

Optimal Combined Overcurrent and Distance Relays Coordination Using a New Genetic Algorithm Method

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Abstract—Several optimal coordination of overcurrent relays have been done in the past by using linear programming such as simplex, two-phase simplex and dual simplex and also intelligent optimization techniques such as genetic algorithm (GA) techniques. In this paper, a powerful optimal coordination method based on GA is introduced. The objective function (OF) is developed in a such way that in addition to the coordination of overcurrent relays, the coordination of overcurrent and distance relays is also achieved. In other words, the novelty of the paper is the modification of the existing objective function of GA, by adding a new term to OF to fulfill the coordination of both overcurrent and distance relays. The method is applied to two power network systems and from the obtained results it is revealed that the new method is efficient and accurate.

Index Terms—Overcurrent Relay, Distance Relay, Optimal Coordination, Genetic Algorithm.

I. INTRODUCTION

Overcurrent (OC) and distance relays are commonly used in transmission and subtransmission protection systems [1]. To consider comprehensive coordination, all the distance and overcurrent relays when one of them is considered to be the main relay and the other is backup, must be coordinated.

When both main and backup (M/B) relays are distance relays, the impedances of the three zones of relays are calculated considering all conditions of the interconnected network such as connection and disconnection of generators and lines [2].

For overcurrent relays the optimal coordination has been performed using linear programming techniques, including simplex [3], two-phase simplex [4] and dual simplex [5] methods. In reference [6] also, optimal solution is made by constraints only. The disadvantage of the above optimization techniques is that they are based on an initial guess and may be trapped in the local minimum values [7]. Intelligent optimization techniques such as genetic algorithm (GA) can adjust the setting of the relays without the mentioned difficulties.

In these methods the constraints are included in objective function [7]. The optimal coordination in [8] has been done

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** Department of Electrical Engineering, Tafresh University, Tafresh, Iran. by a method based on GA and in [9] by an evolutionary algorithm. These methods have two problems. One of them is

miscoordination and the other is not having the solution for relays with both discrete and continuous time setting multipliers (TSMs). In [7] the mentioned problems have been solved.

In the cases that the distance relay is considered to be main and the overcurrent one is the backup relay, it is necessary to find the critical fault locations. The critical fault locations are the locations at which, the discrimination time (Δt) between the backup and main relays is at its minimum. The coordination is made based on the constraints derived from the values of Δt for critical fault locations.

In [1] & [10] coordination of overcurrent, distance and circuit breaker failure (CBF) relays has been done using linear programming techniques.

In this paper a new optimal coordination method based on GA is introduced. The objective function (OF) is developed by adding a new term that is the constraint related to the coordination of the distance and overcurrent relays when a fault occurs at the critical locations.

II. REVIEW OF RECENTLY DEVELOPED GA FOR OPTIMAL OC RELAY COORDINATION

GA like all other optimization methods needs initial values which are chosen randomly. TSMs of relays are the unknown quantities in the optimization problem. Therefore, the TSMs with respect to the number of relays are considered as the genomes of the chromosomes in GA. In other words, some TSMs' sets, i.e. $(TSM_1, TSM_2, TSM_3, \dots, TSM_n)$, $(TSM'_1, TSM'_2, TSM'_3, \dots, TSM'_n)$, ... belonging to relay set $(R_1, R_2, R_3, \dots, R_n)$ are initially randomly selected. The structure of the chromosome is shown in Fig. 1. The number of TSMs' sets is referred as the population size. Then, after each iteration, the new TSMs' sets belong to relays R_1 to R_n are given to the algorithm. The process is terminated when the number of iterations becomes equal to the generation size [7].

To evaluate the goodness of each chromosome, it is essential to define an OF. The purpose of optimization is to minimize the OF. The chromosomes are evaluated regarding the OF and the chromosomes which have more effectiveness

R1	R2	R3	...	Rn
TSM1	TSM2	TSM3	...	TSMn

Fig. 1. Structure of Chromosome

will be used for producing new generation of chromosomes. Mutation in each iteration will cause the algorithm not to be trapped in local minima.

