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Using Evolutionary Imperialist Competitive Algorithm (ICA) to Coordinate Overcurrent Relays

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Abstract—**This paper studies the ability of evolutionary Imperialist Competitive Algorithm (ICA) to coordinate overcurrent relays. Also, in order to show its greater power in optimization, the ICA is compared to the Genetic Algorithm (GA). For this purpose, the two algorithms are used to coordinate overcurrent relays, with the main optimization parameters being similar. The coordination of overcurrent relays by these two algorithms is implemented on a six-bus transmission system. More specifically, the algorithms were compared in terms of the mean convergence speed, mean convergence time, convergence reliability, and the tolerance of convergence speed in obtaining the absolute optimum point. This paper shows that at the first stage of optimization where getting close to the absolute optimum point is of importance the ICA is more powerful, while the GA shows greater power at the second stage where obtaining the exact absolute optimum point is the key question.**

Keywords- imperialist competitive algorithm, genetic algorithm, Power sytem protection, relay

I. INTRODUCTION (HEADING 1)

Accurate setting and coordination of overcurrent relays is vital for power systems. Researchers have described various methods of optimizing overcurrent relay settings [1]. Due to the complexity of the techniques used in nonlinear optimization, the traditional methods of optimizing overcurrent relays were usually performed through linear programming techniques, such as simplex [2, 3], two-phase simplex [4] and dual-simplex methods [1, 5]. It is difficult to solve the problem of coordinating protection relays, which is constrained by discrete optimization, through conventional optimization techniques [6]. Thanks to advances in the development of processors in recent years, optimization problems have made extensive use of various methods which are based on artificial intelligence and random search.

Of all intelligent algorithms, the Imperialist Competitive Algorithm (ICA), proposed by [7], leads to the best results in optimization. Algorithms such as Genetic Algorithm (GA), IGA, and PSO and their combinations have been repeatedly used in optimization problems. Also, the GA has been improved through various operations. In contrast, the potentiality of the young ICA has yet to be studied in its entirety.

A GA-based method for the optimization of the relay coordination [8] had two problems. One was lack of coordination and the other was that there was no solution for discrete Time Setting Multiplier (TSM) or Time Division Setting (TDS) [9]. The next algorithm used for this purpose was Evolutionary Algorithm, which had the same problems. However, its only advantage was that it made concrete the discrete TSM or TDS being made [6, 10, 11].

D. Birla et. Al. made some attempts to obtain additional constraints in coordinating directional overcurrent relays so that problems such as sympathy trips could be solved. The previous objective function was further improved which resulted in better coordination. In other words, lack of coordination for concrete and discrete TSM or TDS has been handled by introducing a new parameter and adding a new term to the existing objective function [9]..

In the method used in [10], relay coordination is optimized by Evolutionary GA. However, ICA is more preferable because of its fast operation. ICA starts with an initial population in which two sets of countries are included, colonies and imperialists. Each imperialist takes possession of some colonies to form an empire. Competition between the empires forms the basis of Evolutionary GA. During this competition, the weakest empire gives one colony to the most powerful empire. In the long run, a powerful empire is created whose imperialist shows the optimum point. Fig. 1 is the flowchart of this algorithm [7].

Here is a summary of the innovations in this paper:

- Solving the problem of relay coordination with evolutionary ICA.
- Comparing the operation of ICA with that of GA by considering the mean of convergence speed, mean of convergence time, convergence reliability, and the tolerance of convergence speed to reach the optimum point.
- Combining these two algorithms and proposing a new algorithm called ICA-GA capturing the best points of each algorithm.

- Providing a method to find the best point for switching from ICA to GA in combinational algorithm.
- Analyzing the operation of these algorithms by changing their initial population and countries.
- Analyzing the Imperialist Competitive Algorithm as a new method of producing population in evolutionary algorithms.
- Improving ICA by adding a new term to the formula used to determine the power of empires.
- Proposing a new method to determine the number of colonies possessed in any iteration of ICA.

