Application of Artificial Bees Colony Algorithm for Optimal Overcurrent Relay Coordination Problems

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ABSTRACT

This paper presents optimal coordination of overcurrent relays by using artificial bees colony algorithm. The objective function of the relay coordination problem is to minimize the operation time of associated relays in the systems. The control variables used in this paper are the pickup current and time dial setting of relays. The proposed method was tested with four systems study consists 5-bus, 6-bus, 9-bus and 14-bus. Quasi-Newton (BFGS), particle swarm optimization (PSO) and artificial bees colony (ABC) are employed to evaluate the search performance. For test, there are study test power system was used. The simulation results showed that the artificial bees colony algorithm is capable to minimize the operation time of relays in the entire system. As a result, all search algorithms can solve optimal coordination relay which the artificial bees colony (ABC) gives the best solutions for coordination relay setting.

Keywords: Optimal Coordination, Time Dial Setting, Time Grand Margin

1. INTRODUCTION

Short-circuit conditions can occur unexpectedly in any part of a power system at any time due to various physical problems. Such situations cause a large amount of fault current flowing through some power system apparatus. The occurrence of the fault is harmful and must be isolated promptly by a set of protective devices. Over several decades, protective relaying has become the brain of power system protection [1]. Its basic function is to monitor abnormal operations as a "fault sensor" and the relay will open a contractor to separate a faulty part from the other parts of the network if there exists a fault event. To date, power transmission and distribution systems are bulky and complicated. These lead to the need for a large number of protective relays cooperating with one another to assure the secure and reliable operation of a whole. There-fore, each protective device is designed to perform its action dependent upon a so-called "zone of protection" [2]. From this principle, no protective relay is operated by any fault outside the zone if the system is well designed. As widely known that old fashion analog relays are inaccurate and difficult to establish the coordination among protective relays, the relay setting is typically conducted based on the experience of an expert or only a simple heuristic algorithm. However, with the advancement of digital technologies, a modern digital protective relay is more efficient and flexible to enable the fine adjustment of the time-dial setting (TDS) different to that of the old fashion electromagnetic one.

This paper proposes an intelligent relay coordination method based on one of the most widely used intelligent search algorithms, called artificial bees colony (ABC) [3,4], for digital relaying, in which the time-dial setting is appropriately adjusted in order to minimize operating time while coordinated relays are also reliable. In this paper, the coordination of digital relaying systems is explained in Section II in such a way that the artificial bees colony (ABC) method in Section III is employed to achieve the system objective. A case study are include 5-bus, 6-bus, 9-bus and 14-bus power system protection, where setting of twelve digital over-current relays was challenged, was discussed in Section IV. The last section provides the conclusions of artificial bees colony algorithm.

2. OPTIMAL RELAY COORDINATION PROBLEMS

Overcurrent relays are devices which have ability to interrupt electricity supply service due to some severe fault. In a modern electrical power system, network interconnection is very complicated. This affects the difficulty of key parameter setting of protective relaying devices [5]. When a total number of overcurrent relays to be coordinated is increased or even feeding in closed-loop configuration is required according to a complex transmission network, overcurrent relay coordination setting is more difficult.

An overcurrent relay is a typical protective relay that allows a protected load operating within a pre-

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set value of the load current. The overcurrent relay is placed at the secondary side of the current transformer. The operating time of the overcurrent relay can vary due to relay type, time-dial setting (TDS) and magnitude of fault currents. For the inverse time overcurrent relay which corresponds to the ANSI device number of 51, the operating time of the overcurrent relay can be expressed as shown in (1) according to the IEC standard 255-4 [6].

$$t = \frac{\beta \times TDS}{PSM^{\alpha} - 1} \tag{1}$$

$$PSM = \frac{I_{act}}{I_{PICKUP}} \tag{2}$$

Where

α and β are arbitrary constant

PSM is the plug setting multiplier

I_{PICKUP} is the pickup current of the relay

I_{act} is the actual current seen by the relay

α and β are constant. In this paper, a type of very inverse time overcurrent relay is used. Therefore, α is 1.0 and β is 13.5 can be specified according to the IEC standard.

A) Primary and Backup Relay Constraints

A primary or main protective device is a relay that is in the nearest position to the fault and must respond to the fault as fast as possible. To achieve a reliable protection system backup, relays are devices which will be initiated within a certain amount of time after the main relay fails to break the fault. An amount of delay time, called time grading margin, must be added to the main relay operating time. This can be explained by Fig. 1 [7]. Relay m and b are the main and the backup relays, respectively. F_1 and F_2 are two fault cases seen by both relays. The operating time of the backup relay must be at least the operating time of the main relay plus the time grading margin for every fault case.

