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Source and transmission line maintenance outage scheduling in a power system using teaching learning based optimization algorithm

M. Abirami*, S. Ganesan, S. Subramanian, R. Anandhakumar

Department of Electrical Engineering, Faculty of Engineering and Technology, Annamalai University, Annamalainagar 608002, Tamil Nadu, India

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ABSTRACT

In order to enhance the performance and lifetime of any equipment, maintenance is essential. The major power system components including generators and transmission lines require periodical maintenance and in this regard, the present work details Integrated Maintenance Scheduling (IMS) for the secure operation. The IMS problem has been formulated as a complex optimization problem that affects unit commitment and economic dispatch schedules. Most of the methodologies adopt decomposition approaches for the solution of IMS. In this work, Teaching Learning Based Optimization (TLBO) has been used as a prime optimization tool as it has been proved to be an effective optimization algorithm when applied to various practical optimization problems and its implementation is simple involving less computational effort. The methodology has been tested on standard test systems and it works well while including generator contingency. Numerical results comparison indicates that this method is a promising alternative for solving IMS problem.

1. Introduction

Maintenance Scheduling (MS) plays an important role in extending the life and improving the overall availability of the equipment. In power systems, MS of source and transmission line aims to operate the system to meet power demands at minimal production and maintenance costs while satisfying maintenance and network constraints. Implementation of the effective maintenance policies helps to reduce the frequency of service interruptions and extends equipment lifetime or at least the mean time to the next failure whose repair may be costly. Most of the MS problems considers preventive maintenance schedule of generating units over a planning period in order to minimize the total operational cost while satisfying energy requirements and maintenance constraints. The thermal capacity of transmission lines creates serious overloading problem when certain lines and/or generators are simultaneously removed for maintenance from the system and the resulting maintenance schedule may not be suitable for the system at all times. The inclusion of transmission line maintenance will increase the complexity of the problem. Hence, it is necessary to consider Integrated Maintenance Scheduling (IMS) that combines source (generation) and transmission maintenance scheduling, for the secure and reliable operation of an electric power system.

The maintenance scheduling problems have been formulated as a nonlinear optimization problem with several equality and inequality constraints. The solution methods for solving this problem can be categorized into three groups as: mathematical, heuristic search and hybrid methods. The mathematical approaches including integer programming, branch-and bound techniques and dynamic programming have been applied for solving Generator Maintenance Scheduling (GMS) problems and these methods are severely limited by the 'curse of dimensionality' and poor in handling the nonlinear objectives and constraints that characterizes the GMS problem [1]. Benders decomposition has been applied to solve GMS problem [2] and it has been extended for the solution of GMS problem including transmission maintenance and network constraints [3]. Benders decomposition based on duality theory has also been reported for the generation and transmission maintenance scheduling with network constraints [4]. In Benders decomposition, the maintenance scheduling problem is decomposed into a master problem and operation sub-problems. The master problem consisting of maintenance scheduling decision variables is solved in the first stage and operation sub-problems are solved in the second stage to minimize the total operating cost subject to operational constraints. Benders cuts based on the solution of the sub-problems are introduced to the master problem for improving the existing solution and this iterative procedure is continued until the optimal or near optimal solution is found.

Benders decomposition have been applied to include network constraints in maintenance scheduling problem and the network

* Corresponding author. Tel.: +91 9944373340.
E-mail address: barath_mabi@rediffmail.com (M. Abirami).

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is modeled as a probabilistic problem in order to include the effect of generator and transmission line outages [5]. Benders decomposition has also been addressed to long term scheduling problem which includes complex network, fuel dispatch problem and emission constraints [6]. A mixed integer programming model has been developed for transmission constrained GMS [7]. Benders decomposition with linearized set of power flow equations has been applied for establishing power systems scheduled generator outages while considering the transmission influence for short-term planning horizon [8].

Evolutionary Programming (EP) based technique has been presented to the unified model of the maintenance scheduling problem of power generation and transmission systems [9]. EP is a random search technique; initialization is to produce initial random solution, mutation is used to produce new individuals according to certain criteria and competition is a random tournament selection. It may happen that the new solution be infeasible, which elongates execution time and increases the probability of trapping in local optimal. To remedy these problems, hill-climbing technique is used in conjunction with EP to ensure the feasibility of new individuals. The maintenance scheduling problem has several uncertainties associated with it and fuzzy model has been developed for maintenance scheduling problem that accounts for such uncertainties [10]. The EP based hill climbing technique and fuzzy comparison technique has been used as a tool to find the solution. EP finds the near optimal solution, hill climbing technique is used to maintain the feasibility during the solution process and fuzzy comparison technique is used to compare individuals. The EP search ability in conjunction with the feasibility watch of the hill climbing technique simplifies the solution of the fuzzy IMS problem. This methodology has been extended to solve security constrained maintenance scheduling problems [11].

