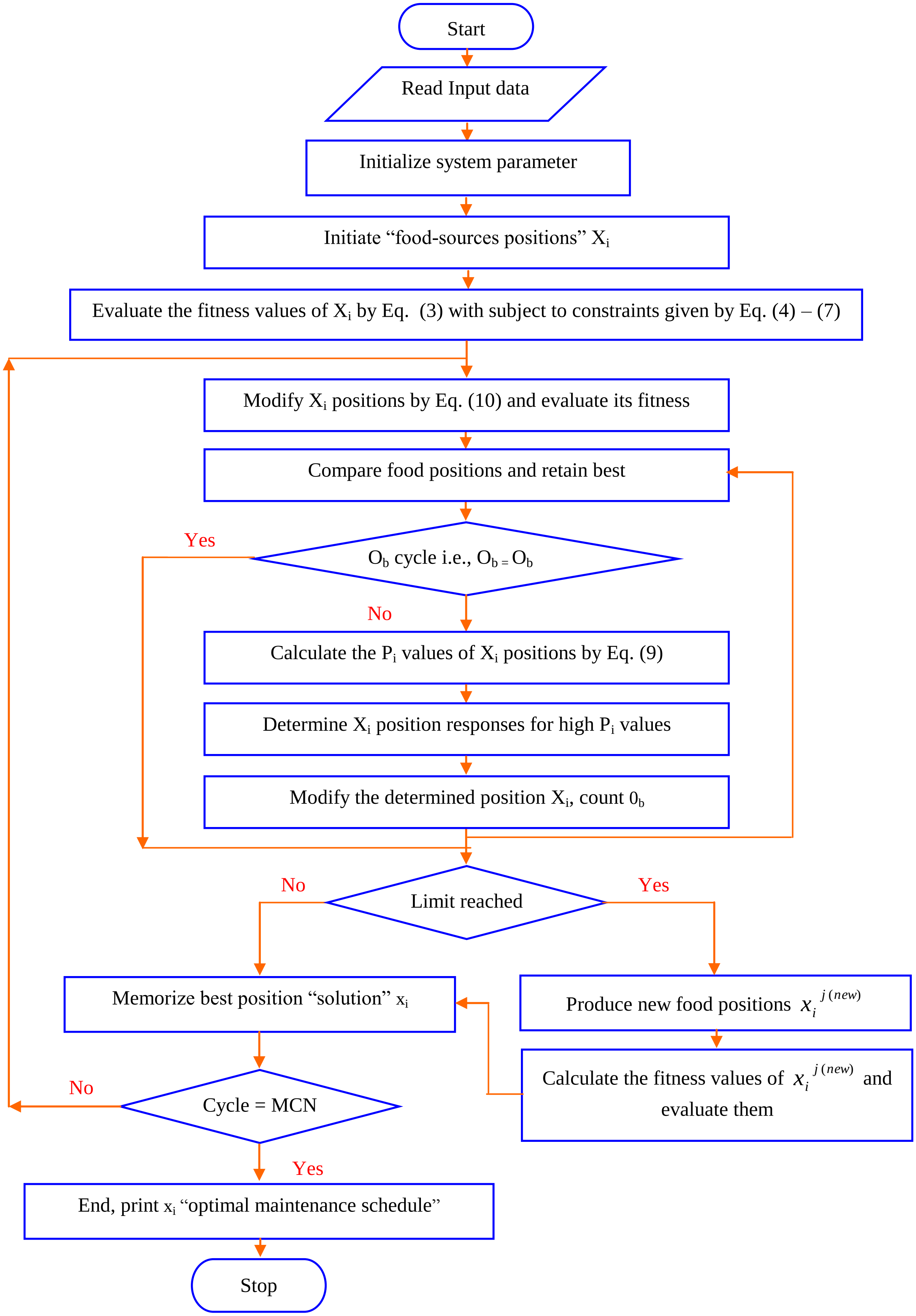

Table 2. Unit maintenance schedule and power output of committed units for 4 unit system

Week no	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	Week no	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)
1	76	100	49	155	**27**	76	***	***	***
2	76	100	60	155	**28**	76	***	***	***
3	76	100	35	155	**29**	76	100	100	***
4	76	100	34	155	**30**	76	100	64	155
5	76	100	61	155	**31**	76	100	49	155
6	76	100	49	155	**32**	76	100	43	155
7	76	100	31	155	**33**	76	100	39	155
8	76	96	25	155	**34**	76	79	25	155
9	76	79	25	155	**35**	***	100	100	155
10	76	0	91	155	**36**	***	100	76	155
11	76	0	87	155	**37**	***	100	54	155
12	76	0	83	155	**38**	76	0	83	155
13	76	82	0	155	**39**	76	0	96	155
14	76	75	0	155	**40**	76	0	73	155
15	76	72	0	155	**41**	76	66	0	155
16	76	68	0	155	**42**	76	72	0	155
17	76	0	65	155	**43**	76	74	0	155
18	76	0	70	155	**44**	76	72	0	155
19	76	0	58	155	**45**	76	0	72	155
20	76	0	67	155	**46**	76	69	0	155
21	76	98	0	155	**47**	76	75	0	155
22	76	100	0	155	**48**	76	89	0	155
23	76	80	0	155	**49**	76	92	25	155
24	76	96	0	155	**50**	76	97	25	155
25	76	100	45	155	**51**	76	97	25	155
26	76	***	***	***	**52**	76	91	25	155

