Comparison of Artificial Immune System (AIS) and Multiagent Immune Evolutionary Programming (MAIEP) in Solving Economic Dispatch Problem

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Abstract—**Economic dispatch problem solution involves the determination of optimal generation power that offered the lowest cost while satisfying systems constraints. In this paper, two optimization techniques, known as Artificial Immune System (AIS) and Multiagent Immune Evolutionary Programming (MAIEP) were engaged to solve the economic dispatch problem. Artificial Immune System has the characteristic such as ability of learning, memory, recognition, self-organizing and adaptive, while Multiagent Immune Evolutionary Programming is a combination of Multiagent System, Evolutionary Programming and Artificial Immune System. The results obtained from both techniques were then compared. Based on the analysis conducted IEEE-26-Bus Reliability Test System, MAIEP optimization technique shows better results compared to AIS in solving economic dispatch problem.**

Keywords: Economic dispatch problem, Multiagent Immune Evolutionary Programming (MAIEP), Artificial Immune System (AIS), Multiagent System (MAS)

I. INTRODUCTION

Economic dispatch problem is an important issue in power system operation. Nowadays, the increasing in power demand is a major problem developed from the rapid industrialization and increasing in population in this country. Most industrials use abundances energy to operate their factories. The increasing in power demand is increased gradually during peak hour because on that time many industrial used more energy and cost for generation also increased. In order to solve the problem, the economic dispatch solution should reduce the generation cost during that period while satisfying with operational constraints.

Economic dispatch is an optimization problem for allocating generation among the committed units. The objective of economic dispatch is to minimize the generation cost in order to satisfy with the operational constraints [1].

A lot of optimization techniques have been developed by researchers to solve economic dispatch problem in power system such are Bacterial Foraging (BFA), Evolutionary Programming (EP), Artificial Neural Network (ANN), Particle Swarm optimization technique, Evolutionary Algorithms, Bees Algorithms and others.

In this paper, the Artificial Immune System (AIS) and Multiagent Immune Evolutionary Programming (MAIEP) are selected for solving the economic dispatch problem. In general, the concept of the Multiagent Immune Evolutionary Programming (MAIEP) is developed based on the combination of Evolutionary Programming (EP), Artificial Immune System (AIS) and Multiagent System (MAS) [2]. In MAIEP, for solving economic dispatch problem, an agent represents a candidate solution and all agents will live in a lattice-like environment. Each agent is fixed in a lattice point [1,2]. They will compete and cooperate with their neighbors and also use their own knowledge to obtain optimal solution. While in AIS, clonal selection principle is used to solve the economic dispatch problem. In this paper, the new cells are cloning 10 times from their parent that is subjected to a mutation mechanism.

The objective of the research is to minimize the total generation cost with satisfy to the operational constraints utilizing the AIS and MAIEP optimization techniques. The load flow technique has been used as a pre-optimization technique to determine the total generation cost by varying Qload in the system. While, post-optimization technique is based on AIS and MAIEP optimization techniques by applying its algorithms. In post-optimization techniques, generated power, Pg is used as the control variable. The results from the pre-optimization technique can be used to compare with the results on post-optimization techniques.

II. BACKGROUND STUDY

In this paper, the topics that will discuss are economic dispatch, Artificial Immune System (AIS) and Multiagent Immune Evolutionary Programming (MAIEP).

A. Economic Dispatch (ED)

The objective function of Economic Dispatch (ED) is to determine the optimal combination of power generation that can reduce the total generation cost while satisfy with the operational constraints [4]. The objective function of the economic dispatch problem and the total generation cost to be minimized is referring to equation (1).

The economic dispatch problem can be formulated as follows:

$$\text{Minimize } C_T = \sum_{i=1}^{n} Ci(Pi) \quad (1)$$

Where:

- C_T is total generating cost
- $Ci(Pi)$ is the cost function of generators unit
- Pi is power output for each generator unit
- n is number of generator

To minimize the total generating cost is given by:

$$C_T = \sum_{i=1}^{n} ai + biPi + ciPi^2 \quad (2)$$

Where:

- ai, bi and ci is the cost coefficient of ith generator unit

The output of generation unit must satisfy with generation limits as below:

$$P_{i,min} \leq P_i \leq P_{i,max} \quad (3)$$

Where:

- $P_{i,min}$ and $P_{i,max}$ is the minimum and maximum generation limit (MW) of ith generator.

