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A Novel Objective Function for Directional Overcurrent Relays Coordination

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ABSTRACT

Directional overcurrent relays (DOCRs) are widely used to protect power systems. For optimal coordination of DOCRs, several techniques have been proposed to solve this problem. A common way of optimal coordination of DOCRs is using evolutionary algorithms such as genetic algorithm (GA). In this paper, a novel strategy for DOCRs coordination is proposed. In the proposed strategy, a new objective function (OF) is introduced. The proposed objective function can removed mis-coordination between paired relays and can result in better coordination. Proposed OF is applied to 6-bus and 30-bus sample networks.

1. INTRODUCTION

Protection of distribution networks is one of the most important issues in power systems. Overcurrent relay is one of the most commonly used protective relays in these systems. There are two types of settings for these kinds of the relays: current and time settings. A proper relay setting plays a crucial role in reducing undesired effects of faults on the power systems [1, 2]. Overcurrent relays commonly have plug setting (PS) ranging from 50 to 200% in steps of 25%. The PS shows the current setting of the overcurrent relays. For an overcurrent relay, PS is defined by two parameters: the minimum fault current and the maximum load current. However, the most important variable in the optimal coordination of overcurrent relays is the time multiplier setting (TMS) [3]. So far, some research has been carried out on coordination of overcurrent relays [3-7]. Due to the difficulty of nonlinear optimal programming techniques, the usual optimal coordination of overcurrent relays is generally carried out by linear programming techniques, including simplex, two-phase simplex and dual simplex methods [3]. In these

methods, the discrimination time of the main and backup relays (Δt_{mb}) are considered as constraints and then the optimal coordination problem is solved using both OF and constraints. A fast method for optimization of the TMS's and current settings by evolutionary algorithm and linear programming has been proposed by Sueiro et al. [8]. An online technique to estimate the setting of DOCRs is introduced in another literature [4]. This technique is based on the estimation of the parameters of a proper equivalent circuit of the network. In relay coordination, which is very constrained, the discrete optimization problem is hardly solved by traditional optimization techniques [5]. The pickup current and the TMS of the relays have been considered as the optimization parameters for optimal coordination of DOCRs by Ezzeddine et al. [9]. The linear programming optimization techniques are started by an initial conjecture and are possibly trapped in a local optimum [3]. The evolutionary optimization techniques have come up in such a way that can adjust the settings of the relays without the mentioned problems. In these methods, the constraints are considered as a part of OF. A developed method based on genetic algorithm (GA) for optimal coordination has been proposed [6]. This method does not resolve the mis-coordination between

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the relays. As a result of the mis-coordination, when a fault occurs in front of the main relay, some backup relays may operate faster than the main one. This causes more lines of network go out due to the occurring faults in some parts of the network. Obviously, in this case, the number of interrupted customers increases and consequently the power quality declines. In other research [10], continuous genetic algorithm has been used in a ring fed distribution system for optimal coordination of overcurrent relays . An OF has been proposed in which the problem of mis-coordination have almost been resolved by Razavi et al. [11]. In their research [11], the OF can prevent the appearance of inappropriate results which make mis-coordination. The OF of Razavi et al. [11] consists of the three coefficients. The coefficients of the OF should be chosen very carefully. These coefficients determine the importance of the minimizing the operating time of the relays or the minimizing the time difference between the main and the backup relays. The main shortcoming of Razavi et al. [11] is that some of the coefficients of OF are set by try and error. It is proved by experience that using such coefficients cannot guarantee accessing to the smallest operation time of the relays. In some cases, using inappropriate parameters in OF may result in some mis-coordination.

In this paper, a new OF is proposed for DOCRs coordination that not only the mis-coordination is omitted but also the operating times of the relays are better than the existing methods. In the novel proposed OF, the number of the mis-coordination is considered as a part of OF. Since the proposed OF contains only one part, the OF do not need any weighting coefficients. The new OF is applied to 6-bus and 30-bus sample networks. The results of this OF are compared with the results of the existing ones. The simulation results and the comparisons demonstrate the effectiveness and the advantage of the proposed OF. Proposed OF for DOCRs coordination in this study is solved by GA.

