The International Conference on Electrical Engineering 2008

Dear Sir,

The International Conference on Electrical Engineering 2008 has been finished successfully.
Official Web Site of ICEE2008 has been closed at November 1st, 2008.

We thank you for your cooperation and attendance to the conference.

ICEE2008 Secretariat

*More than Internet Explorer 5.0 recommendation.

No. O-126

Coordination of Overcurrent Relays Using Intelligent Methods: A Comparative study for GA, PSO and IGA

HOSSEINIAN, Hadi

Department of electrical engineering, Zanjan University, Zanjan, Iran

ASKARIAN ABYANEH, Hossein,

Faculty of electrical engineering, Amir Kabir University of Technology, Tehran, Iran

RAZAVI, Farzad

Department of electrical engineering, Tafresh University, Tafresh, Iran

GALVANI, Sajad

Department of electrical engineering, Zanjan University, Zanjan, Iran

MOHAMMADI, Reza

Faculty of electrical engineering, Amir Kabir University of Technology, Tehran, Iran

Abstract

In this paper in order to determine the abilities and limitations of each random search algorithm for solving the relay coordination problem a comprehensive comparison is made. The algorithms which are chose for comparison are; Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Immune Genetic Algorithm (IGA). These algorithms ability have been tested on two study case. The 8 buss distribution network and 8 buss transmission system. The results of various algorithms and their convergence speed and reliability of algorithms convergence in this problem solving have been compared with each other. Some other properties of each algorithm such as variation of convergence speed and the number of points that each algorithm explore to reach global optimum point have been investigated in this paper. For competition of algorithms in equal condition, all of the algorithms programs have been run in same computer. The results show that GA can be faster than others in this problem whereas PSO will be most reliable in relay coordination solving.

Keywords: Coordination, Genetic Algorithm, PSO, Overcurrent Relay, Optimization,

1 INTRODUCTION

Accurate setting and coordination of overcurrent relays is vital for power systems correct operation. The protection relay coordination problem which is highly constrained discrete optimization problem is difficult to solve by conventional optimization techniques [1]. Researchers have described various optimization methods to find the directional overcurrent relay settings [2]. Due to the complexity of the nonlinear optimal programming techniques, the traditional optimal coordination of overcurrent relays are commonly performed by linear programming techniques, including the simplex [3,4], two-phase simplex [5] and dual simplex methods [2,6].

In recent years with growing in processors capability, methods based on artificial intelligent and random search methods are used for optimization problems extensively. Various intelligent optimization algorithms have been introduced for problems solving. The most famous of them is genetic algorithm. This algorithm has been used for optimization problems in various fields. After introducing of GA very much attempts were made to improve its performance in especial problems. So the vary of algorithms were derived from classic GA. These algorithms were named improved or modified GA. One of these algorithms which showed good performance in some optimization problems was Immune Genetic Algorithm (IGA). Another one of optimization algorithms is Particle swarm optimization (PSO).

