No. O-025

Generation Maintenance Scheduling Using Hybrid Evolutionary Approach

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Abstract

To ensure a reliable supply of demand and reliable operation of the generation units an accurate maintenance scheduling is needed. Maintenance scheduling is a large, mixed integer, nonlinear, multi objective, and multi constraint problem. Evolutionary approaches are used to solve this crucial problem. This paper presents a genetic algorithm approach in combination with extremal optimization to tackle maintenance scheduling problem. The goal is to levelize the reserve throughout the year. Local search is used to improve genetic algorithm members in each iteration. The proposed algorithm is applied to a test problem and the results are compared with other methodologies. The results of the simulation show the capability of the proposed method in maintenance scheduling of the generators in power systems.

Keywords: Maintenance Scheduling, Hybrid Genetic Algorithm, Extremal Optimization
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1 INTRODUCTION

In both centralized and restructured power industry, utility owners try to maximize their profits while maintaining a high level of reliability. Maintenance scheduling as a midterm operational planning, is very crucial for safe and reliable operation of power system. Maintenance scheduling is defined as finding a timetable for outage of equipments for maintenance. Maintenance scheduling can have different goals such as. maximizing reliability, minimizing cost and combination of them. Therefore, maintenance scheduling problem is an optimization problem which can be tackled with various approaches. In [1] ,0-1 linear integer programming is used to solve the problem. The proposed approach guarantees the optimal solution if it exists. In [2] dynamic programming has been employed to address large scale problems. Benders decomposition for maintenance scheduling with transmission constraints has been emplyed in [3]. Metaheuristic approaches such as simulated annealing (SA), genetic algorithm (GA) and ant colony have been also applied to the problem of maintenance scheduling. In [4], simulated annealing is applied to the maintenance scheduling problem and it has been shown that the proposed approach is able find a solution for medium and large scale problem whilst integer programming is not able to tackle the high dimension problems. Genetic algorithm with binary representation has been applied to the problem in [5]. Later, the proposed method is improved by using integer representation [6]. In [7], different hybrid evolutionary techniques are used and the authors have shown that genetic algorithm with Tabu search as a local optimizer gives the best results. In [8] ant colony approach is used with a local search strategy for power plant maintenance scheduling problem. Also in [9], GA, SA and GA-based hybrid approaches are used for generator maintenance scheduling problem. Their results show that inoculated GA/SA approach gives the best average performance.

In this paper a hybrid evolutionary approach is used for generator maintenance scheduling problem. GA is used to find the optimal solution. In each iteration of GA, a local search method based on GA and extremal optimization (EO) is employed to improve the individuals.

This paper is organized as follows. The maintenance scheduling problem is described in Section II. The proposed method is presented in Section III. The proposed method is applied to an earlier case study in Section V and the results are compared with existing methods.

2 MAINTENANCE SCHEDULING PROBLEM

Maintenance scheduling problem is a complicated discrete non-linear optimization problem which is very important for the safe and reliable operation of generating units [10]. The goal of maintenance scheduling problem is either minimizing cost [1, 7] or maximizing the reliability in the planning horizon [9, 11, 12].

Since there is not a noticeable difference between the least and the most expensive feasible solutions, reliability is chosen as the goal of maintenance scheduling [9]. Sum of the squares of the reserves over different weeks in the planning horizon is used as a criterion for measuring reliability. Since sum of the reserves over different weeks in the planning horizon is constant, the objective function is minimized when the reserve is distributed uniformly throughout planning horizon which is called reserve levelizing [7]. The objective function and the constraints are formulated in (1)-(4) [9].

$$\min_{X_{it}} \left\{ \sum_{t \in T} \left(\sum_{i \in I_t} P_{it} - \sum_{i \in I_t} \left(\sum_{k \in S_{it}} X_{ik} P_{ik} \right) - L_t \right)^2 \right\} \qquad (1)$$

Such that,

$$\sum_{t \in T_i} X_{it} = 1 \qquad \text{for all } i \in I \qquad (2)$$

$$\sum_{i \in I} M_{it} \leq AM_t \qquad \text{for all } t \in T \qquad (3)$$

$$\sum_{i \in I} P_{it} - \sum_{i \in I_t} \sum_{k \in S_{it}} X_{ik} P_{ik} \geq L_t \qquad \text{for all } t \in T \qquad (4)$$

