Proceedings of the 6th WSEAS Int. Conf. on EVOLUTIONARY COMPUTING, Lisbon, Portugal, June 16-18, 2005 (pp275-280)

CLONAL SELECTION-BASED ARTIFICIAL IMMUNE SYSTEM OPTIMIZATION TECHNIQUE FOR SOLVING ECONOMIC DISPATCH IN POWER SYSTEM

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Abstract: **-** The main role of electrical power utility is to ensure that electrical energy requirement from the customer is served. However in doing so, the power utility has also to ensure that the electrical power is generated with minimum cost. Hence, for economic operation of the system, the total demand must be appropriately shared among the generating units with an objective to minimize the total generation cost for the system. Economic Dispatch is a procedure to determine the electrical power to be generated by the committed generating units in a power system so that the total generation cost of the system is minimized, while satisfying the load demand simultaneously. This paper presents an Artificial Immune-based optimization technique for solving the economic dispatch problem in a power system. The developed Artificial Immune optimization technique adopted the Clonal Selection algorithm and was implemented with several cloning, mutation and selection approaches. These approaches were tested and compared in order to determine the best strategy for solving the economic dispatch problem. The feasibility of the proposed techniques was demonstrated on a system with 18 generating units at various loading conditions. The results show that Artificial Immune System optimization technique that employed adaptive cloning, selective mutation and pair-wise tournament selection has provided the best result in terms of cost minimization and least execution time. A comparative study with λ-iteration optimization method and Genetic Algorithm was also presented.

Key-Words: - Artificial Immune System, Clonal Selection, Optimization, Economic Dispatch.

1 Introduction

Electrical power system are designed and operated to meet the continuous variation of power demand. The power demand is shared among the generating units and economic of operation is the main consideration in assigning the power to be generated by each generating units. Therefore, Economic Dispatch(ED) is implemented in order to ensure for economic operation of a power system. Economic Dispatch problem is an optimization problem that determines the optimal output of online generating units so as to meet the load demand with an objective to minimize the total generation cost[1].

Various mathematical methods and optimization techniques have been employed to solve for ED problems. Among the conventional methods that were previously employed include lambda iteration method, base point and participation method and the gradient method. These numerical methods assumed the incremental cost curves of the generating units are monotonically increasing piecewise linear functions. However, this assumption may cause these methods to be infeasible because of the nonlinear characteristics of the actual systems. In order to take into account of the nonlinear characteristics of the system, dynamic programming (DP) method has been implemented for solving the ED problem as in reference [2]. Nevertheless, the DP method may cause the dimensions of the ED problem to be solved becomes extremely large, hence requires massive computational effort.

In the past decade, global optimization techniques such as simulated annealing (SA), genetic algorithms (GAs) and evolutionary programming (EP) have been increasingly used to solve for power system optimization problems [3]. The SA method is a powerful optimization technique that employs probabilistic approach in accepting candidate

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solutions in its search process so that it can jump out from the local optimal solutions to approach the near global solution [4]. However, it is difficult to appropriately set the control parameters of the SA based algorithm and in addition, the speed of the algorithm is slow when applied to real power system problems [5]. Since its introduction in late 1980's, GAs has been used to solve many power system optimization problems. It has been successfully employed to solve for economic dispatch problem due its ability to model any kind of constraints using various chromosome-coding schemes according to specific problem [6]. On the other hand, long execution time and non-guaranteed in convergence to the global optimal solution contribute the main disadvantages of GAs. Another biologically inspired optimization-technique, the evolutionary programming has also received increasing attention by many researchers due to its ability to look for near global optimal solution. It has been successfully applied to solve optimization problems in power system such as economic dispatch, unit commitment, optimal power flow and many others. However, its long execution time posed its main disadvantage [7].

Artificial immune systems can be defined as metaphorical systems developed using ideas, theories and components, extracted from the natural immune system [8]. The natural immune system is a very complex system with several mechanisms for defense against pathogenic organisms. The main purpose of the immune system is to recognize all cells within the body and categories those cells as either self or nonself. The immune system learns through evolution to distinguish between dangerous foreign antigens and the body's own cells or molecules. From an information-processing perspective, the immune system is a remarkable parallel and distributed adaptive system. It uses learning, memory and associative retrieval to solve recognition, classification and optimization tasks [9]. A few computational models have been developed based several principles of the immune system such as immune network model, negative selection algorithm, positive selection algorithm and clonal selection principle [10,11].