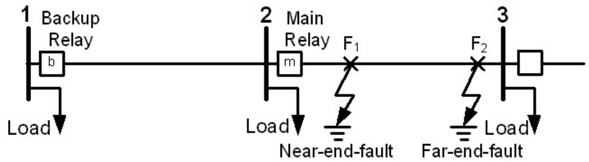

Fig.1: *Simple feeder for overcurrent protection*

To generalize the backup relaying constraint, (3) is defined as follows.

$$\Delta t_{mb} = t_b(F_i) - t_m(F_i) - TGM \geq 0, i \in FC \tag{3}$$

Where

$t_b(F_i)$ is the operating time of the backup relay due to Fault F_i

$t_m(F_i)$ is the operating time of the main relay due to Fault F_i

TGM is the time grading margin, 0.3 - 0.5 s

FC denotes a set of fault cases

B) Objective function To coordinate the protective relaying devices, the operating time of the main relay is minimized. As mentioned in the previous subsection, the operating time of the backup relay is set as inequality constraints. The objective function [8] used in this paper is given as follows.

$$f = w_1 \sum_{i=1}^{n} t_i^2 + w_2 \sum_{j \in FC} [\Delta t_{mb} - w_3(\Delta t_{mb} - |\Delta t_{mb}|)]^2 \tag{4}$$

Where

w_1, w_2, w_3 is the weighting factors

n is a total number of relays

C) Bounds on relay and operation times

$$TDS_{ij} \min \leq TDS_{ij} \leq TDS_{ij} \max$$
$$Ip_{ij} \min \leq Ip_{ij} \leq Ip_{ij} \max$$
$$t_{ijk} \min \leq t_{ijk} \leq t_{ijk} \max$$

3. ARTIFICIAL BEES COLONY ALGORITHM

Artificial Bees Colony algorithm [9,10,11] was proposed by Karaboga for solving numerical optimization problems. It simulates the intelligent behavior of honey bee swarms. In artificial bees algorithm, the colony of artificial bees contains three groups of bees: employed bees, and unemployed bees: onlookers and scouts. First half of the colony consists of employed artificial bees and the second half constitutes the artificial onlookers. The employed bee whose food source has been exhausted becomes a scout bee. The position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality or fitness of the associated solution. The number of the employed bees is equal to the number of food sources, each of which also represents a site, being exploited at the moment or to the number of solutions in the population. In artificial bees algorithm, the steps given below are repeated until a stopping criteria is satisfied. The flow chart of artificial bee colony algorithm as shown in figure 2 [12].

1)Initial phase

Initial population of artificial bee swarms is created randomly by the following formula.

$$X_{ij} = X_{minj} + rand(0,1) \times (X_{maxj} - X_{minj}) \tag{5}$$

2) Employed bees phase

Each employed bee determines a food source representing a site. Each employed bee shares its food source information with onlookers waiting in the hive and then each onlooker selects a food source site depending on the information taken from employed bees. To simulate the information sharing by employed bees in the dance area, probability values are calculated for the solutions by means of their fitness values using the following equation. The fitness values might be calculated using the above definition as expressed in (7).

$$Pf_j = \frac{f_{iti}}{\sum_{j=1}^{n} f_{iti}} \tag{6}$$

$$f_{iti} = \begin{cases} \frac{1}{1+f_i} & , f_i \geq 0 \\ 1 + abs(f_i) & , f_i < 0 \end{cases} \tag{7}$$

3) Onlooker bees phase

Onlookers are placed onto the food source sites by using a fitness based selection technique, for example roulette wheel selection method.

4) Scout bees phase

Every bee swarm has scouts that are the swarm's explorers. The explorers do not have any guidance while looking for food. In case of artificial bees, the artificial scouts might have the fast discovery of the group of feasible solutions. In the searching algorithm, the artificial employed bee whose food source nectar has been exhausted or the profitability of the food source drops under a certain threshold level is selected and classified as the artificial scout. The classification is controlled by "abandonment criteria" or "limit". If a solution representing a food source position is not improved until a predetermined number of trials, then that solution is abandoned by its employed bee and the employed bee becomes a scout.

4. SIMULATION RESULTS

This section verifies the proposed algorithm for relay coordination. The objective is to minimize the different operating time between the primary and backup relays. The time grading margin is assumed to be 0.3 s. TDS is in the range of 0.05-1.0 for all backup-primary relay pairs. The test systems used for this study are the 5-bus, 6-bus, WSCC 9-bus and IEEE 14-bus test systems. Weighting factors for optimal relay coordination relay to verify the effectiveness of the proposed artificial bees colony (ABC) are set as follows: $w_1 = 1$, $w_2 = 100$ and $w_3 = 100$. For comparison, Quasi-Newton with BFGS updating formula, particle swarm optimization (PSO) and artificial bees colony (ABC) were used. A total of 30 trials was conducted for each test case. Minimum, average, maximum and standard deviation of 30 trial solutions were evaluated. All test cases were simulated by using the same computer which is an Intel®, Core 2 Duo, 2.4 GHz, 3.0 GB RAM. The followings are summary of each test case.