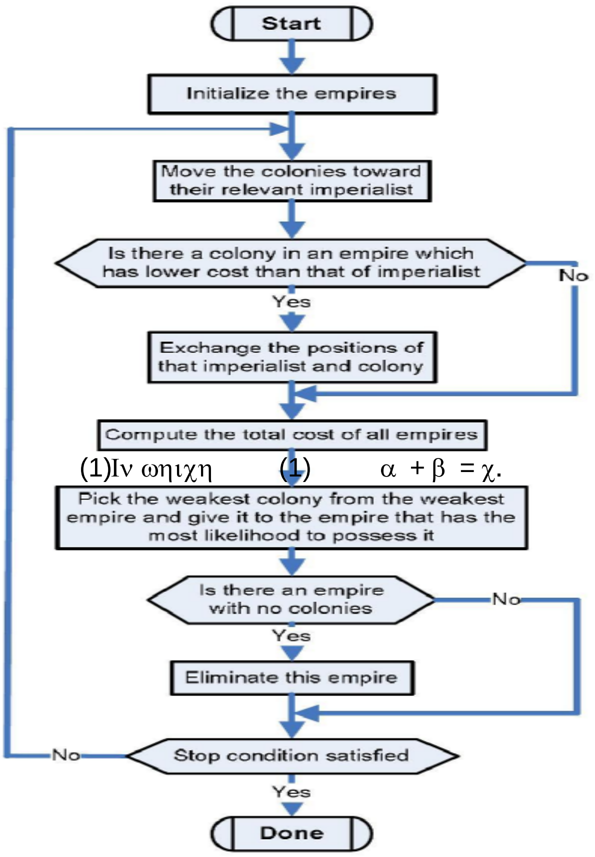

Fig. 1. Flowchart of Imperialist Competitive Algorithm

II. Comparison Theory

A. *Description of ICA as it relates to relay coordination*

The variables of relay coordination are TSM or TDS. So, the time setting of the relays is taken as a parameter to determine the power of a country in ICA. The initial population of the countries is created randomly. In order to create a country, a vector of random numbers is created in which the rows are equal in number to time settings and each arrays represents a time setting. In order to determine the power of each country, the value of its time settings is placed in the objective function. Afterwards, a number of powerful countries are selected as imperialists and the rest are called colonies of these imperialists. All the colonies are randomly divided among the imperialists. More powerful imperialists take possession of more colonies. An imperialist together with its colonies is called an empire. In each iteration, these colonies start moving toward their imperialist country. This movement is done in a special way which is the main character of this algorithm. Then, the power of each empire is calculated again and the most powerful empire takes control of a colony from the weakest empire. After a number of iterations, weak empires collapse and eventually there will be a single powerful empire whose imperialist arrays are those time settings which are used to optimize the objective function.

B. *Comparison factors*

The intelligent methods of GA and ICA are used in relay coordination. In this paper, convergence speed of algorithms is based on the number of iterations which any algorithm requires in order to obtain the absolute optimum point. Although convergence speeds are ranked, at the end of this paper, according to the length of time required to get the absolute optimum point, this factor depends on the program used. Accordingly, it is more advisable to base the ranking on the number of iterations.

Equation below determines the tolerance of convergence speed:

$$S = \frac{\sqrt{\frac{\sum_{i=1}^{N}\left(X_i - \overline{X}\right)^2}{N-1}}}{\overline{X}} \qquad (1)$$

In which

$$\overline{X} = \frac{\sum_{i=1}^{N}\left(X_i\right)}{N} \qquad (2)$$

where X_i is the convergence speed of any implementation, is the total number of implementations, and $\overline{X}$ is the mean of convergence speed in various implementations. In this paper, 40 iterations are done for each algorithm. The ratio of successful to unsuccessful implementation is called convergence reliability.

III. Test Results

A. *General discussion*

The main factors taken into consideration in the tests are as follows:

- The end point in both algorithms is obtaining the optimum point.
- In the ICA, the algorithm is stopped if there is no result after 15000 iterations. This happens in the GA algorithm after 15000 generations.

- The number of countries in ICA and the population size in GA is set to be 5000.
- For bigger iterations, absolute optimum point is proved (TABLE I) but in testing the algorithms, the problem is studied in following two states in order to have reasonable results for convergence reliability; The algorithm is regarded convergent when OF 2.8102 and the algorithm is regarded convergent when OF 2.8110.

TABLE I. OBTAINED RESULTS FOR TSMS IN ABSOLUTE OPTIMIZATION (OF=2.8101)

Relay Number	TSM Before Latest Rounding	Rounded TSM
TSM_1	0.0958	0.10
TSM_2	0.0765	0.08
TSM_3	0.1145	0.11
TSM_4	0.1404	0.14
TSM_5	0.1421	0.14
TSM_6	0.0715	0.07
TSM_7	0.1228	0.12
TSM_8	0.0538	0.05
TSM_9	0.1059	0.11
TSM_{10}	0.1086	0.11
TSM_{11}	0.0884	0.09
TSM_{12}	0.0500	0.05
TSM_{13}	0.0500	0.05
TSM_{14}	0.0751	0.08

