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A New Genetic Algorithm Method for Optimal Coordination of Overcurrent and Earth Fault Relays in Networks with Different Levels of Voltages

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***Abstract*-- In this paper, a new genetic algorithm (GA) method is presented to solve the optimization problem in coordination of overcurrent and earth fault relays. In addition to optimal coordination of overcurrent relays, earth fault relays are also coordinated by GA, considering critical fault condition for the relays located in two sides of network's transformers. The objective function is developed by adding new terms that are the constraints related to the coordination of overcurrent and earth fault relays in critical fault conditions considering different winding arrangements of transformers. The paper concluded by the results of a study carried out on a sample power network. The results demonstrate that the method can obtain feasible and effective solutions and, it is a promising approach for optimal coordination in practical power networks.**

***Index Terms*-- Coordination, Earth Fault Relay, Genetic Algorithm, Overcurrent Relay.**

I. Introduction

OVERCURRENT and earth fault relays are commonly used for protection of power systems. In many references the optimal coordination of overcurrent relays has been performed using linear programming techniques, including simplex [1], two-phase simplex [2] and dual simplex [3] methods. In reference [4] 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 [5]. 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 (OF) [5]. The optimal coordination in reference [6] has been done by a method based on GA and in reference [7] 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 reference [5] the mentioned problems have been solved.

In this paper, in addition to overcurrent relays, earth fault relays have been coordinated optimally using a new GA method. The OF is improved by adding some new terms that are the constraints related to the coordination of overcurrent and earth fault relays for critical fault conditions. By studying different winding arrangements of the network's transformers, the critical fault type will be determined for coordination of the relays which are located at both sides of the mentioned transformers.

II. Review of GA for Optimal Relay Coordination

GA like all other optimization methods needs initial values which are chosen randomly. TSMs of overcurrent and earth fault relays are the unknown quantities in the optimization problem. Therefore, the TSMs in 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, …, TSM_n), (TSM'_1, TSM'_2, TSM'_3, …, TSM'_n), … belonging to relay set (R_1, R_2, R_3, …, R_n) are initially randomly selected. 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. 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 will be used for producing new generation of chromosomes [5], [8], [9].

Mutation in each iteration will cause the algorithm not to trap in local minimums. 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

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generation varies from system to system depending on the system complexity and the size of population [5], [8], [9].

III. Relay Coordination in Networks With Different Levels of Voltages

For coordination of overcurrent and earth fault relays in the networks with two levels of voltages, it should be specified that which fault type (i.e. three phase, two phase or one phase to ground) causes the critical condition. When the relays are coordinated for the critical fault types, it can be said that they are coordinated for other conditions. In the networks with one level of voltage, three phase fault and one phase to ground fault are respectively the critical fault types for coordination of overcurrent and earth fault relays. In the networks with two levels of voltages, the winding arrangement and the phasor group of the transformers must be studied to specify the critical fault type for coordination of the relays located at the sides of those transformers. In the next sections, faults in a transformer with Y-D winding arrangement (that is a common transformer winding arrangement in the power networks) will be analyzed.

A. One Phase to Ground Fault

Consider a three phase transformer with delta winding arrangement at its primary side which is connected to the source and grounded wye winding arrangement at its secondary side. A one phase to ground fault occurs at the *r* phase terminal of wye side of the transformer. Line currents at the wye side can be obtained as below:

$$I_r = I_F = I_{1r} + I_{2r} + I_{0r} \qquad (1)$$
$$I_s = I_t = 0$$

Positive, negative and zero sequence currents at wye side of the transformer are shown in Fig. 1. At delta side, zero sequence current is zero. By considering phasor group of *YD1* for the transformer the positive sequence current at delta side turns 30° clockwise and the negative sequence current at delta side turns 30° anticlockwise.

