Reactive Power Dispatch for Cost and Loss Minimization in Power System during Line Outage Contingency by Using MAIEP

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Abstract – **Electrical power system are designed and operated to meet the continuous variation of power demand. The optimal reactive power dispatch is to optimize the steady state performance of a power system in terms of one or more objective functions while fulfilling both equality and inequality constrains. This paper present a new optimization technique termed as Multi Agent Immune Evolutionary Programming (MAIEP) utilizing Reactive Power Dispatch (RPD) to minimize total generation cost and losses in power system. MAIEP concept is origin from few combinations of optimization technique of Multiagent System (MAS), Artificial Immune System (AIS) and Evolutionary Programming (EP) optimization technique. In a large power system network, there are many possibilities of the contingency occurrence. Contingencies could be line outage, the occurrence of contingency in a nominal voltage and leads to voltage collapse. Line outage could be extreme case when the outage line involving any units of the power supply in the system. The programming codes are written in MATLAB. The propose technique was tested using IEEE-26-Bus Reliability Test System. The result obtained from before contingency and during contingency are comparing with MAIEP optimization technique and pre optimization technique.**

I. INTRODUCTION

The optimal operation of a power system is required to proceed the optimal planning of facilities or devices for the system. Generally, these facilities consist of generating plants, reactive power compensation and transmission network. There are two sub-objective of ORPD which are to maintain the voltage profile of the network in an acceptable range and the other objective is to minimize the total power loss of the network. Lastly is to minimize the transformer tap setting changes and generator VAR source switching. Suitably adjusting the following facilities such as tap changing under load transformers, generating units' reactive power capability variation, switching of inductors, switching of unloaded or unused lines and flexible AC transmission system (FACTS) devices can control reactive power flow. It is therefore clear that reactive power and voltage control is a constrained, nonlinear problem of considerable complexity. Useful studies was done for solving the reactive power dispatch problem have been carried out based on classical techniques which includes nonlinear programming(NLP), successive linear programming, mixed integer programming, Newton and quadratic techniques. Most of these approaches can be broadly categorized as constrained optimization techniques. Not with standing that these techniques have been successfully employed in some sample power systems, there are several issues to be addressed with regard to real power systems. The reactive power control problem is, by nature, a global optimization with several local minima. In an attempt to avoid the extant computational complexity and other limiting mathematical assumptions several search techniques have been proposed. They are expert system (ES), genetic algorithm (GA), tabu search, simulated annealing (SA), particle swarm optimization (PSO), etc. [1-3]. Evolutionary Algorithms (EAs) are optimization techniques based on the concept of a population of individual that evolve and improve their fitness through probabilistic operators like recombination and mutation. These individuals are evaluated and those that perform better are selected to compose the population in the next generation. After several generations these individuals improve their fitness as they explore the solution space for optimal value. The field of evolutionary computation has experienced significant growth in the optimization area.

Stressed power network and caused by line generator and transformer outages was due to contingency as the most contingency that could violate the voltages stability of the entire system. If a contingency occurs in an already stressed system both angular and voltage stability may be lost. Many voltage instability i.e. voltage collapse events have been experienced by the utilities in the recent years. This was mainly due to reactive power shortage during the peak load. These events deserve addition of the voltage stability constraint in the RPD for maintaining the security of modern power systems. In the case of a generation outage, the lost generation will be supplied by the remaining generators, according to some specified redistribution pattern. Some plants need considerable time to increase power and not respond promptly to the contingency occurrence. Contingency may have many different scenarios, and involve simulation of system flows for each possible major disruption to the system, including unplanned power outages, or a line outage (caused by lightning strike for example).

In this paper, MAIEP technique is explored as an optimization tool for controlling the reactive power for the improvement of the voltage profiles and reduction of system losses. The study involved the development of optimization engine implementing EP, AIS and MAS technique in hybrid form. The proposed technique is tested on IEEE-26 reliability test bus system.