B. Applied objective function

The objective function used here is proposed in [9].

$$OF = \alpha_1 \sum_{i=1}^{N} (t_i)^2 + \alpha_2 \sum_{k=1}^{P} \left(\Delta t_{mbk} - \beta\left(\Delta t_{mbk} - |\Delta t_{mbk}|\right)\right)^2 \quad (3)$$

where:

$\Delta t_{mbk} = t_{bk} - t_{mk} - CTI$

OF: Objective function

Δt_{mbk}: Operation time difference and coordination time interval for the kth pair relay

t_i: operation time of the i'th relay to close the breaking circuit of the i'th relay when a fault occurs

t_{bk} and t_{mk}: operation time of main and backup relays to close the breaking circuit of the main relay.

N: number of relays

P: number of P/B pairs

K: is used to represent each P/B pair and varies from 1 to P

i: is used to represent each relay and varies from 1 to N

CTI: is coordination time and can be set to be 0.3 or 0.4 depending on the accuracy of the system.

β: the parameter of lack of coordination

α_1 and α_2: used to determine the weight of the two terms.

C. The network under study

Fig. 2 illustrates the network studied in this paper. This network includes 7 lines, 6 buses and one transformer. The relays of this network are assumed to be of a normal inverse type and their specification is calculated from the relation below:

$$\frac{t}{TSM} = a_1 + \frac{a_2}{M-1} + \frac{a_3}{(M-1)^2} + \frac{a_4}{(M-1)^3} + \frac{a_5}{(M-1)^4} \quad (4)$$

where M is the ratio of the relay's current to the pickup's current. M is the ratio of the relay's current to the pickup's current. a_1, a_2, a_3, a_4, and a_5 are scalar values which identify the characteristics of modeled relay and are assumed as below:

$$\begin{cases} a_1 = 1.98772, a_2 = 8.57922 \\ a_3 = -0.46129, a_4 = 0.036446 \\ a_5 = -0.000319901 \end{cases} \quad (5)$$

The network data are presented in TABLE II to TABLE IV. R(pu) and X(pu) are per-unit values based on 100MVA and 150KV. The data of P/B relays are given in TABLE V. TSM relays are assumed to be discrete and vary between 0.05 and 1.3 at intervals of 0.01. The TSMs of the relay are first calculated as concrete and then are converted to discrete values.

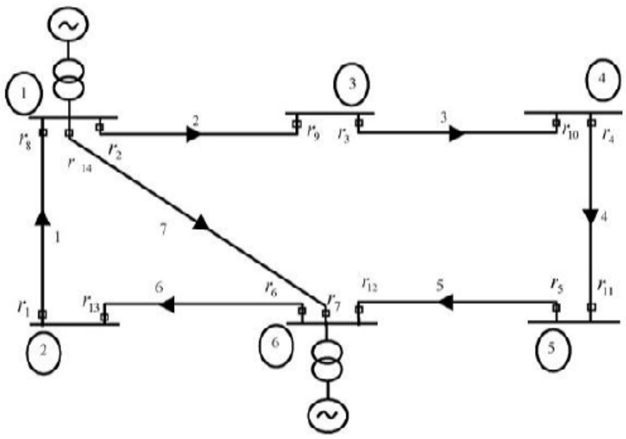

Fig. 2. Sample network

TABLE II. LINE INFORMATION

Line	*R* (pu)	*X* (pu)	*V* (kV)
1	0.0018	0.0222	150
2	0.0018	0.0222	150
3	0.0018	0.02	150
4	0.0022	0.02	150
5	0.0022	0.02	150
6	0.0018	0.02	150
7	0.0022	0.0222	150

TABLE III. GENERATOR INFORMATION

Generator	*R* (pu)	*X* (pu)	*V* (kV)
1	0.000001	0.1	10

TABLE IV. TRANSFORMATION INFORMATION

Transformer	*R* (pu)	*X* (pu)
1	0.000001	0.026666

TABLE V. P/B PAIR INFORMATION

Main Relay	Backup Relay	Primary Relay SC Current	Backup Relay SC 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	2234.3306	2234.3308
5	4	1352.8751	1352.8751
6	5	4695.0442	411.3675
6	14	4695.0442	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

IV. DISCUSSION

A. A comparison of convergence speed and other parameters in the two algorithms in obtaining the absolute optimum point 2.8102

This comparison is drawn in order to obtain the absolute optimum point 2.8102 and prove that ICA is more powerful than GA in achieving the absolute optimum point. The diagram for algorithm convergence for this network is given in Fig. 3. This diagram shows the objective function for the number of iterations. This figure shows the result of 40 implementations of both algorithms and selecting the nearest case to the mean of convergence speed calculated for these 40 implementations. In these implementations, the initial number of countries in ICA and corresponding initial population in GA is assumed to be 5000. ICA obtains the optimum point through 5683 iterations; GA through 6720 generations. This convergence diagram can be used to compare GA and ICA and to show the precedence of ICA.

