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Implementation of Hybrid ABC-PSO Algorithm for Directional Overcurrent Relays Coordination Problem

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Abstract: ***In modern power system, protective relays are playing a vital role for protection of the whole system. The efficiency and reliability of whole protection system depends upon the combined and coordinated operation of protective devices such as relays, circuit breakers etc. Moreover, both types of relays viz., primary and backup relays have been used for smooth and reliable operation of the power system from years. A primary directional over current relay (DOCR) is setup for the fast response of any faulty condition. If it fails, then backup relay perform the same task after some time gap. Three different setting such as plug-setting multiplier (PSM), pickup current settings and time multiplier setting (TMS) are required of performing the operation. In this paper, three very popular swarm based meta-heuristic such as particle swarm optimization (PSO), artificial bee colony (ABC) and a recent hybridization of both, i.e., hybrid ABC-PSO have been implemented for the calculation of optimal coordination problem. This coordination problem is treated for continuous settings optimization for TMS and pickup current. An IEEE 8 bus system without grid has been opted for validation of the results. It is evident from the study that the hybrid ABC-PSO based proves to generate optimal solution providing better convergence rate as compared to individual PSO and ABC algorithm.***

Keywords : **ABC algorithm, Directional over current relays; PSO algorithm, Hybrid ABC-PSO algorithm, relays coordination**

I. INTRODUCTION

A modern power system, safety of its components is one of the most important aspects of electrical network. The aim of electrical protection network is to segregate the defective part of power network quickly without any further damage to the system. Protective relays are essential aspect of an electrical protection network. The directional over current relays (DOCRs) are useful for sub-transmission and distribution networks. In case of main relay fails or malfunction, a backup relay is provided in the system. In order to maintain coordination between both relays a minimum time gap is essential which is further defined as CTI (coordination time interval) [1].

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The time gap inhibit the mal-operation of relays and stop the needless disconnection of working areas of network. The coordination problem compute the optimal settings for plug setting multiplier (PSM), time multiplier setting (TMS), and pickup current of primary and backup relays [2]. It is a constraints optimization problem. To overcome, this several optimization technique have been applied from the past few decades. The complete work in this field can be divided into some categories i.e., topological approach, classical linear techniques, non-linear formulation, and global optimization techniques. In advancement of modern optimization techniques, which assured more improved solution of the problem. The global optimization techniques are more reliable and minimize the probability of convergence to some local best solution [3].

In recent literature, various metaheuristic optimization algorithms have been applied in relay co-ordination problem. Marcolino *et al.* [4] performed the genetic algorithm optimization approach for relay coordination in meshed networks. Bedekar and Bhide [5] applied the continuous GA for coordination optimization of a looped network. The non-dominated sorting GA [6] real coded GA [7] also implemented the solution methods for optimal coordination of over current relays. Mansour *et al.* [8] proposed an improved version of the particle swarm optimization (PSO) to implement in the coordination problem of relays. With the advancement of improving the various variants of the PSO such as evolutionary PSO [9], interior point PSO [10] etc.have been found in the literature. Thangaraj et al. [11] tested three different probability distribution for differential evolution (DE) to calculate the time and plug settings for relays. Yen *et al.* [12] performed a study on the variants of DE regarding optimal coordination. Hussain *et al.* [13] used artificial bee colony (ABC) to solve directional relay coordination problem and proved algorithm search quality for better results particular in constraints optimization problems. Wolpert and Macready [14] remarks that single optimization algorithm cannot be applied for the solution of all optimization problems. Therefore, in recent times, many hybrid techniques have been developed and performing better than single optimization algorithms. In literature, such as Hybrid GA-linear programming (LP) [15], GA-Non LP [16], hybrid PSO-gravitational search [17], hybrid gravitational search (GS) and SQP [18], hybridized whale optimization algorithm (WOA) [19], improved firefly algorithm [20] and hybrid ant colony algorithm [21], simulated annealing-LP [21], Hybrid WHO-grey wolf optimizer algorithm [23] and many more have developed for solving relay coordination problems.

