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Generator Maintenance Scheduling Of Power System Using Hybrid Technique

Suraj Kumhar[1], Mantosh Kumar[2]

[1]*M.Tech Scholar, Mewar University, Chittorgarh, Rajasthan, India*
[2]*Assistant Professor, Mewar University, Chittorgarh, Rajasthan, India*

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Abstract - *This paper presents generator maintenance scheduling of a power system based on minimization of the objective function considering the economical and reliable operation of a power system while satisfying the network constraints along with crew/manpower, generation limits, precedence constraints, demanded load, maintenance window, loss of load probability and reliability constraints. Optimization was carried out on a practical thermal power plant consisting of 19 generating units, over a 25 weeks planning horizon.*

Key Words*: *Maintenance Schedule; Artificial Intelligence; Fuzzy Systems; Genetic Algorithm; Evolution Strategy; Particle Swarm Optimization; Hybrid Intelligent Systems.

1. INTRODUCTION

The scenario of operation and planning in power system such as economic dispatch, unit commitment, load dispatch, generation co-ordination are highly influenced by generator maintenance scheduling. The maintenance schedule is a preventive outage schedule for generating units within a particular time horizon for decreasing operation cost and increasing reliability. Maintenance scheduling turns into a complex problem when the power system includes a number of generating units with different specifications, and when several constraints have to be taken into consideration to achieve a practical and feasible solution.

Generator maintenance scheduling is done to minimise total operation cost satisfying all constraints of units and power system over time horizons of different durations. Short-term maintenance scheduling for one hour to one day ahead is important for day-to-day operations, unit commitment, and operation planning of power generation facilities. Medium-term scheduling for a one day up to a year ahead is essential for resource management. Long-term scheduling of a year or two years ahead is important for future planning.

The complexity and larger size of electric system generation with the more reliability concern and low operation cost have being causing a great interest in automatic scheduling techniques for maintenance of generators and power system, capable of giving feasible or optimal scheduling.

The reliability of the power system assures that the demand is met even though an outage occurred in the system. Generally, the utility provides a spinning reserve, by supplying more power than demanded. This improves the system reliability with increased operating cost. A well-planned schedule for maintenance and repair work should be prepared for each unit in the system, according to the period of maintenance activities, which are based on the operating hours and condition of the engines.

The scheduling starts with all units available for production; then initial schedule has to be generated in some suitable way; then modify this initial schedule subsequently if the method allows for more than one iteration. Efficient and practical maintenance schedule increases system reliability, reduces operation and maintenance costs, and extends the lifetimes of the generators. Moreover, an easily revisable maintenance schedule is required to adapt to increasing load demand and number of generating units in a larger-scale power system.

Maintenance scheduling is an optimization problem to obtain the best schedule while meeting a variety of equality, inequality constraints and thousands of decision variables which are determined and obeyed simultaneously. The objective functions in maintenance scheduling are reliability and cost. The economic objective function includes the maintenance cost and operation cost [1]. The reliability objective function can be either deterministic, where the aim is to maximize the system's net reserve (the system installed capacity minus the maximum load and the maintenance capacity during the period under examination), or random, where goal is to minimize the risk level.

Several hard and soft constraints should be taken into account to reflect the actual operating conditions of the power system in order to make the maintenance plan feasible. Listed below are some constraints for maintenance scheduling:

- Crew constraint
- Availability of maintenance resources
- Maintenance period during which each unit should be maintained
- Load demand
- Total Generation
- Condition of the engine
- Spinning reserve requirement
- Loss of Load Probability
- Transmission network constraints

The approach needs a trade-off between the quality of the solution and number of iterations. The methods may not converge if the stop criterion is inadequately chosen.

2. APPROACHES FOR MAINTENANCE SCHEDULING PROBLEM

The maintenance-scheduling problem has been solved using a number of techniques and methodologies. Integer programming method is the most frequently used mathematical method for maintenance scheduling. A mixed-integer programming technique was used for obtaining optimum schedules in [1] for a planning horizon of one month. The existing methods indicate that the uncertainties in the problem, computational time, generating system size, and long planning horizons are the crucial issues in developing a feasible, practical maintenance-scheduling plan. However, the approach could not be applied to large-scale problems due to excessive processing time and storage requirements. To reduce the storage and computation time, successive approximation dynamic programming was proposed in [2]. Artificial neural networks were employed in [3] to handle the inequality constraints in the maintenance-scheduling problem. The approach was used for a system containing 15 generating units and one year planning horizon. Recently, techniques such as Simulated Annealing (SA) and Genetic Algorithm (GA) have been proposed for maintenance scheduling of large systems. Reference [4] considers a system containing 21 units and one year planning horizon.