2. APPLICATION OF GA IN RELAY COORDINATION

Evolutionary algorithms, such as GA, are used to solve complex optimization problems such as the relay coordination problem. GA is a heuristic method which is used to determine the best coordination of DOCRs. This algorithm has the strings called chromosome. A chromosome consists of the series of genes. The genes are the optimization problem variables which can be represented by binary or real codes. In DOCRs coordination problem, the genes of each chromosome are TMS's of the relays. GA generally includes three basic genetic operators of reproduction, crossover and mutation [12, 13]. In this section, we briefly discuss the application of the GA in DOCRs coordination. A simple flowchart for the GA is shown in Figure 1. The GA

concept in DOCRs coordination is described in 4 steps:
Step 1: Initialization
In the first step, some randomly chromosomes are produced. In coordination problem, the number of the variables is equal to the number of the TMS's of the relays in which the TMS of the relays should be between 0.05 and 1. Suitable values of TMS's determine in the optimization process.
Step 2: Evaluation
In the second step, the value of the OF is calculated for every chromosome. The OF has a basic role to discern between good and bad chromosomes.
Step 3: Selection
In the third step, the chromosomes are compared with the best initial chromosome. The best chromosome is one in which the value of the TMSs are minimum. The best chromosomes are selected by the OF and pass to the next generation.
Step 4: Reproduction
In the last step, update the value of the genes by using the operators of reproduction (crossover and mutation). If the iterations reach to the specified value, the optimal TMSs of the relays are determined.

3. PROBLEM STATEMENT

The main aim of DOCRs coordination problem is to determine the TMS of each relay and minimizing the operating time of the main relays. On the other hand, the constraints must be regarded. A new OF has been proposed by Razavi et al. [11] to prevent DOCRs mis-coordination and to find the optimum results as follows:

$$O.F = \alpha_1 \sum (t_i)^2 + \alpha_2 \sum (\Delta t_{mb} - \beta(\Delta t_{mb} - |\Delta t_{mb}|))^2 \qquad (1)$$

where, α1, α2 and β are weighting coefficients; t_i is the operating time of the i-th overcurrent relay when a fault occurs next to the relay; Δt_{mb} is the discrimination time between the main and backup overcurrent relays. In DOCRs coordination, the constraints are defined based on Δt_{mb}:

$$\Delta t_{mb} = t_b - t_m - CTI \qquad (2)$$

where, t_b and t_m are, respectively, the operating time of the backup and main relays when a fault occurs next to the main relay. The value of coordination time interval (CTI) is mainly chosen based on the practical limitations, which consists of the relay over-travel time, the breaker operating time, and the safety margin for the relay error [14]. Generally, the suitable CTI is selected between 0.2s to 0.5s. In this study, CTI is considered to be 0.3s. If Δt_{mb} is negative, it means that the backup relay is faster than the main relay and mis-coordination occurs between the backup and main relays.

The first term of Equation (1) is the sum of overcurrent relays operating time when a fault occurs next to the relays and the second term is the coordination constraint. To minimize the main relays operating time, a great value must be assigned to α1. To emphasis on minimizing the backup relay operating time, a large value must be assigned to α2. To prevent mis-coordination, a large value for β is chosen.

The main problem of the OF of Razavi et al. [11] is that it consists of two terms. In multi term OFs, the weighting coefficients is necessary to define according to the importance of each term in OF and have important role in the optimization [15]. The weighting coefficients must be chosen according to the importance of each term [16]. The proposed OF of Razavi et al. [11] is not very satisfactory for several reasons:

❖ On the one hand, the selection of the weighting coefficients is very difficult, because both terms have equal importance and setting them by try and error cannot guarantee accessing to the smallest operating time of the relays.

❖ On the other hand, since different weighting coefficients make search space very widespread, obtaining the optimal solution is almost impossible.

❖ By increasing the negative value of Δt_{mb}, the cost of the OF increases. This means that the small negative Δt_{mb}'s may be accepted as a result of the optimization because these values do not increase the OF value very much.

According to the above discussion, Razavi et al. [11], the three weighting coefficients (β, α1, α2) must be set by try and error. Therefore, the proposed OF of Razavi et al. [11] cannot guarantee obtaining the best coordination and the smallest operating time of the relays. To resolve this problem, a new technique should be employed in which the terms of the OF are not stated separately. Therefore, the new technique does not need weighting coefficients. In this paper, we will introduce a novel OF, in section 4, that resolve the mentioned problems of OF of Razavi et al. [11].

4. NEW OBJECTIVE FUNCTION

According to the previous sections, a new OF is proposed to obtain the best solution for DOCRs coordination problem. The proposed OF optimizes the TMS's of the relays in order to have a fast operating time and preventing relay mis-coordination. The new OF is as follows:

$$O.F = \left(\sum_{i=1}^{n} t_i \right)^{(NMC+1)} \tag{3}$$

where n is the number of the relays; t_i is the operating time of DOCRs when a fault occurs next to the ith relay. NMC is an index that shows the total number of mis-coordination i.e., NMC is the summation of the number of the negative Δt_{mb}'s. To satisfy the constraints, they are included in the OF. Equation (3) consists of two terms; the first term is $\left(\sum (t_i) \right)^1$ that minimizes the value of the TMS's; and the second term is $\left(\sum (t_i) \right)^{NMC}$ which indicates the constraints and eliminates the mis-coordination. The OF is obtained by multiplying the two mentioned terms $\left(\left(\sum (t_i) \right)^1 \times \left(\sum (t_i) \right)^{NMC} = \left(\sum (t_i) \right)^{NMC+1} \right)$. Therefore, if a constraint is not satisfied, NMC would be large and the cost of the OF is increased. So, to minimize the OF, the GA does not select the solution with unsatisfied constraints. For each negative value of Δt_{mb}, the OF is large even when Δt_{mb} is small and negative. For the proposed OF of this paper, there is no difference between small and large negative values of Δt_{mb}.