II. BACKGROUND STUDIES

A. Optimal Reactive Power Dispatch (ORPD)

The optimal reactive power dispatch is to optimize the steady state performance of a power system in terms of one or more objective functions while fulfilling both equality and inequality constrains. The problem is formulated as follows:

Maximize or minimize

$$f(x, u) \tag{1}$$

subject to

$$g(\mathbf{x}, \mathbf{u}) = 0 \tag{2}$$

$$h_{min} \leq h(\mathbf{x}, \mathbf{u}) \leq h_{max} \tag{3}$$

where u is the vector of control variables (these include generator active/reactive power/voltage levels and transformer tap setting); x is the vector of dependent variables (load node voltage, generator reactive power); f(x,u) is the objective function; g(x,u) is nodal power constraint and $h_{min}<h(x,u)<h_{max}$ are the inequality constrains of the dependent and independent variables.

B. Evolutionary Programming

EP is one of the popular techniques which falls under the Evolutionary Computation in Artificial Intelligence (AI) hierarchy and has been increasingly applied for solving power system optimization problem in recent years. It is a stochastic optimization strategy, which is based on the mechanics of natural selections-mutation, competition and evolution. This technique stressed on the behavioural linkage between parents and their offspring. EP consists of 3 steps which have been briefly discussed in [4-5]:

i. Initialization

The initial population of μ individuals consists of (x_i, η_i), $\forall i \in \{1, 2, \ldots \mu\}$ are generated randomly based on its limit. x_i denotes the control variables and η_i is the strategic parameter/s for each x_i. According to the objective function of optimize, $f(x_i)$ the fitness value is calculated individually.

ii. Mutation

Process to transform the initial population(parents) to offspring(children) is call mutation. Each parents $(\mathbf{x}_i, \eta_i)$, $i=1,\ldots, \mu$, creates a single offspring $(\mathbf{x}'_i, \eta'_i)$, $j=1,\ldots, n$, where x'_i and η_i are given by:

$$x'_i(j) = x_i(j) + \eta'_i(j) N_j(0, 1) \tag{4}$$

$$\eta'_i(j) = \eta_i(j) \exp \tau' N(0, 1) + \tau N_j(0, 1)) \tag{5}$$

$$\tau = ((2(n)^{1/2})^{1/2})^{-1} \qquad \tau' = ((2n)^{1/2})^{-1} \tag{6}$$

$x_i(j)$, $x'_i(j)$, $\eta_i(j)$ and $\eta'_i(j)$ are the j^{th} component of the vectors $\mathbf{x}_i$, $\mathbf{x}'_i$, η_i and η'_i respectively. N(0, 1) is a normally distributed one-dimensional random number with mean of zero and standard deviation of 1.$N_j(0, 1)$ denotes that the random number is generated anew for each value of j. Each offspring that has been created was calculated its fitness.

iii. Combination and Selection

The combined population will be ranked in ascending order with reference to the fitness value and based on the objective function of total cost minimization. The next generation parents will be selected from the selected the combination population at the highest μ individual. As for the given fitness in (7), the convergence of difference between maximum and minimum value will be defined by the stopping criterion. If it is not achieved, the process of mutation, combination and selection are repeated until it converged.

$$Fitness_{max} - Fitness_{min} \leq 0.0001 \tag{7}$$

C. Contingency Analysis

This paper measured the contingencies due to line outage contingency is simulated by removing one line at a time. The highest losses from every line outage consider as the critical line data.

D. Multiagent System

Newly explored of research MAS has been employed in a few studies as an optimization technique. According to [8], [9], an agent is a physical or virtual entity that has the following properties.

1. It is able to live and act in the environment (global).
2. It is able to sense its local environment.
3. It is driven by certain purposes.
4. It is able to respond to changes that occur in it, based on its learning capability.

E. Artificial Immune System

Artificial Immune System (AIS) have been defined as adaptive systems inspired by the immune system and applied to solve problem [7]. In general, the basic algorithm of AIS involves initialization, cloning, mutation and selection [6].

Cloning stage is a stage whereby the best individual of the population is reproduced to ensure that only the best result will be processed.