The main motivation of using evolutionary techniques lies in the strong adaptability and flexibility for solving difficult multi-objective problem with many constraints. In this research, actual data from a thermal power system is used for developing practical maintenance plans.

One of the options available to the utilities in order to maintain a high level of reliability and economy of the power system is economic dispatch (ED). ED allocates the total power demand among the online generating units in order to minimize the cost of generation while satisfying important system constraints. Some factors that influence ED of the system are operating efficiency of generating units, fuel and operating costs, and transmission losses. The ED problems are in general non-convex optimization problems with many local minima. Numerous classical techniques such as LaGrange based methods, linear programming (LP), non-linear programming (NLP) and quadratic programming (QP) methods have been reported in the literature.

In order to obtain approximate solution of a complex GMS, new concepts have emerged in recent years [7]-[10]. They include applications of probabilistic approach [5], simulated annealing [6], decomposition technique [7] and genetic algorithm (GA) [8]. The application of GA to GMS presented in [10] have been compared with, and confirmed to be superior to other conventional algorithms such as heuristic approaches and branch-and-bound (B&B) in the quality of solutions.

GMS using DE for the minimization of reliability cost function of levelling reserve generation over an entire period of 52 weeks maintenance window for the Nigerian power system have been reported in [9],.

2.1 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) [7] has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied. This algorithm was discovered through simulation of bird flocking and fish schooling (social behavior).

As sociobiologist E. O. Wilson has written, in reference to fish schooling, "In theory at least, individual members of the school can profit from the discoveries and previous experience of all other members of the school during the search for food. This advantage can become decisive, outweighing the disadvantages of competition for food items, whenever the resource is unpredictably distributed in patches". This statement suggests that social sharing of information offers an evolutionary advantage: this hypothesis was fundamental to the development of particle swarm optimization. Similar to Genetic Algorithms (GA) [10-12], PSO is a population based optimization tool. The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, are "flown" through the problem space by following the current optimum particles.

2.2 Simulated Annealing (SA)

Metaheuristic techniques include Tabu Search, Neural Networks, Simulated Annealing, Particle Swarm Optimization and Ant Colony Optimization. Simulated Annealing and Genetic Algorithms are used to address combinatorial problems due to the presence of discrete variables.

Simulated Annealing was developed by Kirkpatrick et al. [13], followed by Aarts and Korst [14] based on the Metropolis algorithm dated from 1953. It is a search procedure in which it is included the possibility of accepting a solution that is worse than the current one. The simulation starts at an initial solution, x_1, evaluates it using an Evaluation Function, $f(x_1)$, and samples a new solution in the neighborhood of x_1. If this new solution improves $f(x_1)$, then it is accepted. If it is worse than the current one, it can still be accepted depending on a so-called probability of accepting worse solutions.

2.3 Tabu Search (TS)

In [15-16] the GMS problem is solved using Tabu Search. In [15] it is used a multi-stage approach to decompose the problem in several sub-problems. The partial results are then combined to pro-duce the global maintenance schedule. In [16] the formulation uses the generation cost and the reserve margin as objectives and the constraints are related with the availability of crews, predefined sequence of maintenance actions for several units and continuity of the maintenance period once a maintenance action starts. The plans provided by the Tabu Search algorithm for two generation systems (one with 4 units and another with 22 units) were compared with the results obtained with an implicit enumeration approach. The results obtained with Tabu Search were very promising given the more reduced computation time and their good quality.

The performance of several meta-heuristic approaches, namely Tabu Search, Simulated Annealing, Genetic Algorithms, an hybrid Simulated Annealing/Genetic Algorithm approach and an hybrid Tabu Search/Simulated Annealing algorithm. The authors report that the combined use of Simulated Annealing/Genetic Algorithm and of Tabu Search/Simulated Annealing produces better results than the isolated use of a single metaheuristic, although the computational time is sometimes longer.

2.4 Evolution Strategy (ES)

Evolution Strategies [17-21] are part of the field of evolutionary algorithms. ES has always been compared with GA and a concluding statement on which is better is certainly not possible. The subtle difference between ES and GA is in the parameter representation. ES works with real values of the variables (phenotype) whereas GA works with binary strings which are subsequently mapped to object variables. Since ES works completely on a phenotypic level, hence one can represent more knowledge about the application domain into the coding of the problem. One important difference between ES and GA is that the main search operator in ES was based on the mutation operator. But more recently, a crossover operator was introduced to facilitate the search process. The traditional ES approach can be represented as follows:

1. For each parent, generate offspring's through mutation process.
2. Select the best individuals from the mutated and current population as the next generation.