The performance of the new OF relies on the minimization of the relays operating time with respect to the total number of mis-coordination (NMC); in which the number of the mis-coordination should be minimized. The formulation of OF shows that the optimal solution is achieved when the value of NMC is zero.

The advantage of this OF is that the shortcomings related to OF of Razavi et al. [11], determination of the weighting coefficients, are resolved.

5. MATHEMATICAL OVERCURRENT RELAY MODEL

There are many mathematical models for the overcurrent relays. In this study, the mathematical model of overcurrent relays is considered to be the standard inverse type. In this mathematical model, the operating time of the overcurrent relay is as follows [17]:

$$t = \frac{k \times TMS}{\left(\frac{i_{sc}}{i_0} \right)^n - 1} \tag{4}$$

where, t is the relay operating time; i_0 is relay current setting; i_{sc} is short-circuit current; and TMS is the time multiplier setting of the relay. TMS varies from 0.05 to 1. From the IEC curves, for standard inverse type relays, the parameters of (4) are assumed to be k=0.14 and n=0.02.

6. RESULTS AND DISCUSSION

As described in section 4, the results of the optimization problem are TMS's. Therefore, the OF value is not suitable for comparing the results of the new OF with the OF of Razavi et al. [11]. In order to compare the results of the proposed OF and the OF of Razavi et al. [11], the following indices are defined:

❖ Summation of TMS's: If there is no mis-coordination in the coordination results, it can be said that the better coordination has smaller summation of TMS's.

❖ Summation $\sum \Delta t_{mb}$'s: To compare two sets of the coordination results, for example set A and set B, which do not have any mis-coordination, if Equation (5) is true, the set of results of set A is better than set B.

$$\sum_{(mb)=1}^{n} (\Delta t_{mb,A} - \Delta t_{mb,B}) \langle 0 \tag{5}$$

where, n is the number of relay main/backup (m,b) pairs of relays.

In Iran, almost all of the distribution networks are radial, but in other contries there are many interconnected or ring networks. Since applying the proposed method to the radial networks is so simple, in this paper we are applying this method to the interconnected network. The proposed OF is applied to two different networks. Case study 1 is a sample 6-bus network and case study 2 is a sample IEEE 30-bus network.

6. 1. Case Study 1   The network of Case study 1 is shown in Figure 2. This network is consists of 7 lines, 6 buses, 2 Generators, 2 transformers, and 14 overcurrent relays [18]. All the information about this network including short circuit currents of backup and main relays has been provided by Razavi et al. [11]. The way of the relay current settings described in (6) [11]:

$$i_0 = 1.2 \times i_{l\max} \tag{6}$$

In this case study, the number of the genes is 14. The results of the proposed OF and the best results of Razavi et al. [11] are compared in Table 1. In this table, the second column shows the results of Razavi et al. [11], and the third column shows the results of the proposed OF. Also, in this table, the first 14 rows show the TMS of the relays. The second 14 rows show the operating time of the relays when a fault occurs next to the relays. In addition, Δt_{mb}'s are calculated according to Equation (2), where in this paper CTI is considered to be 0.3s. For example, $\Delta t_{7,13}$ shows the time difference between operating time of relay 13 and relay 7 when a fault

occurs next to the relay 7. The last two rows are provided to compare the results of the two OF. $\sum \Delta t_{mb}$ shows the summation of the Δt_{mb}'s for each OF and in the last row of the table, $\sum$TMS shows the summation of the TMS's of the relays for each OF.

According to Table 1, all of the Δt_{mb}'s for the two OF are positive values. Also, it is shown that the largest value of the Δt_{mb}'s for the OF of Razavi et al. [11] is 1.4086s and the largest value of the Δt_{mb}'s for the proposed OF is 0.74s. To complete the comparisons, it is shown that the value of the $\sum \Delta t_{mb}$ for the OF of Razavi et al. [11] and the proposed OF is, respectively, 6.699 and 3.4s. It is obvious that the proposed OF results in the smaller value of $\sum \Delta t_{mb}$ with respect to the previous works. Moreover, the $\sum$TMS of the OF of Razavi et al. [11] and the proposed OF are 2.75 and 1.9, respectively. This shows that the operating time of the proposed OF is much better than the OF of Razavi et al. [11]. According to Table 1, most of the operating time of the relays obtained from the proposed OF are smaller than the values obtained from the OF of Razavi et al. [11]. For example, t_{12} obtained from the proposed OF is 0.75s whereas t_{12} obtained from the OF of Razavi et al. [11] is 1.1847s.