The TMS and pickup current (I_p) or PSM have to be optimize to minimize the relay operating times.

In this work, three very popular swarm based meta-heuristic such as an ABC, PSO and a hybrid ABC-PSO are used for the calculation of optimal solution relay coordination problem. The hybridization of different optimization algorithm are gaining popularities in recent times. The hybrid techniques proven more efficient and having good convergence characteristics as compared to a single optimization technique. The process is implemented on a standard IEEE-8 bus system without grid connection and results obtained has been compared between all three algorithms.

The manuscript has been organized in five sections. The coordination problem formulation is introduced in section 2. Steps of implementation of optimization algorithms in the said problem is presented in section 3. The results and discussion of an IEEE 8 bus system are elaborated in section 4. At last, section 5 concludes the work done.

II. PROBLEM FORMULATION FOR COORDINATION OF DOCRS

The main objective function for coordination of DOCRs is minimization of overall tripping time of all the primary relays. The objective function is well-defined function and has been used in almost every relay coordination problem in literature. It is essential to segregate the defective part of power network as early as possible. Thus, remaining safe parts of network continue to work in normal conditions. The main objective function, which is total operating time, is defined as:

$$T_{total} = \sum_{i=1}^{n} \omega_i T_i \quad (1)$$

Where, ωi and Ti are allocated burden and operating time, respectively of the ith relay; Ttotal represents total operating time.

According to the relation provided by IEC standards, the operating time for inverse characteristic overcurrent relays is given as:

$$T_i = \frac{\alpha \times TMS^i}{\left(I_F^i / I_p^i\right)^{\beta} - \gamma}, \; i = 1,2,\ldots..N \quad (2)$$

Where TMSi represents the time multiplier setting for ith relays; I_P^i represents the pickup current of the ith relay, I_F^i represents the magnitude of fault current passing from the ith relay; α , β and γ are fixed parameters of relay. In this work, the value of α =0.14, β= 0.02 and γ=1 have been considered.

The decision variables TMS and IP are continuous in nature and should be within bound as:

$$TMS_{min}^i \leq TMS^i \leq TMS_{max}^i \quad (3)$$

$$Ip_{min}^i \leq Ip^i \leq Ip_{max}^i \quad (4)$$

where TMS_{min}^i and TMS_{max}^i considered to be least and highest values for the TMS of the i^{th} relay, respectively; Ip_{min}^i and Ip_{max}^i are the least and highest values for the I_P of the i^{th} relay, respectively.

In addition to these limitations on decision variables, the operating time of each relay should be within limit and given as:

$$T_{min}^i \leq T^i \leq T_{max}^i \quad (5)$$

where, T_{min}^i and T_{max}^i are the least and highest ranges for operating time of the i^{th} relay.

The CTI should involves the addition of time taken by circuit breaker (CB) of primary relay to operate, the outreach duration for backup relay and some additional security time-gap. The relation for coordination balance is termed as:

$$T_{backup} - T_{primary} \geq CTI \quad (6)$$

Where, Tprimary and Tbackup are the execution intervals for primary and backup relay, respectively. Normally, the range for the CTI is selected between 0.2 sec and 0.5 sec, which is based upon various criteria and situations. CTI is considered 0.3 in this study. The numerical value of different parameters used in the study in given as in Table III of appendix [1,4,19].

III. IMPLEMENTATION OF HYBRID ABC-PSO ALGORITHM

The three main meta-heuristic algorithms, viz. ABC, PSO and a recent hybrid ABC-PSO are used in this paper for relay coordination problem. The meta-heuristic algorithm have advantages over conventional techniques such as better convergence and less computational time. The ABC algorithm was designed and proposed by Karaboga and Basturk , while PSO was implemented for optimization first time by Kennedy and Eberhart. Both algorithms are swarm based optimization algorithms and have been successfully implemented in the various engineering and other design problems for system optimization [24-25]. A complete and detailed description of steps of hybridization of ABC and PSO can be found in [26]. The main steps of hybridization of a hybrid ABC-PSO can been summarized as follows.

