Modified ABC Algorithm for Generator Maintenance Scheduling

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***Abstract*—The goal of an optimal Generator Maintenance Scheduling (GMS) is solved in order to generate optimal preventive maintenance schedule of generating units for economical and reliable operation of a power system while satisfying system load demand and crew constraints. In this paper a Modified Artificial Bee Colony (MABC) algorithm is applied to solve the GMS optimization problem efficiently. The MABC algorithm is proposed in order to handle the system constraints effectively and obtain the better maintenance schedules. The efficacy of the proposed algorithm is illustrated with 13 generating units and 21 generating units with two different load demands. The simulation results are compared with Discrete Particle Swarm Optimization (DPSO), Modified Discrete Particle Swarm Optimization (MDPSO) and Multiple Swarms - Modified discrete Particle Swarm Optimization (MS-MDPSO) which is also population based heuristic search algorithms. From the numerical results, it is found that the MABC based approach is able to provide a better solution for GMS.**

***Index Terms*—Generator maintenance scheduling, optimal scheduling, modified artificial bee colony (MABC) algorithm, meta – heuristic algorithm.**

I. Nomenclature

AM_t	available manpower at period t
C	cycles
D	number of optimization parameter in ABC algorithm
d_i	duration of maintenance for unit i
e_i	earliest period for maintenance of unit i begin
f_i	fitness value or nectar amount
fit_i	fitness associated with i th solution
i	index of generating units
I_t	set of units allowed to be in maintenance in period t
k	discrete time step
L_t	anticipated load demand for period t
l_i	latest period for maintenance of unit i to end
M_{ik}	manpower needed by unit i in period k
P	initial population
P_{ik}	generating capacity of unit i in start time period k
P_{it}	generating capacity of unit i in period t
RI	reliability index
S_{it}	set of start time period
T	set of indices of periods in planning horizon
T_i	set of periods when maintenance of unit i may start
t	index of period
$\|V_1\|, \|V_2\|, \|V_3\|$	amount of violations of maintenance window, crew and load constraints respectively
ω_c	inertia weight constant
$\omega_1, \omega_2, \omega_3$	weighting coefficients of maintenance window, crew and load constraints respectively
X_{it}	maintenance start indicator for unit i in period t
X_{ik}	maintenance start indicator for unit i in start time period k
X_i	random generation of food source positions
x_i	position found by scout bee
$x_i^{j(new)}$	new position found by scout bee

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II. Introduction

The thermal generator maintenance scheduling problem is a complex combinatorial optimization. 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 [1]. 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. Modern power system is experiencing increased demand for electricity with related expansions in system size, which has resulted in higher number of generators and lower reserve margins making the GMS more complicated. There are two categories of criteria for GMS problem; based on economic cost and reliability [2].

In the last decade, many kinds of intelligence computational methods have been applied to solve the unit maintenance scheduling problem. The GMS problem is formulated as a mixed integer programming model for the thermal generator maintenance scheduling, and it is solved by Simulated Annealing (SA) [3]. A code specific and constraint transparent coding method has been developed and is applied to the Genetic Algorithm (GA) for unit maintenance scheduling of power systems [4]. The GA optimization of the maintenance scheduling of generating units in a power system has also been proposed [5]. Tabu Search technique also been applied to determine the optimal generator maintenance schedule of thermal units [6].

The hybrid solution techniques are also been applied to determine the optimal solution for GMS problems. The Constraint Logic Programming (CLP) synthesizes logic programming, constraint satisfaction technique and branch and bound search scheme, has been used to determine the optimal solution [7]. Logic programming and constraint satisfaction technique are used to prune away the infeasible solutions from the search domain. The optimal solutions are obtained by using the depth first branch and bound technique in the reduced search domain. The detailed comparative study of on the applications of a number of GA based approaches, namely GA/SA, GA/SA/heuristic approach has also been applied to solve GMS problem [8]. The Bender's decomposition approach has also been applied to power plant preventive maintenance scheduling [9]. The Particle Swarm Optimization (PSO), an algorithm motivated from the simulation of the behavior of social systems such as fish schooling and birds flocking. The PSO and its modified versions namely Discrete PSO, Modified Discrete PSO and Multiple Swarm MDPSO have been applied to determine the optimal maintenance schedule [10], [11] and [12].