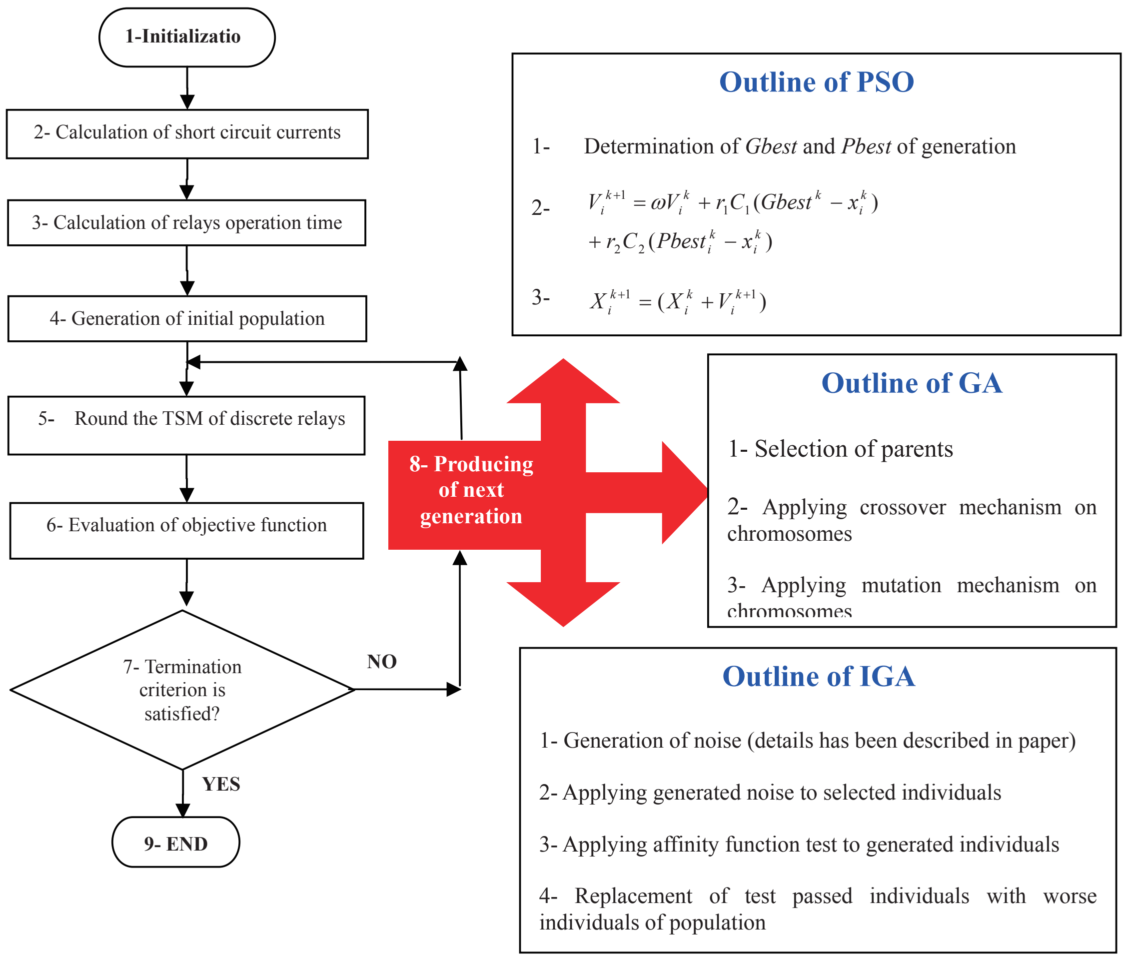


Figure (1): flowchart of intelligent methods application to solving relay coordination problem

This algorithm is one of the evolutionary optimization techniques proposed by Kennedy and Eberhart in 1995 [7]. This algorithm is frequently used in optimization problems too. Relay coordination problem has been solved using GA and evolutionary programming [1, 8] but it hasn't been paid attention with IGA by now.

The most common optimization methods such as GA, PSO and IGA use the same structure to find the solution of problems. Flowchart of this algorithm outline is seen in figure 1. Since these various intelligent optimization methods can have different efficiency in various problem solving and because not tested methods on relay coordination problem (PSO and IGA) have better results rather than GA in some problems solving, it has been decided to solve relay coordination problem using these three algorithms to find out advantages and disadvantages of each method in this case.

C.W.So et. al. developed a method based on GA for optimal coordination [5]. This method has two problems. One of them is miscoordination and another is discrete TSM or TDS.

C.W.So et. al. also developed Evolutionary Algorithm [1,9] and [10]. This method has the same problems as the previous except that the problem of discrete TSM or TDS changed to continuous.

Recently authors of this paper have improved the previous objective function to give better coordination. In other words, in that paper with modification of the existing objective function of GA, by introducing a new parameter and adding a new term to OF, miscoordination problems both for continues and discrete TSM or TDS has been handled [11].