After a fixed number of generations, the process will be terminated. Increasing the number of generations will lead to the better solutions and on the other hand, will increase the run time. The required number of generation varies from system to system depending on the system complexity and the size of population [7].

III. PROBLEM STATEMENT

As mentioned in section I, relay coordination must be done for the cases below:

- 1) Coordination of overcurrent relays with overcurrent ones.
- 2) Coordination of distance relays with distance ones.
- 3) Coordination of distance relays with overcurrent ones.

As mentioned in section II, the first one has been made in the frame of GA. In this research, the optimal coordination is done in such a way that all above three cases are satisfied. For the third case it is assumed that the distance relay is the main relay and the overcurrent relay is the backup. This assumption is a routine protection scheme in power networks. In interconnected networks, an overcurrent relay can be the backup of some other distance relays. Therefore, TSMs of all overcurrent relays and the operating time of the second zone of all distance relays must be determined for critical conditions. The critical condition is defined and shown in Fig. 2. An overcurrent relay is located at B and a distance one at M. The overcurrent relay is the backup of distance relay. When a fault occurs at F, the discrimination time between the operating time of overcurrent relay and that of the distance one is minimum. Therefore, the expression below must be appointed at the critical fault location, F.

$$t_b(F) - t_{z2} > CTI \quad (1)$$

Where $t_b(F)$ is the operating time of overcurrent relay at F, t_{z2} is the operating time of the second zone of the distance relay and CTI is the coordination time interval.

As mentioned above, coordination between overcurrent and distance relays must be made by adding a new constraint to OF in GA. The details of this method are described in section IV.

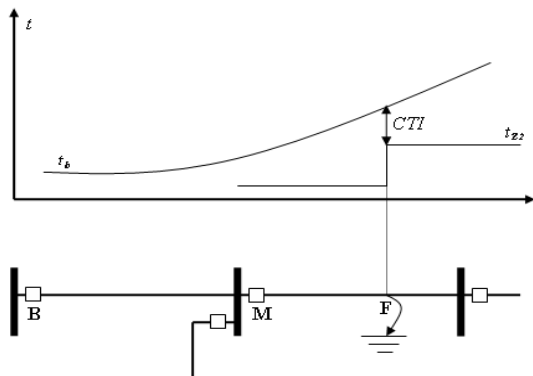


Fig. 2. Critical fault location in coordination between overcurrent and distance relays

IV. NEW METHOD

In the new method, the OF is formulated as:

$$OF = \alpha_1 \times \sum_{i=1}^N (t_i)^2 + \beta_2 \times \sum_{k_1=1}^{P_1} \left(\Delta t_{mb|k_1} - \left| \Delta t_{mb|k_1} \right| \right)^2 + \beta_3 \times \sum_{k_2=1}^{P_2} \left(\Delta t_{mbDISOC|k_2} - \left| \Delta t_{mbDISOC|k_2} \right| \right)^2 \quad (2)$$

Where $\alpha_1, \beta_2, \beta_3$ are the weighting factors, i is the number of overcurrent relays that changes from 1 to N , k_1 is the number of main and backup overcurrent relays that changes from 1 to P_1 , k_2 is the number of main distance and backup overcurrent relays changing from 1 to P_2 , $\Delta t_{mb|k_1}$ is the discrimination time between the main and backup overcurrent relays. $\Delta t_{mbDISOC|k_2}$ is the discrimination time between the main distance and backup overcurrent relays which is obtained from the equation below:

$$\Delta t_{mbDISOC|k_2} = t_{bOC|k_2} - t_{mDIS|k_2} - CTI \quad (3)$$

Where $t_{bOC|k_2}$ is the operating time of backup overcurrent relay for the fault at the end of the first zone of main distance relay (critical fault locations), $t_{mDIS|k_2}$ is the operating time of the second zone of main distance relay and CTI is the coordination time interval that is equal to 0.3(sec).