2.5 Genetic Algorithm (GA)

Genetic algorithms (GA) were first described by John Holland, who presented them as an abstraction of biological evolution and gave a theoretical mathematical framework for adaptation. Holland's GA are a method of moving from one population of "chromosomes" (bit strings representing candidate solutions to a problem), to a new population of solutions using selection, together with a set of genetic operators of cross-over, mutation and inversion. Each chromosome consists of "genes" (e.g. bits) with each gene representing an instance of a particular "allele"(e.g. a 0 or 1). Genetic algorithms are based on models of genetic change in a population of individuals.

These models consist of three basic elements;

- A 'fitness' measure which governs an individual's ability to influence future generations,
- A selection and reproduction process which produces offspring for the next generation,
- Genetic operators which determine the genetic make-up of the offspring

The distinguishing feature of a GA with respect to other function optimisation techniques is that the search towards an optimum solution proceeds not by incremental changes to a single structure (candidate solution) but by maintaining a population of solutions from which new structures are created using the genetic operators.

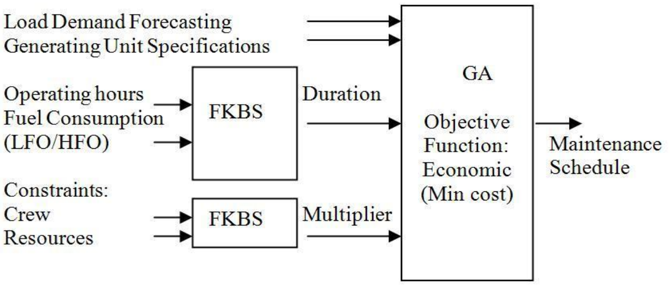

Fig -1: The overall strategy for maintenance scheduling of generating unit

3. PROBLEM DISCRIPTION

The objective function considered in a GMS problem consists of the sum of the maintenance costs of the off-line units and the operational costs of the on-line generators. The maintenance costs of a generating unit would not change during the study period and can be regarded as constant in the GMS problem. The values will not influence the search for the optimisation operational costs.

Table -1: GENERATOR RATINGS

Unit	Rating (MW)	a	B	C
1	6.1	0.0038	5.44	52.6
2	6.1	0.0038	5.44	52.6
3	6.1	0.0038	5.44	52.6
4	6.1	0.0038	5.44	52.6
5	6.1	0.0038	5.44	52.6
6	6.1	0.0038	5.44	52.6
7	6.1	0.0038	5.44	52.6

8	6.1	0.0046	6.34	53.7
9	6.1	0.0050	5.34	51.5
10	6.4	0.0050	5.34	51.5
11	6.4	0.0057	5.34	52.5
12	6.4	0.0057	5.34	52.5
13	8.0	0.0346	8.06	76.5
14	8.0	0.0346	8.06	76.5
15	2.1	0.0076	6.90	55.4
16	2.1	0.0076	7.10	55.4
17	2.1	0.0076	6.95	55.4
18	2.1	0.0076	7.30	55.4
19	6.1	0.0079	7.10	59.3

The following table shows the data used in the evaluation of maintenance cost.

Table -2: DOWNTIME AND MAINTENANCE COST PER WEEK OF EACH GENERATOR

Unit	Downtime (D)	V ($/week)	Unit	Downtime (D)	V ($/week)
1	1	750	11	3	850
2	4	750	12	3	850
3	1	750	13	4	1500
4	2	750	14	3	1500
5	3	750	15	1	600
6	2	750	16	1	600
7	1	750	17	1	600
8	1	750	18	1	600
9	2	750	19	4	900
10	3	850			

The objective function for GMS model

$$\min \sum_{z=1}^{Z}\sum_{y=1}^{Y}\left[U_{zy}\left(A_y + B_y P_{yz} + C_y P_{yz}^2\right)\right] + \sum_{y=1}^{Y} FV_y\left(P_y\right)$$

where $FV_y(P_y)$ is expressed as a linear equation of production cost.

$$F\,V_y\left(P_y\right) = V_y D_y$$

$$D_{y\,z} = \begin{cases} 1 & \text{if unit y start maintenance at week z} \\ 0 & \end{cases}$$

For each time period z, z =1,2, 3,……,Z.

