IMMUNE GENETIC ALGORITHM PERFORMANCE IN OPTIMIZATION OF POWER FLOW IN POWER SYSTEMS

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Abstract: *In this paper two conventional random search methods that are Genetic Algorithm and Immune Genetic Algorithm has been compared in optimal power flow problem in power system. The IEEE 14-bus test system has been selected as case study. This comparison has been done in equal conditions for two algorithms. Objective function in this problem is the minimization of cost of network losses and the cost of reactive power injection in the period of five years. Control variables are voltage magnitude of generator buses, active power of generators and reactive power injection of load buses. The results show that the IGA is more accurate than the GA and global optimal solutions can be found by the IGA.*

Keywords: *Immune Genetic, Genetic Algorithm, Optimal Power Flow, Losses.*

1. Introduction

The optimization of the reactive power is an extended non-linear optimization problem with many variables and many constraints. To solve this problem, conventional methods such as non-linear and linear programming methods are the common ways, which these methods usually converge to local optimums rather than global optimal points [1]. Whereas using heuristics method, such as Genetic Algorithm (GA), can find optimal points. In this regards, using GA, modified GA or IGA have been studied in many researches [1]-[5]. The GA is a modern method based on way searching multi points randomly where the optimal points may be within them. Therefore, the possibility of finding optimal points by GA is more likely than the conventional methods. However, GA may converge to local optimal points when, crossover and mutation rates were selected unsuitable [2]. Considering to these deficiencies in conventional GA, a new method called Immune Genetic Algorithm (IGA) has been created. The IGA is derivated from body defensive system. This algorithm has ability to regulate itself in order to reach global optimal points [4].

In this paper, a modified Immune Genetic Algorithm will be proposed and a comparison will be done between GA and IGA algorithms in equal condition. The proposed method will be applied on the IEEE 14 bus network which has been used as case study.

2. The GA and IGA Theories

Genetic Algorithm: The GA is an optimization method based on evolution adaptations in nature. The GA works with a population of individuals (chromosomes) which each individual stands for a solution. Each part of chromosomes (genes) stands for special variable of mentioned problem. New generation is produced with considering individuals fitness function and Genetic operators (selection, crossover and mutation) and individual's fitness improve through the algorithm iterations

Immune Genetic Algorithm: The IGA has been derived from the body defensive system operation against external invaders. According to this theory, if adaptivity of a new B-cell produced by mutation mechanism with current population will be more than the threshold then can be entered to new cell populations. In this algorithm, the initial population will be haphazardly produced and a random individual will be generated in each generation. This new individual can enter to the next generation instead of the worst individuals in the population if its affinity to population be more than a specific value [6], [7].

3. Problem Formulation

The aim of the optimization is to minimize the total cost of losses and reactive power injection cost in all buses within a period of five years. In this regards, the objective function of the problem has been defined in expression (1).

3.1. Objective Function

Objective function in this problem has been defined as follows:

$$k_p.T.P_{Loss} + k_c \sum_{i=1}^{N_L} Q_{Ii} + C_p \qquad (1)$$

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Where:

k_p is the cost of 1 kWh active power losses,

T is the duration of studying,

P_{Loss} is active power losses,

k_c is the cost of 1 kVAR reactive power injection,

Q_I is the injected reactive power to each load bus,

C_p is the punishment factor.

Punishment factor prevents the violation of state variables from their limits. Individuals that cause the value of the objective function be high will have less chance to survive in next generation.

3.2. Constraints

Nodal active and reactive power balance equations are defined as in (2) and (3).

$$P_{Gi} - P_{Di} - V_i \sum_{j \in i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \quad (2)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j \in i} V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) = 0 \quad (3)$$

Where: $i \in \{N_L, N_{PV}\}$ and

$$\theta_{ij} = \theta_i - \theta_j \quad (4)$$

Also,

P_G is the active power generation,

P_D is the active power consumption,

Q_G is the reactive power generation,

Q_D is the reactive power consumption,

N_L is the set of load buses,

N_{PV} is the set of PV buses,

θ_{ij} is the difference between phase of voltage at bus i and j.

$$V_{i\min} \le V_i \le V_{i\max} \quad (5)$$

Where:

V is the voltage magnitude of bus,

$V_{\min}$ and $V_{\max}$ are the lower and upper limit of voltage magnitude, respectively.

$$Q_{Gi\min} \le Q_{Gi} \le Q_{Gi\max} \quad (6)$$

In equation 6, $i \in \{N_{PV}, N_0\}$.