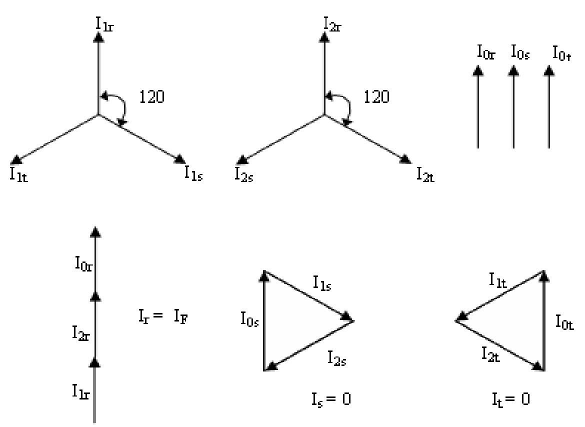

Fig. 1. Positive, negative and zero sequence currents at wye side

Therefore, the one phase to ground fault at the wye side changes to the two phase fault at the delta side which is shown in Fig. 2 and Fig.3. So, it is not necessary to coordinate the earth fault relays located at two sides of this transformer [10], but earth fault relay at wye side must be coordinated with overcurrent relay at delta side of the transformer [11].

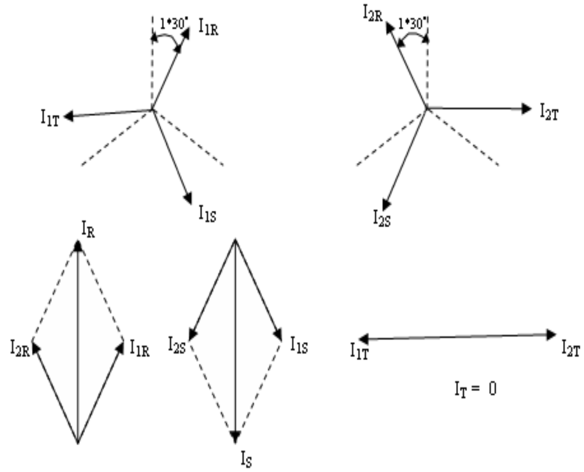

Fig. 2. Positive and negative sequence current at delta side

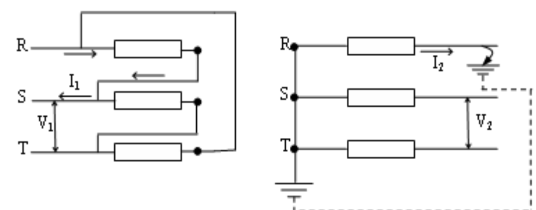

Fig. 3. One phase to ground fault in transformer with Y-D winding arrangement

B. Two Phase and Three Phase Fault

As shown in Fig. 4 and Fig. 5 the critical fault type for overcurrent relays at wye side of the transformer with Y-D winding arrangement is two phase fault and the critical fault type for overcurrent relays at delta side is three phase fault. The reason is that the value of two phase fault current in wye side is about 86.6% of the three phase current value and causes a current equal to the three phase current at the delta side of the transformer.

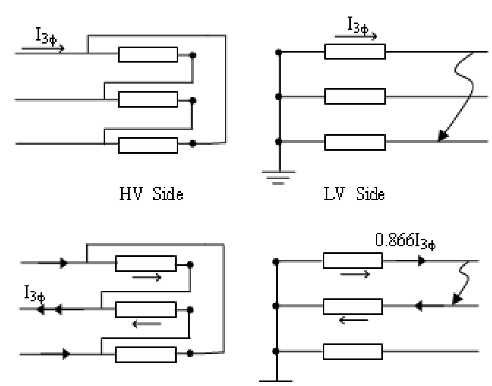

Fig. 4. Two phase and three phase fault at wye side

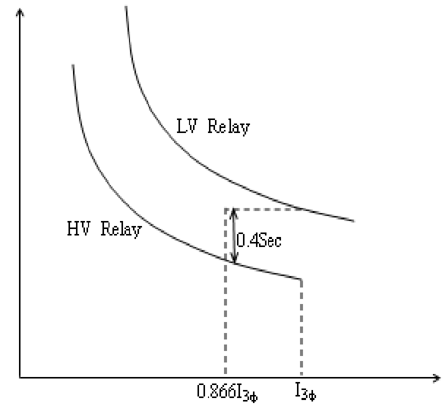

Fig. 5. Two phase and three phase fault currents at wye side

IV. New Method

In the new method, the OF is formulated as:

$$
\begin{aligned}
O.F &= \alpha_1 \times \sum_{i=1}^{N} (t_i)^2 + \alpha_2 \times \sum_{j=1}^{M} (t_j)^2 \\
&+ \beta_1 \times \sum_{k_1=1}^{P_1} \left(\Delta t_{mb|k_1|} - \left| \Delta t_{mb|k_1|} \right| \right)^2 \\
&+ \beta_2 \times \sum_{k_2=1}^{P_2} \left(\Delta t_{mb|k_2|} - \left| \Delta t_{mb|k_2|} \right| \right)^2 \\
&+ \gamma_1 \times \sum_{l_1=1}^{Q_1} \left(\Delta t_{mb|l_1|} - \left| \Delta t_{mb|l_1|} \right| \right)^2 \\
&+ \gamma_2 \times \sum_{l_2=1}^{Q_2} \left(\Delta t_{mb|l_2|} - \left| \Delta t_{mb|l_2|} \right| \right)^2
\end{aligned} \quad (2)
$$