6. 2. Case Study 2   To have another case study, the 30-bus IEEE sample network is considered. It consists of 30 buses (132- and 33-kV buses), 37 lines, 6 generators, 4 transformers, and 86 DOCRs [19]. Figure 3 shows the single line diagram of the second case study [20]. The information of the generators, transmission lines, and transformers is taken from [2].
In this paper, four different cases are simulated in order to have a better comparison. Three cases are simulated according to the OF of Razavi et al. [11] in which the OF coefficients are set manually. The last case is simulated according to the proposed OF of this paper.

The results obtained from the proposed OF by GA (the fourth case) are shown in Tables 2 and 3. For simplicity, the results of the first three cases are not shown in this paper, but the comparisons are provided according to the results of the simulations. The first column of Table 2 shows relay number, the second column shows relay operating time for a fault next to the circuit breaker of each relay and the third column indicates the TMS of the relays. From Table 2, all Δt_{mb}'s are positive numbers. The positive values of Δt_{mb}'s show that there is no mis-coordination in the results. For

example, $\Delta t_{4,1}$ refers to the relay pairs 4 and 1 that is 0.5s.

In the network all of the loads are considered to be the static loads. Therefore, in accordance to this fact that all of the relays are directional, the relays 57 and 79 in network of Figure 3 are not needed to be considered. So, in this study, the TMS's of these relays are set to be 0.05 [21, 22]. Of course, the other TMS's of the relays should be calculated by the coordination optimization problem.
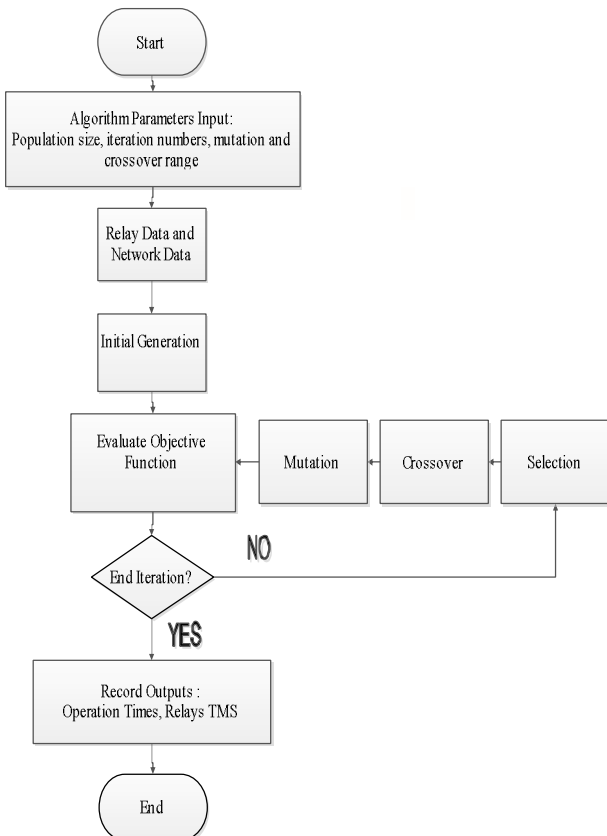

Figure 1. Flowchart of GA
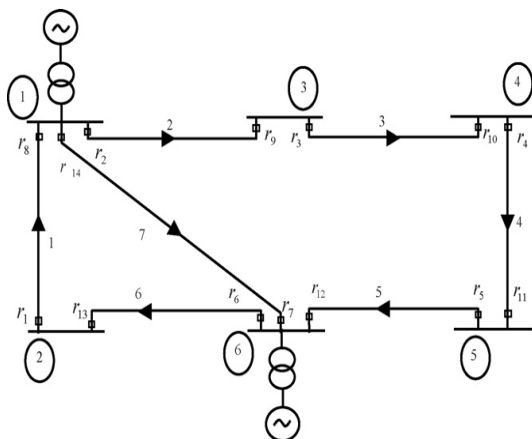
Figure 2. Case study 1
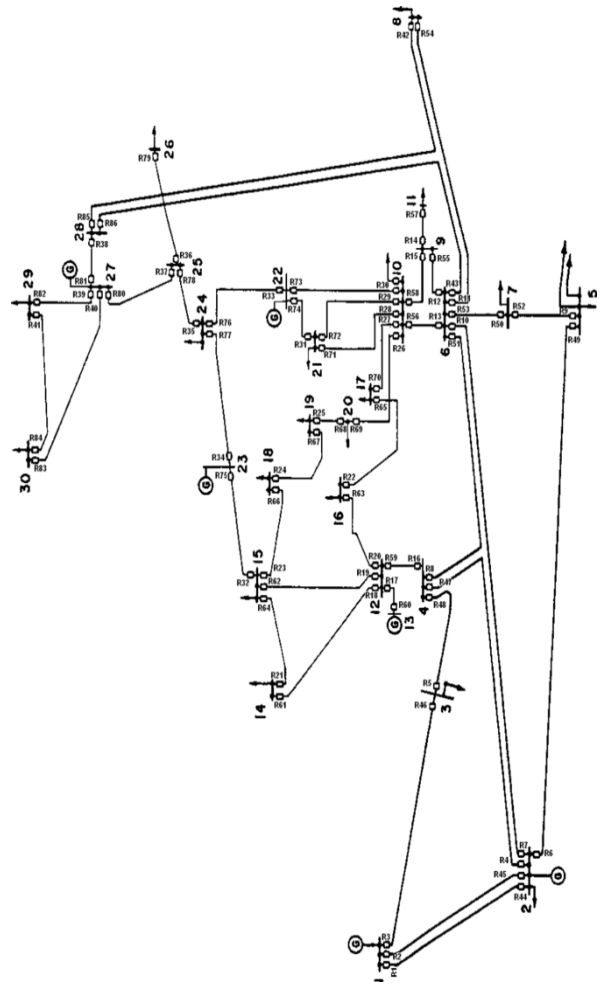
Figure 3. IEEE 30-bus system

