Electrical Power and Energy Systems 33 (2011) 131–136

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Artificial immune system for dynamic economic dispatch

M. Basu

Department of Power Engineering, Jadavpur University, Kolkata 700098, India

ARTICLE INFO

Article history:
Received 16 July 2008
Received in revised form 25 February 2010
Accepted 7 June 2010

Keywords:
Dynamic economic dispatch
Artificial immune system
Clonal selection principle

ABSTRACT

Dynamic economic dispatch determines the optimal scheduling of online generator outputs with predicted load demands over a certain period of time taking into consideration the ramp rate limits of the generators. This paper proposes artificial immune system based on the clonal selection principle for solving dynamic economic dispatch problem. This approach implements adaptive cloning, hyper-mutation, aging operator and tournament selection. Numerical results of a ten-unit system with nonsmooth fuel cost function have been presented to validate the performance of the proposed algorithm. The results obtained from the proposed algorithm are compared with those obtained from particle swarm optimization and evolutionary programming. From numerical results, it is found that the proposed artificial immune system based approach is able to provide better solution than particle swarm optimization and evolutionary programming in terms of minimum cost and computation time.

1. Introduction

Static economic dispatch (SED) allocates the load demand which is constant for a given interval of time, among the online generators economically while satisfying various constraints including static behavior of the generators. Dynamic economic dispatch (DED) is an extension of static economic dispatch problem. It schedules the online generator outputs with the predicted load demands over a certain period of time so as to operate an electric power system most economically. In order to avoid shortening the life of the equipment, plant operators try to keep gradients for temperature and pressure inside the boiler and turbine within safe limits. This mechanical constraint is transformed into a limit on the rate of increase or decrease of the electrical power output. This limit is called ramp rate limit which distinguishes DED from SED problem. Thus, the dispatch decision at one time period affects those at later time periods. DED is the most accurate formulation of the economic dispatch problem but it is the most difficult to solve because of its large dimensionality. Further, due to increasing competition into the wholesale generation markets, there is a need to understand the incremental cost burden imposed on the system by the ramp rate limits of the generators.

Since the DED was introduced, several classical methods [1–7] have been employed for solving this problem. However, all of these methods may not be able to find an optimal solution and usually stuck at a local optimum solution. Classical calculus-based methods address DED problem with convex cost function. But in reality large steam turbines have a number of steam admission valves, which contribute nonconvexity in the fuel cost function of the generating units. Dynamic programming (DP) can solve such type of problems but it suffers from the curse of dimensionality.

Recently, stochastic search algorithms [8–16] such as simulated annealing (SA), Genetic algorithm (GA), evolutionary programming (EP) and particle swarm optimization (PSO) have been successfully used to solve power system optimization problems due to their ability to find the near global solution of a nonconvex optimization problem. The SA is a powerful optimization technique but in practice, the annealing schedule of SA should be carefully tuned otherwise achieved solution will still be of locally optimal. Nevertheless, an appropriate annealing schedule often requires tremendous computation time. Both GA and EP based on the metaphor of natural biological evolution can provide near global solution. EP differs from GA in aspect that EP relies primarily on mutation and selection but not crossover as in GA. Hence, considerable computation time may be saved in EP. In spite of their successful implementation, both GA and EP posses some weakness leading to more computation time and less guaranteed convergence in case of highly epistatic objective functions i.e. the parameters being optimized are highly correlated. Although PSO can be used to solve nonlinear and noncontinuous optimization problem, it suffers from premature convergence especially while handling problems with more local optima.

Artificial immune system (AIS) [17–22] has emerged in the 1990s as a new branch in computational intelligence. AIS is inspired by immunology, immune function and principles observed in nature. It is now interest of many researchers and has been successfully used in power system optimization problems [23–26].

E-mail address: mousumibasu@yahoo.com

0142-0615/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2010.06.019

Nomenclature

P_{it}	real power output of ith unit during time interval t	B_{ij}	loss coefficient
$P_i^{\min}$, $P_i^{\max}$	lower and upper generation limits for ith unit	N	number of generating units
P_{Dt}	load demand at the time interval t	N_P	population size
P_{Lt}	transmission line losses at time t	N_c	number of clones
a_i, b_i, c_i, d_i, e_i	cost coefficients of ith unit	T	number of intervals in the scheduled horizon
$F_{it}(P_{it})$	cost of producing real power output P_{it} at time t		
UR_i, DR_i	ramp-up and ramp-down rate limits of the ith generator		

In this paper AIS algorithm is developed for solving the DED problem. The proposed approach is based on the clonal selection principle and implements adaptive cloning, hyper-mutation, aging operator and tournament selection. In order to show the validity of the proposed approach the developed algorithm is illustrated on a ten-unit system [10] with nonsmooth fuel cost function. Results obtained from the proposed approach are compared with those obtained using particle swarm optimization and evolutionary programming. The comparison shows that the proposed AIS based approach performs the best amongst three in terms of minimum production cost and computation time.