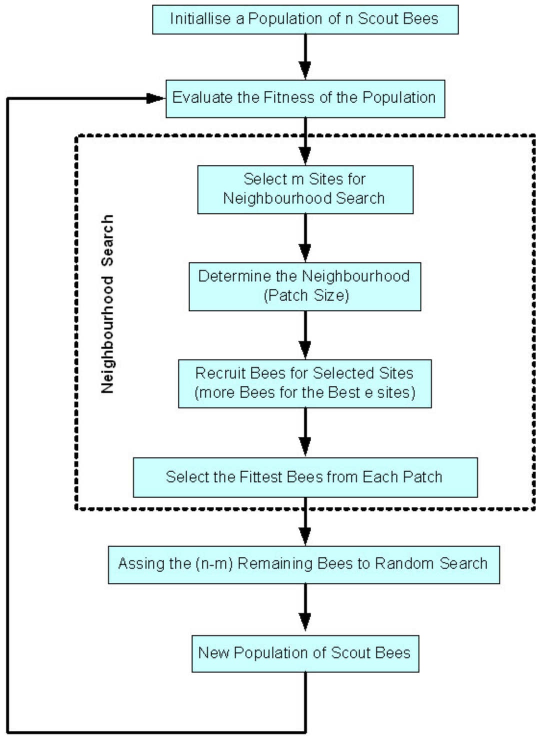

Fig.2: *Flowchart of the Artificial Bees Colony Algorithm*

Case I. The proposed method was tested with the 5-bus test system as shown in figure 3 [13]. Assume that loads were connected across bus 2, 3, 4 and 5 as 20+j10 MVA, 20+j15 MVA, 50+j30 MVA and 60+j40 MVA, respectively. The 14 over-current relays of the very inverse time type were used in this system. The zone protection and short circuit current of primary and back-up relay were shown in Table 2.

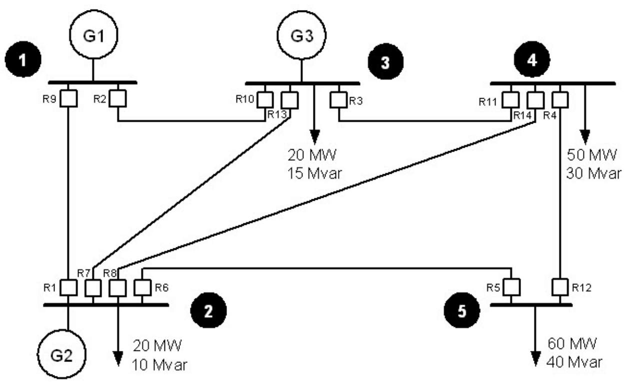

Fig.3: *The 5 bus test system*

The results of time dial settings and pickup current setting of over-current relays for the system were shown in Table 3. The results in Table 1 revealed the optimal value of objective function. It gave the best result when compared with those obtained from Quasi-Newton and particle swarm optimization.

Table 1: *Computational results for the 5-bus test system.*

Method	Objective function (sec)				CPU time(s)
	Min.	Average.	Max	SD	
BFGS	3.7801	62.6515	329.2785	72.300	0.2355
PSO	3.4379	6.3730	12.5700	3.6784	10.500
ABC	*2.6748*	*2.7430*	*2.8336*	*0.0705*	*1.9491*

Table 2: *Primary and backup information for the 5-bus test system.*

Fault BUS	Main Relay	Backup Relay	Primary SC current	Secondary SC current	Line
1 Gen1	9	10	7248.27	2576.53	1-3
	2	1	7773.89	7160.60	1-2
2 Gen 2	1	13	7248.27	1060.68	2-3
	1	14	7248.27	848.55	2-4
	1	5	7248.27	424.27	2-5
	7	14	8631.34	1415.92	2-4
	7	5	8631.34	707.96	2-5
	8	13	8993.04	1777.33	2-3
	8	5	8993.04	703.93	2-5
	6	13	9754.76	1797.38	2-3
	6	14	9754.76	1433.23	2-4
3 Gen 3	10	7	7773.89	1021.89	3-2
	10	11	7773.89	1226.26	3-4
	13	2	8631.34	942.46	3-1
	13	11	8631.34	2123.88	3-4
	3	2	8152.82	1273.79	3-1
	3	7	8152.82	1912.94	3-2
4	11	8	6962.53	6962.53	4-2
	4	3	1170.96	1170.96	4-3
	14	5	2341.92	2341.92	4-5
5	12	6	3540.91	3540.91	5-4
	5	4	6814.41	6814.41	5-2

Table 3: *Optimal time dial setting and pick-up current for the 5-bus system*

Relay	Time Dial Setting (TDS)			Pick-up Current (Ip)		
	BFGS	PSO	ABC	BFGS	PSO	ABC
R1	0.2468	0.5149	0.5017	7.9050	6.9470	6.1861
R2	0.5273	0.2909	0.5544	9.0955	8.4028	3.9600
R3	0.4971	0.4260	0.5284	4.4100	5.1351	3.6480
R4	0.2073	0.1368	0.2893	6.0972	6.1382	7.4495
R5	0.9958	0.3034	1.0000	6.3976	3.6279	3.5440
R6	0.5856	0.7910	0.6896	8.3134	4.7262	3.6931
R7	0.2661	0.1952	0.4383	7.4225	6.0573	6.8597
R8	0.2251	0.6618	0.6379	9.9419	10.4542	12.0000
R9	0.4364	0.3052	0.4520	8.8191	5.0916	5.0820
R10	0.0843	0.1464	0.1200	10.5426	8.8706	7.5763
R11	0.9224	0.2028	1.0000	5.3186	3.8624	3.6480
R12	0.1777	0.2449	0.4111	7.8515	6.7461	5.4659
R13	0.1298	0.2581	0.1743	9.9183	4.5315	4.7384
R14	0.2691	0.4790	0.3083	11.4706	6.6380	4.5550

The minimum operation time acquired were 3.7801 s, 3.4379 s and 2.6748 s for quasi-Newton, particle swarm and artificial bees colony, respectively. When considering the average operation time, the artificial bees colony gave the least average operation time of 2.7430 s. The standard deviations of artificial bees colony (ABC) was as small as 0.0705 s.