In Table 4, the results of the simulations for the four cases are illustrated. In this table, the first row shows the four different cases; and the second and the third rows show the results of the $\sum \Delta t_{mb}$'s and $\sum$TMS's for these cases, respectively. The three first cases are related to the OF of [11] and the last case shows the results of the proposed OF. The values of the coefficients of the OF of [11] are shown in the first row of the Table 4. The values of Δt_{mb}'s in all cases are positive and have no mis-coordination. The advantage of the proposed OF is revealed when the results of case 4 are compared with the best results of the traditional OF of [11].

According to Table 4, the best $\sum$TMS and $\sum \Delta t_{mb}$ for OF of [11] (between three cases 1, 2 and 3) are 20.75 and 110.3416s, respectively. Whereas $\sum$TMS and $\sum \Delta t_{mb}$ of the proposed OF are 10.3 and 72.36s, respectively. This means that the results obtained from case 4, related to the new OF, return the best coordination.

TABLE 1. The coordination results

Coordination Output	Reference [11]	Proposed OF
TMS_1	0.15	0.1
TMS_2	0.35	0.25
TMS_3	0.25	0.2
TMS_4	0.1	0.1
TMS_5	0.1	0.05
TMS_6	0.25	0.2
TMS_7	0.2	0.15
TMS_8	0.25	0.15
TMS_9	0.05	0.05
TMS_{10}	0.15	0.1
TMS_{11}	0.25	0.15
TMS_{12}	0.4	0.25
TMS_{13}	0.1	0.05
TMS_{14}	0.15	0.1
t_1	0.5894	0.41
t_2	1.2173	0.9
t_3	0.9621	0.8
t_4	0.6636	0.67
t_5	0.7660	0.38
t_6	0.7623	0.62
t_7	0.7059	0.55
t_8	0.7625	0.47
t_9	0.3479	0.35
t_{10}	0.6883	0.48
t_{11}	0.9835	0.61
t_{12}	1.1847	0.75
t_{13}	0.4665	0.24
t_{14}	0.5944	0.41
$\Delta t_{8,9}$	0	0
$\Delta t_{8,7}$	0.4673	0.46
$\Delta t_{2,7}$	0.0028	0.01
$\Delta t_{2,1}$	0.6290	0.26
$\Delta t_{3,2}$	0.2657	0.11
$\Delta t_{4,3}$	0.2057	0.07
$\Delta t_{5,4}$	0.1885	0.64
$\Delta t_{6,5}$	0	0
$\Delta t_{6,14}$	0.4825	0.16
$\Delta t_{14,1}$	1.3181	0.74
$\Delta t_{14,9}$	0	0
$\Delta t_{1,6}$	0.0532	0.16
$\Delta t_{9,10}$	0.3173	0.06
$\Delta t_{10,11}$	0.2195	0.03
$\Delta t_{11,12}$	0.0492	0.01
$\Delta t_{12,14}$	0.0489	0.02
$\Delta t_{12,13}$	0.8135	0.13
$\Delta t_{13,8}$	0.2292	0.14
$\Delta t_{7,5}$	0	0
$\Delta t_{7,13}$	1.4086	0.4
$\sum \Delta t_{mb}$	6.699	3.4
$\sum TMS$	2.75	1.9

