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Mathematical approach assisted differential evolution for generator maintenance scheduling

G. Balaji *, R. Balamurugan, L. Lakshminarasimman

Department of Electrical Engineering, Annamalai University, Annamalainagar, Chidambaram 608002, Tamil Nadu, India

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ABSTRACT

Maintenance scheduling of power generating units is very essential for the economical and reliable operation of a power system. The objective of Generator Maintenance Scheduling (GMS) problem is to find the exact time interval for preventive maintenance of power generating units in order to minimize the operating cost, maximize the system reliability and to extend the life time of the generating units. In this paper, the problem of scheduling of generating units for maintenance is formulated as a mixed integer optimization problem by considering minimizing the operating cost. Since generator maintenance scheduling is a mixed integer problem, differential evolution algorithm is suitably modified to handle the integer variables. The control variables in differential evolution algorithm are integers which denote the starting period of each generating unit for carrying out maintenance work. The lambda iteration method is used to determine the optimal generation schedule of committed generating units. This paper presents a mathematical approach assisted differential evolution (MADE) to solve maintenance scheduling problem in a power system. The performance of the proposed algorithm is validated by considering two test systems. The result obtained by the proposed MADE method is compared with mathematical approach assisted particle swarm optimization. The test results reveal the capability of the proposed MADE algorithm in finding optimal maintenance schedule for the GMS problem.

Introduction

The generator maintenance scheduling problem is a large scale, stochastic and nonlinear optimization problem which is a sub problem of integrated long term operations planning problem [1,2]. The aim of GMS problem is to determine the period for which, units should be taken off line for planned maintenance on a yearly time horizon in order to minimize the operating cost and increase the system reliability. The complexity of the problem increases with increase in system size. The problem has two types of variables, integer variables for denoting the status of the unit and continuous variables for denoting the power generation of various units and hence it is a mixed integer problem. If a unit is taken off for maintenance too early, a part of the investment made in the previous maintenance is foregone; on the other hand, if the maintenance of the unit is postponed beyond the maximum period, the expenses for maintenance activities gets increased due to partial or full damage of equipment. A good maintenance schedule reduces production cost, increases system reliability and extends lifetime of generators. Lot of contributions are made by various authors towards GMS by considering either minimizing the operation cost or maximizing the reliability as objective.

Traditional optimization methods are used for solving GMS; Integer Programming (IP) [6]. To overcome the difficulties of introducing complex constraints of GMS problem into IP, in [7] branch and bound algorithms in IP is proposed to solve GMS. Due to curse of dimensionality, dynamic programming (DP) can be used for solving only small systems [3]. To alleviate the problems of DP in solving GMS for large systems, Successive Approximation Dynamic programming (SADP) has been presented [4,5]. Apart from the traditional methods, intelligent optimization techniques have been applied to solve GMS. Simulated Annealing [8] approach has been applied to the GMS in which minimizing the production costs and maintenance costs were considered as an objective function and the problem is formulated as 0–1 mixed integer programming problem. To reduce the computational time of Simulated Annealing (SA), in [9] a new Genetic Algorithm with special encoding/decoding techniques that combines the acceptance probability of SA is proposed. To combine the intensification and diversification aspects, Genetic Algorithm (GA), SA and Tabu search (TS) are combined to solve GMS problem [10]. Dahal, et al. proposed the

* Corresponding author. Tel.: +91 9443111631.
E-mail address: balaji.g.au@gmail.com (G. Balaji).