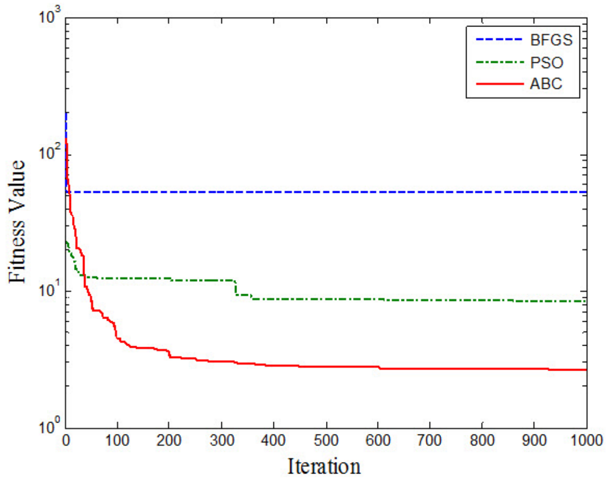

Fig.4: *Evolution of fitness value for 5 bus test system.*

Figure 4 showed the convergence properties among the proposed method and the others. It illustrated the comparative convergence performance of the objective functions. Remarkably, although artificial bees colony method convergences rapidly towards the solution, it exhibits relatively smallest standard deviation.

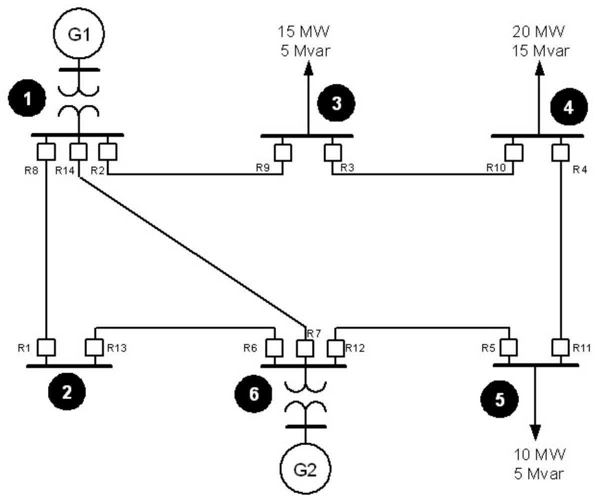

Fig.5: *The 6 bus test system*

<u>*CaseII*</u>. The proposed method was tested with the 6-bus system as shown in figure 5 [14-15]. Assume that loads were connected across bus 3, 4 and 5 as 15+j5 MVA, 20+j15 MVA and 10+j5 MVA respectively. The over-current relays of the very inverse

time type were used. Information of this test case was shown in Table 4.

Table 4: *Primary and backup information for the 6-bus test system*

Fault BUS	Main Relay	Backup Relay	Primary SC current	Secondary SC current	Line
1 (Gen1)	8	9	4961.85	410.84	1-3
	8	7	4961.85	1520.96	1-6
	2	7	5362.40	1528.13	1-6
	2	1	5362.40	804.91	1-2
	14	1	4232.78	811.00	1-2
	14	9	4232.78	415.90	1-3
2	1	6	2702.58	2702.58	2-6
	13	8	2508.30	2508.30	2-1
3	9	10	1453.21	1453.21	3-4
	3	2	3347.84	3347.84	3-1
4	4	3	2243.81	2243.81	4-3
	10	11	2244.37	2244.37	4-5
5	5	4	1361.52	1361.52	5-4
	11	12	3494.81	3494.81	5-6
6 (Gen2)	6	5	4965.19	411.37	6-5
	6	14	4965.19	1522.91	6-1
	12	14	5365.20	1529.36	6-1
	12	13	5365.20	805.56	6-2
	7	5	4232.78	407.25	6-5

Table 5: *Optimal time dial setting and pick-up current for the 6-bus system*

Relay	Time Dial Setting (TDS)			Pick-up Current (Ip)		
	BFGS	PSO	ABC	BFGS	PSO	ABC
R1	0.9974	0.5969	0.6629	6.2635	12.1536	10.9097
R2	0.2222	0.3447	0.4522	10.3231	7.2907	5.5882
R3	0.8009	0.3133	0.4340	3.3738	7.7525	5.7331
R4	0.4626	0.5105	0.6019	7.9332	7.1947	6.1680
R5	0.4699	0.4848	0.3577	8.3015	8.1199	10.5489
R6	0.1738	0.2066	0.5124	9.7362	8.3626	3.5918
R7	0.1034	0.0642	0.0789	3.0211	4.2341	3.6764
R8	0.1441	0.2845	0.1513	11.4539	6.2068	10.9319
R9	0.7177	0.6654	0.5707	6.9412	7.4374	8.5034
R10	0.3568	0.7662	0.4784	10.8834	5.3846	8.3360
R11	0.6338	0.5096	0.2689	5.4808	6.5989	11.7740
R12	0.5737	0.6136	0.4103	4.0510	3.8102	5.6344
R13	0.8315	0.6560	0.7858	8.2878	10.3181	8.7349
R14	0.5433	0.2967	0.2598	4.1946	7.1038	8.0640

Table 6: *Computational results for the 6-bus test system.*

Method	Objective function (sec)				CPU time(s)
	Min.	Average.	Max	SD	
BFGS	1.0827	54.9455	255.7974	62.6153	0.3222
PSO	1.0805	1.2174	2.0781	0.2068	69.9275
ABC	*1.0724*	*1.0725*	*1.0727*	*0.000142*	*1.9089*