1. Initialize control parameters of ABC-PSO, *viz.*, population size (*NS*), maximum no. of iterations IT^{max} and take food source equals to half of the colony size, swarm members (X_p, v_{pq}), *Cycle*=1 and acceleration constants.
2. The following equations has been used to calculate position (X_{pq}) and initial velocity (v_{pq}) of initial bees
$$v_{pq} = v_q^{min} + rand(0,1)(v_q^{max} - v_q^{min}) \quad (7)$$
$$X_{pq} = X_q^{min} + rand(0,1)(X_q^{max} - X_q^{min}) \quad (8)$$

Where, p=1…...NS, and q=1…D. D is the number of optimization parameters .

3. Objective function as mentioned in equation [1] is evaluated using initial population and corresponding fitness is obtained for each solution.
4. Initialize the swarm best position g_{best}.
5. Upgrade the velocity and positions of the particles by
$$v_p^{IT+1} = w[v_p^{IT} + c_1 rand(0,1)(p_p^{IT} - x_p^{IT}) + c_2 rand(0,1)(g_p^{IT} - x_p^{IT})] \quad (9)$$
$$x_p^{IT+1} = x_p^{IT} + v_p^{IT+1} \quad (10)$$

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Where, c_1 and c_2 are the acceleration parameters, rand () are uniformly distributed random numbers, p_p^{IT} and g_p^{IT} are p_{best} and g_{best} and w is an inertia weight factor. The capabilities of searching is managed by the inertia weight factor.

6. Produce a set of new parameters, check their value in boundaries of employee bees, and check their upper and lower limits.
7. Further, objective function as defined in Eq. no. [1] is evaluated by using generated parameter value and using fitness value the probability value, P_p, is calculated for the solutions by the following equation

$$P_p = \frac{f_p}{\sum_{i=1}^{NP} f_p} \qquad (11)$$

Where, f_p is the fitness value according to p^{th} solution.

8. To know that if mutant solution is better than the current solution *p*, implement greedy selection process.
9. For onlooker bees repeat steps 7 to 9 and remember the best food source.
10. Validate solution range, if violets its ranges replace it with a new random solution for scout bees and memorize g_{best} at the end of each iteration.
11. Increment Cycle by one
12. While $Cycle{+}{+}<= IT^{max}$, otherwise go to step 7 [26].

IV. TEST SYSTEMS AND RESULTS

The discussed meta-heuristic swarm based algorithms have been implemented to minimization of the operating trip time of directional overcurrent relays for the purpose of optimal coordination of protection system. This method is applied in IEEE-8 bus systems for verification purpose. The bus system includes the combination of generators, transformers, transmission lines and directional overcurrent relays. All the standard data used from the bus system have been detailed in Appendix A (Table I, II and III).

A. Description of test system i.e., IEEE-8-bus test system.

The relay coordination problem has been tested on different standard IEEE bus system so far. The standard IEEE 8-bus test network referenced in [4,15] has been considered for results validation in this work. The IEEE 8 bus system standard data is available in various literature and summarized in the appendix. The IEEE 8 bus system is considered without any link and it is assumed that system is not connected to any external grid. Figure 1 shows simple layout of the test system. As seen from the figure that the test system have eight buses, two electrical sources, seven transmitting lines, two transformers, and fourteen directional-relays.

Further, for TMS setting, least and maximum values have been considered 0.05 and 1.1, respectively. The value of T_{max} is considered as 2 second. A total 28 design parameters (14 + 14, for TMS and I_p) and 40 constraints (20 + 20, for CTI and T_{max}, respectively) have been considered in the calculations.