$Q_{G\min}$ and $Q_{G\max}$ are the lower and upper limit of reactive power generation in generators,

N_0 is the slack bus.

$$Q_{Ii\min} \le Q_{Ii} \le Q_{Ii\max} \quad (7)$$

$i \in \{N_L\}$

$Q_{I\min}$ and $Q_{I\max}$ are the lower and upper limit of reactive power injection at load buses.

4. Case Study

IEEE 14-bus network has been selected as case study of this paper which is shown in Figure 1.

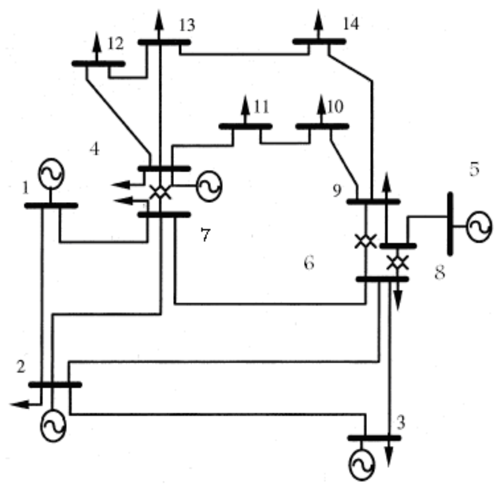

Figure 1. One line diagram of IEEE 14 bus test system.

This system has four PV buses and nine load buses and one slack bus. The initial state of the system has been shown in table 1.

Variables have been marked with yellow color are state variables and those have been shown inside thick lines are control variables. Control variables and state variables limits have been shown in table 2 and 3, respectively.

5. Problem Solving with GA And IGA

IGA Method: The IGA has ability to self regulating and achieves a good regulation of dynamic balance between individuals diversity. In addition, it assures convergence to global optimum points. In this algorithm, the real coded method was used for chromosomes because of its high speed calculations and no need to decode chromosome.

Table 1. Initial State of IEEE 14 Bus Test System

Bus Number	Voltage (pu)	Generated Reactive Power (Mvar)	Generated Active Power (MW)	Load Reactive Power (Mvar)	Load Active Power (MW)
1	1.06	44.43	140.23	0.0	0.0
2	1.04	27.98	80.39	12.7	21.7
3	1.01	0.0	104.45	19.0	94.2
4	1.07	49.19	10.07	7.5	11.2
5	1.08	0.0	0.0	0.0	0.0
6	1.0	0.0	0.0	33.83	96.7
7	1.0	0.0	0.0	39.2	4.8
8	1.0	0.0	0.0	0.0	0.0
9	1.0	0.0	0.0	-14.21	33.91
10	1.0	0.0	0.0	3.2	5.86
11	1.0	15.57	0.11	2.8	1.96
12	1.0	0.0	0.0	2.71	36.74
13	1.0	0.0	0.0	5.8	13.50
14	1.0	0.0	0.0	5.0	14.90

Table 2. Control Variables Limits

		Lower Limit	Upper Limit
Generated Active Power of Generators (MW)	2	0	180
	3	0	254
	4	0	60
	5	0	25
PV Buses Voltage (pu)		0.95	1.1
Variation of Injected Reactive Power to Load Buses (Mvar)		-50	+150

Table 3. State Variables Limits

	Reactive Power of Generator Buses (MW)	Load Buses Voltage (pu)	Active Power of Slack Bus (MW)
Max	100	1.1	200
Min	-50	0.95	0

Figure 2 shows the selected chromosome. The chromosomes have 17 genes that each gene stands for a control variable. The first four genes are relevant with PV voltage buses and the next four genes are relevant with generators output active powers. Finally, the nine last genes show injected reactive power to load buses.