The results of the optimal setting value for 14 over-current relays of the 6-bus test system were presented in Tables 5 - 6. The optimal values of the objective function, the minimum operation time, were 1.0827 s, 1.0805 s and 1.0724 s for quasi-Newton, particle swarm and artificial bees colony, respectively. From this test, the artificial bee colony exhibited the least average operation time and also standard deviation at 1.0725 s and 0.000142 s, respectively. This revealed that the ABC method is the most efficient method among these three methods for solving the optimal relay coordination problem. Figure 6 showed the convergences among the proposed method and the other two methods. Remarkably, although artificial bees colony method convergences rapidly towards the solution, it exhibits relatively smallest standard deviation.

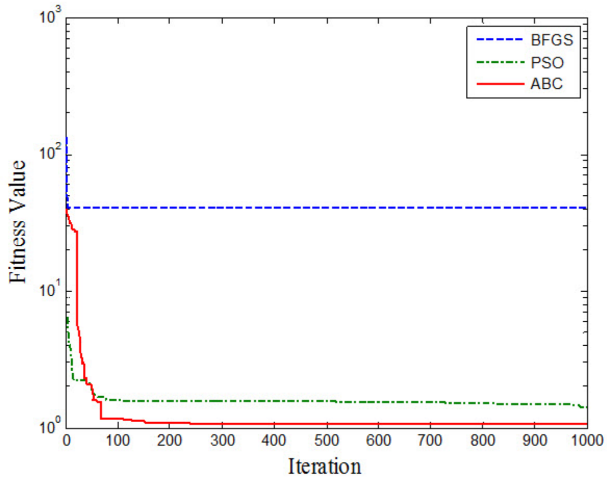

Fig.6: *Convergence for the 6-bus test system.*

<u>*CaseIII*</u>. This paper employed the WSCC 9-bus test system as shown in figure 7. It consisted of 3 generators, 6 lines, 3 transformers and 12 over-current relays. The load are connected across bus 5, 7 and 9 as 20+j15 MVA, 50+j30 MVA and 20+j10 MVA, respectively. The optimal solutions obtained for this test case were given in Table 7 [16-18]. Information of the zone protection and short-circuit current of primary and back-up relays were shown in Table 8.

Table 7: *Computational results for WSCC 9 bus test system.*

Method	Objective function (sec)				CPU time(s)
	Min.	Average.	Max	SD	
BFGS	0.3589	15.6982	358.0720	64.8504	1.4877
PSO	0.7959	5.2780	11.6640	2.6800	7.0128
ABC	*0.4359*	*0.4515*	*0.4650*	*0.0089*	*1.2654*

The results showed the optimal setting value of the relay coordination time for the WSCC 9-bus test system. The ABC method gave the best results when compared with those obtained from quasi-Newton and particle swarm optimization. The average op-

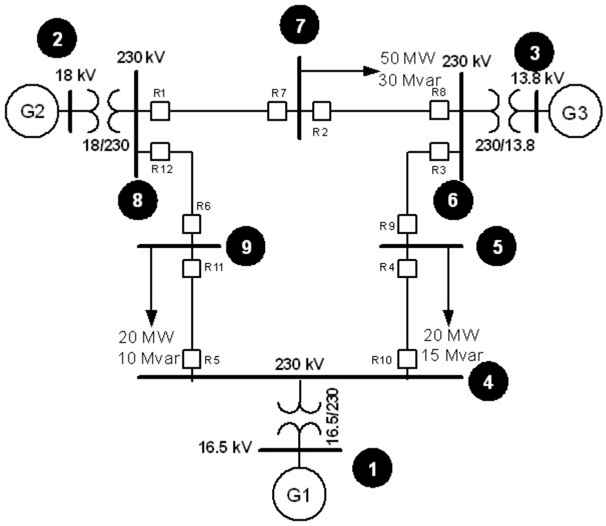

Fig.7: *WSCC 9 bus test system*

Table 9: *Optimal time dial setting and pick-up current for the WSCC 9-bus test system*

Relay	Time Dial Setting (TDS)			Pick-up Current (Ip)		
	BFGS	PSO	ABC	BFGS	PSO	ABC
R1	0.0510	0.0529	0.0500	4.0252	6.7526	4.0252
R2	0.0500	0.0633	0.0500	5.0029	3.9334	5.7186
R3	0.4228	0.1276	0.4653	3.7542	8.3976	4.9564
R4	0.0537	0.1815	0.0500	4.5062	2.3994	5.0689
R5	0.1449	0.4968	0.2664	1.4225	6.7444	8.1072
R6	0.0506	0.0591	0.0500	3.2858	3.4401	3.2835
R7	0.0564	0.0978	0.0500	4.9314	4.2067	5.7677
R8	0.0500	0.1093	0.0500	4.5983	5.5715	2.4960
R9	0.0500	0.1103	0.0500	7.8188	5.5220	6.5437
R10	0.0874	0.0616	0.2038	7.5040	6.0308	3.8362
R11	0.0616	0.1064	0.0887	6.7397	4.6002	5.6487
R12	0.0531	0.2446	0.1704	7.7758	3.6853	3.3254