Where,

- i index of generating units
- I set of generating unit indices
- N total number of generating units
- t index of periods
- T set of indices of periods in planning horizon
- P_{it} generating capacity of unit i at period t
- L_t forecasted load demand for period t
- M_{it} manpower needed by unit i at period t
- AM_t available manpower at period t
- T_i set of periods when maintenance of unit i may start, $T_i = \{ t \in T : e_i \leq t \leq l_i - d_i + 1 \}$
- e_i earliest period for maintenance of unit i to begin
- l_i latest period for maintenance of unit i to end
- di duration of maintenance for unit i
- X_{it} maintenance start indicator is defined as

$$X_{it} = \begin{cases} 1 & \text{if unit } i \text{ starts maintenance in period t} \\ 0 & \text{Otherwise} \end{cases}$$

- S_{it} set of start time periods if unit i is in maintenance in period t, $S_{it} = \{ k \in T_i : t - d_i + 1 \leq k \leq t \}$.
- I_t set of units which are allowed to be in maintenance in period t, $I_t = \{ i : t \in T_i \}$

The objective function is equal to sum of squares of reserves over planning weeks. Equation (2) models maintenance window constraint. The *i*th constraint of (2) shows that unit *i* must start maintenance at T_i. It also says that unit *i* can not start maintenance more than one time at T_i.. Constraint (3) stands for manpower constraint. It explains that units must be maintained so that the sum of the required manpower at each period does not exceed available manpower at that period. Equation (4) indicates that units must be maintained so that the available units meet the load of each period.

3 THE PROPOSED METHOD

3.1 Genetic Algorithm

Genetic algorithm as a stochastic global search is a powerful tool for combinatorial optimization problems especially when the objective function is discrete, nonlinear and undifferentiable. Genetic algorithm starts with a potential set of solutions or individuals and tries to improve them in subsequent iterations [13, 14]. A fitness function is allocated to each individual according to its objective value. Then individuals are combined to each other with operators borrowed from natural biology and new children are created from their breeding. The worst member of the population is then replaced by the best offspring member and this trend is repeated until the termination criterion is satisfied. Although of the great advantages of genetic algorithm, it has some drawbacks. Therefore, researches have tried to combine genetic algorithm with other search algorithms as local search to cover its disadvantages. The combined method is named memetic algorithms [15, 16].

3.2 Local Search

The role of local search is to improve one or more members of an offspring. Then, the worst members of the population are replaced by improved ones, which is named elitism strategy [13, 14]. Different local search methods such as tabu search, simulated annealing and hill climbing are presented in the literature [6, 7]. Recently, extremal optimization is proposed which is employed for optimization problems. In order to improve an individual using this algorithm, this individual is divided into some components and a fitness is allocated to each component. The component fitness should be defined so that the sum of components' fitness is proportional to individual fitness. Then the worst component of the individual is found and its value is replaced by a random value. In long term, this procedure will lead to the improvement of the component fitness and hence the whole individual fitness.

3.3 Hybrid Genetic Algorithm

The proposed hybrid evolutionary algorithm uses GA as the evolutionary algorithm and EO&GA as the local search. In the proposed approach, the best individual found from GA, is processed in local search phase. In this phase, the individual is divided into n components. Component fitness is defined and is computed for each component. Then the components which have fitness value less than the average component fitness are identified. The average fitness component is computed over all the components of the under study individual. The identified components are improved using another GA which is named Local Search GA (LSGA). The best individual found from local search phase is then used for reinsertion in the main population. For example, consider the following individual and suppose that C_2 and C_n have fitness values less than the average component fitness. The selected components for improving by LSGA are dashed in Fig 1.

C_1	C_2	C_3	$\cdots$	C_n

Fig. 1 n components of an individual

Now LSGA is executed to improve the selected components. The initial population for the LSGA is depicted in Fig 2. In this figure only the selected components are changed and other components are remained without any change. After the creation of initial population of LSGA, LSGA is continued with selection, creating offspring using GA operators, and reinsertion. Note that GA operators only act on selected components. The above-mentioned procedure is repeated until LSGA stop criterion is satisfied. Then the best individual of the final population of the LSGA is selected and reinserted on the worst member of the population of the main GA.

C_1	C_{21}	C_3	$\cdots$	C_{n1}
C_1	C_{22}	C_3	$\cdots$	C_{n2}
C_1	C_{23}	C_3	$\cdots$	C_{n3}
⋮	⋮	⋮	⋮	⋮
C_1	C_{2n}	C_3	$\cdots$	C_{nn}

Fig. 2 Initial population of the LSGA

The best individual of the LSGA is depicted in Fig 3 where the dashed squares indicate the improved components. The flowchart of the proposed algorithm is shown in Fig. 4.