*** - Units under maintenance 0 – Units are not committed

Table 3. Comparison of producer benefit and maintenance cost

Case	V_{Benefit} ($)	Maintenance cost ($)
Best	61 248 329	423 212
Average	60 872 361	
Worst	60 333 108	

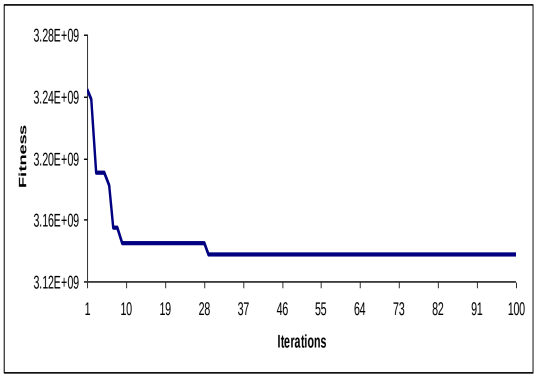

Fig 4: Fitness versus iterations of 4 unit test system

5.2 Case II: Thirty two unit system [15]

Numerical results on the large – scale IEEE reliability 32 unit test system are considered to ascertain the applicability and efficacy of the proposed ABC algorithm. The test system is comprised of 32 units, of which 4 units are combustion turbine, 2 units are nuclear steam and remaining 26 units are fossil steam [15]. The generating unit data and operating cost data are presented in Table 6. The annual peak load for the test system is 2850MW. The weekly load demands are depicted in Figure 5. The annual peak load occurs in week 51. The weekly electricity price of norpool deregulated power system (http://www.nordpool.com) is plotted in Figure 6. The entire maintenance schedule is obtained by ABC and GA is given in Table 5. The ABC algorithm obtain the high available generation of 3996MW in the weeks 1 to 4, 18 and 42 to 52 due to no unit is scheduled for maintenance. Where as GA obtain the high available generation only in the weeks 47 to 52.

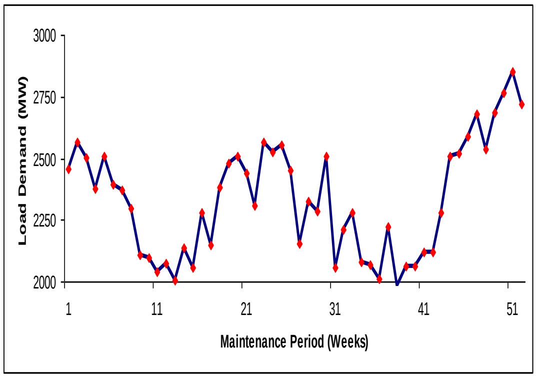

Fig 5: Load demand versus maintenance period of 32 unit test system

The comparison of producer benefit and maintenance cost is presented in Table 4. The maintenance cost is same for both algorithms. The proposed algorithm obtain the better economic benefit of 381 370 698$ because of no unit is scheduled for maintenance in the higher energy prizes as shown in Table 5. Figure 7 shows the typical convergence of the objective function (fitness) obtained over 100 trials. The figure shows that the minimization of the objective function converged to 1.21E+10 to 1.16E+10. The converged results clearly present minimization of the objective function given by Eq. (3). The optimization process demonstrates the capabilities of the ABC algorithm in minimizing large variations of system net reserve in case they occur. From the discussion it is clear that the ABC algorithm is produce better results than reported method.