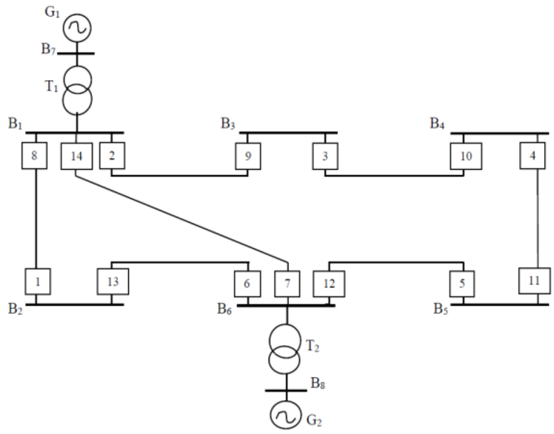

Figure 1. Standard IEEE 8 bus test system without grid connection diagram depicting all components

B. Setting of algorithm parameters.

For the different algorithms, the need of some control parameters to be initialized. The control parameters settings of all used algorithms are presented in table 1. Various different setting can be used in different literature for algorithm parameters to obtain the results.

Table 1: Setting of the different control parameters for three algorithms

ABC algorithm	PSO algorithm	Hybrid ABC-PSO
Parameter/ Values	Parameter/Value	Parameter/ Value
Colony size (NS): 50 Optimization parameter (D): 2 Maximum cycle number (MCN): 500 Employed bees=Onlooker bees= Food number: NS/2 limit: 100	Population size (NS): 50 D: 2 Maximum number of iterations IT^{max}: 500 c1 and c2: 2.0; w: 0.7	Population size (NS): 50 D: 2 IT^{max} :500 Employed bees=Onlooker bees= Food number: NS/2 c1 and c2: 2.0; w: 0.7

C. Obtained simulation output

The implementation of all three algorithm has been done in the computation of optimized settings of time multiplier and pickup current for determination of minimum possible operating time of directional over current relays. Applying the parameters shown above in table, problem for continuous relay settings has been computed. Table-2 shows different total time interval obtained for all three optimization algorithms. It is evident from the ABC algorithm provide better result than PSO and further hybrid ABC-PSO outperforms both ABC and PSO algorithms. The ABC predicts 11.57 sec, PSO predicts 12.827 seconds. Moreover, Hybrid ABC-PSO predicts 10.19 sec overall tripping time which is further compared with other algorithm such as GA and it is found that Hybrid ABC-PSO provides a better solution as compared to other algorithms. Figure 2 depicts the convergence characteristics obtained for the all three different optimization algorithms.

It can be observed that all three algorithm converges within 100 iterations and provides optimal results. The solution for TMS and Ip is provided in Table-3. A comparison of output for test system-1 is given in Table-3.

Table 2 : Result comparison for test system obtained by different algorithms

Algorithm	Operating time (Sec)
PSO	12.83742
ABC	11.5723
HYBRID ABC-PSO	**10.19426**
GA [15]	11.011
GA-LP[15]	10.949

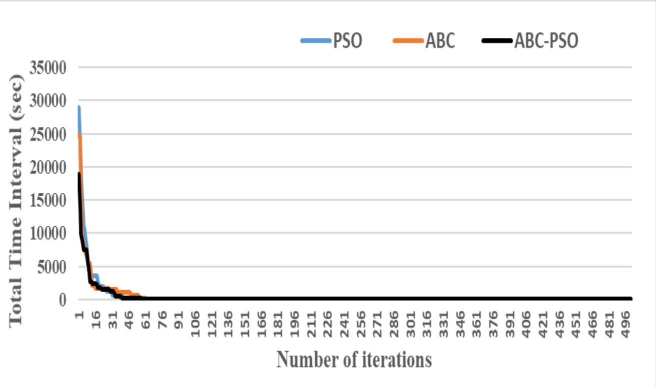

Figure 2: ABC, PSO and ABC-PSO algorithms convergence characteristics

Table- 3 shows results obtained for the test system as shown in Figure 1. The Table shows TMS, I_p, T_{backup} and $T_{primary}$ for all three algorithms. The TMS and I_p was two-decision variable which were obtained by various optimization techniques and T_{backup} and $T_{primary}$ were calculated on the basic of TMS and I_p. Table 4 demonstrates CTI obtained from different techniques, as there is constraints on CTI has been considered 0.30; therefore, CTI constraints have not been violated in the all three algorithms. Figure 3, 4 and 5 shows the operating time for each combination of primary and backup relays with respect to the CTI for all three algorithms, respectively. It is observed that the all the constraints are within the normal values and have not been violated.