Two first terms of (2) are the same as the OF in [7]. The third term is added to OF to fulfill the requirement of overcurrent and distance relays. To describe the role of this new term, assume that $\Delta t_{mbDISOC|k_2}$ is positive (fully coordinated), then the relative term in (2) becomes zero and OF also has a small value. However if $\Delta t_{mbDISOC|k_2}$ is negative (miscoordination) the mentioned term will be equal to $2\beta_3 \times \Delta t_{mbDISOC|k_2}$ and obviously for positive values of β_3 the new term will have large values. Then, based on the concept of the evaluation and selection, those values that have more optimal OF values (less value) in the chromosomes, are granted more opportunities to be selected for the next iteration.

The flowchart of new method is shown in Fig. 3. At first, after entering the network data, the impedances of the first, second and the third zones of distance relays are calculated. The operating time of the second and third zones of distance relays are selected respectively 0.3(sec) and 0.6(sec). Then, the short circuit currents for the faults exactly close to the circuit breaker (CB) of the main overcurrent relays and for the faults at the end of the first zone of main distance relays (critical fault locations) are calculated. After that, GA

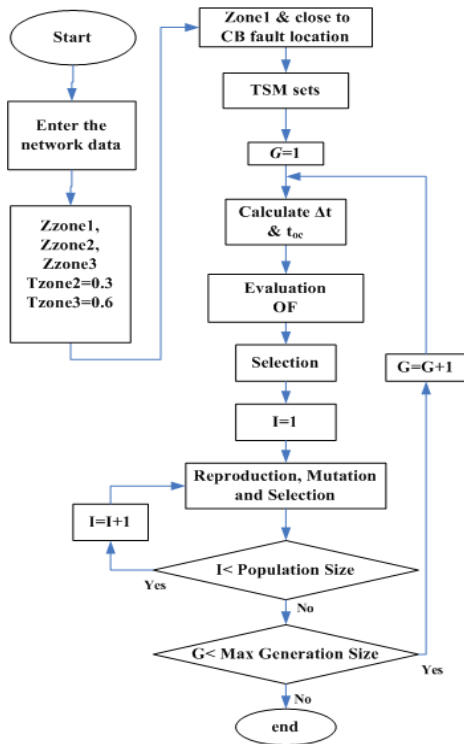


Fig. 3. Flowchart of new method

will start. $t_i, \Delta t_{mb|k_1}$ and $\Delta t_{mbDISOC|k_2}$ are calculated short circuit currents. The other steps of GA are described in section II and in [7].

V. TEST CASES

The new method proposed in this paper, is applied to two power networks:

1) Case I

This network consists of 6 buses, 7 lines, 2 transformers and 2 generators and is shown in Fig. 4. The information data of the network is given in Tables I, II and III. R (pu) and X (pu) are based on 100 MVA and 150 kV. It is assumed that all the lines are protected by both overcurrent and distance relays. All distance relays have moho characteristic.

It should be noted that for finding the overcurrent relays operating times, a more common formula for approximating the relay characteristic is used [11]:

$$t = TSM \left(\frac{K}{M^a - 1} + L \right) \quad (4)$$

Where M is the ratio of short circuit current (I_{sc}) to the pickup current (I_b) of relay ($M = I_{sc} / I_b$), t is the relay operating time and K, α, L are the scalar quantities. By the values of 0.14, 0.02 and 0 respectively for K, α and L the normal inverse characteristic will be obtained for overcurrent relays that are used in this paper[11].

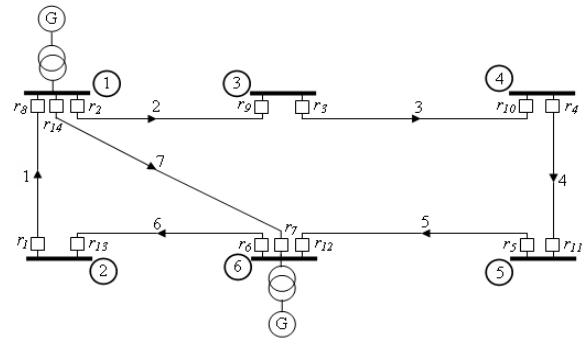


Fig. 4. Sample network

It is also assumed that TSMs of the relays are continuous and TSMs vary from 0 to 1.