V2	…	V5	P2	…	P5	QG6	…	QG14

Figure 2. Selected chromosome for this problem with 17 gene

Population size has been selected 20 in this method and affinity function is defined as:

$$m_{ij} = \frac{k_m}{\sqrt{\sum (x_i - x_j)^2}} \tag{8}$$

$$T = \frac{\sum f_i}{20} \tag{9}$$

m_{ij} is the affinity function between i'th and j'th individual, k_m km is affinity coefficient, x_i, x_j are genes of these individuals and f_i is objective value of individuals. T is threshold limit of acceptance or rejection of new individual in last population and has been assumed like that average of population objective values. Stopping criteria determine the causes of the algorithm stopping and include two parts. The algorithm will terminate if each of these conditions is satisfied:

- Performance of algorithm up to 10000 iterations.
- If there is no improvement in the best fitness value for 3000 generations.

In the GA method the chromosome in this method is selected like chromosome in IGA. Population size is 20 individuals and crossover rated is 0.5. Termination criteria are like IGA stopping criteria for comparison of two algorithms in equal conditions.

6. Results

Two mentioned methods were applied to IEEE 14-bus test system and following results was obtained.

Initially IGA algorithm was applied to test system for various affinity coefficients from 10 to 100 in steps of 10 for determination of most efficient affinity coefficient in IGA method. The best solution was obtained in k_m equal to 30. Then algorithm was performed for coefficients from 30 to 40 in steps of 1 again for accurate determination of this coefficient and k_m equal to 32 was selected as the best coefficient for this problem. Result of problem solving for various coefficients is seen in Figure 3.

The algorithm was performed 5000 iterations for each coefficient. With applying this coefficient obtained results for minimum and average of objective value for each generation in 10000 iterations have been shown in Figure 4 and Figure 5, respectively.

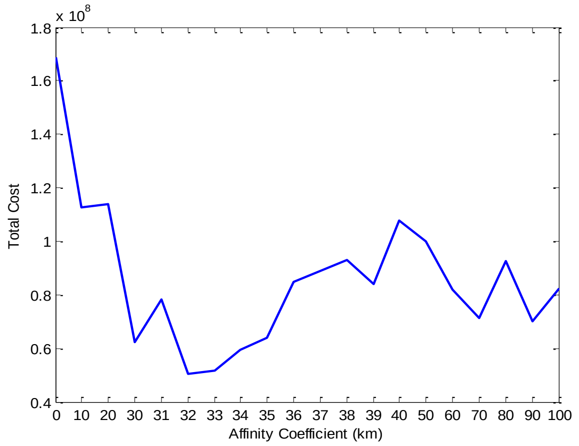

Figure 3. Problem solving results with IGA method for various affinity coefficients.