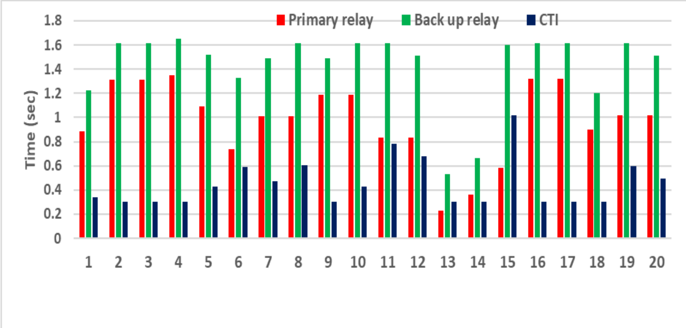

Figure 3: Primary, backup relay time and CTI obtained in ABC algorithm.

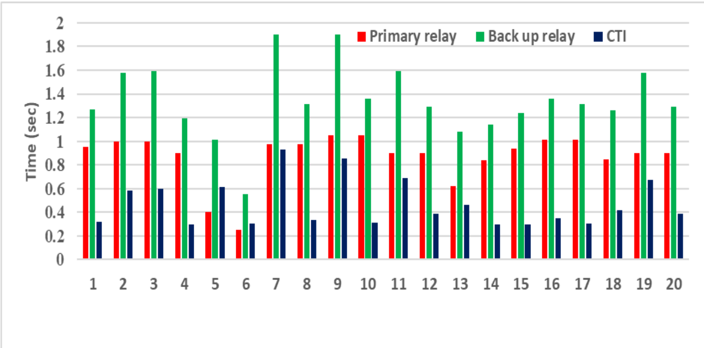

Figure 4 : Primary, backup relay time and CTI obtained in PSO algorithm.

TABLE 3: Optimal relay settings and their corresponding operating time for test system

Relay	PSO				ABC				HYBRID ABC-PSO			
	TMS	*Ip*	$T_{primary}$ (sec)	T_{backup} (sec)	TMS	*Ip*	$T_{primary}$ (sec)	T_{backup} (sec)	TMS	*Ip*	$T_{primary}$ (sec)	T_{backup} (sec)
1	0.351	179.755	0.888	1.617	0.436	120	0.9546	1.5745	0.37	120	0.809	1.334
2	0.465	480	1.315	1.649	0.424	295.48	0.9936	1.1964	0.458	266.46	1.035	1.237
3	0.746	80	1.35	1.521	0.496	80	0.8972	1.0108	0.398	184.44	0.937	1.094
4	0.469	120	1.093	1.33	0.106	353.85	0.3985	0.5538	0.263	226.13	0.789	1.019
5	0.261	120	0.74	1.488	0.05	335.94	0.2503	1.9039	0.206	120	0.585	1.175
6	0.559	120	1.013	1.224	0.396	314.9	0.9769	1.2702	0.327	380.65	0.867	1.152
7	0.701	80	1.188	1.614	0.475	197.38	1.0511	1.5907	0.375	228.56	0.873	1.355
8	0.286	480	0.835	1.199	0.331	407.62	0.9022	1.2599	0.47	120	0.851	1.055
9	0.05	320	0.231	1.511	0.221	123.09	0.6168	1.2878	0.05	320	0.231	1.511
10	0.083	480	0.364	0.53	0.275	245.87	0.839	1.0774	0.157	186.56	0.425	0.53
11	0.289	120	0.581	0.664	0.325	325.42	0.9392	1.1385	0.165	480	0.573	0.724
12	0.488	429.206	1.319	1.601	0.357	480	1.0104	1.2388	0.434	120	0.769	0.872
13	0.338	190.584	0.899	1.619	0.377	120	0.8466	1.3613	0.26	230.95	0.748	1.437
14	0.419	258.107	1.019	1.618	0.445	150.2	0.9014	1.3101	0.265	319.98	0.7	1.167