C_1	$C_{2,improved}$	C_3	$\cdots$	$C_{n,improved}$

Fig. 3 Improved individual in the local search phase

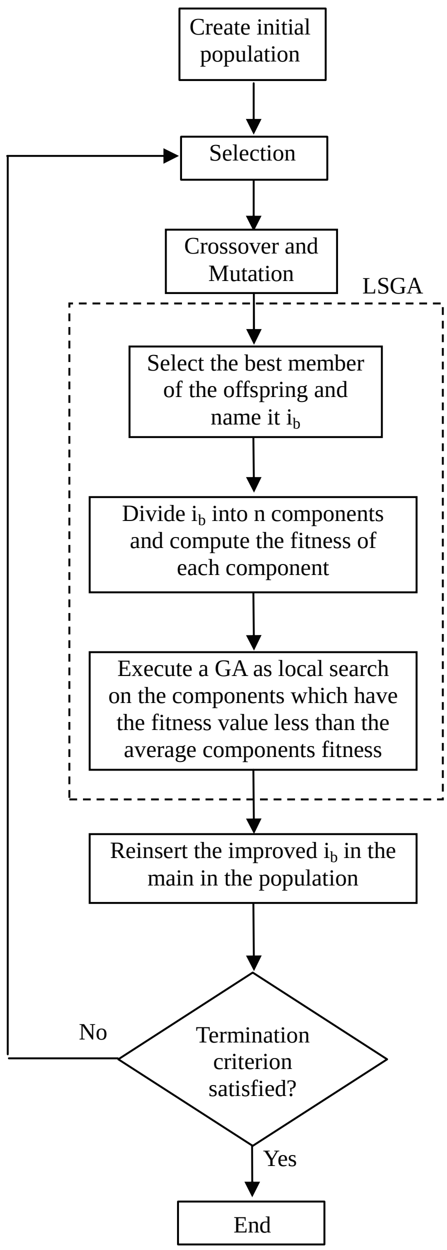

Fig. 4 Flowchart of the proposed hybrid evolutionary algorithm

4 CASE STUDY

The proposed method is used for maintenance scheduling of 21-machine power system which is used in [19], with some modifications. This case study has been used in [8, 9] too. The problem is to schedule 21 generating units over a year horizon (52 weeks). Maintenance data of the generating units including capacity, allowed maintenance periods (maintenance window), and duration of maintenance outages for each unit are given in table I [9]. Maintenance of units 1-13 must be started in the first half of the year, i.e. in weeks 1-26, and maintenance of units 14-21 must be started in the second half of the year, i.e. in weeks 27-52. The load is constant over the year and is equal to 4739 MW. There are 20 technical staffs in each week. Required manpower in each maintenance week for each unit is given in the fifth column of table I. Each unit must be maintained once in the scheduling horizon without interruption while satisfying the constraints, i.e. allowed period, load, and available manpower constraints.

Each individual is a outage timetable for maintenance of all units. The value of the component *i* is equal to start maintenance week of unit *i*. If no constraint is considered, the reserve is distributed uniformly. The ideal reserve at each week is 471.4 MW which leads to the objective value of 115.56×10^5 MW^2 [9]. The fitness of component *i* is defined as the standard deviation of reserve from the ideal reserve over the outage duration of the unit *i*. A high component fitness shows that the related unit is not maintained in proper time while a low component fitness shows the related unit is maintained in proper time. The LSGA is terminated, if the reserve in the outage duration of each unit is close to the ideal reserve.

Table I- Maintenance data of 21-machine test system [19]

Unit	Capacity (MW)	Allowed maintenance period (Weeks)	Outage duration (Weeks)	Required manpower at each maintenance week
1	555	1-26	7	10,10,5,5,5,5,3
2	180	1-26	2	15,15
3	180	1-26	1	20
4	640	1-26	3	15,15,15
5	640	1-26	3	15,15,15
6	276	1-26	10	3,2,2,2,2,2,2,2,2,3
7	140	1-26	4	10,10,5,5
8	90	1-26	1	20
9	76	1-26	2	15,15
10	94	1-26	4	10,10,10,10
11	39	1-26	2	15,15
12	188	1-26	2	15,15
13	52	1-26	3	10,10,10
14	555	27-52	5	10,10,10,5,5
15	640	27-52	5	10,10,10,10,10
16	555	27-52	6	10,10,10,5,5,5
17	76	27-52	3	10,15,15
18	58	27-52	1	20
19	48	27-52	2	15,15
20	137	27-52	1	15
21	469	27-52	4	10,10,10,10

5 SIMULATION RESULTS

In this section, GA and the proposed hybrid GA are employed for maintenance scheduling of 21-machine test system. The value of objective function in different iterations of GA and hybrid GA is depicted in Fig. 5. Comparison of results reveals that the value of objective function in hybrid GA method is much smaller than the value of objective function in GA method. In addition, the proposed method converges in much smaller iterations compared to the conventional GA method. For example, the value of the objective function in the proposed algorithm reaches to the value of 13339479 MW^2 in 100 iterations, while it reaches to 15745517 MW^2 in 10000 iterations in the conventional GA method without local search.