Recently, inspired by the foraging behavior of honeybees, researchers have developed Artificial Bee Colony (ABC) algorithm for solving various optimization problems. 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 PSO algorithm in terms of quality of solution [13–16]. 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, MABC algorithm is proposed to determine the optimal solution for GMS problems.

III. Problem Formulation

Generator maintenance schedule is a preventive outage schedule for generating units in a power system within a specified time horizon. Maintenance scheduling becomes a complex optimization problem when the power system contains a number of generating units with different specifications, and when numerous constraints have to be taken into consideration to obtain an optimal, practical and feasible solution. It is done for a time horizon of different durations. Generally, there are two main categories of objective functions in GMS, such as, based on reliability and economic cost [2]. This study applies the reliability criteria of leveling reserve generation for the entire period of study. This can be realized by minimizing the sum of squares of the reserve over the entire operational planning period. The problem has a series of unit and system constraints to be satisfied. The constraints include the following:

- Maintenance window and sequence constraints – defines the starting of maintenance at the beginning of an interval and finishing at the end of the same interval. The maintenance cannot be aborted or finished earlier than scheduled.
- Crew and resource constraints – for each period, number of people to perform maintenance schedule cannot exceed the available crew. It defines manpower availability and the limits on the resources/tools needed for maintenance activity at each time period.
- Load and spinning reserve constraints – total capacity of the units running at any interval should not be less than predicted load at the interval.

Suppose $T_i \subset T$ is the set of periods when maintenance of unit i may start, $T_i = \{t \in T : e_i \le t \le l_i - d_i + 1\}$ for each i.

Define

$$X_{it} = \begin{cases} 1 \ \textit{if unit i starts maintenance in the} \\ \quad \textit{period t} \\ 0 \ \textit{otherwise} \end{cases} \tag{1}$$

to be the maintenance start indicator for unit i in period t. Let S_{it} be the set of start time periods k such that if the maintenance of unit i starts at period k that unit will be maintenance at period t,

$$S_{it} = \{k \in T_i : t - d_i + 1 \le k \le t\}$$

Let I_t be the set of units which are allowed to be in maintenance in period t, $I_t = \{i : t \in T_i\}$.

The objective function to be minimized is given by Eq. (2) subject to constraints given by Eq. (3) – (5).

$$\mathrm{M}in\ \mathrm{X}_{it}\left\{\sum_{t}(\sum_{i \in I_t}\sum_{k \in S_{it}}\mathrm{X}_{ik}.\mathrm{P}_{ik} - L_t)^2\right\} \tag{2}$$

subject to the maintenance window constraint

$$\sum_{t \in T_i}\mathrm{X}_{it} = 1 \quad \forall i \tag{3}$$

the crew constraint

$$\sum_{i \in T_i}\sum_{k \in S_{it}}\mathrm{X}_{ik}.\mathrm{M}_{ik} \le \mathrm{AM}_t \quad \forall t \tag{4}$$

and the load constraint

$$\sum_{i}\mathrm{P}_{it} - \sum_{i \in I_t}\sum_{k \in S_{it}}\mathrm{X}_{ik}.\mathrm{P}_{ik} \ge L_t \quad \forall t \tag{5}$$

Penalty cost given by Eq. (6) is added to the objective function in Eq. (2) if the schedule cannot satisfy the maintenance window, crew and load constraints. The penalty value for each constraint violation is proportional to the amount by which the constraint is violated.

$$Penalty\ \cos t = \sum_{c=1}^{3} w_c|v_c| = w_1|v_1| + w_2|v_2| + w_3|v_3| \tag{6}$$

IV. Artificial Bee Colony (ABC) Algorithm

The foraging bees are classified into three categories; employed bees, onlookers and scout bees. All bees that are currently exploiting a food source are known as employed. The employed bees exploit the food source and they carry the information about food source back to the hive and share this information with onlooker bees. Onlookers bees are waiting in the hive for the information to be shared by the employed bees about their discovered food sources and scouts bees will always be searching for new food sources near the hive. Employed bees share information about food sources by dancing in the designated dance area inside the hive. The nature of dance is proportional to the nectar content of food source just exploited by the dancing bee. Onlooker bees watch the dance and choose a food source according to the probability proportional to the quality of that food source. Therefore, good food sources attract more onlooker bees compared to bad ones. Whenever a food source is exploited fully, all the employed bees associated with it abandon the food source, and become scout. Scout bees can be visualized as performing the job of exploration, whereas employed and onlooker bees can be visualized as performing the job of exploitation.