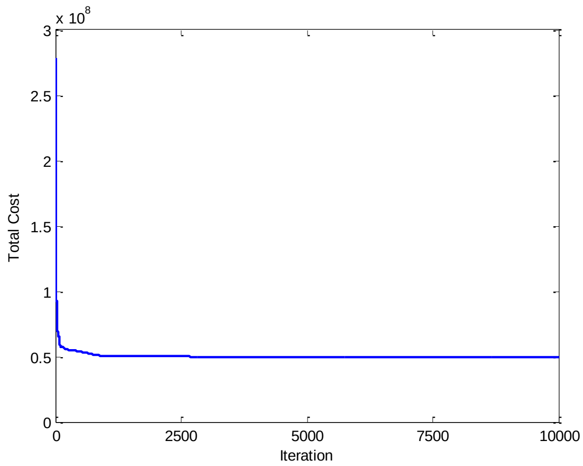

Figure 4. Improvement of minimum cost in each generation in IGA

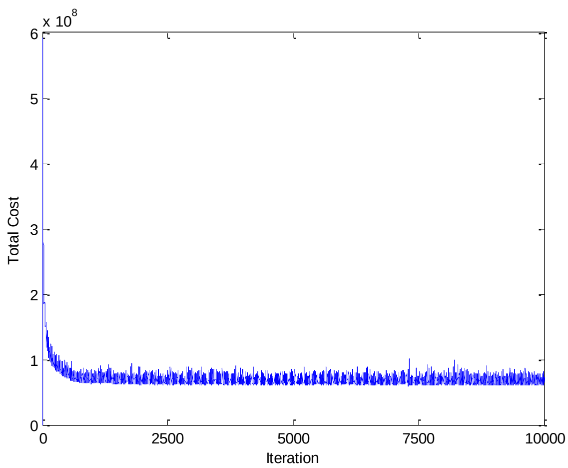

Figure 5. Average cost of each generation in IGA

Besides, in GA method the algorithm was performed for mutation rates from 0 to 1 in steps of 0.1. For each mutation rate, the algorithm was performed 5000 iterations. After obtaining the best solution for 0.1, the algorithm was performed for mutation rate from 0 to 0.1 in steps of 0.01. Finally, the mutation rate of 0.03 was selected as the best rate. Problem solving results for various mutation rates are shown in Figure 6.

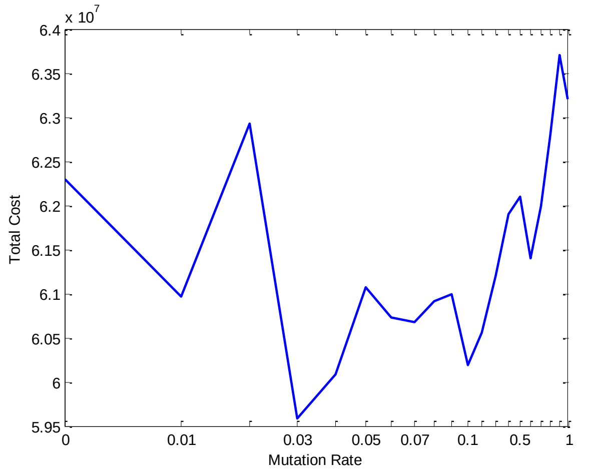

Figure 6. Problem solving results for various mutation rates in GA.

With applying the best mutation rate (0.03) to GA method with 10000 iterations, the obtained results for each generation has been shown in Figures 7 and 8.

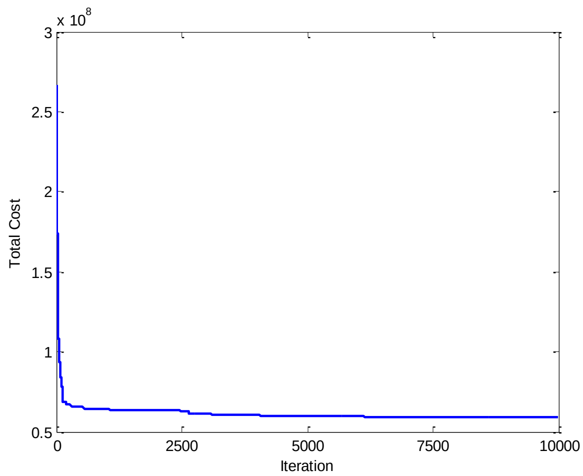

Figure 7. Improvement of minimum cost of each generation in GA

Figure 5 and Figure 8 show that the diversity of individuals in GA method is more than IGA. This deficiency in GA method causes that it can not converge to global optimum properly. Proposed results of two algorithms are shown in table IV.