The control parameters of GA are listed in Table IV. To compose OF, the values of $\alpha_1, \beta_2, \beta_3$ are mentioned as below:

$$\alpha_1 = 1, \beta_2 = 200, \beta_3 = 200 \quad (5)$$

By applying the GA with selected values, the output results for TSMs are obtained. These TSMs are given in Table V. The operating time of the second and third zones of distance relays are selected respectively 0.3(sec) and 0.6(sec).

From the second column of Table V, it can be seen that the values of TSMs are small and they are in valid range, i.e. between 0.05 and 1.

Discrimination time between M/B overcurrent relays and discrimination time between the main distance and backup overcurrent relays are given in Table VI. All $\Delta t_{mb|k_1}$ and $\Delta t_{mbDISOC|k_2}$ values are positive and most of them are small. That means, the relay settings are accurate, fit and have not any miscoordination.

TABLE I
LINES' INFORMATION OF SAMPLE NETWORK

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 II
GENERATORS' INFORMATION OF SAMPLE NETWORK

Generator	X (pu)	V (kV)
	0.1	10

TABLE III
TRANSFORMERS' INFORMATION OF SAMPLE NETWORK

Transformer	X (pu)
	0.02666

TABLE IV
CONTROL PARAMETERS OF GA

GA Parameters	Value
Number of Generations	3000
Size of population	150
Initial Population	Random
Mutation	1

TABLE V
TSMs OF OVERCURRENT RELAYS, SAMPLE 1

Relay Numbers	TSM
1	0.091
2	0.183
3	0.122
4	0.05
5	0.05
6	0.194
7	0.083
8	0.147
9	0.05
10	0.110
11	0.126
12	0.255
13	0.05
14	0.101

2) Case 2

This network is IEEE 30 buses system which can be considered as a meshed subtransmission /distribution system. The network consists of 30 buses (132 and 33 kV buses), 37 lines, 6 Generators, 4 transformers and 86 overcurrent relays and 86 distance relays. Fig. 5. shows the system. The generator, transmission lines and transformer information are given in [12].

Again GA with selected values of α_1 , β_2 and β_3 given in (5) and GA parameters given in Table IV, has been applied to the network of Fig. 5. The average value of TSMs is 0.114(sec) that is small and within the range. The summary of the discrimination times are given in Table VII. The detailed relative information of all relays is not given because of space limitation.

The first column of Table VII consist of $\Delta t_{mb|k_1|}$ and $\Delta t_{mbDISOC|k_2|}$ greater than zero (fully coordination), and $\Delta t_{mb|k_1|}$ and $\Delta t_{mbDISOC|k_2|}$ smaller than zero (miscordination). The values of the second and the third columns are respectively the numbers of M/B relays and the average of the related discrimination times. It can be seen that most of the $\Delta t_{mb|k_1|}$ and $\Delta t_{mbDISOC|k_2|}$ have positive values and the related M/B relays are fully coordinated. Only a few numbers of the $\Delta t_{mb|k_1|}$ and $\Delta t_{mbDISOC|k_2|}$ have negative values that are very small. That means, we almost have no miscordination.

VI. CONCLUSION

A new computer program for distance and overcurrent relay coordination based on GA has been developed. In the proposed method, the OF has been modified by adding a new term which presents the constraint for distance and overcurrent relay coordination. The computer program has been tested on two power system networks. From the obtained results, it has been shown that the new method is successful and accurate.