Fig. 4 gives a schematic representation of convergence speed of the two algorithms in various implementations. The tolerance of convergence speed in ICA is not suitable to find the absolute optimum point. TABLE VI presents the mean of convergence speed, mean of convergence time, convergence speed reliability, and the tolerance of convergence speed for both algorithms in order to obtain the optimum point. As it is obvious in this table, there is not a significant difference between the two algorithms in terms of convergence time. However, this is not a suitable comparison factor due to different programming methods used in the two algorithms. If the optimum point is not obtained after more than 10000 iterations or generations, the algorithm will be regarded divergent. TABLE VII shows the optimum point obtained in this sample.

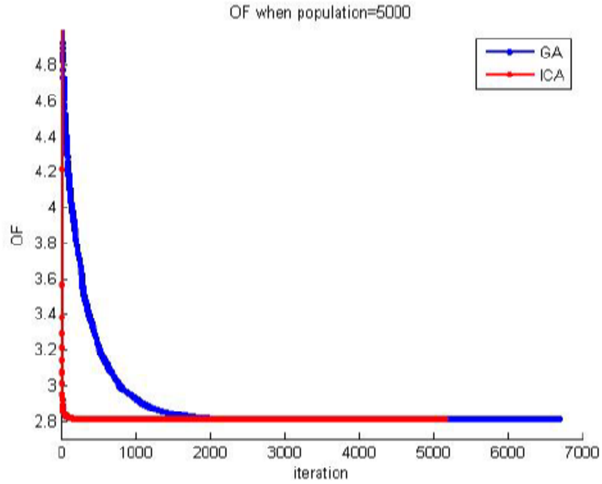

Fig. 3. Algorithm convergence in relay coordination (2.8102)

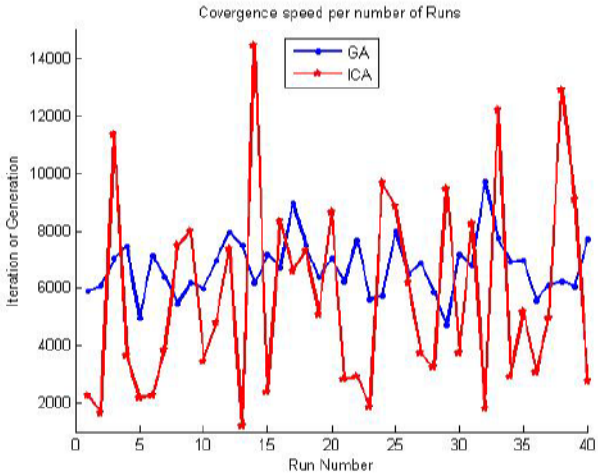

Fig. 4. Diagram of algorithm convergence speed (2.8102)

TABLE VI. OBTAINED RESULTS FOR OPTIMIZATION FROM 10 RUNS (OF=2.8102)

	ICA	GA
Mean Convergence Speed	5683	6720
Mean Convergence Time (Sec)	601	612
Convergence Speed Reliability	0.9	1
Convergence Speed Tolerance	61%	15%

TABLE VII. OBTAINED RESULTS FOR TSMS IN ABSOLUTE OPTIMIZATION (OF=2.8102)

Relay Number	TSM Before Latest Rounding		Rounded TSM
	ICA	*GA*	
1	0.0950	0.0965	0.10
2	0.0750	0.0771	0.07
3	0.1125	0.1152	0.11
4	0.1382	0.1411	0.14
5	0.1398	0.1430	0.14
6	0.0707	0.0720	0.07
7	0.1212	0.1233	0.12
8	0.0536	0.0540	0.05
9	0.1059	0.1063	0.11
10	0.1079	0.1089	0.11
11	0.0884	0.0886	0.09
12	0.0500	0.0500	0.05
13	0.0500	0.0501	0.05
14	0.0784	0.0756	0.07

Comparison of the two algorithms in obtaining the absolute optimum point is categorized below:

- Convergence speed in ICA is more than in GA.
- Consumed time for convergence in the two algorithms is approximately equivalent.
- The tolerance of convergence speed in GA is better than in ICA.
- Convergence speed reliability of GA is better than that of ICA.