III. METHODOLOGY

MULTIAGENT-BASED IMMMUNE EVOLUTIONARY PROGRAMMING

MAIEP integrates all the above optimization technique; EP, AIS and MAS to optimize the desired objective function. The purposed technique is quite general and the engine can be later utilized for solving other optimization problem. Initially, the characteristic of an agent is specified as follows:

A. Definition of Global Environment

All agents in MAIEP are arranged in the form of lattice like environment. It is also identified as the global environment, L. The size of L is L_{size} x L_{size}, where L_{size} is an integer. The structure of the global environment is shown in Fig. 3. An agent in MAIEP is represented in each circle in the above model and the data it carries represents the coordinate in the lattice. Indirectly, each agent also contains certain fitness value and a set of control variables of the optimization problem which in this approach, it is generated during initialization procedure in the EP.

B. Agent's Behaviour

Each agent has some distinctive behaviour in order to react to change that occurs in the environment. In order to obtain optimal solution quickly, each agent competes and cooperates with their neighbours to disseminate the information using competition and cooperation operator, use the evolution mechanism (EP operator) as its knowledge in the competition and use the self learning operator as the learning capability to solve the problem. The description on these 3 operators is briefly discussed as follow:

i. Competition and Cooperation Operator

The main function of this operator is to compare the fitness of the selected agents with its neighbours' fitness. Agent which has the best fitness value is chosen to replace or maintain the selected agent's location in the lattice. Suppose that this operator is performed on agent $L_{i,j} = (I_1, I_2 ...., I_n)$ and $M=Max_{i,j} =(m_1,m_2,....m_n)$ is the agent with maximum fitness(depending on the objective function) value among the neighbours of $L_{i,j}$ if agent $L_{i,j}$ satisfies (9) it is a winner, otherwise it is a loser.

$$f(L_{i,j})>f(Max_{i,j}) \quad (9)$$

If winner agent can be maintained at it position while the loser will be eliminated and replaced by $Max_{i,j}$. $l_1, l_2, \ldots, l_n$ and $m_1, m_2, \ldots, m_n$ are the set of control variables represented by agent $L_{i,j}$ and $Max_{i,j}$ respectively.

ii. EP Operator

A newly individual generated are capable to provide robust and reliable results based on EP operator idea as previously mentioned. The evolution mechanism of EP generally use in EP operator. The process consists of mutation, competition and selection procedures.

iii. Self learning Operator

Self learning operator is opted to realize the behaviour of using knowledge. After the execution of the EP operator in first stage, the best agent was cloned. After that it will go through back the EP operator for the second stage.

C. Definition of Local Environment

Each agent is fixed on a lattice point and it can only interact or share information with its neighbours. The information is spread in the local environment. From fig3 neighbours of an agent are chosen if there is a line connecting them. Suppose that the agent located at (i, j) is represented by $L_{i,j}$, i, j = 1, 2,..., L_{size}, then the neighbours are defined as follows [10]:

$$N_{ij}=\{Li', j, Li, j'', Li'', j, Li, j''\} \quad (8)$$

where

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

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

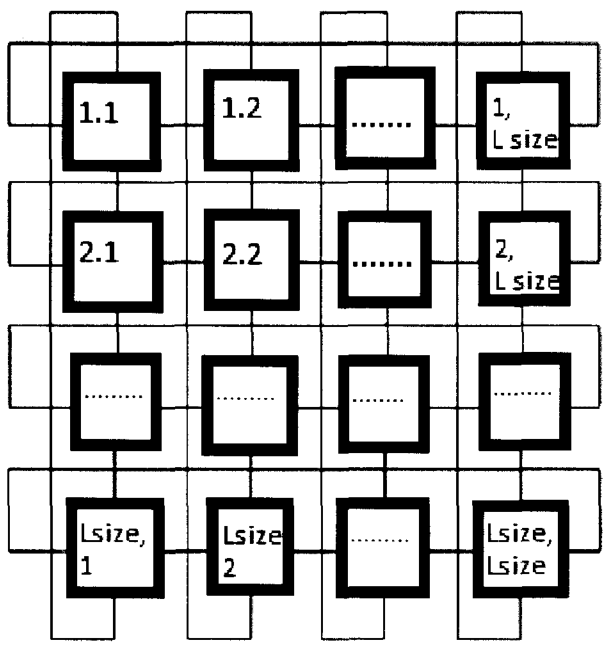

Figure1: Model of the agent lattice

IV. IMPLEMENTATION OF MAIEP IN MINIMIZING GENERATION COST BY CONSIDERING CONTINGENCY

The methodology of RPD by considering contingency by using MAIEP is depicted in Fig. 4 and Fig. 5 as follow:

