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Deterministic and stochastic approach for safety and reliability optimization of captive power plant maintenance scheduling using GA/SA-based hybrid techniques: A comparison of results

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Abstract

This paper presents a comparison of results for optimization of captive power plant maintenance scheduling using genetic algorithm (GA) as well as hybrid GA/simulated annealing (SA) techniques. As utilities catered by captive power plants are very sensitive to power failure, therefore both deterministic and stochastic reliability objective functions have been considered to incorporate statutory safety regulations for maintenance of boilers, turbines and generators. The significant contribution of this paper is to incorporate stochastic feature of generating units and that of load using levelized risk method. Another significant contribution of this paper is to evaluate confidence interval for loss of load probability (LOLP) because some variations from optimum schedule are anticipated while executing maintenance schedules due to different real-life unforeseen exigencies. Such exigencies are incorporated in terms of near-optimum schedules obtained from hybrid GA/SA technique during the final stages of convergence. Case studies corroborate that same optimum schedules are obtained using GA and hybrid GA/SA for respective deterministic and stochastic formulations. The comparison of results in terms of interval of confidence for LOLP indicates that levelized risk method adequately incorporates the stochastic nature of power system as compared with levelized reserve method. Also the interval of confidence for LOLP denotes the possible risk in a quantified manner and it is of immense use from perspective of captive power plants intended for quality power.
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Keywords: Maintenance scheduling; Captive power plant; Genetic algorithm (GA); Simulated annealing (SA); Levelized reserve method; Levelized risk method; Loss of load probability (LOLP); Hybrid GA/SA; Confidence interval

1. Introduction

The fundamental operating feature of the power system is that the electrical energy production and consumption are simultaneous. Therefore, the reliability requirement within the electricity industry is very high. The maintenance of power system equipment and especially the maintenance of generating units are implicitly related to power system reliability and have a tremendous bearing on the operation of the power system. Hence the maintenance problem has always been investigated together with system reliability engineering research [1–5]. In practice the maintenance schedules of power-generating units attracts great attention in both planning and designing of power system and also in operation management because the generating unit maintenance outage touches upon many other short-term and long-term planning activities such as unit commitment, generation dispatch, import/export of power and generation expansion planning.

The maintenance scheduling for thermal generating units in power system is a long-term scheduling of planned outages for regular maintenance [1,2,6]. Thermal units take

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Nomenclature

i	Index of thermal generating unit
maxunit	Max number of generating units
j	Index of period
J	Total number of periods
$R[j]$	Reserve for jth period
R_o	Minimum reserve requirement
q	Forced outage rate (FOR)
$C[j]$	Total generating capacity scheduled for service during period j
D	Detailed class maintenance
S	Simplified class maintenance
M	Minor class maintenance
T^k	Temperature at kth iteration
LOLP	Loss of load probability
SA	Simulated annealing
GA	Genetic algorithm
nm	Maintenance count in the planning horizon
$P[i][j]$	Generating capacity of unit i in period j
PM[i] [j]	Power loss due to maintenance of unit i during period j
PD[j]	Maximum power demand during period j with uncertainties
$Q_{\min}[i][nm]$	The earliest starting period of maintenance for unit i for nmth count
$Q_{\max}[i][nm]$	Maximum allowable period of maintenance for unit i for nmth count
$Q[i][nm]$	Starting period of maintenance for unit i for nmth count
S[i] [nm]	Type of maintenance for unit i for nmth count
$M[S[i][nm]]$	Duration for a particular type of maintenance
$F[i][nm]$	Max available extension terms for ith unit for nmth count
dec[i][nm]	Decoded value of binary string for ith unit for nmth maintenance count
$P_{eq}[i][j]$	Effective load carrying capacity for ith unit for jth period
$PM_{eq}[i][j]$	Effective power loss due to maintenance of unit i during period j
$PD_{eq}[j]$	Equivalent load in jth period
$L_d[j]$	Maximum load of day d in period j
m	Risk characteristic coefficient

relatively long duration of maintenance and particularly for captive power plant it is very crucial to maintain a proper level of reserve margin between available supply capacity and estimated load demand from the system reliability point of view. Since the captive power plants are set up by the user industry itself for power-intensive industries like aluminium extraction plant, steel plant, cement manufacturing, sugar manufacturing, chemicals preparation laboratories etc., to supply continuous and quality power else leading to adverse effects, therefore reliability objective function is considered for problem formulation. There are normally two categories of objective functions used in power system maintenance scheduling, namely, either deterministic or stochastic [2]. The deterministic reliability objective function maximizes the system's net reserve. The main drawback of this approach is that it neglects the randomness of the available generating unit's capacity, meaning that a system fulfilling the minimum reserve requirements may not be completely reliable. The random reliability objective function removes the above defect by taking into account the random forced outage of the units. In this paper both types of objective functions have been considered for the purpose of comparison using loss of load probability (LOLP) reliability index.

The ever-increasing demand of electrical energy has manifested in the form of establishment of larger and more complex power systems having larger units to generate energy. Therefore the safety norms for pressure parts in boiler and turbine as well as high voltage level in generators have become statuary to ensure minimization of industrial hazards. In this paper, the statuary safety norms for the maintenance of boiler, turbine and generator have been formulated mathematically to include in the optimization algorithm for reliability.

Many maintenance-scheduling methods have been proposed using conventional mathematical programming methods or heuristic techniques. The conventional approaches suffer from 'curse of dimensionality' with the increase of system variables [6]. These approaches tend to suffer from an excessive computational time with increase of variables. Also those methods may not generally lead to the global optimum for a complex problem, i.e., the procedure tends to fall into a local minimum if a starting point is not carefully chosen.

In order to overcome these discrepancies, the solution algorithm based on intelligent computational techniques such as genetic algorithm (GA) and simulated annealing (SA) have been implemented for solving complex scheduling problems [7,17]. These techniques are completely distinct from classical programming and trial-and-error heuristic methods. GA method mimics the principles of natural genetics and natural selection to constitute search and optimization procedures [8]. Simulated annealing mimics the cooling phenomenon of molten metals to constitute a search procedure [19]. The GA and SA approaches have been reported to solve a range of optimization problem in electrical power systems with encouraging results [9]. GAs have recently been applied to generating unit maintenance-scheduling problem based on

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