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meta-heuristic based hybrid approach for GMS problem in which heuristic approach is combined with GA/SA hybrid to seed the initial population [11]. The objectives of minimizing the total operating cost and leveling the reserve are considered and solved using new TS algorithm in [12]. Knowledge based expert system is applied in [13] to schedule the generator for maintenance in which the knowledge has been built in consultation with experienced operators and are expressed by rules and logic representations. To include the uncertainties present in the GMS, the objectives and constraints are expressed in fuzzy notation and embedded with dynamic programming to find the units maintenance schedule [14]. In [15], the objectives and constraints are fuzzified through the guidance of GA and the maintenance schedule for generating units is obtained with the help of fuzzy dynamic programming. Leou [16] formulated the GMS problem as 0–1 integer programming problem and search proceeds towards feasible solution. If feasible solution exists, it is adopted for maintenance scheduling, otherwise constraints are formulated using fuzzy model and problem has been reformulated as fuzzy 0–1 integer programming model and used for finding the minimum violation solution. GA has been used for solving GMS problem [17,18]. Particle swarm optimization (PSO) is used for finding the good schedule for maintenance of generating units by considering leveling the reserve generation as objective [19,20]. Multi objective formulation of GMS model is considered and is solved for non inferior solution in [21]. Differential Evolution (DE) is a powerful evolutionary optimization algorithm developed by Storn and Price [22,23]. It is a simple algorithm, which is very easy to implement, significantly faster and robust [24]. Because of the successful application of PSO to many real world problems [25], in this paper PSO is considered for making comparison with DE algorithm. This paper presents MADE algorithm for solving GMS problem with the objective criterion of minimizing total generator operation cost while satisfying maintenance window constraint, crew constraint, precedence constraint, load balance constraint and generator constraint. In the proposed approach, an integer coded differential evolution is acting as an main optimizer to identify the optimal starting period for carrying out maintenance work on each generating unit and lambda iteration approach is used to economically dispatch the available generation of committed generating units to meet out the load demand. To validate the effectiveness of the proposed algorithm, the results obtained are compared with that obtained using mathematical approach assisted particle swarm optimization (MAPSO) scheme.

Formulation of GMS problem

The objective criterion of minimizing the total generator operating cost over the operational planning period is given by

$$Min\ C(u) = \sum_{i=1}^{N}\sum_{t=1}^{T} H \cdot F_i(P_{it}) \cdot (1 - U_{it}) + \sum_{i=1}^{N}\sum_{t=1}^{T} H \cdot P_{it} \cdot v_i \cdot (1 - U_{it}) \tag{1}$$

Here the first part of the objective function is the production cost whereas second part is variable operation and maintenance cost; where $F_i(P_{it}) = a_i + b_i P_{it} + c_i P_{it}^2$, for $i = 1, 2, \ldots, N$ and a_i, b_i, c_i are fuel cost coefficients. H is the number of hours in a period (week), P_{it} denotes real power output (MW) from generator i in sub period t. v_i is the variable operation and maintenance cost of unit i, \$/MW h. N is the total number of generating units. T is the total number of periods (weeks) in the planning horizon and U_{it} is the state variable which is equal to 1 if the unit is on maintenance and 0 otherwise. The constraints to be satisfied are.

Load balance constraint

It ensures total available generation must be greater than or equal to load demand. For the sake of simplicity, the losses are assumed to be zero. The load balance constraint is given by

$$\sum_{i=1}^{N} P_{it} \cdot (1 - U_{it}) \geqslant D_t \tag{2}$$

where D_t – system load demand in sub period (week) t.

Generators limit constraint

It guarantees the output of each generator lies within its maximum and minimum limit and is given by

$$P_i^{\min} \leqslant P_{it} \leqslant P_i^{\max} \tag{3}$$

where P_i^{max} and P_i^{min} are maximum and minimum limits of generator i respectively.

Maintenance window constraint

This constraint ensures that once maintenance of the unit i is initiated, the work have to be continued without any interruption for the time period that is exactly equal to maintenance duration of unit i (M_i) in weeks. The state variable can be stated as follows

$$U_{it} = \begin{cases} 1, & t = S_i, \ldots, S_i + M_i - 1 \\ 0, & \textit{otherwise} \end{cases} \tag{4}$$

Crew constraint

It depends on the manpower availability. It ensures no two units can be maintained by the same maintenance personnel. This is expressed in terms of U_{it} variables of the second unit $i2$ as follows.

$$\sum_{t=S_{i1}}^{S_{1i}+M_{i1}-1} U_{i2,t} = 0 \tag{5}$$

Precedence constraint

In some situations, the most critical generator needs to be maintained first before committing the other generators in the system for maintenance. Such requirements in maintenance scheduling problem can be handled using precedence constraints. This constraint specifies the order in which maintenance on the generators has to be carried out. For example, if unit 1 must be finished maintenance prior to the staring of that of unit 2, this constraint is given by

$$S_1 + M_1 \leqslant S_2 \tag{6}$$

Mathematical approach assisted differential evolution (MADE) approach for GMS

Differential evolution algorithm creates new solutions by combining the parent individual and several other individuals of the same population. A candidate replaces the parent only if it has better fitness. Thus, the fittest offspring competes one-to-one with its parent, which is different from the other evolutionary algorithms. This one-to-one competition improves the convergence rate considerably [26]. DE uses floating-point numbers that are more appropriate than integers for representing variables in a continuous space. DE has been successfully applied to solve various