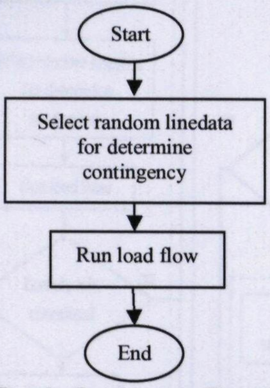

Fig. 4. Contingency Flowchart

Fig. 4 shows the flowchart for the calculation of contingency which is employed at the 3[th] step in Fig. 6 during contingency. In the approach, one of the critical line data have been removed from the list of the line data. The initial condition is in Fig. 5 implies for the before contingency situation.

V. RESULTS AND DISCUSSION

In this study, two different cases were performed. In case1 measure system's cost and loss before the occurrence of line outage and case 2 will measure system's cost and loss when the contingency occur. The clone value is set to 10 and the size of lattice, L_{size} is set to 4. The proposed algorithm has been tested on the IEEE 26-bus system. The optimization technique is written and execute in Mathlab(7.6) using Pentium (R) D 2.13 GHz computer.

A. Case1- Multiagent Immune Evolutionary System (MAIEP) compare to pre optimization technique before contingency condition

During before contingency situation, the overall buses can withstand according to resulted power loss, cost and voltage profile. The result for MAIEP optimization technique and without optimization technique is shown in Table 1.

TABLE 1
VALUE FOR BEFORE CONTINGENCY RESULT

	MAIEP	*PRE OPTIMIZATION TECHNIQUE*
Cost($K/h)	15.3956	15.4472
Vmin(p.u)	0.9857	0.9690
Vmax(p.u)	1.0800	1.0500
Total Loss(MW)	12.1457	12.8003

The results for total system losses, total generation cost and voltage profile obtained before contingency stage.

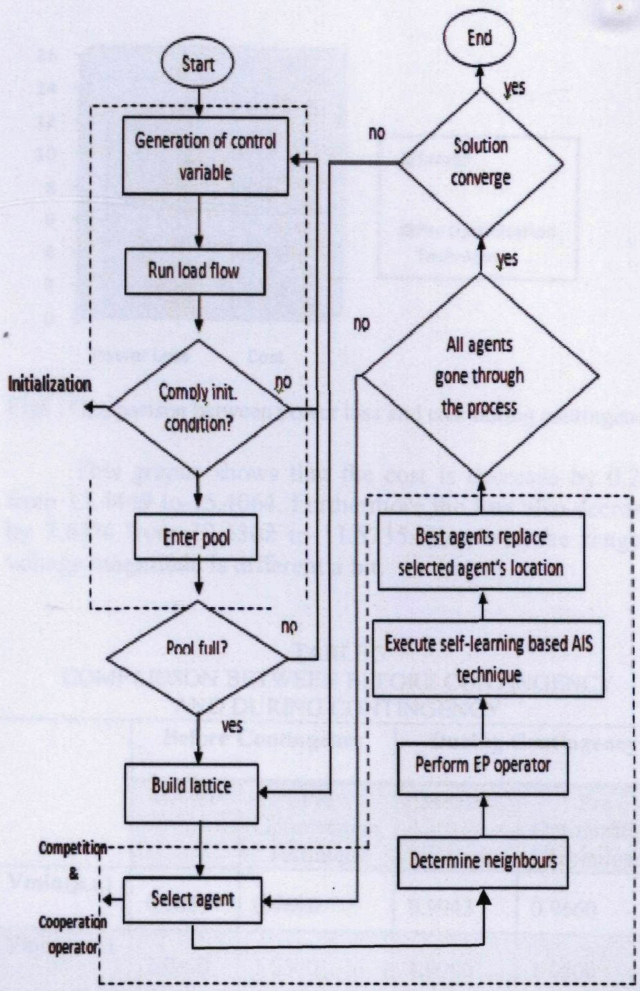

Fig. 5. Flowchart of the overall procedure of minimizing generation cost and loss by using MAIEP before contingency