TABLE VI
DISCRIMINATION TIMES OF M/B RELAYS, CASE 1

Main Relay	Backup Relay	$\Delta t_{mb k_1 }$ (sec)	$\Delta t_{mbDISOC k_2 }$ (sec)
14	1	0.6351	0.0000
3	2	0.0023	0.2613
4	3	0.1067	0.0015
5	4	0.1000	0.0000
1	6	0.0035	0.2109
2	7	0.1689	0.1691
8	7	0.2736	0.0024
13	8	0.0030	0.0523
9	10	0.0026	0.0000
10	11	0.0037	0.0171
11	12	0.0021	0.2024
7	13	0.0000	0.0000
6	14	0.2781	0.0000
12	14	0.1443	0.2201
2	1	0.1362	0.0000
12	13	0.0110	0.0000

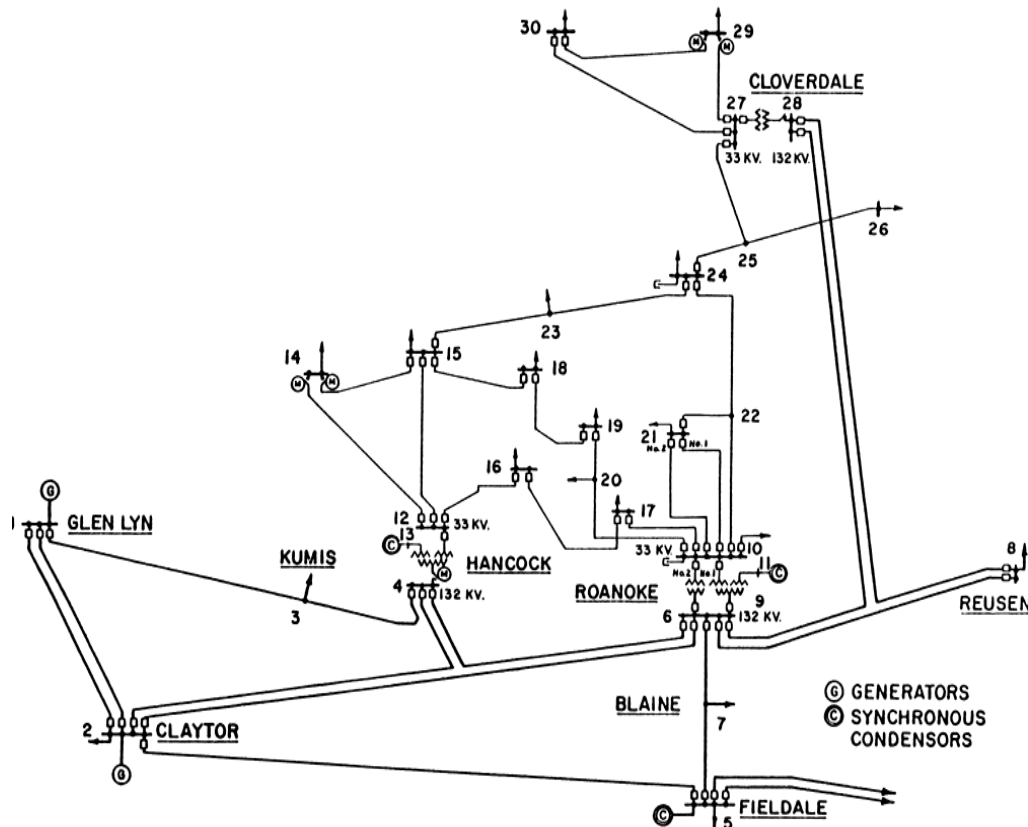


Fig. 5. IEEE 30 Buses Network

TABLE VII
DISCRIMINATION TIMES OF M/B RELAYS, CASE 2

Δt	Numbers of M/B Relays	Average Value
$\Delta t_{mb k_1 }(\text{sec}) > 0$	226	0.1051
$\Delta t_{mb k_1 }(\text{sec}) < 0$	2	-0.0023
$\Delta t_{mbDISOC k_2 }(\text{sec}) > 0$	225	0.0625
$\Delta t_{mbDISOC k_2 }(\text{sec}) < 0$	3	-0.0019

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