In this paper, a new method for solving ED problem based on the Artificial Immune System (AIS) is presented. The developed AIS adopted the Clonal Selection algorithm in determining the optimal active power to be generated by the generating units in a power generation system. The aim of the clonal operator is to produce a variation in the population around the parents according the affinity [12]. Hence, the searching area is enlarged and premature convergence can be avoided. The feasibility study of the proposed technique was conducted on a practical system having 18 generating units. Several loading scenarios with a number of equality and in equality constraints were tested in order to demonstrate the effectiveness of the proposed technique. The results obtained from the proposed technique were also compared with those obtained from the GA optimization methods in order to assess the solution quality and computational efficiency.

2 Economic Dispatch Mathematical Formulation

Solving the Economic Dispatch problem is to solve an optimization problem with an objective to minimize the total cost of generation. The solution gives the optimal generation output of the online generating units that satisfy the system's power balance equation under various system and operational constraints. The Economic Dispatch problem can be formulated mathematically as follows:

Equation 1 is the total generation cost to be minimized and therefore the objective function to the problem. Its value is taken to be the affinity to antibody in the AIS optimization technique.

$$F_T = \sum_{i=1}^{N} F_i(P_i) \qquad (1)$$

$$F_i(P_i) = a_i + b_i P_i + c_i p_i^2 \qquad (2)$$

The cost of power generation for each generating unit is given by equation 2. Parameters a_i, b_i, c_i in the equation symbolizes constants on the Input-Output Curve of a generating unit.

The ED problem considered in this paper is the classic ED, whereby the losses are neglected. Hence, the power balance equation is given by equation 3 and it is the equality constraint that has to be satisfied. While equation 4 is the inequality constraint, indicating the generation limits for each generating unit in the system .

$$P_1 + P_2 + P_3 + \ldots.. + P_N = P_D \qquad (3)$$

$$P_{i\,min} <= P_i <= P_{i\,max} \qquad (4)$$

P_D is the total load demand (Megawatts). P_i is the output of generating unit i. $P_{i,min}$ and $P_{i,max}$ are the lower and upper limits of power generated by unit i. N is the number of generators in the power generation system.

3 Artificial Immune System

The natural immune system is a complex pattern recognition system that defends the body from foreign pathogens. In a simple manner, it recognizes all the body's own cells within the body as the self-cells and the foreign disease causing elements or the antigens as the non-self-cells. The non-self cells are further characterized in order to activate the suitable defense mechanism which is unique with respect to a particular antigen. 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. The process taken place in the immune system can be looked as a distributed task force that has the intelligence to take action from a local and global perspective using a network of chemical messengers for communication [11].

In order to understand the theoretical concept of AIS, the biological process of the immune system need to be appreciated. B-lymphocytes and T-lymphocytes are the two main components in the lymphocyte structure responsible for the defense mechanism in the body immune system. The B-lymphocytes are cells produced by the bone marrow and the T-lymphocytes are cells produced by the thymus. B-lymphocyte will produce only one antibody that is placed on its outer surface that acts as a receptor. When our body is exposed to an antigen, B-lymphocytes would respond to secrete antibodies specific to the particular antigen.

The portion on the antigen recognized by the antibody is called epitope that acts as an antigen determinant. Hence, each type of antibody has its specific antigen identifier called idiotope. The matching antibody-antigen are bounded and a second signal from the T-helper cells, would then stimulates the B-lymphocyte to proliferate and maturate forming a large clone of the plasma cells. Plasma cells are non-dividing cells that secrete large amount of antibodies. Since the lymphocytes can only make only one antibody, therefore the antibodies secreted by the plasma cell will be identical to that which was originally acted as the lymphocyte receptor [11]. Besides maturing into plasma cells, the lymphocytes also differentiate into long-lived B-memory cells. These memory cells circulate through the blood, lymph and tissue, so that when exposed to a second antigenic stimulus, they will differentiate into large lymphocytes that are capable to produce high affinity antibodies to fight against the same antigens that stimulated the first response [13].

Figure 1 shows the mechanism of the immune system [11]. The figure shows that after the selective activation through the binding of antigens, the lymphocytes will duplicate themselves through clonal proliferation and maturate into plasma cells and also long-lived memory cells. The plasma cells then secrete antibodies that are similar to the receptor of the B-lymphocytes and they are ready to bind the antigens. During the process, T cells are responsible in regulating the B cells response to produce antibodies.