In this paper it has been tried to optimize the 8th box of this algorithm and compare the ability of common intelligent methods (which can be settled in this box position) in solving of relays coordination problem. Some new combined methods have been tested for this problem and efficiency of them has been investigated also.

Since likelihood and randomness are inherent characters of random search methods, for comparison of each property of algorithms we can't trust to once run results in these algorithms. It is necessary to execute these algorithms many times to be confident from their results. In end the average of these runs values is used as final results of speed and convergence probability in each algorithm. In this paper each algorithm has been executed 40 times and average results of this 40 time will be come in algorithms comparison tables.

2 OBJECTIVE FUNCTION

For finding of relays operation time, relation (1) is used. This equation is most common relation for estimation of relay characteristic.

$$\frac{t}{TSM} = a_0 + \frac{a_1}{(M-1)} + \frac{a_2}{(M-1)^2} + \frac{a_3}{(M-1)^3} + \cdots \qquad (1)$$

Where:

M Ratio of relay current to setting current

a_0, a_1, a_2, a_3 Variable coefficients which their value determine simulated relays type

t Relay operation time

In this paper the method which has been introduced in reference [11] has been used in all of algorithms. This method cover either continues or discrete states of TSM. In this method TSM of relays has been considered continuously. The results can be applied directly for relays with continues TSM. For relays with discrete TSM in each iteration before evaluation stage obtained TSMs are rounded to upper steep in relay. Therefore optimal value of O.F is achieved for discrete value of TSMs.

However, the variables of interest in the optimal coordination problem are the TSM or TDS.

The used objective function is as below. [11]

$$\mathrm{OF} = \alpha_1 \times \sum (t_i)^2 + \alpha_2 \times \sum \left(\Delta t_{mb} - \beta_2 \times \left(\Delta t_{mb} - |\Delta t_{mb}|\right)\right)^2 \qquad (2)$$

$$\Delta t_{mb} = t_b - t_m - CTI \qquad (3)$$

Where:

Δt_{mb} is the operation time difference for each relays pair:

t_i is i th relay operating time for a fault close to the CB (circuit breaker)of the i th relay.

t_m and t_b are the operating times of the main and backup relays for a fault exactly close to the CB of the i th relay.

CTI is the coordination time interval and is taken to be 0.4 seconds.

β_2 is the parameter to consider the miscoordination.

α_1 and α_2 are used to control the weighting of $\sum (t_i)^2$ and $\sum (\Delta t_{mb})^2$ respectively.

All of algorithms in this paper have solved coordination problem using above fitness function.

3 ABOUT USED INTELLIGENT METHODS

In all of intelligent methods such as GA, IGA, PSO,… the algorithm need to initial value of variables for commence. These initial values can be produced randomly. After producing initial population and evaluation of fitness functions of each chromosome, all of these algorithms encounter a question. How produce next generation and how continue to reach global optimum point? Each algorithm has an answer to this question and their answers are basic character of each algorithm. Indeed the answers difference determines difference of algorithms. Details of these methods are available in many refrences [7, 12, and 13]. and the summary of each algorithm are came below.

In GA new generation is produced with considering individuals fitness function and Genetic operators (selection, crossover and mutation) and individual's fitness is improved through the algorithm iterations.

In GA, three operators are generally used, i.e. selection, crossover and mutation [12]. In this paper it has been tried to set this parameters in their best values.