In the ABC algorithm, each food source is a possible solution for the problem under consideration and the nectar amount of a food source represents the quality of the solution represented by the fitness value. The number of food sources is same as the number of employed bees and there is exactly one employed bee for every food source. This algorithm starts by associating all employed bees with randomly generated food sources (solution). In each iteration, every employed bee determines a food source in the neighbor- hood of its current food source and evaluates its nectar amount (fitness). The i^{th} food source position is represented as X_i where i=1, 2, …, N is a D-dimensional vector. The nectar amount of the food source located at X_i is calculated by using the Eq. (7). After watching the dancing of employed bees, an onlooker bee goes to the region of food source at X_i by the probability p_i defined in Eq. (8).

$$fit_i = \frac{1}{1+f_i} \tag{7}$$

$$p_i = \frac{fit_i}{\sum_{n=1}^{N} fit_n} \tag{8}$$

The onlooker finds a neighborhood food source in the vicinity of X_i by using the Eq. (9)

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) \tag{9}$$

where $k\in\{1,2,...N\}$ and $j\in\{1,2,...D\}$ are randomly chosen indexes. Although k is determined randomly, it has to be different from i. □$_{ij}$ is a random number between [-1, 1]. If its new fitness value is better than the best fitness value achieved so far, then the bee moves to this new food source abandoning the old one, otherwise it remains in its old food source. When all employed bees have finished this process, they share the fitness information with the onlookers, each of which selects a food source according to probability given in Eq. (8). With this scheme, good food sources will get more onlookers than the bad ones. Each bee will search for better food source around neighborhood patch for a certain number of cycles (limit), and if the fitness value will not improve then that bee becomes scout bee.

It is clear from the above explanation that there are three control parameters used in the basic ABC: The number of the food sources which is equal to the number of employed or onlooker bees (N), the value of limit and the maximum cycle number (MCN).

Parameter-tuning, in meta-heuristic optimization algorithms influences the performance of the algorithm significantly. Divergence, becoming trapped in local extrema and time-consumption are such consequences of setting the parameters improperly. The ABC, algorithm, as an advantage has few controlled parameters. Since initializing a population "randomly" with a feasible region is sometimes cumbersome, the ABC algorithm does not depend on the initial population to be in a feasible region. Instead, its performance directs the population to the feasible region sufficiently [13].

V. Modified ABC Algorithm for GMS Problem

Though the ABC algorithm described in the preceding Section provides the optimal schedule for GMS problem it does not guarantee the constraint satisfaction. Therefore it should be included with the suitable penalty factor during the fitness evaluation. Hence modifications are carried out at the initialization steps in the main ABC algorithm to efficiently deal the various equality and inequality constraints. The subsequent sections describe in detail the implementation strategies of improved ABC.

A. Initialization

The following modifications are carried out in the initialization process.

- The elements of an individual are selected at random satisfying the inequality constraints such as maintenance window, maintenance area and crew constraints.
- The generating units to be committed are identified based on their maximum generation capacity and should satisfy the spinning reserve constraint.
- The preceding steps are repeated until the individual satisfies these constraints.

The initial population of N individuals thus created satisfies the equality and inequality constraints. The fitness values of the individuals are computed using Eq. (7).

B. Limit

The controlled parameter (limit) is important in the ABC algorithm because it prevents the algorithm from trapped in local extrema. The limit is taken as 0.5 × N × D [13-16], however assume that one of the initial solutions was "fortunately" the optimal or near the optimal one, then after a predetermined number of trails this solution, intuitively, will never be improved; consequently the ABC algorithm will abandon this (presumed optimal) solution, if it is discovered, is memorized at least once before releasing it, the proposed limit value is set equal to $1+O_b^2$.

VI. MABC Algorithm for Generator Maintenance Scheduling

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

Step1: Read the system data.

Step2: Initialize the control parameters of the algorithm.

Step3: An initial population of N solution is generated as detailed in the Section V. Each solution X_i *(i=1, 2 ... N)* is represented by a D-dimensional vector.

Step4: Evaluate the fitness value of each individual in the colony.

Step5: Produce neighbor solutions for the employed bees and evaluate them.

Step6: Apply the selection process.

Step7: If all onlooker bees are distributed, go to step 10. Otherwise, go to the next step.