The objective function of the problem is subjected to constraints as given below:

a) Load Balance

$$\sum_{z=1}^{Z} U_{z\,y} P_{z\,y} = D_y$$

b) Generator Output Limit

$$P_{y\ \min} \le P_{zy} \le P_{y\ \max}$$

c) Spining Reserve

$$\sum_{y=1}^{Y} U_{zy} P_{y\max} \ge D_y (1 + r_z \%)$$

d) Maintenance Window

$$U_{zy} = \begin{cases} 1, t < ey, t > l_y + d_y \\ 0, s_y \le t \le s_y + d_y \\ 0,1, e_y \le t \le l_y \end{cases}$$

e) Maintenance Area

$$\sum_{y=1}^{Y} (1 - U_{zy}) \le \beta$$

f) Crew Constraint

$$\sum_{z=1}^{Z}\sum_{y=1}^{Y} (1 - U_{zy}) < Cr$$

4. PROBLEM SOLUTION

The schedule for GMS is obtained by using mixed genetic algorithm which is explained below in flowchart as:

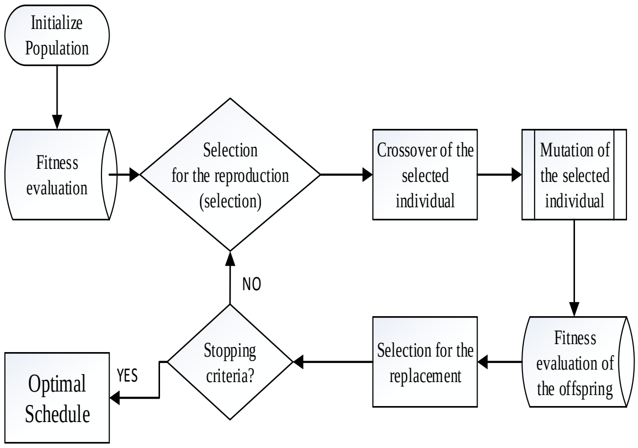

Fig -2: The flowchart of GMS using GA.

5. RESULTS

Test system consider of 19 generating units for time span of 25 weeks with an objective to minimize the economic cost function over planning horizon subjected to various constraints is optimized using genetic algorithm. The result of optimization compared with other metaheuristic techniques is shown below in TABLE IV. The total maintenance cost is obtained using fixed maintenance cost data. The operational cost Plot obtained is shown below in figure 3 and the schedule obtained using GA is tabulated below.

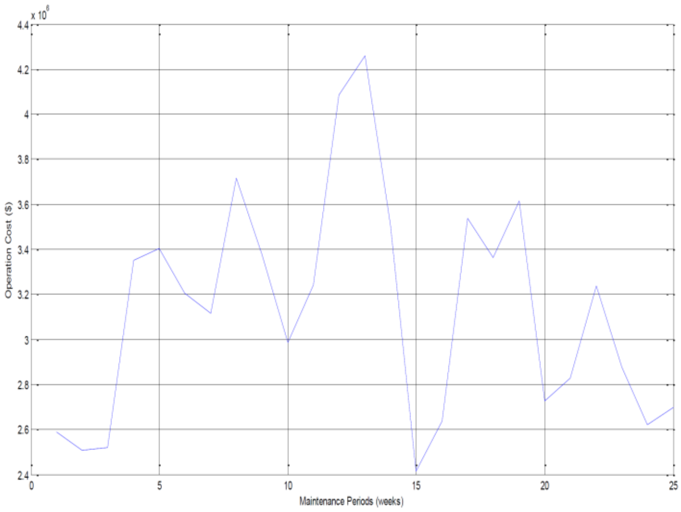

Fig -3:. Operational Cost Plot

Table-3: SCHEDULE OBTAINED USING GENETIC ALGORITHM

Maintenance Period	Generating unit's index of scheduled maintenance																		
(weeks)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0
4	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
5	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
6	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1
7	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
8	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1
9	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1
12	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
14	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
15	1	0	1	1	0	0	1	1	0	0	1	1	1	1	1	1	1	1	0
16	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0
21	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1
22	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table-4: RESULTS

S.No.	Techniques	Optimised Cost
1.	Heuristic	73932889.326
2.	GA	73928747.045
3.	PSO	76930465.182
4.	PSO with multiple changes	76930383.249
5.	ES	7632895.839
6.	ES with multiple mutation	76932699.485
7.	ES with multiple mutation and crossover	76932745.216

6. CONCLUSIONS

The generator maintenance scheduling problem done for 19 units test system subjected to various number of constraints using genetic algorithm as optimisation tool to obtain best schedule to minimize the economic cost function is carried out. Economic dispatch has been used to find an optimal combination of power generation that minimizes the total generation cost while satisfying constraints. The GA gives the most promising results.

The unplanned maintenance allowances and deferred maintenance can be consider for further work on this area with the use of hybrid heuristic techniques. One can also consider a frequency-based maintenance outage formulation or multi-objective modeling approach.

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