In order to show the performance of the proposed method, the problem is solved using GA and the proposed hybrid GA 100 times. In each run, stop criterion in GA is 5000 iterations and in hybrid GA is 100 iterations. The optimal value of the objective function in 100 runs GA and hybrid GA is shown in Fig. 6. As Fig. 6 shows the hybrid GA method has a lower objective function in 88 runs. After each run the mean of objective function of GA and hybrid GA over executed runs are computed. The mean of objective function after each run of GA and Hybrid GA is depicted in Fig. 7. Fig. 7 shows that the proposed method has a lower mean in comparison with conventional GA without local search.

In each run, the individual which has the lowest value of objective function determines optimal maintenance scheduling. Optimal maintenance scheduling using hybrid GA method is given in table II. This table shows the starting week for the outage of each unit. For example the maintenance of unit 10 starts at week 25. According to table I maintenance of this unit ends at the end of week 28.

6 CONCLUSION

In this paper a new hybrid evolutionary algorithm is presented. In the proposed combination of EO&GA are used as local search to improve an individual. GA and the proposed hybrid GA are applied to generating units maintenance scheduling problem. The result shows that the proposed hybrid GA performs much more better than GA in finding the optimal solution.

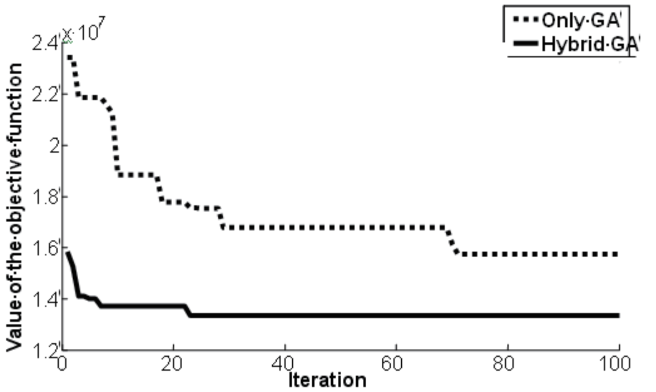

Fig. 5- Objective function in different iterations of GA and hybrid GA

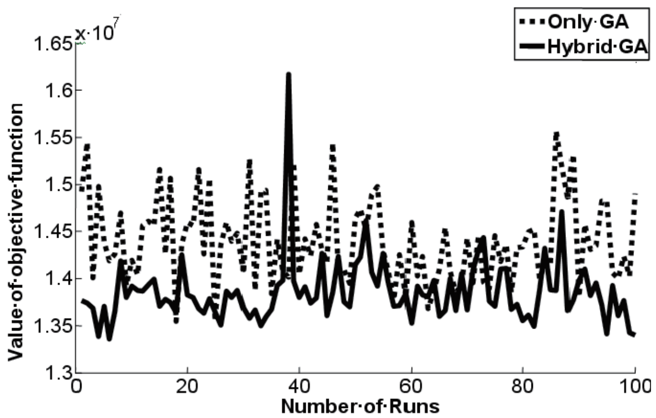

Fig. 6- Optimal value of objective function in 100 different runs of GA and hybrid GA

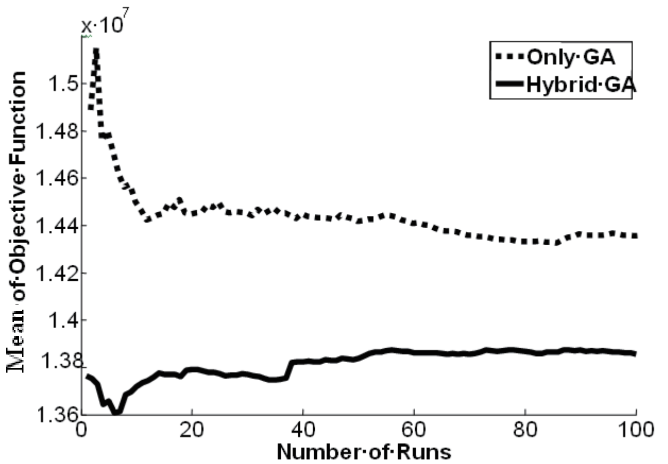

Fig. 7- Mean of objective function after each run over executed runs

Table II- Optimal maintenance timetable

Units	Maintenance start week
1	1
2	11
3	20
4	17
5	14
6	21
7	8
8	13
9	21
10	25
11	4
12	23
13	8
14	31
15	47
16	41
17	33
18	52
19	29
20	40
21	36

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