The PSO algorithm searches in parallel using a group of individuals similar to other AI based heuristic optimization techniques [7]. Each individual corresponds to a candidate solution to the problem. Individuals in a swarm approach to the optimum through its present velocity, previous experience, and the experience of its neighbors. In a physical *n* dimensional search space, the position and velocity of individual *i* are represented as the vectors $X_i=(x_{i1}, \ldots, x_{in})$ $V=(v_{i1},\ldots,v_{in})$ in the PSO algorithm. Let $Pbest_i = (x_{i1}^{Pbest}, \ldots, x_{in}^{Pbest})$ and $Gbest_i = (x_{i1}^{Gbest}, \ldots, x_{in}^{Gbest})$ be the best position of individual *i* and its neighbors' best position so far, respectively. Using the information, the updated velocity of individual *i* is modified under the following equation in the PSO algorithm.

$$\begin{aligned} V_i^{k+1} &= \omega V_i^k + r_1 C_1 (Gbest^k - x_i^k) \\ &+ r_2 C_2 (Pbest_i^k - x_i^k) \end{aligned} \qquad (4)$$

Where:

V_i^k Velocity of individual *i* at iteration *k*

ω: Weight parameter

c_1, c_2 Weight factors

r_1 , r_2 Random numbers between 0 and 1

x_i^k Position of individual at iteration *k*

$Pbest_i^k$ Best position of individual i until iteration k

$Gbest^k$ Best position of the group until iteration *k*.

Each individual moves from the current position to the next one by the modified velocity in (4) using the following equation:

$$X_i^{k+1} = (X_i^k + V_i^{k+1}) \tag{5}$$

The IGA has ability to self regulating and achieves a good regulation of dynamic balance between individuals diversity. [13]

The basic property of immune system inspired algorithms is in existence of affinity function in their structure which lead to population of each generation is closer to each other during algorithm. In immune genetic algorithm we have used affinity function as below:

$$m_{ij} = \frac{k_m}{\sqrt{\sum (x_i - x_j)^2}} \tag{6}$$

$$T = \frac{\sum f_i}{N} \tag{7}$$

Where:

m_{ij} is affinity function between ith and jth individual and x_i , x_j are genes of these individuals.

T is threshold limit of acceptance or rejection of new individual in last population and has been assumed equal to average of population objective values.

In this algorithm which we have used in this paper in each generation random individuals will be generated based on adding a noise to genes of chrompsom. For determination of best noise for this section we have tested some type of noises. Finally the fitness proportional push restricted noise selected as best choice from speed and reliability aspects. This new generated individuals can enter to the next generation instead of the worse individuals in the population if their affinity to population be more than a specific value.

4 CASE STUDIES

First case study was selected for seeing these algorithms performance on solving relay coordination with continues TSM. Network consists of 7 lines, 6 buses and 1 transformer. This network was shown in figure 2. In this network there are 14 variables stands for 14 existing relays TSM. It is assumed that all the lines are protected by overcurrent relays and the overcurrent relays are normal inverse type and the relay characteristic is formulated by Eq.1.

a_1, a_2, a_3, a_4, a_5 For the particular overcurrent device (normal inverse) is given below:

$$\begin{cases} a_1 = 1.98772 \\ a_2 = 8.57922 \\ a_3 = -0.46129 \\ a_4 = 0.0364465 \\ a_5 = -0.000319901 \end{cases} \tag{8}$$

To obtain the OF, SC (short circuit) current of backup and primary relays must be calculated for the fault close to the CB of the primary relay of each P/B. The relevant information including P/B relays numbers and SC current flowing is given in Table 1.

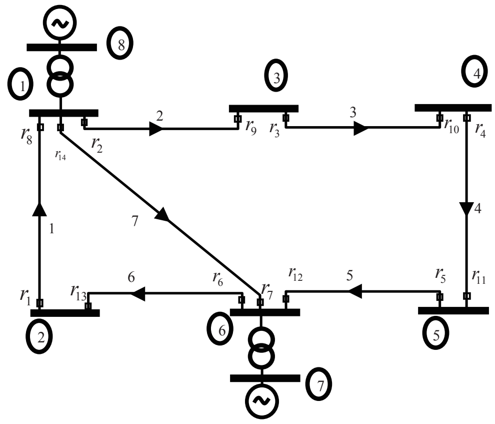


Figure 2. Sample network (8 buses)