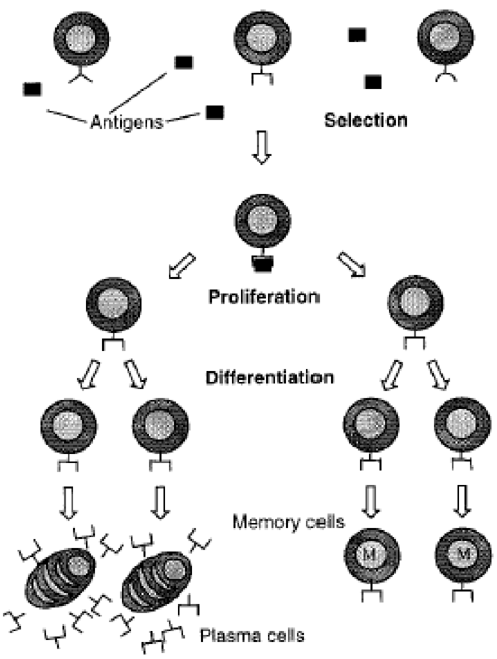

Fig. 1 Mechanism of Immune System

3.1 Clonal Selection Algorithm

The immune process described in section 3.0 is known as Clonal Selection Algorithm. Only only those cells that recognized the specific antigens would be selected to proliferate and thus go through the process of affinity maturation depict this. The main features of the clonal selection principle are as follows [10] :-

a) New cells are copies of their parents (clone) subjected to a mutation mechanism.
b) Elimination of newly differentiated lymphocytes carrying self-reacting receptors.

c) Proliferation and differentiation on contact of mature cells with antigens
d) The persistence of forbidden clones provides resistant to early elimination by self-antigens as the basis of autoimmune diseases.

In the selection stage of the clonal selection algorithm, B cells with high affinity with respect to an antigen would be able to recognized the antigen. They are then activated and stimulated to proliferate producing a large number of clones. In the maturation process, these clones mutate and turn into plasma cells which then that secrete large number of antibodies. Some of the B cells clones maturate into memory cells that have the memory of the antigenic pattern for future infections. The antibodies secreted from the second response would have higher affinity than those of the earlier response. In the computational point of view, this strategy suggests that the process perform a greedy search, where the individual will be locally optimized and the newcomers would yield a broader exploration of the search space. This characteristics makes the clonal selection algorithm is suitable for solving multi-modal optimization problems[14].

When the clonal selection algorithm is implemented for solving optimization problem, a few adaptations have to be made as follows [11] :-
a) There is no explicit antigen to be recognized, but an objective function is to be optimized. Therefore the affinity of an antibody refers to the evaluation of the objective function.
b) All antibodies are to be selected for cloning.
c) The number clones generated by the antibodies are equal.

However, this study investigated the effect of varying the number of clones according to the affinity and the results were compared to that obtained from standard cloning process.

5 Implementation of Clonal Selection-Based AIS for Economic Dispatch

The developed AIS optimization technique adopting Clonal Selection algorithm was implemented to solve the economic dispatch problem on a practical system having 18 generating units [6]. Real number was used to represent the attributes of the antibodies. Each antibody attribute will be in a form of a pair of real valued vector (x_i, η_i), $\forall i \in \{1,\dots,\mu\}$, where η_i is a strategy parameter[15]. Each antibody will go through the mutation process according to the expression given by equations 5 and 6.

$$\eta_i'(j) = \eta_i(j)\exp(\tau' N(0,1) + \tau N_j(0,1)), \quad (5)$$
$$x_i'(j) = x_i(j) + \eta_i'(j) N_j(0,1), \quad (6)$$

where,
$N(0,1)$ is a normally distributed random number with zero mean and standard deviation equals to one.

$$\tau = ((2(n)^{1/2})^{1/2})^{-1} \quad (7)$$
$$\tau' = ((2n)^{1/2})^{-1} \quad (8)$$
n = number of attribute for an antibody

The clonal selection was implemented according to the following procedures :-
a) Initial population is formed by a set of randomly generated real numbers. Each antibody was tested for any constraint violation using equations (3) and (4). Only antibodies that satisfy the constraint are included in the population set.
b) The affinity value of each antibody in the population set is evaluated using equation (1).
c) Clone the individuals in the population, giving rise to a temporary population of clones.
d) The population of clones undergoes maturation process through genetic operation i.e mutation. The fitness of the mutated clones are evaluated.
e) A new population of the same size as the initial population is selected from the mutated clones based on their affinity.
f) The new population will undergo the same process as stated in steps a – e.
g) The process is repeated until the solution converged to an optimum value.

Two other mutation techniques were also tested namely Cauchy mutation and selective mutation. Cauchy mutation scheme used Cauchy distributed random number to generate mutated the individuals and selective mutation selects the best individual resulted from Gaussian and Cauchy mutation schemes. Finally, two selection strategies namely ranking and pair-wise tournament were implemented for comparison.