Table 8: *Primary and backup information for the WSCC 9-bus test system*

Fault BUS	Main Relay	Backup Relay	Primary SC current	Secondary SC current	Line
4 (Gen 1)	5	4	8204.39	3076.08	4-5
	10	11	8296.05	3182.82	4-9
5	4	3	7028.55	7028.55	5-6
	9	10	8274.09	8274.09	5-4
6 (Gen 3)	8	9	8075.53	2178.60	6-5
	3	2	8234.69	1978.90	6-7
7	7	12	8098.53	8098.53	7-8
	2	3	7296.58	7296.58	7-6
8 (Gen 2)	1	6	9749.44	4513.97	8-9
	12	7	10875.63	5633.89	8-7
9	11	12	7136.62	7136.62	9-8
	6	5	8183.53	8183.53	9-4

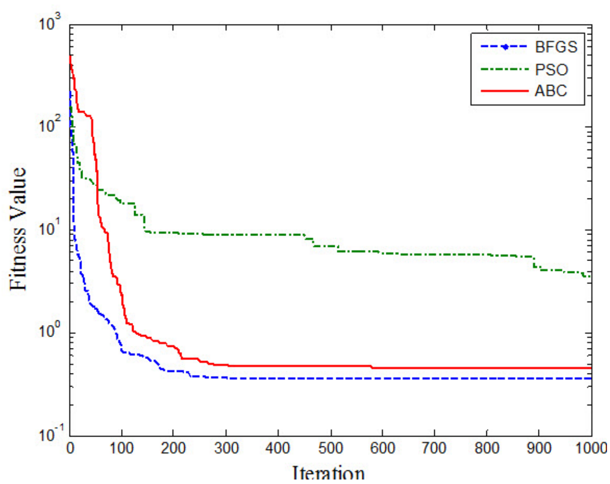

Fig.8: *Evolution of fitness value for WSCC 9 bus test system.*

eration times were 15.6982 s, 5.2780 s and 0.4515 s for quasi-Newton, particle swarm and artificial bees colony, respectively. The artificial bees colony gave the least CPU time consumed when compared with those of other methods.

Figure 8 illustrated the convergence performance of objective function. Remarkably, although quasi-Newton method convergences rapidly towards the solution, it exhibits relatively large standard deviation. In addition, the artificial bees colony (ABC) gave the accurate and fast convergence.

CaseIV. This case considered the IEEE14-bus test system as shown in figure 9. This test system consisted of two subsystems, 69-kV sub-transmission and 13.8-kV distribution. These two sub-transmissions were connected through the 69/13.8 kV transformers. The optimal results obtained by all three methods were put in Table 10 - 13. The system consisted of 30 over-current relays. Information of this test system was shown in Table 14 - 15 [19].

For the sub-transmission, the minimum operation times of this test case were 2.4741 s, 28.6930 s and 3.9024 s for quasi-Newton, particle swarm and artificial bees colony, respectively. However, when considering the average operation time, the artificial bee colony gave the least operation time at 3.9114 s with standard deviations as small as 0.0103 s (see also Table 10).

For the distribution, the minimum operation times of this test case were 4.8582 s, 18.7067 s and 9.2999 s for quasi-Newton, particle swarm and artificial bees colony, respectively. However, when considering the average operation time, the artificial bee colony gave the least operation time at 9.3146 s with standard deviations as small as 0.0092 s (see also Table 11).