Table 1. P/B pair information

Main Relay	Backup Relay	Primary Relay SC Current	Backup Relay Current
8	9	4961.7704	410.8226
8	7	4961.7704	1520.8911
2	7	5362.2983	1528.0660
2	1	5362.2983	804.8782
3	2	3334.5191	3334.5191
4	3	2234.3308	2234.3308
5	4	1352.8751	1352.8751
6	5	4965.0442	411.3675
6	14	4965.0442	1522.9084
14	1	4232.7243	794.0920
14	9	4232.7243	407.2292
1	6	2682.4959	2682.4959
9	10	1443.6699	1443.6699
10	11	2334.6515	2334.6515
11	12	3480.7511	3480.7511
12	14	5365.0609	1529.3638
12	13	5365.0609	805.5618
13	8	2490.7454	2490.7454
7	5	4232.6340	407.2472

In this case study the continues TSMs for relays have been used with steep of 0.001.from 0.05 to 1. Obtained results for TSMs using GA, IGA and PSO algorithms is shown in Table 2.

The operation time of relays and time difference between relays operation consequently achieved from obtained TSMs and they have been same in all of used methods. These results have been tabulated on Table 3.

Second sample network selected for shows algorithms ability on solving coordination problem with discrete TSMs. This case study is eight busses network which is shown in figure 3. This network consists of 8 lines, 8 buses and 1 transformer and 1 generator.

Table 2. Obtained results for TSM of relays using various algorithms

Relay Number	TSM before latest rounding			Rounded TSM
	GA	PSO	IGA	
TSM_1	0.01153214	0.03024897	0.03351367	0.050
TSM_2	0.16609365	0.16664715	0.16680640	0.167
TSM_3	0.12334412	0.12335202	0.12342317	0.124
TSM_4	0.04771158	0.02104490	0.04786553	0.050
TSM_5	0.03037748	0.03958449	0.01703482	0.050
TSM_6	0.11808412	0.11829389	0.11806032	0.119
TSM_7	0.01343841	0.00180290	0.02913234	0.050
TSM_8	0.12154102	0.12100543	0.12154131	0.122
TSM_9	0.04255478	0.01921782	0.02558552	0.050
TSM_{10}	0.09027102	0.09056280	0.09009191	0.091
TSM_{11}	0.13630410	0.13614254	0.13656465	0.137
TSM_{12}	0.23343569	0.23330925	0.23358713	0.234
TSM_{13}	0.04227102	0.04494846	0.00459603	0.050
TSM_{14}	0.00158753	0.00233108	0.03803320	0.050

Table 3. Obtained result for relay coordination using intelligent algorithms

Relay Operation Time				Discrimination Time	
				Δt_{27}	0.7430
t_1	0.1965	t_8	0.4464	Δt_{32}	0.0000
t_2	0.6846	t_9	0.3479	Δt_{43}	0.0000
t_3	0.4772	t_{10}	0.4176	Δt_{54}	0.0000
t_4	0.3318	t_{11}	0.5389	Δt_{16}	0.0000
t_5	0.3830	t_{12}	0.7721	$\Delta t_{9,10}$	0.0000
t_6	0.4263	t_{13}	0.2332	$\Delta t_{10,11}$	0.0000
t_7	0.2446	t_{14}	0.2924	$\Delta t_{13,8}$	0.0000

It is assumed that the relays types installed on the lines of the network are the same as previous sample.

It is clear this need to lesser time to be solved rather than previous sample because of lesser variables need to be found. This rule is correct in all algorithms but its intense is different from one method to another. Because of paper page limitation the output results of algorithms for variables of this case study (TSMs) are not showed in paper. But the results of algorithms performance in this case study will come in all of next sections which will discuses about comparison of performance of algorithms in coordination of relays with continues and discrete TSM.