Total output power must equal to the total demand plus the losses as stated in equation (4). But the transmission losses are not considered in economic dispatch problem. The inequality constraint for each generating unit in the system as stated in equation (3). Equation (5) gives the equality constraint that has to be satisfied [3, 5].

$$\sum_{i}^{n} Pi = P_D + P_L \quad (4)$$

$$\sum_{i}^{n} Pi = P_D \quad (5)$$

Where:

- P_D is power demand while P_L is power losses.

B. Artificial Immune System (AIS)

Artificial Immune System (AIS) is inspired by the human immune system which is a remarkable natural defense mechanism that learns about foreign substances [5]. The AIS can be applied to various areas such as robotics, machine, computer security and analysis. In this paper, clonal selection principle has been used. The clonal selection principle is an algorithm used by immune system to explain the basic characteristics of an immune response to an antigenic stimulus. The main characteristic of clonal selection principle is when new cells are copies of their parents or can stated as clone is subjected to a mutation mechanism [6]. Generally, the basic algorithm of AIS consists of initialization, clone, mutation, selection and convergence test. The basic algorithm of AIS was discussed as follows:

1) Initialization

The initialization also can call as parents. During initialization, random number will be generated to represents the control variable and tested for any constraint violation using equation (3) and (5). In this paper, generated power, Pg is used as control variable. The fitness value in population set by using equation (1).

2) Clone

Generally in clone process, the individual in the population will be clone and can be temporary population of clone. In this research, the parents will clone 10 times.

3) Mutation

In general mutation process is used to generate an offspring. Gaussian mutations technique will be used at this mutation process [7]. In AIS technique, it will mutate the number from clone population to produce offspring. The mutation process is implemented based on the following equation below:

$$\chi'_i = \chi_i(j) + \eta'_i(j)N_j(0,1) \quad (6)$$

$$\eta'_i = \eta_i(j)\exp[\tau' N(0,1) + \tau N_j(0,1)] \quad (7)$$

Where τ and τ' is:

$$\tau = \frac{1}{\sqrt{2\sqrt{n}}} \quad (8)$$

$$\tau' = \frac{1}{\sqrt{2n}} \quad (9)$$

From the equation above, χ'_i is refer to mutated random number or objective variables, η'_i refer to mutated strategy parameters and η_i is refer to strategy parameter distributed random number [7].

4) Selection

In general, selection process is used to produce better population among parents and offspring. Its will be selected as a parent for new population. Since the objective function in this paper is to minimize the total generation cost, therefore the total generation cost will be ranked from the lowest cost to the highest cost. Then the best 20 of mutated population with the lowest total generation cost were selected to become new population.

5) Convergence Test

The new population will repeated the same process until the solution is converged.

C. Multiagent Immune Evolutionary Programming (MAIEP)

MAIEP is the combination of Multiagent System (MAS), Evolutionary Programming (EP) and Artificial Immune System (AIS). In this research, the proposed technique is to minimize the total generation cost (CT) on the IEEE-26-Bus Reliability Test System. Generally, agent characteristics are specified as below:

1) Global Environment

Agents in MAIEP are arranged in the form of lattice-like environment or global environment, L. The size of global environment, L is Lsize x Lsize where Lsize is an integer [8]. Figure 1 show that the model of the lattice agent. The coordinate in lattice represent as the data carries. For each agent contains fitness value and a set of control variable that generated during initialization process in EP.

2) Local Environment

The agents in local environment only capable to interact and share their information with its own neighbors. Based on Figure 1, the neighbors of an agent can select if there is a line connecting with them. Assume that the agent located at (i,j) is represented as $L_{i,j}$, i,j =1, 2,..., *Lsize* and the neighbors, $N_{i,j}$ are defined as follows:

$$N_{i,j}= \{ L_{i',j} , L_{i,j''} , L_{i'',j} , L_{i,j''} \} \tag{10}$$

Where:

$$i'=\begin{cases} i-1 & i \neq 1 \\ Lsize & i = 1 \end{cases} \qquad j'=\begin{cases} j-1 & j \neq 1 \\ Lsize & j = 1 \end{cases}$$

$$i''=\begin{cases} i+1 & i \neq Lsize \\ 1 & i = Lsize \end{cases} \qquad j''=\begin{cases} j+1 & j \neq Lsize \\ 1 & j = Lsize \end{cases}$$

In general, each agent only has four neighbors. Before the information diffused to the global environment, the information is spread in local environment.

