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Clonal selection algorithm for power generators maintenance scheduling

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ABSTRACT

This paper introduces a technique based on the one of the artificial immune system (AIS) technique known as the clonal selection algorithm (CSA) to obtain the optimal maintenance schedule outage of generating units. Based on a weekly load profile, the proposed technique provides the optimal maintenance window and calculates the optimal output power from each generator over a one year horizon. The maintenance scheduling problem is decoupled into two interrelated sub-problems namely, the maintenance scheduling and the power system sub-problems. The CSA is used to solve the maintenance scheduling subproblem to obtain the optimal maintenance outage of each unit. Based on the schedule generated by the CSA, the economic dispatch iterative lambda technique is used to find the optimal output power from each unit. Due to the search nature of the CSA, infeasible solutions may be introduced during the solution process. Therefore, a local search technique is used to watch the feasibility of the new solutions. The paper reports test results of the proposed algorithm to find the optimal maintenance schedule of the IEEE 30 bus system with 6 generating units and the IEEE 118 bus system with 33 generating units. Results are compared against the results obtained by complementary decision variables structure (CDV) and the evolutionary programming based techniques. Results are encouraging and indicate the viability of the proposed CSA technique.

1. Introduction

Due to the high competition between electric companies and the requirements of strict power quality and system reliability, new approaches to reduce the overall power production cost became essential. Optimal generating unit maintenance scheduling (MS) is one of the problems that could save a considerable amount of the production and maintenance costs every year [1]. Such saving would help electric companies to be more competitive in terms of energy price, while increasing system reliability and reducing forced outage rates of generating units. The MS problem objective is to determine the optimal maintenance outage for each generating unit in a weekly period over one year horizon, while satisfying system constraints and maintaining system reliability.

The MS is a mixed integer and nonlinear optimization problem. In addition, due to the nature of the problem, MS is characterized by high dimensionality and complexity. In literature, MS has been solved by many different techniques, which can be classified into two groups: traditional optimization techniques, and approximation and heuristic techniques. Traditional optimization techniques such as integer programming [1–5], branch-and-bound approach [4–6], and dynamic programming [7–20] are used to solve the MS problem. While most of the traditional techniques have the capability of finding the optimal solution, they have a limitation on the system size due to the exponential increase of computer memory requirements.

Recently, new approximation and heuristic approaches have been used to solve the MS problem. These methods include the application of modern optimization techniques such as simulated annealing, particle swarm, expert systems, fuzzy logic sets, evolutionary programming, and genetic algorithms [21–33]. The new approaches have been able to obtain improved solutions over those obtained by classical methods.

This paper presents a new technique based on the artificial immune system (AIS) to solve the maintenance schedule problem of the generation system. AIS is a new optimization technique that shares many concepts with other heuristic approaches. Nevertheless, AIS has a distinctive feature of its ability to produce robust solutions. In addition, AIS reaches diverse set of local minima, which in turn increases the probability of reaching the near global optimal solution [34,37]. During the solution process, the AIS is used to search for the optimal solution, while the hill climbing (HC) technique [38] is used to watch for the feasibility of the new solutions. In addition to the feasibility watch, HC is used to make the same solution climb to the nearest local optimum. Therefore, the AIS's search for the near global optimal solution will be

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Nomenclature

α_{it}	fuel cost of unit i at time t
C_{it}	maintenance cost for unit i at time t in $/week
d_i	duration of maintenance for generating unit i
D_t	load demand at time t
H_i	heat rate of unit i
nc	total number of the available maintenance crews
P_{it}	output power from generating unit i during period t
P^{max}	maximum output power from unit i
P^{min}	minimum output power from unit i
t	the time period in (weeks)
x_i	starting time of maintenance for generating unit i
y_{it}	1, if unit i is on maintenance at time period t (weeks), and zero, otherwise

easier and faster. In addition, using the HC technique in conjunction with the AIS reduces the chance for the AIS to be trapped in the local optimum and motivates the decomposition of the MS problem into two interrelated subproblems. These subproblems are the maintenance subproblem with integer variables, and the power system subproblem with continuous variables as described in the next section. AIS is used to solve the maintenance subproblem while the iterative lambda technique is used to solve economic load dispatch sub-problem.

This paper is organized as follows: Section 2 describes the integrated model of the generation MS problem; Section 3 presents the AIS-based technique and the MS solution methodology; the application and results of using the proposed technique to solve the MS of the IEEE 30-bus and 118-bus systems are included in Sections 4; Section 5 presents the conclusions.

2. Maintenance schedule model

The MS is a constrained mixed integer optimization problem with maintenance and power system constraints. The most common used objective function has been the cost objective function [1–25], which can be written as:

$$Objective\ Function = Min \sum_t \left(\sum_i \alpha_{it} H_t(P_{it})(1 - y_{it}) + \sum_i C_{it} y_{it} \right) \tag{1}$$

The first term of the objective function is the sum of the production cost of the online units. The second term is the sum of the maintenance cost of the generators that are off for maintenance.

The problem constraints can be categorized into two main groups: the maintenance constraints and the power system constraints.

The maintenance constraints are:

- The maintenance window, which is used to define the starting and ending time of maintenance for each generator based on the maintenance interval.
- The crew constraint, which is used to assign one unit to one crew at a time.
- Number of maintenance outage constraint, which is used to limit the number of outages of each unit to one time during the time horizon.

The power system constraints are:

- The maximum limit constraint, which is used to guarantee that each unit is working at or below its maximum limit.
- The power balance constraint, which guarantees that the sum of the output power of the online units at any time can meet the system demand.

Mathematically, the maintenance and power system constraints are as follows:

$$y_{it} = \begin{cases} 1 & \text{for } x_i \leqslant t \leqslant x_i + d_i \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$\sum_i y_{it} = nc \qquad \forall t \tag{3}$$

$$\sum_t y_{it} = 1 \qquad \forall i \tag{4}$$

$$P_i^{min} \leqslant P_{it} \leqslant P_i^{max} \qquad \forall i, \forall t \tag{5}$$

$$\sum_i P_{it}(1 - y_{it}) = D_t \qquad \forall t \tag{6}$$

3. Artificial immune algorithms

In recent decades, a new branch of science called the artificial immune system (AIS) was developed, replicating the mechanism and function of the T and B-cells in the human immune system. The applications discovered, go beyond the area of medicine and biology. With some modifications, AIS is found to be adaptable to many other applications such as optimization, pattern recognition, neural networking, and machine learning problems in different fields [34–46]. The proposed technique is mainly based on the clonal selection algorithm (CSA) [34].

3.1. Clonal selection algorithm based solution methodology

The CSA imitates the mechanisms of basic adaptive immune responses towards foreign substances such as viruses and bacteria. The CSA is based on the property of proliferation and differentiation of B-cells and T-cells. Proliferation can be viewed as reproduction and differentiation can be seen as a somatic mutation.

In this paper the search ability of the CSA combined with the feasibility watch of the HC technique are used to decouple the generators maintenance scheduling problem into two interrelated subproblems: the maintenance subproblem with integer variables and the power system subproblem with continuous variables as described below.

Maintenance subproblem is to minimize the maintenance cost while satisfying the maintenance constraints as follows:

$$Objective\ Function = Min \sum_t \sum_i C_{it} y_{it} \tag{7}$$

Subject to:

$$y_{it} = \begin{cases} 1 & \text{for } x_i \leqslant t \leqslant x_i + d_i \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

$$\sum_i y_{it} = nc \qquad \forall t \tag{9}$$

$$\sum_t y_{it} = 1 \qquad \forall i \tag{10}$$