TABLE 2. Coordination output results

Relay numbers	T (s)	TMS
1	0.3959	0.15
2	0.3959	0.15
3	0.5794	0.2
4	0.3057	0.1
5	1.1119	0.15
6	0.4993	0.2
7	0.272	0.1
8	0.769	0.2
9	0.7921	0.15
10	0.5445	0.2
11	0.5552	0.2
12	0.2642	0.1
13	0.6364	0.2
14	0.1882	0.05
15	0.2722	0.05
16	0.3168	0.1
17	0.1972	0.05
18	0.3014	0.1
19	0.5615	0.15
20	0.5202	0.15
21	0.4534	0.1
22	0.8469	0.15
23	0.5869	0.15
24	1.0868	0.2
25	0.8594	0.25
26	0.5332	0.2
27	0.593	0.2
28	0.1723	0.05
29	0.1723	0.05
30	0.1731	0.05
31	0.7228	0.15
32	0.4539	0.1
33	0.4159	0.15
34	0.4523	0.15
35	0.3954	0.1
36	0.2374	0.05
37	0.4596	0.1
38	0.3464	0.1
39	0.2807	0.1

Relay numbers	T (s)	TMS
40	0.2382	0.1
41	0.4934	0.1
42	0.3568	0.15
43	0.5248	0.2
44	0.4146	0.15
45	0.4	0.15
46	0.2424	0.05
47	0.3135	0.1
48	0.4608	0.15
49	0.2504	0.05
50	0.2913	0.1
51	0.618	0.2
52	0.3945	0.1
53	0.7155	0.15
54	0.2985	0.05
55	0.2311	0.05
56	0.6103	0.15
58	0.3447	0.1
59	0.3988	0.1
60	0.5391	0.15
61	0.2447	0.05
62	0.4998	0.1
63	0.5979	0.1

Relay numbers	T (s)	TMS
64	0.2146	0.05
65	0.566	0.15
66	0.5287	0.1
67	0.5888	0.1
68	0.9227	0.2
69	0.5355	0.1
70	0.8657	0.15
71	0.2904	0.1
72	0.1645	0.05
73	0.2942	0.1
74	0.6378	0.2
75	0.4821	0.15
76	0.6786	0.15
77	0.39	0.1
78	0.5789	0.15
80	0.4741	0.15
81	0.1763	0.05
82	0.2776	0.05
83	0.2293	0.05
84	0.3302	0.05
85	0.3632	0.15
86	0.4487	0.1

TABLE 3. Time difference for any relays pairs

Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)
$\Delta t_{4,1}$	0.50	$\Delta t_{18,16}$	0.58	$\Delta t_{3,44}$	0.40	$\Delta t_{15,57}$	0.00	$\Delta t_{51,86}$	0.28	$\Delta t_{56,71}$	0.24
$\Delta t_{6,1}$	0.31	$\Delta t_{19,16}$	0.29	$\Delta t_{1,45}$	0.45	$\Delta t_{55,57}$	0.00	$\Delta t_{30,71}$	0.73	$\Delta t_{58,71}$	0.52
$\Delta t_{7,1}$	0.53	$\Delta t_{20,16}$	0.35	$\Delta t_{3,45}$	0.27	$\Delta t_{14,58}$	0.27	$\Delta t_{51,56}$	0.09	$\Delta t_{26,72}$	0.00
$\Delta t_{45,1}$	0.41	$\Delta t_{21,18}$	0.09	$\Delta t_{1,46}$	0.00	$\Delta t_{55,58}$	0.22	$\Delta t_{2,44}$	0.57	$\Delta t_{27,72}$	0.00
$\Delta t_{4,2}$	0.50	$\Delta t_{23,19}$	0.32	$\Delta t_{2,46}$	0.00	$\Delta t_{8,59}$	0.50	$\Delta t_{17,16}$	0.65	$\Delta t_{28,72}$	0.00