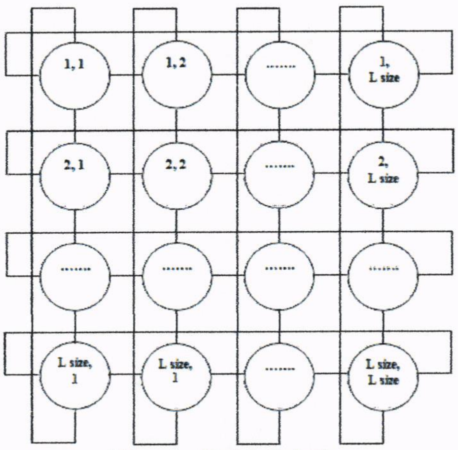

Figure 1. Model of a lattice

3) Objectives of Agents

According in this research, in order to minimize the total generation cost, each agent is assigned to identify the minimum total generation cost.

4) Agent Behavior

Each agent has some behaviors to respond any changes that occur in the environment. Each agent competes and cooperates with their neighbors to diffuse information by using competition and cooperation operator in order to get faster optimal solution. In this case, EP operator are use as its knowledge in the competition and also use the self learning operator to solve the problem. The explanations on these operators were discussed as follows:

a) Competition and Cooperation Operator

The aim of this operator is to compare the fitness of the selected agent with its neighbor's fitness. Only the best fitness value is chosen to replace the selected agent's location in lattice. Assume that, this operator is performed on agent $L_{i,j} = (l_1 , l_2 ,..., l_n)$ and $M = Max_{i,j}=(m_1 , m_2,...,m_n)$ is an agent with the highest value of fitness to achieved the objective function between the neighbor's of $L_{i,j}$. If the $L_{i,j}$ is a winner, otherwise will be a loser.

$$f(L_{i,j}) > f(Max_{i,j}) \tag{11}$$

If $L_{i,j}$ is a winner, it can maintain its position in the lattice. However, if $L_{i,j}$ is loser, $Max_{i,j}$ will replace its position. So $l_1, l_2,..., l_n$ and $m_1, m_2,...,m_n$ are the set of control variables represented by agent $L_{i,j}$ and $Max_{i,j}$ [8].

b) EP Operator

Mutations are the only search operator in order generates a population of solutions that competes with parent population to survive in the next generation based on selection scheme.

c) Self learning Operator

Each agent is able to learn by using its knowledge [8]. It was introduced AIS technique based on clone concept. After execution of the first stage of EP operator, the best agent will produce and the best agent is clone before its goes through the second stage of EP operator operation [2].

III. METHODOLOGY

In order to solve the economic dispatch problem, there are some procedures, algorithm and methodology had to consider. In this paper, the optimization techniques were used to compare the total generation cost in pre-optimization technique and post-optimization technique. Each optimization techniques, the reactive power load, Qload at Bus 11 were varied from 0MVar until 100MVar by increased 20MVar for each step to determine the total generation cost. In pre-optimization technique, the controlling variables are not considered while in post-optimization technique, the controlling variables are considered. AIS and MAIEP optimization techniques were used as post-optimization techniques to solved economic dispatch problem. The developed AIS and MAIEP optimization technique were tested on IEEE-26-Bus Reliability Test System by using MATLAB software. The flowcharts show the pre-optimization technique and post-optimization technique as follows:

A. Pre-Optimization Technique

Figure 2 show that the flowchart for pre-optimization technique in implementing economic dispatch to determine the total generation cost without controlling any variables.

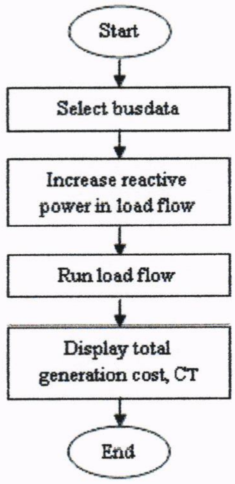

Figure 2. Flowchart of pre-optimization technique to determine total generation cost

B. *Post-Optimization Technique*

Figure 3 present the flowchart for post-optimization techniques of implementing AIS optimization technique to determine the total generation cost. The processes in AIS optimization technique involved generate initial population, clone, mutation, selection and convergence test.