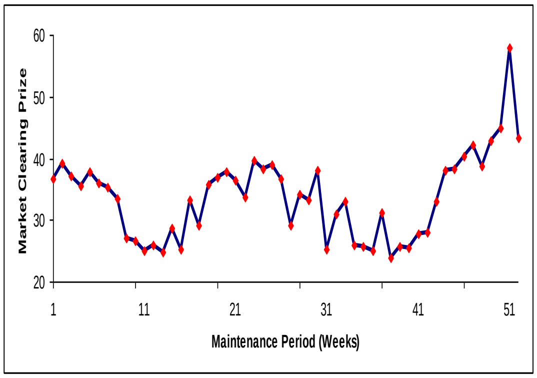

Fig 6: Market clearing prize versus maintenance period of 32 unit test system

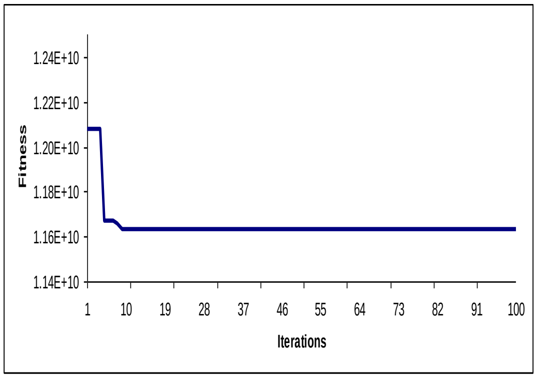

Fig 7: Fitness versus iterations for 32 unit test system

Table 4. Comparison of producer benefit and maintenance cost

Algorithm	$V_{Benefit}$ ($)	Maintenance cost ($)
ABC	381 370 698	2 813 909
GA [15]	381 370 000	

6. CONCLUSION

The Generator Maintenance Scheduling in deregulated power system is a challenging task for power engineers and it requires some traditional approach to prepare the maintenance schedule. The effective GMS of power system are very important to a power utility for the economical and reliable operation of a power system. An optimal GMS increases the operating system reliability, reduces power generating cost and extends the generator lifetime.

Table 5. Unit maintenance schedule for 32 unit test system

Week no	**Generating units scheduled for maintenance**		**Week no**	**Generating units scheduled for maintenance**	
	ABC	**GA [15]**		**ABC**	**GA [15]**
1	---	11,15	**27**	3,30,32	32
2	---	11,15	**28**	11,15,27,30,32	32
3	---	11,15,19	**29**	9,11,13,15,19,27,30,32	32
4	---	6,10,14,15,19	**30**	11,13,15,16,19,25,27,30	32
5	18	10,14,19	**31**	13,14,15,16,19,25,27,30	24,32
6	2,18,28	10,14,19	**32**	14,16,19,22,25,27,30,31	24,32
7	6,18,28	14,21	**33**	10,14,16,22,25,27,31	24,32
8	18,28	21,31	**34**	1,8,10,14,22,25,31	13,24,28,30
9	23,28	21,31	**35**	10,22,25,31	13,24,28,30
10	23,28	21,31	**36**	12,22,29,31	13,24,28,30
11	23,28	5,21,31	**37**	12,20,29,31	28,30
12	4,17,23,26	20,31	**38**	12,20,29,31	3,26,28,30
13	17,23,26	20,31	**39**	20,29,31	22,26,28,30
14	17,26	20,31	**40**	5,7,20,29,	22,26,30
15	17,26	20,29,31	**41**	20,29	22,26,27,30
16	26	12,16,18,20,29	**42**	---	4,7,17,22,26,27
17	26	1,2,8,9,12,16,18,25,29	**43**	---	17,22,26,27
18	---	12,16,18,25,29	**44**	---	17,27
19	21,24	16,18,25,29	**45**	---	17,27
20	21,24	25,29	**46**	---	27
21	21,24	23,25	**47**	---	---
22	21,24,32	23,25	**48**	---	---
23	21,24,32	23	**49**	---	---
24	24,32	23	**50**	---	---
25	30,32	23	**51**	---	---
26	30,32	32	**52**	---	---

In this paper, a novel bio-inspired search technique namely; Artificial Bee Colony (ABC) algorithm is applied to solve the GMS to maximize the potential benefit of a power producer. The ABC is a novel bio inspired algorithm suitable for engineering optimization problems, which is simple, robust and efficient in handling the constraints. The performance of the proposed algorithm for solving GMS is tested with the generation producer with 4 and 32 generating unit test system is adopted. Numerical simulation results demonstrate that this method is to be a promising alternative approach for solving generator maintenance scheduling problems in a deregulated power system.

Table 6. Generating unit data and operating cost data of 32 unit test system

Unit No	Type	Unit Size MW		No. Units	Maintenance Duration (Week)	Maintenance Costs	
		Pmax	Pmin			Fixed S/Kw/YR	Variable $/MWh
1-5	Fossil Steam	12	2.4	5	1	10	5
6-9	Combustion turbine	20	4	4	1	0.3	5
10-13	Fossil Steam	76	15.2	4	3	10	0.9
14-19	Fossil Steam	100	25	6	4	8.5	0.8
20-23	Fossil Steam	155	54.25	4	5	7	0.8
24-29	Fossil Steam	197	68.95	6	6	5	0.7
30	Fossil Steam	350	140	1	8	4.5	0.7
31-32	Nuclear steam	400	100	2	8	5	0.3

7. ACKNOWLEDGEMENTS

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