Step8: Calculate the probability values p_i for the solutions X_i.

Step9: Produce neighbor solutions for the selected onlooker bee, depending on the p_i value and evaluate them.

Step10: Determine the abandoned solution for the scout bees, if it exists and replace it with a completely new randomly generated solution and evaluate them.

Step11: Memorize the best solution attained so far.

Step12: Stop the process if the termination criterion is satisfied. Otherwise, go to step 3.

VII. Simulation Results and Discussions

This paper considers a test problem of scheduling maintenance of 21 generating units over a planning period of 52 weeks and 13 generating units over a planning period of 26 weeks. This test problem is loosely derived from the example presented in the literature [10], [11] and [12]. The performance of the proposed Modified ABC based generator maintenance scheduling algorithm is implemented using Matlab on a Intel (R) Core*(TM)*^{2} Duo 2.10 GHz personal computer. The selected control parameters of ABC are N = 100, MCN =100 and Limit = 30. For Modified ABC, the control parameters are N=100, MCN=100 and Limit = 2501.

A. Case 1: 21 Unit System [10]

The proposed MABC algorithm is applied to GMS problem, with 21 generating units. The maintenance outages for the generating units are scheduled to minimize the sum of the squares of reserves and satisfying the following constraints. Maintenance window – each unit must be maintained exactly once every 52 weeks without interruption, the system peak load demand including 6.5% spinning reserve is 5047 MW, and there are 40 crew available each week for the maintenance work [8].

The maintenance schedule is obtained by DPSO, MDPSO, ABC and MABC is presented in Table 1. In the DPSO and MDPSO algorithm there is no low maintenance task for first 26 weeks i.e. entire 26 weeks the maintenance activities are carried out resulting in high available generation is not possible. Where as in ABC and MABC week 26 indicate period with low maintenance activity (no unit is scheduled for maintenance) resulting in comparatively high available generation on same week 26. In the last 26 weeks, using the DPSO algorithm week 33 and using the MDPSO algorithm week 43 are indicate periods with low maintenance activity (no unit is scheduled for maintenance) resulting in comparatively high available generation on same weeks 33 and 43. Where as in ABC algorithm, weeks 28 and 52 with low maintenance activity (no unit is scheduled for maintenance) resulting in comparatively high available generation on same weeks 28 and 52. The proposed MABC algorithm attains the maximum generation of 5688 MW in the weeks 28, 45, 46 and 52. From the comparison it is clear that the proposed MABC algorithm produce the better maintenance schedule in terms of attains maximum generation many times. The existing as well as the proposed algorithms is satisfying the load demand and crew requirements are exposed in Figs. 1 and 2.

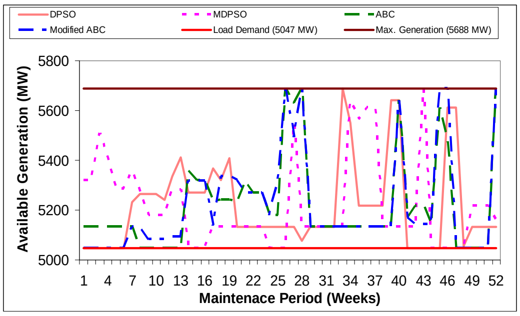

Fig. 1. Available generation of case 1

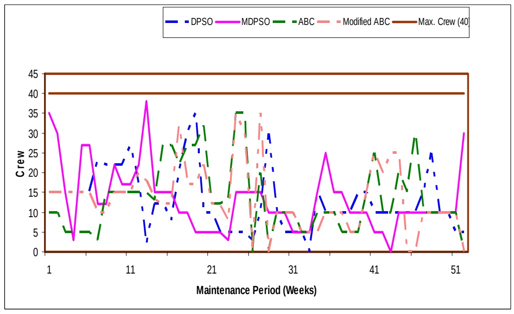

Fig. 2. Crew requirements of case 1

The convergence of the objective function (fitness) obtained over 5000 trials for ABC and MABC are presented in Fig. 3 and it is clear that the MABC converged quickly then ABC.