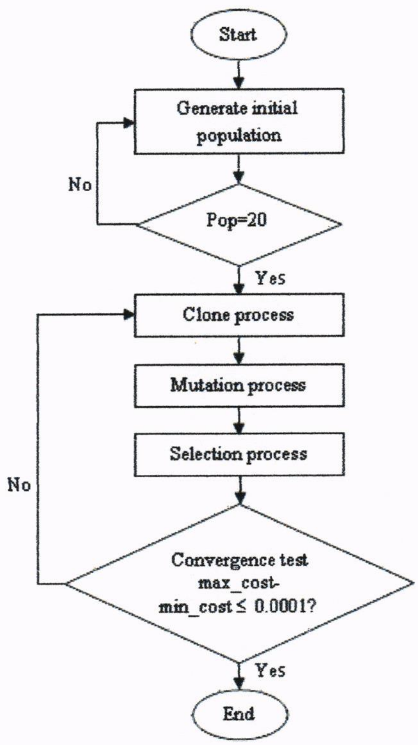

Figure 3. Flowchart of implementing AIS technique to determine total generation cost

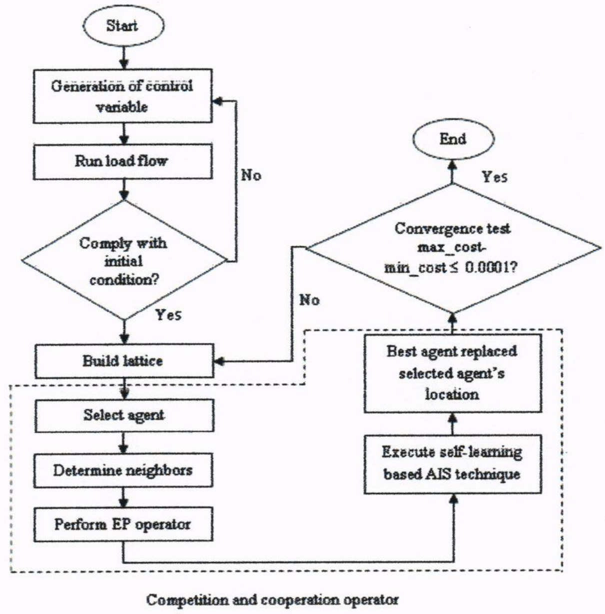

Figure 4. Flowchart of implementing MAIEP technique to determine total generation cost

Figure 4 shows the flowchart for post-optimization technique of implementing MAIEP optimization technique to solved economic dispatch problem. MAIEP have several criteria such as global environment, competition and cooperation operator, EP operator and self learning operator. Each criteria of MAIEP plays an important role to ensure the optimization process were succeed by followed the objective function which is to minimize the total generation cost.

IV. RESULTS AND DISCUSSION

In this paper, pre and post-optimization technique are used to solve the economic dispatch problem. This optimization technique was tested on the IEEE- 26-Bus Reliability Test System. For both techniques, total generation cost was determined by varying the reactive power load, Qload at Bus 11. The reactive power load, Qload was varied from 0MVar until 100MVar by increased 20MVar for each step.

TABLE I. PRE-OPTIMIZATION TECHNIQUE OF THE TOTAL GENERATION COST

Qload at Bus 11 (MVar)	Total generation cost ($/h)	Total losses (MW)	Vmin (p.u)	Vmax (p.u)
15	16760.73	15.534	0.9682	1.0500
35	16764.01	15.726	0.9672	1.0500
55	16768.37	15.981	0.9661	1.0500
75	16775.15	16.378	0.9634	1.0500
95	16784.01	16.897	0.9582	1.0500
115	16792.17	17.374	0.9501	1.0500

Table I shows the result for total generation cost in pre-optimization technique when the reactive power load, Qload was increased from 0MVar until 100MVar. Based on the result above, the total generation cost and total losses were increased when Qload increased at Bus 11. While the minimum voltage, Vmin approaches to voltage instability when raise Qload.

The result on Table II and Table III obtained the results of the total generation cost for post-optimization techniques. In this paper, Artificial Immune System (AIS) and Multiagent Immune Evolutionary Programming (MAIEP) optimization techniques were used to minimize the total generation cost.