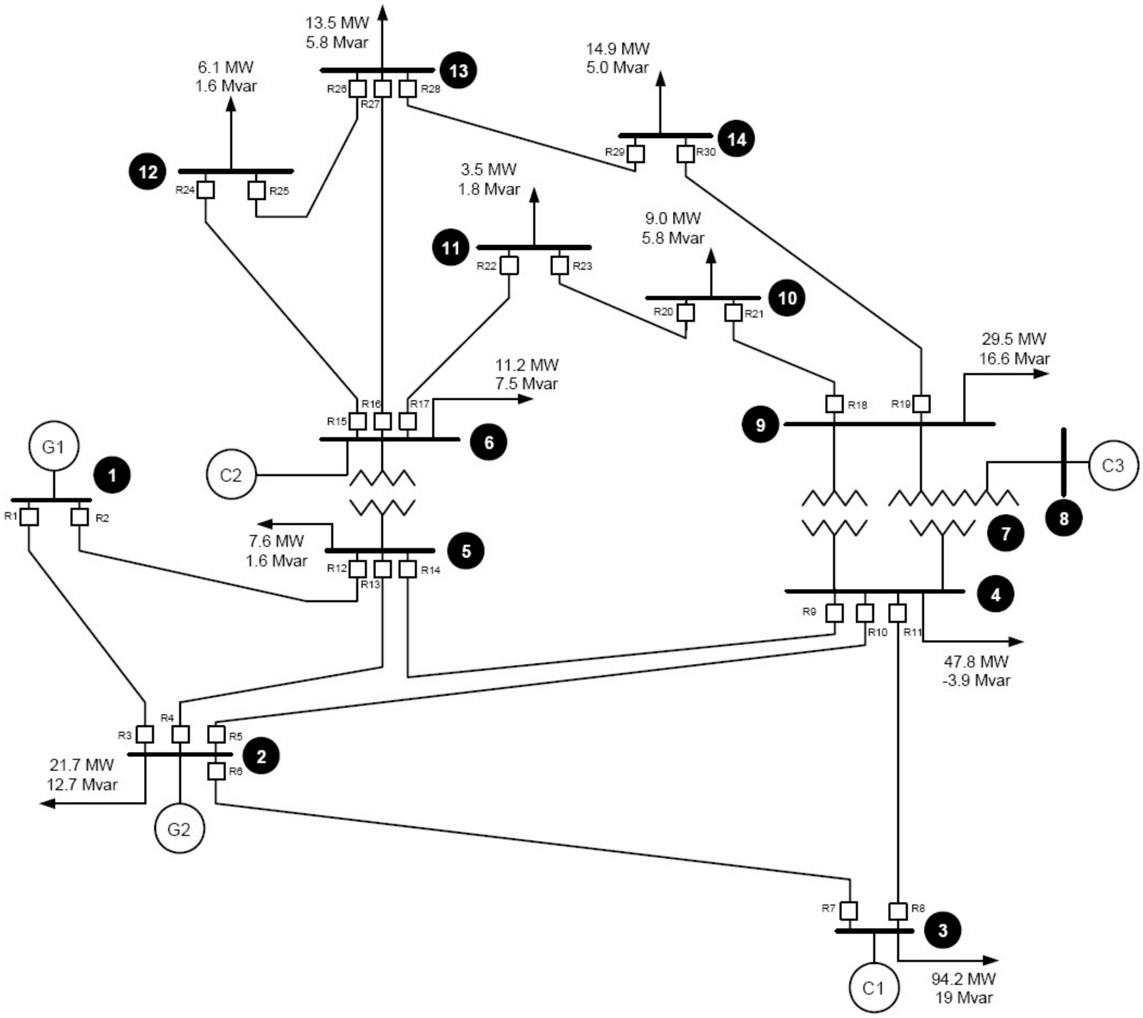

Fig.9: *IEEE 14-bus test system*

Table 10: *Optimal results for the IEEE 14-bus test system (sub-transmission side)*

Method	Objective function (sec)				CPU time(s)
	Min.	Average.	Max	SD	
BFGS	2.4741	27.9928	118.5417	50.8337	6.0696
PSO	28.6930	43.1894	60.8138	16.1312	12.1442
ABC	*3.9024*	*3.9114*	*3.9253*	*0.0103*	*2.0630*

Table 11: *Optimal results for the IEEE 14-bus test system (distribution side)*

Method	Objective function (sec)				CPU time(s)
	Min.	Average.	Max	SD	
BFGS	4.8582	5.2247	6.2516	0.5821	2.7330
PSO	18.7067	27.3693	36.8830	8.7906	12.7359
ABC	*9.2999*	*9.3146*	*9.3232*	*0.0092*	*2.1445*

Table 12: *Optimal settings for the IEEE 14-bus test system (sub-transmission side)*

Relay	Time Dial Setting (TDS)			Pick-up Current (Ip)		
	BFGS	PSO	ABC	BFGS	PSO	ABC
R1	0.0505	0.3863	0.0500	4.7370	9.1755	3.9060
R2	0.0545	0.6382	0.0500	3.7478	6.9652	3.7440
R3	0.0500	0.2132	0.0569	7.2877	8.1256	5.0022
R4	0.1894	0.7797	0.2709	6.4680	7.9899	4.1890
R5	0.1035	0.3047	0.1370	9.5232	11.6311	5.7589
R6	0.0500	0.0500	0.0500	11.9997	8.3813	12.0000
R7	0.0760	0.8429	0.0500	6.6899	7.3617	4.5890
R8	0.0770	0.2782	0.0500	10.1156	9.6583	4.1430
R9	0.0500	0.5130	0.0565	7.9446	3.9933	4.3084
R10	0.0567	0.3289	0.0500	4.6650	5.6900	5.0856
R11	0.0500	0.2824	0.0500	4.5347	4.5150	4.1430
R12	0.0500	0.0616	0.0500	3.7814	4.6007	3.7440
R13	0.0499	0.2994	0.0500	7.3780	4.7717	6.9209
R14	0.0500	0.0839	0.0771	6.6495	11.5116	3.9120

Table 13: *Optimal settings for the IEEE 14-bus test system (distribution side)*

Relay	Time Dial Setting (TDS)			Pick-up Current (Ip)		
	BFGS	PSO	ABC	BFGS	PSO	ABC
R15	0.0500	0.1395	0.0822	8.3157	9.2617	5.4393
R16	0.0500	0.0501	0.0500	11.997	10.678	12.0000
R17	0.1219	0.5955	0.0500	5.4330	5.9484	12.0000
R18	0.4121	0.7376	0.3316	6.6078	7.1155	8.5621
R19	0.1196	0.6273	0.1749	10.085	6.9045	7.5920
R20	0.0888	0.1755	0.0611	4.6467	5.9589	5.5453
R21	0.0699	0.3275	0.1745	10.150	6.9914	5.0515
R22	0.0500	0.4898	0.0500	5.3064	7.2980	4.0101
R23	0.0890	0.2918	0.0903	5.7198	6.5130	6.2055
R24	0.0643	0.6326	0.1126	8.8098	10.391	7.4784
R25	0.0540	0.5098	0.0500	10.149	10.317	4.1460
R26	0.1029	0.6767	0.1125	11.402	8.2657	12.0000
R27	0.0500	0.0502	0.0500	9.8218	7.9989	11.0836
R28	0.0694	0.0505	0.0777	7.9831	10.538	7.7493
R29	0.1349	0.8571	0.2814	9.8867	5.2955	6.3700
R30	0.0549	0.5279	0.0703	6.4432	4.7875	5.5754