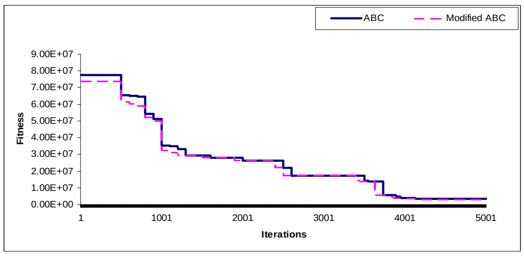

Fig. 3. Fitness versus iterations for case 1

The Reliability Index (RI) given by Eq. (10) describes the degree of performance of the algorithms that results in optimal maintenance schedules. It is computed by taking the minimum of the ratio of available generation to load demand over 5000 trials and the entire operational period [8]. The functional aspect of the reliability indices is that they show the generation adequacy and the ability of the system to supply the aggregate electrical energy and meet demand requirements of the customers at all times during maintenance period.

$$RI = Min(over\,5000\,trails)\left(Min(over\,52\,weeks)\left(\begin{cases} \frac{Avail.Gen}{Load} & if\ Avail.Gen. \le Load \\ 1 & otherwise \end{cases} \right)\right) \tag{10}$$

The RI s versus iterations for ABC and MABC are plotted in Fig. 4.

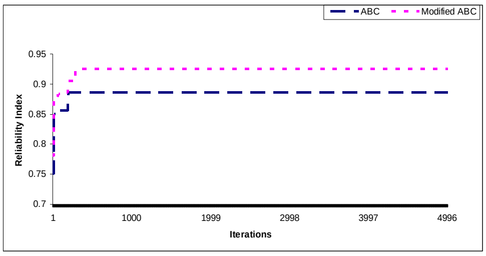

Fig. 4. Reliability index versus iterations for case 1

The MABC is seen to produce the most reliable schedule compared with ABC over 5000 trials. The result reveals that MABC produce better maintenance schedules then ABC.

B. *Case 2: 21 Unit System [11]*

In order to test the performance of the MABC algorithm, the same sample system is considered with the system peak load demand of 4739 MW, and 35 crew available each week for the maintenance work [11]. The complete maintenance schedule is obtained by MDPSO, MS-MDPSO, ABC and MABC is given in Table 2.

In the MDPSO algorithm the weeks 23 & 35, the weeks 30 & 36 in MS-MDPSO algorithm and the weeks 26, 33, 40 & 52 in ABC and the weeks 25, 26, 32, 39, 40, 50, 51 & 52 in MABC represents the low maintenance activities that is no unit is scheduled for maintenance. From the comparison it is clear that the MABC algorithm produce the improved maintenance schedules then existing algorithms. The weekly available generation and crew requirements are depicted in Figs. 5 and 6 respectively.

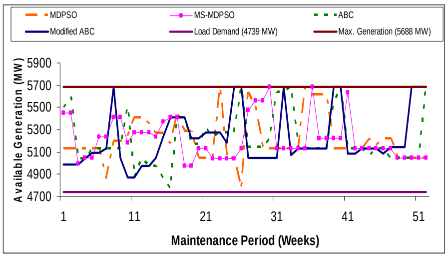

Fig. 5. Available generation of case 2

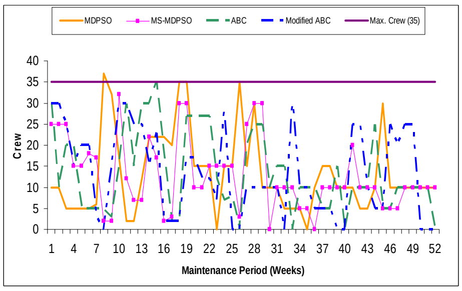

Fig. 6. Crew requirements of case 2

All the algorithms are satisfying the load requirements and crew requirements excepting MDPSO. The MDPSO algorithm does not satisfy the crew requirement on week 8 due to heightened maintenance activities carried out simultaneously on units 3, 6 and 11. The convergence of the objective function and reliability index are presented in fig. 7 & 8 respectively. The converged results clearly present minimization of the objective function and the optimization process demonstrates the capabilities of the MABC algorithm in minimizing large variations of system net reserve in case they occur