TABLE II. POST-OPTIMIZATION TECHNIQUE OF THE TOTAL GENERATION COST (AIS)

Qload at Bus 11 (MVar)	Artificial Immune System (AIS)			
	Total generation cost ($/h)	Total losses (MW)	Vmin (p.u)	Vmax (p.u)
15	15452.18	12.965	0.9691	1.0500
35	15454.68	13.156	0.9681	1.0500
55	15458.01	13.410	0.9670	1.0500
75	15463.38	13.819	0.9642	1.0500
95	15467.00	14.096	0.9568	1.0500
115	15473.25	14.571	0.9488	1.0500

Table II represented the result obtained during used AIS optimization technique to solved economic dispatch problem. In this section, the total generation cost and total losses are reduced compared with pre-optimization technique. Based on table II, when Qload rise to 100MVar, total generation cost also increased to 15473.25$/h.

TABLE III. POST-OPTIMIZATION TECHNIQUE OF THE TOTAL GENERATION COST (MAIEP)

Qload at Bus 11 (MVar)	Multiagent Immune Evolutionary Programming (MAIEP)			
	Total generation cost ($/h)	Total losses (MW)	Vmin (p.u)	Vmax (p.u)
15	15450.21	12.817	0.9692	1.0500
35	15452.73	13.009	0.9680	1.0500
55	15456.09	13.264	0.9670	1.0500
75	15461.55	13.679	0.9642	1.0500
95	15465.20	13.956	0.9589	1.0500
115	15471.48	14.433	0.9488	1.0500

Table III present, the result for MAIEP optimization technique. Based on the result, total generation cost and total losses increased respectively due to the Qload increased. From the findings, total generation cost was observed to be 15471.48$/h when Qload increased to be 100MVar.

The generated power has a minimum and maximum limit. The power output of any generator should not exceed their limit. Table IV show the generator real power limit:

TABLE IV. GENERATOR REAL POWER LIMITS

Generating unit, Pg	Minimum generation power (MW)	Maximum generation power (MW)
2	50	200
3	80	300
4	50	150
5	50	200
26	50	120

In this paper, the generated power Pg is used as control variables. There are five control variables that has been control in IEEE- 26-Bus Reliability Test System such as P_{g2}, P_{g3}, P_{g4}, P_{g5} and P_{g26}. The AIS and MAIEP optimization technique was expected to minimize the total generation cost. Therefore, the value of control variables should within the range of generator real power limits. So that, the generated power produce can be controlled.

TABLE V. CONTROL VARIABLES IN POST-OPTIMIZATION TECHNIQUE

Generating unit, Pg	Post-optimization Generated power (MW)	
	AIS	MAIEP
2	185.6511	192.8581
3	256.9850	252.7398
4	134.7631	149.4564
5	182.1766	167.0107
26	77.9014	78.7084

Table V shows the results for the best values of all control variables (P_g) after implementing AIS and MAIEP optimization techniques. Based on Table V, the results show the values were within the permitted values in Table IV.

TABLE VI. COMPARISON OF PRE AND POST-OPTIMIZATION TECHNIQUE OF THE TOTAL GENERATION COST

Optimization technique	Pre-optimization	Post-optimization	
		AIS	MAIEP
Reference loading at Bus 11 (MVar)	15	15	15
Vmin (p.u)	0.9682	0.9691	0.9692
Vmax (p.u)	1.0500	1.0500	1.0500
Total generation cost ($/h)	16760.73	15452.18	15450.21
Total losses (MW)	15.534	12.965	12.817
Computation time (s)	-	3379.790	684.527

Table VI present the comparison of pre and post-optimization technique to minimize total generation cost when varied the Qload and 15 MVar was taken as reference loading in Bus 11. From the observation, total generation cost was reduced respectively by implementing optimization technique. It can be observed that, MAIEP is better than AIS optimization technique because MAIEP gave lowest generation cost compared to AIS optimization technique. The MAIEP optimization technique was capable to offer faster computation time than AIS optimization technique. The objective function in this study was successfully achieved.

V. CONCLUSION

In this case of study, the purposed of this research is to minimize the total generation cost. This research also needed the student to employ the AIS and MAIEP optimization techniques in solving economic dispatch problem were implemented on the IEEE-26-Bus Reliability Test System. By using both techniques, it seems to meet the objectives of this research which is to reduce the total generation cost during increased Qload. Based on the result, the MAIEP optimization technique is reliable technique because MAIEP capability to minimize the total generation cost and give faster computation time compared with AIS optimization technique. Finally, it can be concluded that the objective of this research was achieved. For recommendation in the future, the reactive power load, Qload and real power load, Pload should be varies at the same time by using AIS and MAIEP optimization technique to solve the economic dispatch problem.

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