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A clonal algorithm to solve economic load dispatch

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Abstract

This paper presents a novel optimization approach to constrained economic load dispatch (ELD) problem using artificial immune system (AIS). The approach utilizes the clonal selection principle and evolutionary approach wherein cloning of antibodies is performed followed by hypermutation. The proposed methodology easily takes care of transmission losses, dynamic operation constraints (ramp rate limits) and prohibited zones and also accounts for non-smoothness of cost function arising due to the use of multiple fuels. Simulations were performed over various systems with different number of generating units and comparisons are performed with other prevalent approaches. The findings affirmed the robustness, fast convergence and proficiency of proposed methodology over other existing techniques.

Keywords: Artificial immune system; Clonal selection algorithm; Prohibited operating zones; Ramp rate

1. Introduction

Among different issues in power system operation, economic load dispatch (ELD) problem lies at the kernel [1,2]. Essentially, ELD problem is a constrained optimization problem. Over the years, many efforts have been made to solve the problem, incorporating different kinds of constraints or multiple objectives, through various mathematical programming and optimization techniques. The conventional methods include lambda iteration method [3,4], base point and participation factors method [3,4], gradient method [3,5], etc. Among these methods, lambda iteration is most common one and, owing to its ease of implementation, has been applied through various software packages to solve ELD problems. But for effective implementation of this method, the formulation needs to be continuous [14]. Consequently, this method is accompanied by its inability to solve discontinuous ELD problems taking into account the prohibited operating zones. In addition, they have oscillatory problems in large scale and mixed- generating unit systems leading to high computation time. An ELD problem with valve point loading has also been solved by dynamic programming (DP) [6,7]. Though promising results are obtained in small sized power systems while solving it with DP, it unnecessarily raises the length of solution procedure resulting in its vulnerability to solve large size ELD problems in stipulated time frames.

Moreover, evolutionary and behavioral random search algorithms such as genetic algorithm (GA) [8–10], particle swarm optimization (PSO) [11,29], etc. have previously been implemented on the problem at hand. Infact, genetic algorithms, based on the theory of genetic evolution, due to their parallel search techniques, have attracted much attention in the past, and were successfully implemented to a variety of electrical engineering problems, viz. hydrogenerator governor tuning [12], load flow problems [13], etc. In addition, an integrated parallel GA incorporating ideas from simulated annealing (SA) and tabu search (TS) techniques was also proposed in Ref. [14] utilizing generator's output power as the encoded parameter. Yalcionoz has used a real-coded representation technique along with arithmetic genetic operators and elitistic selection to yield a quality solution [16]. GA has been deployed to solve ELD with various modifications over the years. In a similar attempt, a unit independent encoding scheme has also been proposed based on equal incremental cost criterion [15]. In spite of its successful implementation, GA does posses some weaknesses leading to longer computation time and less guaranteed convergence, particularly

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in case of epistatic objective function containing highly correlated parameters [17,18]. Moreover, premature convergence of GA is accompanied by a very high probability of entrapment into the local optimum [19].

In order to alleviate the aforementioned difficulties, this paper proposes a new optimization approach, to solve the ELD, inspired by the characteristics of immune system. Immune system (IS) is a very intricate biological system which accounts for resistance of a living body against harmful foreign entities. Artificial immune system (AIS) imitates the immunological ideas to develop some techniques used in various areas of research [20]. It works on the principle of pattern recognition (distinguishing antibody and antigen) and clonal selection principle, whereby clonal selection algorithm (invariably called as AIS) is implemented to accomplish learning and memory acquisition tasks. In IS, receptors present on the antibodies are responsible for antibody–antigen interaction. In these interactions, different antibodies have different affinity towards an antigen and the binding strength is directly proportional to this affinity [20,21]. AIS effectively exploit these interactions and the corresponding affinity by suitably mapping it to fitness (objective function) evaluation, constraint satisfaction or other relevant amenities of operations research. These ideas are further emulated and thereby harnessed into learning, memory and associative retrieval to solve the optimization problems. A more detailed description relating to theoretical and implementational aspects of the proposed approach is provided in later sections. However, despite its potential, AIS approach has seldom been applied to solve ELD problem [28].

This paper solves the economic load dispatch problem using AIS based solution methodology. In order to establish the capability of AIS to optimize smooth as well as non-smooth cost functions, two alternative models are considered. One being a constrained quadratic cost function with generator constraints, power loss and ramp rate limits while the other being an unconstrained non-smooth cost function with multiple fuels. AIS is tested on 3 generators, 6 generators and 15 generators systems in case of smooth cost curves, and for 10 generator system in case of multiple fuels. The results obtained are compared with those of GA, lambda iteration, PSO and others. The proposed methodology emerges out to be a robust optimization technique for solving ELD problem for various curve natures and different power systems.

2. Problem description

In a power system, the unit commitment problem has various sub-problems varying from linear programming problems to complex non-linear problems. The concerned problem, i.e., economic load dispatch (ELD) problem is one of the different non-linear programming sub-problems of unit commitment. The ELD problem is about minimizing the fuel cost of generating units for a specific period of operation so as to accomplish optimal generation dispatch among operating units and in return satisfying the system load demand, generator operation constraints with ramp rate limits and prohibited operating zones. Hereby, two alternative models for ELD are considered, viz. one with smooth cost functions and the other with non-smooth cost function as detailed below.

2.1. ELD formulation with smooth cost function

The objective function corresponding to the production cost can be approximated to be a quadratic function of the active power outputs from the generating units. Symbolically, it is represented as

$$\text{Minimize } F_t^{\text{cost}} = \sum_{i=1}^{N_G} f_i(P_i) \tag{1}$$

$$\text{where } f_i(P_i) = a_i P_i^2 + b_i P_i + c_i, \quad i = 1, 2, 3, \ldots, N_G \tag{2}$$

is the expression for cost function corresponding to ith generating unit and a_i, b_i and c_i are its cost coefficients. P_i is the real power output (MW) of ith generator corresponding to time period t. N_G is the number of online generating units to be dispatched.

This constrained ELD problem is subjected to a variety of constraints depending upon assumptions and practical implications like power balance constraints, ramp rate limits and prohibited operating zones. These constraints are discussed as under.

(1) Power balance constraints or demand constraints: This constraint is based on the principle of equilibrium between total system generation $\left(\sum_{i=1}^{N_G} P_i\right)$ and total system loads (P_D) and losses (P_L). That is,

$$\sum_{i=1}^{N_G} P_i = P_D + P_L \tag{3}$$

where P_L is obtained using B-coefficients, given by

$$P_L = \sum_{i=1}^{N_G}\sum_{j=1}^{N_G} P_i B_{ij} P_j \tag{4}$$

(2) The generator constraints: The output power of each generating unit has a lower and upper bound so that it lies in between these bounds. This constraint is represented by a pair of inequality constraints as follows:

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{5}$$

where $P_i^{\min}$ and $P_i^{\max}$ are lower and upper bounds for power outputs of the ith generating unit.

(3) The ramp rate limits: One of unpractical assumption that prevailed for simplifying the problem in many of the earlier research is that the adjustments of the power output are instantaneous. However, under practical circumstances ramp rate limit restricts the operating range of all the online units for adjusting the generator operation between two operating periods [10,11]. The generation may increase or decrease with corresponding upper and downward ramp rate limits. So, units are constrained due to these ramp rate limits