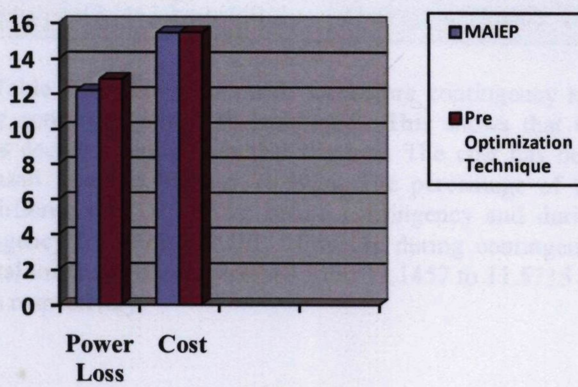

Fig. 6 : Comparison between power loss and cost before contingency

The graph shows the comparison between using MAIEP optimization technique and pre optimization technique. It shows that the cost is decrease from 15.4472 to 15.3956 with 0.33%. Besides that the total cost also decrease from 12.8003 to 12.1457 with 5.11%. However the range of voltage magnitude is different a bit.

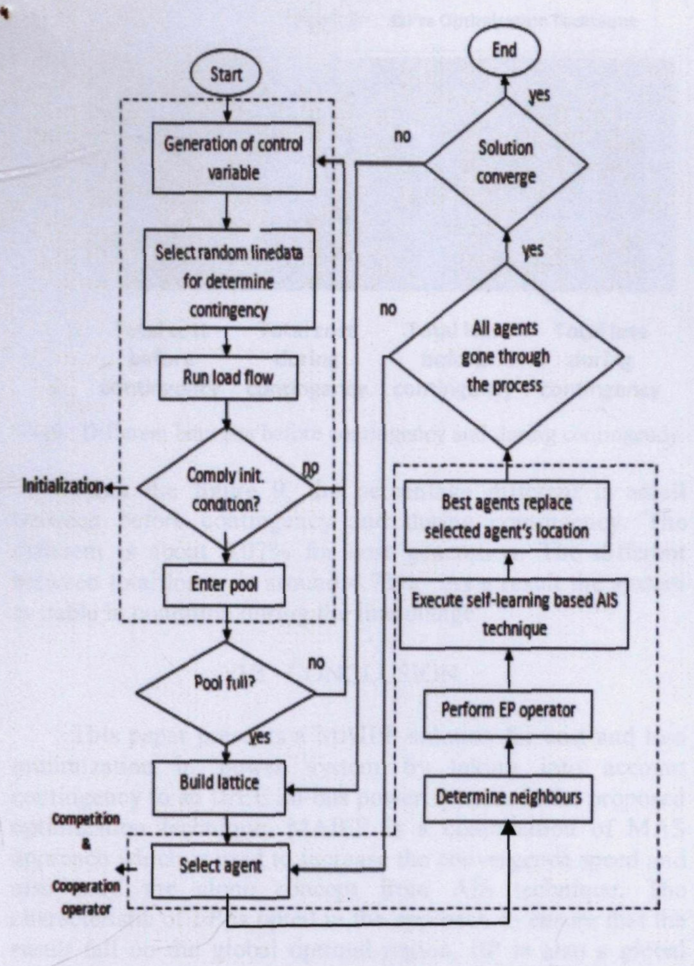

Fig. 7. Flowchart of the overall procedure of minimizing generation cost using MAIEP for during contingency

B. Case 2 - Multiagent Immune Evolutionary System (MAIEP) compare to pre optimization technique during contingency condition

In this case, the same values of constrains condition and generator setting as in the case 1. However one of the line data was removed. The removal of the lines in the list may affect the system stability. The results during contingency by using MAIEP and pre optimization technique are shown in Table 2.