$\Delta t_{6,2}$	0.31	$\Delta t_{32,19}$	0.44	$\Delta t_{6,47}$	0.75	$\Delta t_{47,59}$	1.01	$\Delta t_{29,71}$	0.74	$\Delta t_{30,72}$	0.00
$\Delta t_{7,2}$	0.53	$\Delta t_{64,19}$	0.70	$\Delta t_{7,47}$	0.98	$\Delta t_{48,59}$	0.81	$\Delta t_{50,56}$	0.44	$\Delta t_{56,72}$	0.00
$\Delta t_{44,2}$	0.40	$\Delta t_{22,20}$	0.10	$\Delta t_{44,47}$	0.76	$\Delta t_{18,60}$	0.42	$\Delta t_{85,43}$	0.12	$\Delta t_{58,72}$	0.00
$\Delta t_{5,3}$	0.35	$\Delta t_{23,21}$	0.53	$\Delta t_{45,47}$	0.77	$\Delta t_{19,60}$	0.14	$\Delta t_{56,15}$	0.00	$\Delta t_{26,73}$	0.50
$\Delta t_{8,4}$	0.43	$\Delta t_{32,21}$	0.64	$\Delta t_{46,48}$	0.04	$\Delta t_{20,60}$	0.19	$\Delta t_{27,71}$	0.27	$\Delta t_{27,73}$	0.39
$\Delta t_{16,4}$	0.98	$\Delta t_{62,21}$	0.62	$\Delta t_{4,49}$	0.00	$\Delta t_{59,60}$	0.31	$\Delta t_{43,56}$	0.19	$\Delta t_{28,73}$	0.86
$\Delta t_{48,4}$	0.74	$\Delta t_{70,22}$	0.42	$\Delta t_{7,49}$	0.00	$\Delta t_{17,61}$	0.00	$\Delta t_{38,43}$	0.14	$\Delta t_{29,73}$	0.86
$\Delta t_{8,5}$	0.44	$\Delta t_{24,23}$	0.09	$\Delta t_{44,49}$	0.00	$\Delta t_{19,61}$	0.00	$\Delta t_{30,15}$	0.00	$\Delta t_{56,73}$	0.36
$\Delta t_{16,5}$	0.96	$\Delta t_{25,24}$	0.32	$\Delta t_{45,49}$	0.00	$\Delta t_{20,61}$	0.00	$\Delta t_{50,86}$	0.66	$\Delta t_{58,73}$	0.65
$\Delta t_{47,5}$	0.95	$\Delta t_{69,25}$	0.10	$\Delta t_{4,50}$	0.79	$\Delta t_{59,61}$	0.00	$\Delta t_{26,71}$	0.37	$\Delta t_{71,74}$	0.17
$\Delta t_{9,6}$	0.25	$\Delta t_{68,26}$	0.06	$\Delta t_{6,50}$	0.60	$\Delta t_{17,62}$	0.87	$\Delta t_{12,56}$	0.49	$\Delta t_{72,74}$	0.30
$\Delta t_{10,7}$	0.23	$\Delta t_{65,27}$	0.07	$\Delta t_{44,50}$	0.61	$\Delta t_{18,62}$	0.86	$\Delta t_{86,42}$	0.10	$\Delta t_{23,75}$	0.33
$\Delta t_{11,7}$	0.21	$\Delta t_{31,28}$	0.00	$\Delta t_{45,50}$	0.63	$\Delta t_{20,62}$	0.58	$\Delta t_{29,13}$	0.00	$\Delta t_{62,75}$	0.41
$\Delta t_{12,7}$	0.55	$\Delta t_{72,28}$	0.00	$\Delta t_{16,51}$	0.20	$\Delta t_{59,62}$	0.71	$\Delta t_{13,86}$	0.27	$\Delta t_{64,75}$	0.71