2. Problem formulation

Normally, the DED problem minimizes the following total production cost of committed units:

$$F = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{it}(P_{it}) \tag{1}$$

The fuel cost function of each unit considering valve-point effect [11] can be expressed as

$$F_{it}(P_{it}) = a_i + b_iP_{it} + c_iP_{it}^2 + |d_i \sin\{e_i(P_i^{\min} - P_{it})\}| \tag{2}$$

Subject to the following equality and inequality constraints for the tth interval in the scheduled horizon

(i) Real power balance

$$\sum_{i=1}^{N} P_{it} - P_{Dt} - P_{Lt} = 0 \quad t \in T \tag{3}$$

(ii) Real power operating limits

$$P_i^{\min} \leqslant P_{it} \leqslant P_i^{\max} \quad i \in N,\ t \in T \tag{4}$$

(iii) Generating unit ramp rate limits

$$\begin{aligned} P_{it} - P_{i(t-1)} &\leqslant UR_i, \quad i \in N,\ t = 2,\ldots,T \\ P_{i(t-1)} - P_{it} &\leqslant DR_i, \quad i \in N,\ t = 2,\ldots,T \end{aligned} \tag{5}$$

3. Determination of generation levels

In this approach, the power loading of first $(N-1)$ generators are specified. From the equality constraints in Eq. (3) the power level of the Nth generator (i.e. the remaining generator) is given by

$$P_{Nt} = P_{Dt} + P_{Lt} - \sum_{i=1}^{N-1} P_{it} \quad t \in T \tag{6}$$

The transmission loss P_{Lt} is a function of all the generators including that of the dependent generator and it is given by

$$P_{Lt} = \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} P_{it}B_{ij}P_{jt} + 2P_{Nt}\left(\sum_{i=1}^{N-1} B_{Ni}P_{it}\right) + B_{NN}P_{Nt}^2 \quad t \in T \tag{7}$$

Expanding and rearranging, Eq. (6) becomes

$$B_{NN}P_{Nt}^2 + \left(2\sum_{i=1}^{N-1} B_{Ni}P_{it} - 1\right)P_{Nt} + \left(P_{Dt} + \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} P_{it}B_{ij}P_{jt} - \sum_{i=1}^{N-1} P_{it}\right) = 0 \quad t \in T \tag{8}$$

The loading of the dependent generator (i.e. Nth) can then be found by solving Eq. (8) using standard algebraic method.

4. Immune system

The immune system of vertebrates including human is composed of cells, molecules and organs in the body which protect the body against infectious diseases caused by foreign pathogens such as viruses, bacteria, etc. To perform these functions, the immune system has to be able to distinguish between the body's own cells as the self cells and foreign pathogens as the non-self cells or antigens. After distinguishing between self and non-self cells, the immune system has to perform an immune response in order to eliminate non-self cell or antigen. Antigens are further categorized in order to activate the suitable defense mechanism and at the same time, the immune system also developed a memory to enable more efficient responses in case of further infection by the similar antigen.

Clonal selection theory explains how the immune system fights against an antigen. It establishes the idea that only those cells which recognize the antigen, are selected to proliferate. The selected cells are subjected to an affinity maturation process which improves their affinity to the selected antigens.

Clonal selection operates both on B-lymphocytes or B cells produced by the bone marrow and T-lymphocytes or T cells produced by the thymus. When the body is exposed to an antigen, B cells would respond to secrete specific antibodies to the particular antigen. Thereafter, a second signal from the T-helper cells, a subclass of T cells, would then stimulate the B cell to proliferate and mature into terminal (non-dividing) antibody secreting cells called plasma cells. In proliferation, clones are generated in order to achieve the state of plasma cells as they are the most active secretors of the antibodies at a larger rate than rate of antibody secretion by the B cells. The proliferation rate is directly proportional to the affinity level i.e. higher the affinity level of B cells more clones is generated. Clones are mutated at a rate inversely proportional to the antigen affinity i.e. clones of higher affinity are subjected to less mutation compared to those which exhibit lower affinity.