Table 4: CTI obtained by the different optimization algorithms

Primary relay	Back-up relay	Coordination Time interval (CTI)		
		PSO	ABC	PSO-ABC
1	6	0.34	0.32	0.34
2	1	0.3	0.58	0.3
2	7	0.3	0.6	0.32
3	2	0.3	0.3	0.3
4	3	0.43	0.61	0.31
5	4	0.59	0.3	0.43
6	5	0.48	0.93	0.31
6	14	0.61	0.33	0.3
7	5	0.3	0.85	0.3
7	13	0.43	0.31	0.56
8	7	0.78	0.69	0.5
8	9	0.68	0.39	0.66
9	10	0.3	0.46	0.3
10	11	0.3	0.3	0.3
11	12	1.02	0.3	0.3
12	13	0.3	0.35	0.67
12	14	0.3	0.3	0.4
13	8	0.3	0.41	0.31
14	1	0.6	0.67	0.63
14	9	0.49	0.39	0.81

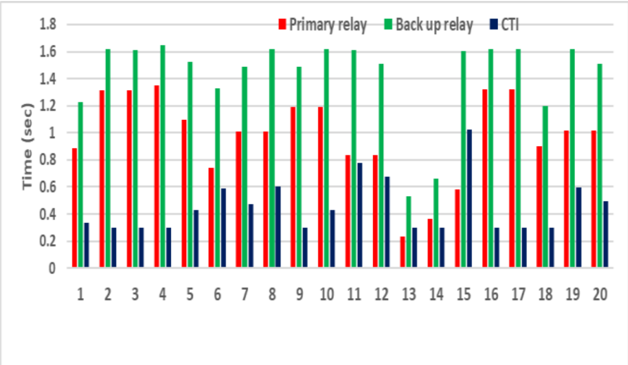

Figure 5: Primary, backup relay time and CTI obtained in ABC-PSO algorithm.

V. CONCLUSIONS

In this work, three different metaheuristic algorithms, *viz.* ABC, PSO and a hybridization of both. hybrid ABC-PSO have been implemented for relay co-ordination problem at standard IEEE-8 bus system. The hybrid ABC-PSO algorithm provide better results in terms of convergence characteristics and time interval for the system as compared to individual ABC or PSO system. The results have been validated with the other optimization algorithms, and it has been found that hybridization of different algorithms has an edge over an individual algorithm.

In the discussed approach, the tests on IEEE 8-bus system for computation of trip time in relay coordination is conducted. Further, it can be concluded that relay coordination problem has more potential and vast scope for further reduction of total operating time. In future, more hybrid techniques may be applied for better results.

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APPENDIX-A

Table I: Values of 3 phase short circuit currents corresponding to their relay pairs for IEEE-8 bus system

Primary relay	I^{p}_{F1} (A)	Backup relay	I^{b}_{F1} (A)
1	2666.3	6	2663
2	5374.8	1	804.7
2	5374.8	7	1531.5
3	3325.6	2	3325.6
4	2217.1	3	2217.1
5	1334.3	4	1334.3
	4975	5	403.6
6	4975	14	1533
7	4247.6	5	403.6
7	4247.6	13	805.5
8	4973.2	7	1531.5
8	4973.2	9	403.2
9	1420.9	10	1420.9
10	2313.5	11	2313.5
11	3474.3	12	3474.3
12	5377	13	805.5
12	5377	14	1533
13	2475.7	8	2475.7
14	4246.4	1	804.7
14	4246.4	9	403.2

Table II: Properties of relays for test system

Relay	CT Ratio	Pickup Current (A)	
		Lowest Value	Highest Value
1	1220/5	120	480
2	1200/5	120	480
3	800/5	80	320
4	1200/5	120	480
5	1200/5	120	480
6	1200/5	120	480
7	800/5	80	320
8	1200/5	120	480
9	800/5	80	320
10	1200/5	120	480
11	1200/5	120	480
12	1200/5	120	480
13	1200/5	120	480
14	800/5	80	320

Table III: Boundary values for decision variables

TMS_{min}	0.05 (Continous), 0.1(Discrete)
TMS_{max}	1.1
CTI	0.3

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