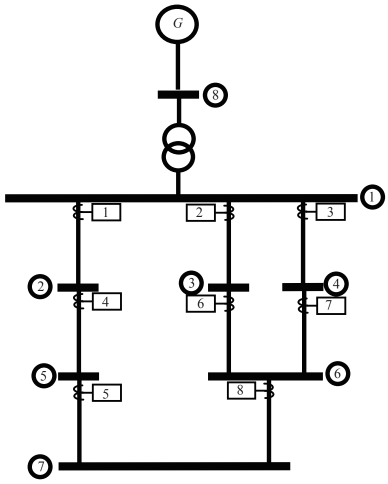


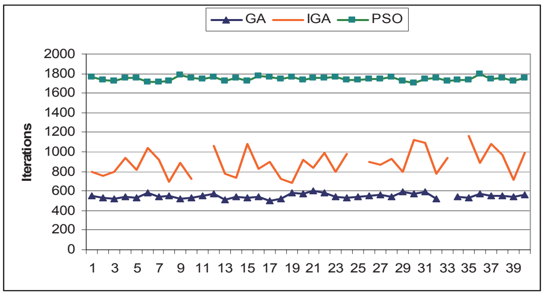
Figure (3): Sample network (8 bus

4 RESULTS AND DISCUSSION

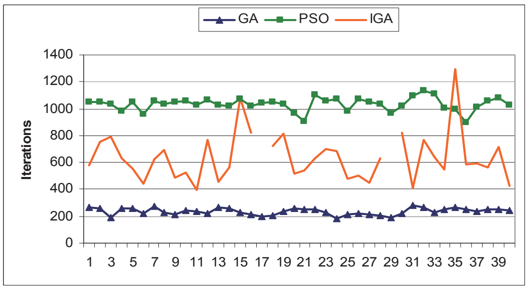
This will be essential that have a description about convergence concept which is used in this paper. When it is said unconverge, it means that the algorithm can't reach to global optimum point in period of determined iterations. In this problem for first case study this iterations is equal 4000 and for second case study is 6000 (because of its larger variables dimension). Therefore it is possible that algorithms reach to solution after determined maximum iterations to best solution but it will be very bad and non real result for that algorithm and if that result has been share with algorithms other results, it will be injustice judgment. So these cases aren't collaborated on our investigations on convergence speed. For having a precise discussion such cases show their effects on algorithms convergence probability.

4.1 Discussion on convergence speed

As mentioned in previous sections all of algorithms have been executed for 40 times in this paper and their results have been shown in figure (4_a) and (4_b) for first and second case study respectively. According to these curves it is obvious that GA can reach to global optimum point in lesser time rather than others in both first and second study casees which follow continues and discrete TSM respectively. IGA in next position in convergence speed ranking and PSO hasn't suitable convergence. The diagrams of algorithms convergence for first and second case study have been shown in figure (5_a) and (5_b) respectively. These figures make clearer the weakness of PSO in latest part of searching in this problem.

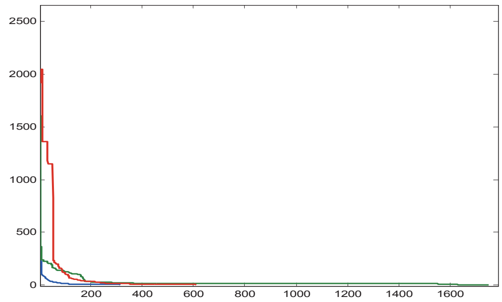


(a)

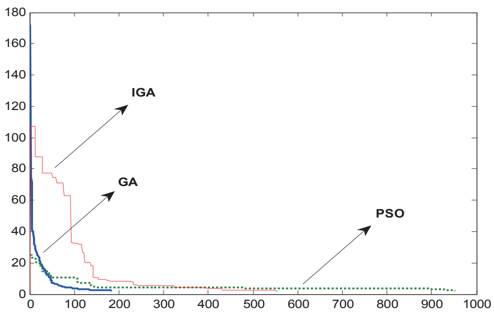


(b)