TABLE 2
VALUE FOR DURING CONTINGENCY RESULT

	MAIEP	PRE OPTIMIZATION TECHNIQUE
Cost($K/h)	15.4064	15.4449
Vmin(p.u)	0.9943	0.9660
Vmax(p.u)	1.0900	1.0500
Total Loss(MW)	11.5735	12.5302

The above Table 2 shows that the overall result achieved during contingency stage which decrease the total system losses and decrease generation cost as well as enhancing the system.

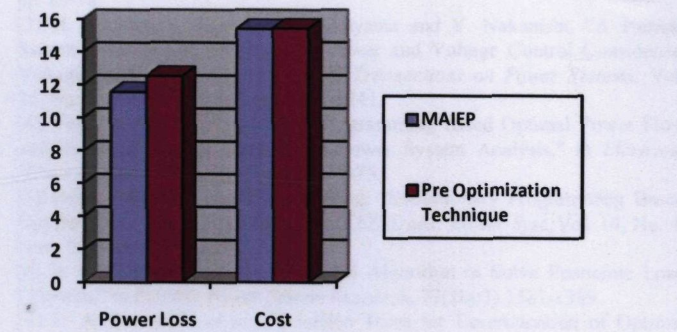

Fig8 : Comparison between power loss and cost during contingency

This graphs shows that the cost is decrease by 0.25% from 15.4449 to 15.4064. Furthermore the loss also decreases by 7.63% from 12.5302 to 11.5735. However the range of voltage magnitude is different a bit.

TABLE 3
COMPARISON BETWEEN BEFORE CONTINGENCY AND DURING CONTINGENCY

	Before Contingency		During Contingency	
	MAIEP	Pre Optimization Technique	MAIEP	Pre Optimization Technique
Vmin(p.u)	0.9857	0.9690	0.9943	0.9660
Vmax(p.u)	1.0800	1.0500	1.0900	1.0500
Cost($K/h)	15.3956	15.4472	15.4064	15.4449
Power Loss(MW)	12.1457	12.8003	11.5735	12.5302

Table 3 tabulates the result for before contingency and during contingency in both techniques. This shows that the cost is decrease along with that the loss. The cost has been decreased from 15.4064 to 15.3956. The percentage of the cost difference is 0.07% for before contingency and during contingency by using MAIEP. However during contingency the total loss have been decreased from 12.1457 to 11.5735 by 4.71% respectively.

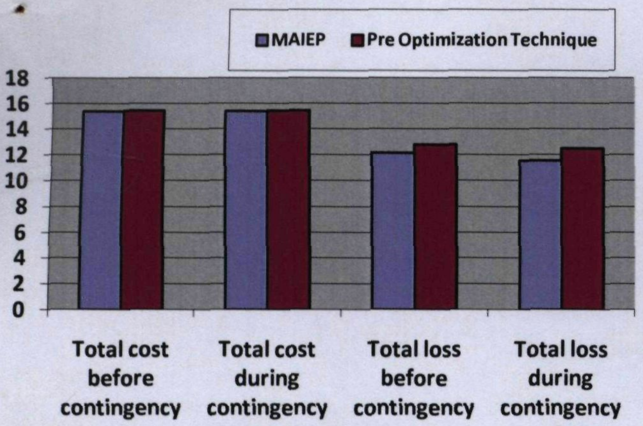

Fig9 : Different between before contingency and during contingency

From the figure 9, the percentage different is small between before contingency and during contingency. The different is about 0.07% for cost generation. The different between total losses is around 4.71%. As a result the system is stable in condition during the line outage.

VI. CONCLUSION

This paper presents a MAIEP solution for cost and loss minimization in power system by taking into account contingency to an IEEE 26-bus power system. In the proposed optimization technique, MAIEP is a combination of MAS approach which is used to increase the convergence speed and also used the clone concept from AIS technique. The characteristic of EP is opted in the approach to ensure that the result fall on the global optimal region. EP is also a global search method starting from a population of candidate solution and finds its solution in parallel using evaluation process. MAIEP is able to minimize the system losses and cost during the line outage contingency. As the result the system's losses, generation cost and voltage profile are also improved consequently. This optimization technique can be applied for solving economic dispatch with complex system, larger bus network and other optimization problems in power system analysis such as maximize the maximum loading point.

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