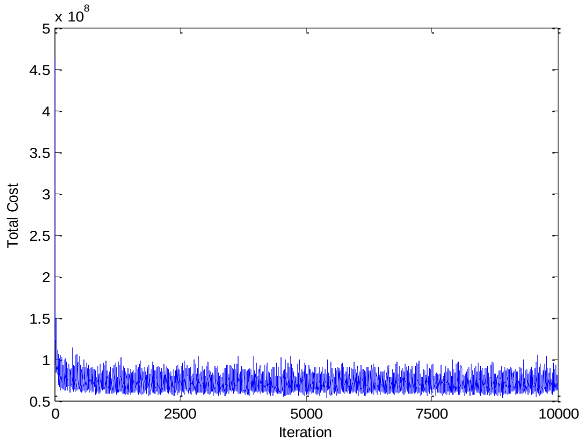

Figure 8. Average cost of each generation in GA

Table 4. Proposed Solution of Two algorithms for This Problem

Variables	IGA Method	GA method
Voltage of Bus 2 (pu)	1.060	1.072
Voltage of Bus 3 (pu)	1.059	1.073
Voltage of Bus 4 (pu)	1.055	1.093
Voltage of Bus 5 (pu)	1.063	1.088
Generated Active Power in Bus 2 (MW)	61.242	47.227
Generated Active Power in Bus 3 (MW)	150.942	140.997
Generated Active Power in Bus 4 (MW)	60.009	114.815
Generated Active Power in Bus 5 (MW)	17.105	15.731
Required Reactive Power Injection in Bus 6	14.124	25.316
Required Reactive Power Injection in Bus 7	24.994	57.198
Required Reactive Power Injection in Bus 8	-1.087	-5.451
Required Reactive Power Injection in Bus 9	-3.841	-9.101
Required Reactive Power Injection in Bus 10	0.286	2.327
Required Reactive Power Injection in Bus 11	0.385	-4.247
Required Reactive Power Injection in Bus 12	-0.174	-7.928
Required Reactive Power Injection in Bus 13	0.170	-3.433

Table 4. Continuation

Required Reactive Power Injection in Bus 14	2.434	3.850
Total Reactive Power Injection in Load Buses	47.498	153.424

The cost of reactive power injection and the cost of active power loss within period of five years and economic results from both methods was shown in table V. The obtained results was calculated 50$ for 1 MWh energy and 45$ for 1 kVAR injected reactive power. (The numbers in the figures are different from numbers in table because they are converted to M$ from Milliard Rial).

Table 5. Calculated Costs Using Two Algorithms (Million Dollars)

	IGA method	GA method
Total Cost of Reactive Power Injection (M$)	0.211000	0.681777
Cost of Losses After Modification in Period of 5 Years (M$)	5.307555	5.921555
Cost of Losses Before Modification in Period of 5 Years (M$)	20.189222	20.189222
Economic Save Resulted From Modification (M$)	14.670667	13.585889
Losses Percentage Before Network Modification	%2.74	%2.74
Losses Percentage After Network Modification	%0.721	%0.805

The losses in IGA method is %0.721 as is shown in table V. This losses amount is less than results obtained by GA method. In addition, the IGA results cause economic saves equal to 596666 US$. Economic save resulted from modification of operation conditions of power network by two methods is shown in Figure 9. In IGA method after 1 mount reactive power injection cost offset with losses decrease, while in GA method this duration is 3 mount approximately. The results are shown in Figure 9.

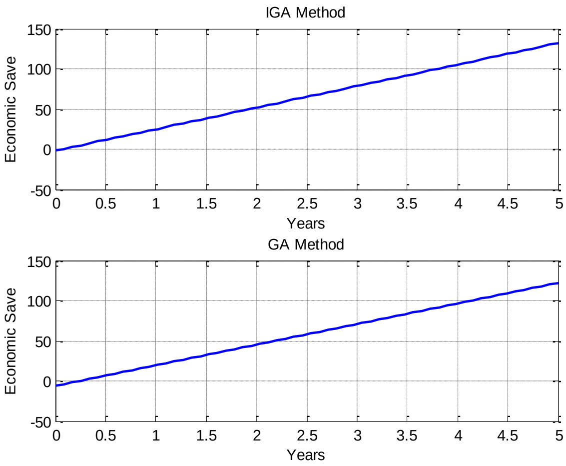

Figure 9. Economic save within period of 5 years resulted from IGA and GA methods.

7. Conclusion

In this paper, in order to survey two GA and IGA ability, advantages and disadvantages in optimal power flow problem, was compared. IEEE 14 bus test system was considered as case study.

The basic parameters of two algorithms such as the population, the size and the initial population were selected identical for comparison of the two algorithms. The best mutation rate for GA and the best affinity coefficient for IGA were selected by a proper method. Finally it was shown that the IGA method because of its self regulation property and the existence of affinity proviso in its structure converges to the global optimum solution more powerfully than the GA method. The GA method because of its too much individual's diversity especially in the vicinity of global optimum points has less efficiency rather than IGA in optimal power flow problem.

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