Figure 4. Diagram of algorithms convergence speed in coordination of overcurrent relays (a): with continues TSM (b): with discrete TSM



(a)



(b)

Figure 5. Convergence diagram of algorithms in relay coordination with (a) continues TSM (b) discrete TSM

4.2 Discussion on diversity of Convergence speed

From figures (4-a) and (4-b) it is obvious that diversity of IGA results is more than PSO and GA. It means that the time and iterations needed for convergence in GA in various runs aren't more different with each other and this shows that the dependence of convergence speed of this algorithm to initial population and random generated variables, which are only factors that are different in various runs, is less than others. This claim will be more obvious and will be confirmed by finding of statistical variance of these data for each algorithm as a criterion of diversity of convergence speed. This criterion is ratio of variance root to average value of data. We named this S criterion.

$$S = \frac{\sqrt{\dfrac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N-1}}}{\bar{X}} \tag{9}$$

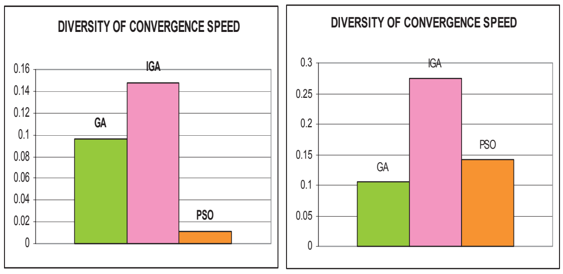
$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \tag{10}$$

Where:

X_i Speed of convergence in each run

N Number of total runs

Figure 6 show the chart of S criterion of various runs in both case studies (with continues and discrete TSM) which is obtained from relation (9).



(a) (b)

Figure 6. Statistic variance of convergence speed in various algorithms in relay coordination

(a) with continues TSM (b) with discrete TSM

With a glance on both figures (6_a) and (6_b) it is understood that there is an outstanding different point in this charts. Indeed diversity of convergence speed in PSO with continues TSM is very lesser than with discrete TSM. Also this phenomena and judgment is correct about immune system algorithm with lesser intense. Diversity of convergence speed in GA seemingly is not sensitive to continues or discrete TSM usage in coordination.

4.3 Discussion on convergence reliability and other factors

Total comparison of algorithms in coordination of relays has been shown in tables 4. In this tables convergence speed in two states (time ranking and number of needed iterations for convergence) are calculated. The reliability value of each method in relay coordination solving with continues and discrete TSM have been shown in fourth row of table 4. From convergence reliability aspect it can be seen in these values, PSO is very reliable in results and these algorithms can be converged in all of their runs in both states of continues and discrete TSM. GA has one case disconvergence in its results on continues TSM state which is seen in curve in 32nd run of figure (4_b). But GA has been converged in all of runs in first case study which use relays with discrete TSM. Immune system algorithms is not enough reliable because of its disconvergence in three times from forty times of its runs in coordination of relays with continues TSM and two times disconvergence in coordination of relays with discrete TSM as was seen in figure 4.

Needed time to algorithms convergence depends on two factors. These factors are the number of searched points and algorithms inherent searching speed.

Number of searched points in each optimization can be stand for adaptivness of algorithms with searched surface. With view from this angle, GA in both states has good performance and although PSO are very reliable but it hasn't good adaptivness with surface of coordination problem. High reliability of PSO is achieved by its long time and dull searching in every place in surface even with very low probability of existence of points with good value of fitness function.