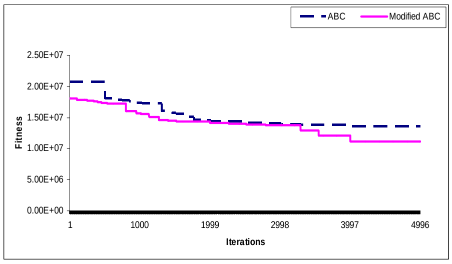

Fig. 7. Fitness versus iterations for case 2

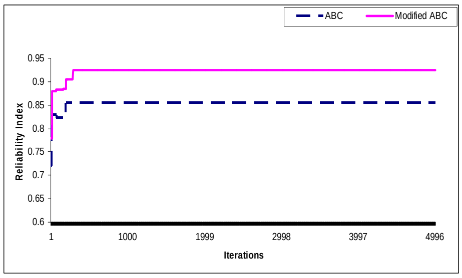

Fig. 8. Reliability index versus iterations for case 2

C. *Case 3: 13 Unit System [12]*

The test system consists of 13 generating units with the system peak load with 6.5% spinning reserve is 2500 MW, available man power for maintenance per week is limited to 40 and the maximum generation is 3150 MW [12]. The complete maintenance schedules obtained by DPSO, MDPSO and ABC are presented in Table 3. In DPSO and MDPSO algorithms entire 26 weeks the maintenance activities are carried out resulting in high available generation is not possible. The ABC algorithm reaches the high available generation of 3150 MW in week 13 since no units is scheduled for maintenance whereas the proposed MABC algorithm produce the better maintenance schedules in terms of attains the high available generation in the weeks 14, 25 and 26. The weekly available generation and crew requirements are plotted in Fig. 9 & 10 respectively. From the comparison it is clear that the proposed ABC algorithm produce the better maintenance schedules than existing algorithms.

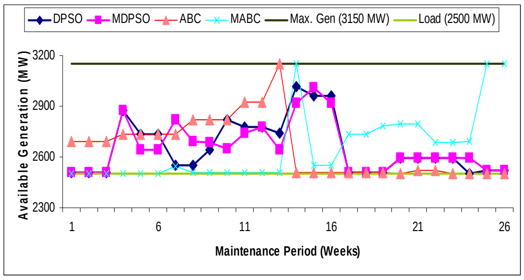

Fig. 9. Available generation of case 3

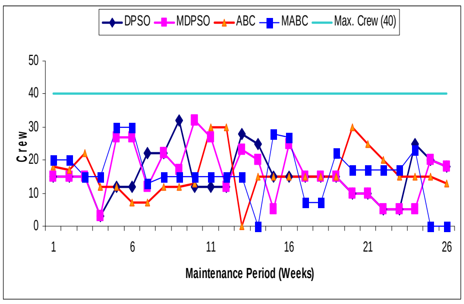

Fig. 10. Crew requirements of case 3

TABLE I: GMS SCHEDULE FOR CASE 1

WEEK NO	GENERATING UNITS SCHEDULED FOR MAINTENANCE				WEEK NO	GENERATING UNITS SCHEDULED FOR MAINTENANCE			
	DPSO	MDPSO	ABC	MABC		DPSO	MDPSO	ABC	MABC
1	5	3,12	1	4	27	16	20	18	18,20
2	5	2,12	1	4	28	16,18	16	----	----
3	5	2	1	4	29	16	16	14	16
4	4	6	1	5	30	16	16	14	16
5	4	6,9,13	1	5	31	16	16	14	16
6	4	6,9,13	1	5	32	16	16	14	16
7	3,6	6,13	1	1	33	---	16	14	16
8	6,10,13	6,7	5	1	34	20	19	16	16
9	6,10,13	6,7,10	5	1,13	35	21	17,19	16	14
10	6,10,13	6,7,10	5	1,13	36	21	17	16	14
11	6,9,10	6,7,10	4	1,13	37	21	17	16	14
12	6,9	6,7,11	4	1,11	38	21	14	16	14
13	6	6,8,11	4	1,11	39	19	14	16	14
14	6,7	5	6,13	6,10	40	19	14	19	19
15	6,7	5	6,11,13	6,10	41	15	14	19,21	19,21
16	6,7	5	6,11,13	6,10	42	15	14	21	17,21
17	2,7	1	3,6	3,6,10	43	15	---	21	17,21
18	2,12	1	6,9,10	6,9	44	15	15	17,21	17,21
19	8,12	1	6,9,10	6,9	45	15	15	17	---
20	1	1	6,8,10	6,8	46	17	15	17,20	---
21	1	1	6,10	6,7	47	17	15	15	15
22	1	1	6,7	6,7	48	14,17	15	15	15
23	1	1	6,7	6,7	49	14	21	15	15
24	1	4	2,7,12	2,7,12	50	14	21	15	15
25	1	4	2,7,12	2,12	51	14	21	15	15
26	1	4	---	---	52	14	18,21	----	----