TABLE 3. Continued

Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)	Δt_{mb}	T (s)
$\Delta t_{13,7}$	0.13	$\Delta t_{31,29}$	0.00	$\Delta t_{47,51}$	0.20	$\Delta t_{17,63}$	0.79	$\Delta t_{58,70}$	0.59	$\Delta t_{73,76}$	0.68
$\Delta t_{43,7}$	0.24	$\Delta t_{71,29}$	0.00	$\Delta t_{48,51}$	0.04	$\Delta t_{18,63}$	0.73	$\Delta t_{11,56}$	0.16	$\Delta t_{74,76}$	0.30
$\Delta t_{51,7}$	0.15	$\Delta t_{33,30}$	0.00	$\Delta t_{49,52}$	0.10	$\Delta t_{19,63}$	0.43	$\Delta t_{38,42}$	0.22	$\Delta t_{75,77}$	0.09
$\Delta t_{10,8}$	0.19	$\Delta t_{74,30}$	0.00	$\Delta t_{11,53}$	0.27	$\Delta t_{59,63}$	0.62	$\Delta t_{28,15}$	0.00	$\Delta t_{76,78}$	0.08
$\Delta t_{11,8}$	0.17	$\Delta t_{33,31}$	0.22	$\Delta t_{12,53}$	0.59	$\Delta t_{61,64}$	0.00	$\Delta t_{12,86}$	0.70	$\Delta t_{77,78}$	0.00
$\Delta t_{12,8}$	0.48	$\Delta t_{73,31}$	0.35	$\Delta t_{13,53}$	0.19	$\Delta t_{63,65}$	0.20	$\Delta t_{56,70}$	0.31	$\Delta t_{37,79}$	0.00
$\Delta t_{13,8}$	0.09	$\Delta t_{34,32}$	0.26	$\Delta t_{43,53}$	0.30	$\Delta t_{32,66}$	0.09	$\Delta t_{10,56}$	0.18	$\Delta t_{78,79}$	0.38
$\Delta t_{43,8}$	0.20	$\Delta t_{35,33}$	0.35	$\Delta t_{50,53}$	0.57	$\Delta t_{62,66}$	0.04	$\Delta t_{83,41}$	0.47	$\Delta t_{36,80}$	0.69
$\Delta t_{50,8}$	0.46	$\Delta t_{77,33}$	0.34	$\Delta t_{51,53}$	0.21	$\Delta t_{64,66}$	0.34	$\Delta t_{27,15}$	0.00	$\Delta t_{78,80}$	0.34
$\Delta t_{53,9}$	0.26	$\Delta t_{35,34}$	0.71	$\Delta t_{10,54}$	0.00	$\Delta t_{66,67}$	0.00	$\Delta t_{11,86}$	0.38	$\Delta t_{85,81}$	0.00
$\Delta t_{52,10}$	0.16	$\Delta t_{76,34}$	0.40	$\Delta t_{12,54}$	0.00	$\Delta t_{67,68}$	0.21	$\Delta t_{30,70}$	0.77	$\Delta t_{86,81}$	0.00
$\Delta t_{42,11}$	0.09	$\Delta t_{36,35}$	0.80	$\Delta t_{13,54}$	0.00	$\Delta t_{27,69}$	0.08	$\Delta t_{51,55}$	0.00	$\Delta t_{40,82}$	0.00
$\Delta t_{14,12}$	0.29	$\Delta t_{37,35}$	0.54	$\Delta t_{43,54}$	0.00	$\Delta t_{28,69}$	0.51	$\Delta t_{84,40}$	0.55	$\Delta t_{80,82}$	0.00
$\Delta t_{15,12}$	0.19	$\Delta t_{39,37}$	0.08	$\Delta t_{50,54}$	0.00	$\Delta t_{29,69}$	0.51	$\Delta t_{26,15}$	0.00	$\Delta t_{81,82}$	0.00
$\Delta t_{26,13}$	0.13	$\Delta t_{40,37}$	0.13	$\Delta t_{51,54}$	0.00	$\Delta t_{30,69}$	0.51	$\Delta t_{10,86}$	0.37	$\Delta t_{39,83}$	0.00
$\Delta t_{27,13}$	0.06	$\Delta t_{81,37}$	0.17	$\Delta t_{10,55}$	0.00	$\Delta t_{56,69}$	0.05	$\Delta t_{29,70}$	0.76	$\Delta t_{80,83}$	0.00
$\Delta t_{28,13}$	0.49	$\Delta t_{39,38}$	1.00	$\Delta t_{11,55}$	0.00	$\Delta t_{58,69}$	0.33	$\Delta t_{50,55}$	0.00	$\Delta t_{81,83}$	0.00
$\Delta t_{29,13}$	0.49	$\Delta t_{40,38}$	1.12	$\Delta t_{13,55}$	0.00	$\Delta t_{26,70}$	0.43	$\Delta t_{41,39}$	0.68	$\Delta t_{82,84}$	0.17
$\Delta t_{30,13}$	0.49	$\Delta t_{80,38}$	0.71	$\Delta t_{43,55}$	0.00	$\Delta t_{28,70}$	0.76	$\Delta t_{58,13}$	0.31	$\Delta t_{54,85}$	0.29

TABLE 4. Compartion beetwen proposed OF and OF of Razavi et al. [11]

	(Case 1) β =100 $\alpha_1 = 1$ $\alpha_2 = 100$	(Case 2) β =1000 $\alpha_1 = 10$ $\alpha_2 = 5$	(Case 3) β =500 $\alpha_1 = 1$ $\alpha_2 = 1$	(Case 4) New OF
$\sum \Delta t_{mb}$	125.011	115.4904	110.3416	72.36
$\sum TMS$	34.45	20.75	28.1	10.3

7. CONCLUSION

In this paper, a new flexible method for overcurrent relays coordination has been proposed. In this method, a new useful OF has been introduced which is not dependent on the value of time differences of the relay pairs. The proposed OF of this paper, is dependent on the number of the mis-coordination. The proposed OF is solved by GA. This proposed method was tested on 6-bus and 30-bus IEEE case studies. The results of the simulations show the flexibility of the proposed OF and the best reliability because of the smaller $\sum TMS$ and $\sum \Delta t_{mb}$ compared to the conventional coordination methods.

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A Novel Objective Function for Directional Overcurrent Relays Coordination

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چکیده

رله های جریان زیاد جهت دار، بطور وسیعی در شبکه های قدرت مورد استفاده قرار می گیرند. برای هماهنگی بهینه رله های جریان زیاد جهت دار روش های متفاوتی پیشنهاد شده است. یکی از روش های مرسوم برای هماهنگی این رله ها، استفاده از تکنیک های هوش مصنوعی مانند الگوریتم ژنتیک می باشد.در این مقاله، روش جدیدی برای هماهنگی رله های جریان زیاد پیشنهاد شده است. در این روش پیشنهادی تابع هدفی جدید معرفی می شود. تابع هدف پیشنهادی جدید می تواند ناهماهنگی ها میان زوج رله ها را حذف کرده و موجب هماهنگی بهتری میان آن ها شود. تابع هدف پیشنهادی در شبکه های 6 و 30 باسه بکار گرفته شده است.

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