Table 4. Results of algorithms performance on relay Coordination problem in discrete and continues TSM

Method	CONTINUES TSM			DISCRETE TSM		
	PSO	**IGA**	**GA**	**PSO**	**IGA**	**GA**
Convergence Time(S)	246.5	125.4	83.7	117.3	83.5	33.4
Number of Iterations need to Convergence	1745	889	547.7	1033	637	236
Estimation of Convergence Probability (Percent %)	100	92.5	97.5	100	95	100
Number of Searched Points ($*10^3$)	174.5	44.5	27.43	103.3	31.90	11.85
Needed Time for One Point Explore(mS)	1.41	2.82	3.05	1.13	2.61	2.81

6 CONCLUSIONS

In this paper the comparison of intelligent optimization methods on solving of relay coordination has been paid attention. To be complete comparison two case studies were chosen which in both continues and discrete TSM, algorithms were tested. Investigated algorithms ability analyzed in various aspect. It was shown that in this problem solving among three main discussed algorithms GA has best convergence speed and PSO is most reliable in convergence. Some other important factors of algorithms ability such as number of searched points to reach optimum point and tolerance of convergence speed in various runs have been investigated in relay coordination problem.

REFRENCES

[1] So C. W. and Li K. K., “Overcurrent Relay Coordination by Evolutionary Programming”, Electric Power Systems Research, Vol.53, pp. 83-90, 2000.

[2] Dinesh Birla ,Rudra Prakash Maheshwari, Hari Om Gupta, “Time-Overcurrent Relay Coordination: A Review”, International Journal of Emerging Electric Power Systems, Vol.2, Issue 2, 2005.

[3] Urdaneta Alberto J., Nadira Raman and Perez Jimenej L. G., “Optimal Coordination of Directional Overcurrent Relay in Interconnected Power Systems”, IEEE Transactions on Power Delivery, Vol.-3, No.-3, pp. 903-911, July 1988.

[4] Urdaneta A. J., Resterpo H., Sanchez J. and Fajardo J., “Coordination of Directional Overcurrent Relays Timing using Linear Programming”, IEEE Transactions on Power Delivery, Vol.-11, No.-1, pp.122-129, January 1996.

[5] B. Chattopadhyay, M. S. Sachdev, and T. S. Sidhu, “An on-line relay coordination algorithm for adaptive protection using linear programming technique,” IEEE Trans. Power Delivery, vol. 11, pp. 165–173, Jan. 1996.

[6] H. A. Abyaneh and R. Keyhani, “Optimal co-ordination of overcurrent relays in power system by dual simplex method,” in Proc. Conf., vol. 3, Perth, Australia, pp. 440–445, AUPEC 1995.

[7] J. Kennedy and R. Eberhart, " Particle Swarm Optimization", Proc. of IEEE International Conference on Neural Networks, Vol. IV, pp.1942-1948, Perth, Australia, 1995.

[8] C. W. So, K. K. Li, K. T. Lai, and K. Y. Fung, “Application of genetic algorithm for overcurrent relay coordination,” Proc. IEE Conf. Developments in Power System Protection, pp. 66–69, 1997.

[9] So C. W. and Li K. K., “Time Coordination Method for Power System Protection by Evolutionary Algorithm”, IEEE Transactions on Industry Applications, Vol.36, No.-5, pp. 1235-1240, September-October 2000.

[10] So C. W. and Li K. K., “Intelligent Method For Protection Coordination”, IEEE International Conference Of Electric Utility Deregulation Restructuring and Power Technology, Hong Kong, Apr. 2004.

[11] F. Razavi, H. Askarian, M. Aldabbagh, R. Mohammadi ,”A new comprehensive genetic algorithm method for optimal overcurrent relays coordination”, Electr. Power Syst. Res. doi:10.1016/j.epsr.2007.05.013. (2007).

[12] R. L. Haupt, S. E. Haupt, “Practical Genetic Algorithms”, Second Edition, John Wiley & Sons, Inc., Publication, 2004.

[13] Lei, W.; Licheng, J,"The immune genetic algorithm and its convergence",Fourth International Conference on Signal Proc,98 ICSP, Volume 2, Page(s):1347 – 1350, Oct. 1998.