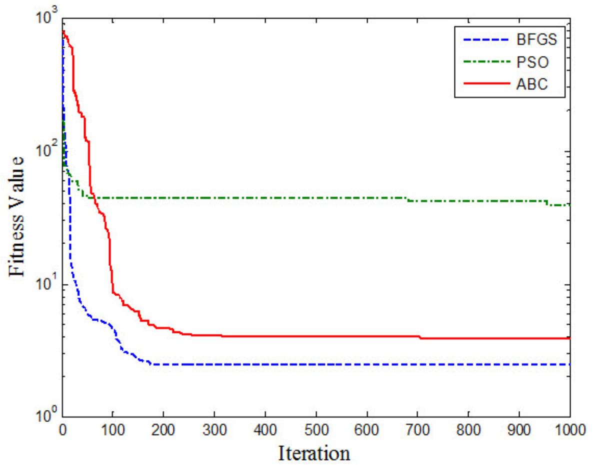

Fig.10: *Convergences for the IEEE 14-bus test system (sub-transmission side)*

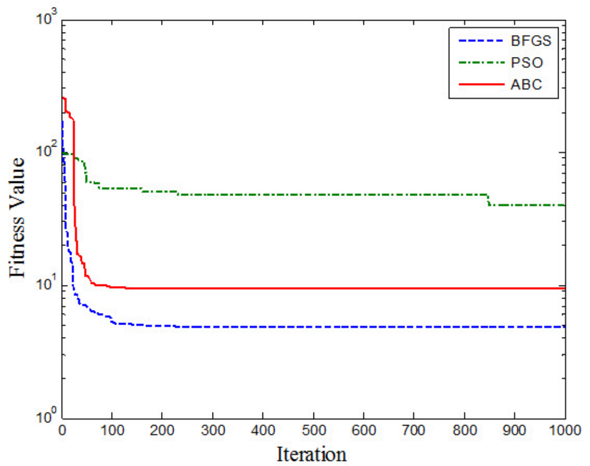

Fig.11: *Convergences for the IEEE 14-bus test system (distribution side)*

Table 14: *Primary and backup information for the IEEE 14-bus test system (sub-transmission side)*

Fault BUS	Main Relay	Backup Relay	Primary SC current	Secondary SC current	Line
1 (Gen1)	1	12	14,689.85	2,186.84	1-2
	2	3	19,415.45	7,376.35	1-5
2	3	7	14,689.85	1,162.20	2-1
	3	10	14,689.85	488.30	
	3	13	14,689.85	232.41	
	6	1	22,264.66	6,345.65	2-4
	6	10	22,264.66	1,990.35	
	6	13	22,264.66	1,935.10	
	5	1	23,003.82	6,362.65	2-4
	5	7	23,003.82	2,716.67	
	5	13	23,003.82	1,908.22	
	4	1	23,069.35	6,357.32	2-5
	4	7	23,069.35	2,722.79	
	4	10	23,069.35	1,969.74	
3	7	11	22,264.66	949.19	3-2
	8	6	11,325.47	580.43	3-4
4	9	5	3,192.71	3,192.71	4-2
	10	14	5,467.79	5,467.79	4-5
5	13	2	2,831.07	2,831.07	5-1
	14	4	3,293.31	3,293.31	5-2
	13	9	5,852.46	5,852.46	5-4

Table 15: *Primary and backup information for the IEEE 14-bus test system (distribution side)*

Fault BUS	Main Relay	Backup Relay	Primary SC current	Secondary SC current	Line
6 (Gen2)	17	24	77,524.56	564.51	6-12
	17	27	77,524.56	2,214.90	6-13
	15	22	80,132.39	4,429.87	6-11
	15	27	80,132.39	1,938.10	6-13
	16	22	80,494.12	4,536.14	6-11
	16	24	80,494.12	445.10	6-12
9	18	30	27,538.81	4,471.05	9-14
	19	21	29,663.69	6,961.43	9-10
10	20	18	17,348.97	17,348.97	10-9
	21	23	8,820.66	8,820.66	10-11
11	22	20	9,024.42	9,024.42	11-10
	23	17	16,068.79	16,068.79	11-6
12	25	15	12,437.68	12,437.68	12-6
	24	26	8,645.27	8,645.27	12-13
13	26	16	21,155.55	21,155.55	13-6
	27	25	5,438.20	5,438.20	13-12
	27	29	4,619.46	4,619.46	13-14
14	29	19	9,608.65	9,608.65	14-9
	30	28	7,742.59	7,742.59	14-13

5. CONCLUSIONS

In this paper, the implementation of Artificial Bees Algorithm for solving the Optimal coordination overcurrent relay problem was established. The effectiveness of the Bees Algorithm was verified by testing with system study and compared its simulation results with those obtained by Quasi-Newton (BFGS) and particle swarm optimization approaches. The results are in boundary relay characteristics as the results from the artificial bees colony are given smallest standard deviation of the 30 trial solutions for every test case. The artificial bees colony algorithm can converge towards the better solution slightly to decrease on small system, it can be considered as a potential alternative that is suitable for solving the relay coordination problem.

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