As other optimization technique, several parameters have to be determined before its implementation such as the population size, number of clones generated by each antibody (for fixed clones size) and mutation rate. Based on the simulation results, the following parameters are found to be suitable: 20

members in a population pool, the number of proliferated clones is 10 and the mutation probability is 0.03.

6 Results

Table 1 gives the generator operating limits and quadratic cost function coefficients for the 18 generators in the test system. The maximum total power output *P* of the generators is 433.22 MW. Various tests were made with varying percentage of the maximum power as the power demand.

Table 1. Generator operating limits and quadratic cost function coefficients.

No.	P_{max} (MW)	P_{min} (MW)	a $/hr	b S/MWhr	c $/MW^{2}hr
1	15.00	7.00	85.74158	22.45526	0.602842
2	45.00	7.00	85.74158	22.45526	0.602842
3	25.00	13.00	108.9837	22.52789	0.214263
4	25.00	16.00	49.06263	26.75263	0.077837
5	25.00	16.00	49.06263	26.75263	0.077837
6	14.75	3.00	677.7300	80.39345	0.734763
7	14.75	3.00	677.7300	80.39345	0.734763
8	12.28	3.00	44.3900	13.19474	0.514474
9	12.28	3.00	44.3900	13.19474	0.514474
10	12.28	3.00	44.3900	13.19474	0.514474
11	12.28	3.00	44.3900	13.19474	0.514474
12	24.00	3.00	574.9603	56.70947	0.657079
13	16.20	3.00	820.3776	84.67579	1.236474
14	36.20	3.00	603.0237	59.59026	0.394571
15	45.00	3.00	567.9363	56.70947	0.420789
16	37.00	3.00	567.9363	55.96500	0.420789
17	45.00	3.00	567.9363	55.96500	0.420789
18	16.20	3.00	820.3776	84.67579	1.236474

The results from the simulation are summarized in Table 2. This table shows the minimum generation cost obtained by each AIS technique implementing different strategies of cloning, mutation and selection. The simulation was done when the demand is 70% of the total maximum power output. It can be observed that the minimum generating cost is obtained by the real number AIS technique that implemented adaptive cloning, selective mutation strategy and tournament selection with total generation cost of $19888.37. The average execution time for all of AIS techniques is 2 s.

Table 2. Minimum Generation Cost From the Simulation

Cloning	Mutation	Selection	Fitness (Minimum Generation Cost) /$h^{-1}
Standard	Gaussian	Ranking	19993.1401
		Tournament	20039.0749
	Cauchy	Ranking	19926.5094
		Tournament	20088.0232
	Selective	Ranking	19894.9573
		Tournament	19893.3673
Adaptive	Gaussian	Ranking	19957.0999
		Tournament	19911.1857
	Cauchy	Ranking	19957.0999
		Tournament	19971.9569
	Selective	Ranking	19909.2739
		Tournament	19888.3696

The results obtained from the proposed real number AIS technique implementing adaptive cloning, selective mutation strategy and tournament selection were compared with those obtained from the classical optimization technique namely λ-iteration method and Genetic Algorithm technique as shown in Table 3. From these results, it shows that the proposed technique has performed much better than the classical optimization technique, binary-coded GA and also real-coded GA for various power demands. The proposed AIS optimization technique was much faster than the other techniques. It takes only 2 seconds to provide the optimal solution. The tests were carried out a Pentium IV personal computer.

Table 3. Comparison in Minimum Generation Cost Obtained From Various Optimization technique

Demand	λ-iteration (cost/$)	Binary GA (cost/$)	Real GA (cost/$)	Real AIS (cost/$)
95% ***P***	29731.05	29733.42	29731.05	28911.25
90% ***P***	27652.47	27681.05	27655.53	26937.50
80% ***P***	23861.58	23980.24	23861.58	23383.98
70% ***P***	20393.43	20444.68	20396.39	19888.37
Executi-on time (s)	1	15	3	2

7 Conclusion

A new approach of using clonal selection based AIS to solve for economic dispatch in power system is presented. The developed AIS technique is capable to determine the power to be generated by each generating unit in power system so that the cost of generation could be minimized while satisfying the operating constraints. Several modifications were made on the cloning, mutation and selection schemes of the developed AIS optimization technique. The results obtained from various combinations of schemes were compared. It was found that the developed AIS optimization technique employing adaptive cloning scheme, selective mutation and tournament selection gives the best result. A comparative study was carried out between the proposed technique, the λ-iteration method and also Genetic Algorithm technique. The results has shown that the proposed real number AIS optimization technique with adaptive cloning scheme, selective mutation and tournament selection is also capable to provide better results with reduced computation time. This study also shows that AIS could be a promising technique for solving complicated optimization problems in power system operation.

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