TABLE II: GMS SCHEDULE FOR CASE 2

WEEK NO	GENERATING UNITS SCHEDULED FOR MAINTENANCE				WEEK NO	GENERATING UNITS SCHEDULED FOR MAINTENANCE			
	MDPSO	MS - MDPSO	ABC	MABC		MDPSO	MS - MDPSO	ABC	MABC
1	1	12,13	8,10	1,10,13	27	19	17,20	17,21	15
2	1	12,13	10	1,10,13	28	19,20	17,19	17,21	15
3	1	4,13	1,10	1,10,13	29	16	17,19	17,21	15
4	1	4	1,10	1,10	30	16	---	21	15
5	1	4	1	1,11	31	16	14	19	15
6	1	2,6	1	1,11	32	16	14	19	---
7	1,6	2,6	1	1	33	16	14	---	16,18
8	3,6,11	6	1	---	34	16	14	14	16
9	2,6,11	6	1	4	35	---	14	14	16
10	2,6	6,7,8	2	2,4	36	17	---	14	16
11	6	6,7	2,4	2,4	37	17	21	14	16
12	6	6,7	4	5,9	38	17	21	14	16
13	6,13	6,7	4,9	5,9	39	14	21	20	---
14	6,10,13	6,7,11	5,9	5	40	14	21	---	---
15	6,10,13	6,11	3,5	3,6	41	14	18	16	14,19
16	6,7,10	6	5,6	6	42	14	16	16	14,19
17	7,10	6	6	6	43	14	16	16	14
18	7,9,12	5,9	6	6	44	21	16	16,18	14
19	7,9,12	5,9	6,12,13	6,12	45	18,21	16	16	14
20	4	1	6,12,13	6,12	46	21	16	16	20,21
21	4	1	6,11,13	6,7	47	21	16	15	17,21
22	4	1,10	6,7,11	6,7	48	15	15	15	17,21
23	---	1,10	6,7	6,7	49	15	15	15	17,21
24	5	1,10	6,7	6,7,8	50	15	15	15	---
25	5	1,10	6,7	----	51	15	15	15	---
26	5,8	1	---	----	52	15	15	---	---

TABLE III: GMS SCHEDULE FOR CASE 3

WEEK NO	GENERATING UNITS SCHEDULED FOR MAINTENANCE			
	DPSO	MDPSO	ABC	MABC
1	4	4	2,6	1,10
2	4	4	2,6	1,10
3	4	4	6,3	1,10
4	6	6	6,7	1,10
5	6,7	2,6,13	6,7	1,11,13
6	6,7	2,6,13	6,7	1,11,13
7	2,6,7	6,13	6,7	1,13
8	2,6,7	3,6	6,13	4
9	3,6,13	6,12	6,13	4
10	6,13	6,11,12	6,13	4
11	6,10	6,10,11	11,12	5
12	6,10	6,10	11,12	5
13	6,10,11	6,7,10	----	5
14	10,11	7,10	4	----
15	12	7	4	2,6,7
16	12	7,8	4	2,6,7
17	5	5	5	6,7
18	5	5	5	6,7
19	5	5	5	6,8
20	1	1	1,8	6,9
21	1	1	1,9	6,9
22	1	1	1,9	6,12
23	1	1	1,10	6,12
24	1,8	1	1,10	6,3
25	1,9	1,9	1,10	---
26	1,9	1,9	1,10	---

VIII. CONCLUSION

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 this paper, a Modified Artificial Bee Colony (MABC) algorithm is proposed to solve a challenging power system optimization problem of generating unit maintenance schedule. The MABC is a novel bio inspired algorithm suitable for engineering optimization problems, which is simple, robust and efficient in handling the constraints and produce better maintenance schedules. The modifications are made in the initialization stage and control parameter (limit) of the ABC algorithm, however these do not alter but improve the inherent search process of the algorithm. The performance of the proposed algorithm for solving GMS is tested with the 13 and 21 unit test system and the results are compared with earlier reported methods. It is evident from the comparison the Modified ABC provides a competitive performance in terms of optimal solution. It is also found that this method is to be a promising alternative approach for solving GMS problems in practical power system.

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