The impact of generator and transmission maintenance strategies have been focused on the system reliability and on the associated costs and a methodology that captures all chronological aspects of the maintenance procedures through Monte Carlo simulation algorithm has been developed [12]. A proper maintenance outage scheduling provides wide range of options for managing short-term security and economics. The short-term operation strategies may yield secure and economic operation for maintenance scheduling over a longer time span. The coordinated maintenance scheduling problem has been formulated that provides coordination between generation and transmission outages, mid-term maintenance outage and hourly security constrained generation scheduling, midterm allocation and short-term utilization of resources, short-term transmission security and optimal maintenance outage scheduling [13]. Mathematically, this problem is a very large-scale, mixed-integer, non-convex optimization problem. Lagrangian relaxation and Benders decomposition techniques have been applied to decompose a large-scale optimization problem into many small-scale sub-problems. The adjusted Lagrangian multipliers and Benders cuts are effective linking constraints and the hourly results for maintenance outages and generation scheduling are obtained based on hourly load curve.

Particle Swarm Optimization (PSO) has been applied for most of the engineering optimization problems. The discrete PSO has been developed for solving discrete engineering optimization problems such as generator maintenance scheduling. The modified discrete PSO, a combination of discrete PSO and evolutionary strategy enhances searching capability of the algorithm under complex and constrained environment. The incorporation of the mutation operator in the modified discrete PSO algorithm has significantly improved the diversity of the PSO's population and ensured convergence toward satisfactory solutions [14].

Ant colony optimization algorithm has been applied to hard combinatorial optimization problems including IMS problem [15]. An optimization model has been proposed for coordinating the midterm maintenance scheduling with the short-term generation scheduling, which has been applied to large-scale, nonlinear, nonconvex and mixed-integer problems [16]. This model consists of effective acceleration strategies that enhance the existing solution methodology [13] in various aspects like decomposition and cooperation strategy, computational time, etc. Coordinated preventive maintenance scheduling of generating and transmission companies in restructured power markets have been presented [17]. A stochastic model has been presented for coordinated long-term MS of generation units and transmission lines with short-term Security Constrained Unit Commitment (SCUC) under deregulated environment [18]. A hybrid evolutionary algorithm derived from extremal optimization and genetic algorithm, has been developed and applied to solve GMS problem under reliability criterion [19].

An innovative optimization technique, Teaching–Learning Based Optimization (TLBO), inspiring natural phenomena of teaching–learning process in a class room between teacher and students (learners) has been developed by Rao et al. (2011). TLBO is an algorithm-specific, parameter-less algorithm that does not require any algorithm-specific parameters to be tuned [20,21]. This algorithm can find the global optimal solution for nonlinear constrained optimization problems with less computation effort and high consistency. The effectiveness of TLBO algorithm and its modified versions [22–26] have been reported in various fields of engineering such as Civil Engineering [27], Mechanical Engineering [28,29] and Electrical Engineering [30–32]. However, from the literature it is clear that the application of TLBO for IMS problem has not been explored. This motivates the authors to use TLBO to determine optimal maintenance schedules in order to minimize total operation cost over the operational planning horizon with the satisfaction of several equality and inequality constraints. In the present work, IMS is formulated as a highly complex and non-linear optimization problem and TLBO is used as a main optimization tool to determine the optimal maintenance schedules for planned maintenance outages of generating units and transmission lines in a power system.

The contributions of this paper are as follows:

(i) A unified solution for IMS problem has been obtained by utilizing TLBO as a primary tool which determines the optimal generator and transmission line maintenance schedules. The classical methods have been used to obtain the optimal real power schedules.
(ii) The generation and transmission line maintenance scheduling methods in the literature were mostly based on weekly or monthly basis. In this paper, IMS problem has been solved on hourly basis which helps to obtain more efficient and suitable midterm strategies for the scheduling and the coordination of generating units and transmission line maintenance outages.
(iii) Preventive security strategy that enhances IMS has been included in this paper.
(iv) The proposed approach handles the system and operational constraints effectively. Moreover, it is easy to implement and can be recommended for practical applications.

This paper is structured as follows. In Section 2, the IMS problem is formulated. In Sections 3 and 4, a brief description of TLBO and its application for solving IMS problem are presented. Section 5 analyses the results of the proposed technique to solve the IMS problem. Section 6 outlines the conclusion.