B. A comparison of the two algorithms in terms of convergence speed and other parameters in obtaining the relative optimum point 2.8110

This comparison is drawn to find the relative optimum point 2.8110 in order to prove that ICA is much more powerful and its convergence reliability enhances. According to all considerations, this algorithm is the best option for real-time optimization. Fig. 5 is the diagram of algorithm convergence. This diagram illustrates the objective function according to the number of iterations, and is the result of implementing the two algorithms 40 times and then selecting the nearest case to the mean of convergence speed which is calculated from these 40 implementations. In these implementations, the initial number of countries in ICA and the initial population in GA is assumed to be 5000. GA obtains the optimum point through 2777 iterations; ICA through 455 iterations. Fig. 6 illustrates the convergence speed for the algorithms in various implementations. This figure shows that the mean convergence speed in ICA is lower than in GA but that the ICA's variation of convergence speed is comparable to the GA's in various implementations. TABLE VIII presents the mean convergence speed, mean convergence time, convergence speed reliability, and convergence speed tolerance of the two algorithms in finding the relative optimum point. Implementations that last for more than 3000 iterations or generations are assumed to be divergent. It can be seen that ICA is better than in GA in all respects except in the tolerance of convergence speed.

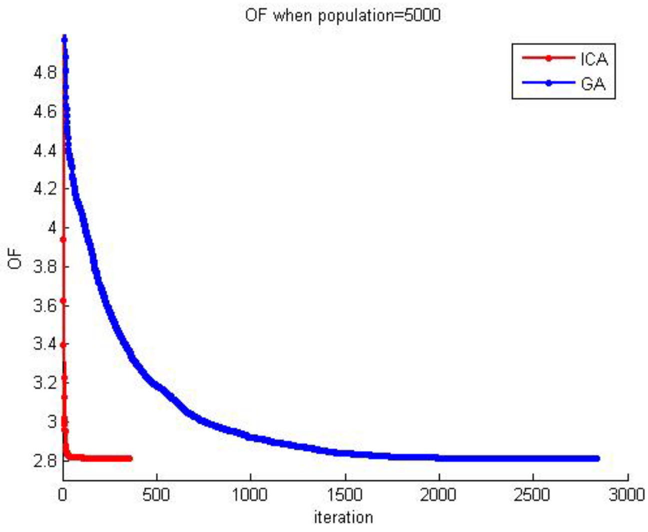

Fig. 5. Convergence diagram (2.8110)

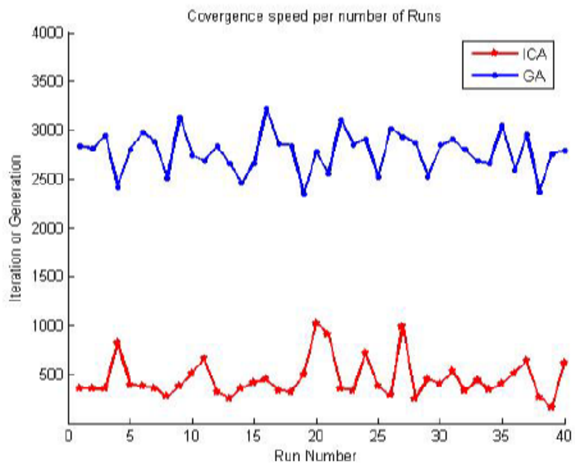

Fig. 6. Diagram of algorithm convergence speed (2.8110)

TABLE VIII. OBTAINED RESULTS FOR OPTIMIZATION FROM 10 RUNS (OF=2.8110)

	ICA	GA
Mean Convergence Speed	455	2777
Mean Convergence Time (Sec)	44	253
Convergence Speed Reliability	1	0.88
Convergence Speed Tolerance	44%	7%

V. CONCLUSION

In this paper, the two algorithms of ICA and GA were used to optimally coordinate overcurrent relays and the results were compared. The mean convergence speed, mean convergence time, convergence speed reliability, and the tolerance of convergence speed were analyzed and compared for the two algorithms. It was proved that ICA is much more powerful than GA in the first stage of optimization which is finding the approximate location of the optimum point. However, in the proximity of the optimum point, where the absolute optimum point should be accurately located, GA operates more powerfully. It was also proved that in the first stage of optimization, convergence speed, convergence time, and convergence reliability was better in ICA. It was also shown that the tolerance of convergence speed is better in GA than in ICA.

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