Where $\alpha_1, \alpha_2, \beta_1, \beta_2, \gamma_1, \gamma_2$ are the weighting factors, i is the number of overcurrent relays changes from 1 to N, j is the number of earth fault relays changes from 1 to M, k_1 is the number of main and backup overcurrent relays changes from 1 to P_1, k_2 is the number of main and backup earth fault relays changes from 1 to P_2, Q_1 is the number of main and backup overcurrent relays that located at the sides of transformer and two phase fault is their critical fault type, Q_2 is the number of main and backup overcurrent and earth fault relays at the sides of transformer that their coordination is necessary according to the transformer winding arrangement. l_1 is the number of main and backup overcurrent relays changes from 1 to Q_1, l_2 is the number of main and backup overcurrent and earth fault relays changes from 1 to Q_2. Δt_{mb} is the discrimination time between the main and backup relays which is obtained from the equation below:

$$\Delta t_{mb} = t_b - t_m - CTI' \quad (3)$$

Where t_b is the operating time of backup relay, t_m is the operating time of main relay and CTI' is the coordination time interval that is equal to 0.3(sec). The first and the second terms of (2) are the overcurrent and earth fault relays operating times and the other terms are the coordination constraints. It can be seen that some new terms are added to OF in [5] to fulfill the optimal coordination of overcurrent and earth fault relays. The first and the third terms of (2) are the same as OF in [5] and the second and forth to sixth terms are added for coordination of earth fault and overcurrent relays in the networks with different levels of voltages. These new terms are the novelity of this paper. It should be noted that normally inverse characteristic has been assumed for overcurrent and earth fault relays to obtain their operating times (t_i, t_j).

V. Test Case

The new method proposed in this paper, is applied to a sample power network shown in Fig. 6. This network consists of 8 buses, 7 lines, 2 Yn-D transformers and 2 generators. 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 earth fault relays.

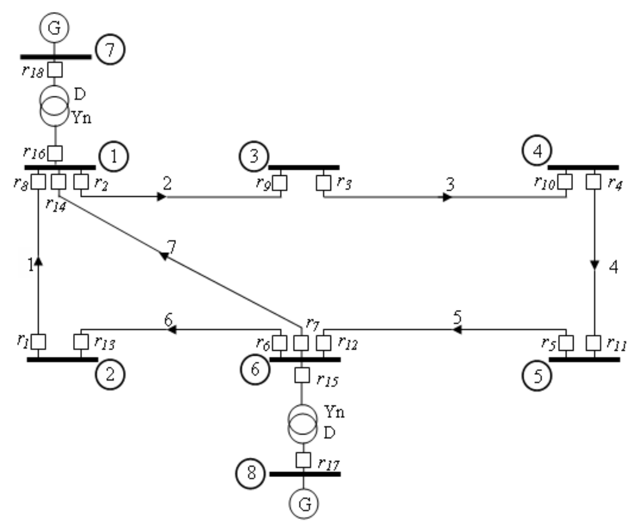

Fig. 6. Sample network

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)	Winding Arrangement
	0.02666	Yn-D

It should be noted that for finding the overcurrent and earth fault relays operating times, a more common formula for approximating the relay characteristic is used [5]:

$$\frac{t}{TSM} = a_0 + \frac{a_1}{(M-1)} + \frac{a_2}{(M-1)^2} + \frac{a_3}{(M-1)^3} + \cdots \quad (4)$$

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 $a_0, a_1, a_2, a_3, ...$ are the scalar quantities and for overcurrent and earth fault relays with normal inverse characteristics that are used in this paper, these quantities are [5]:

$$\begin{aligned} a_0 &= 1.98772 \\ a_1 &= 8.57922 \\ a_2 &= -0.46129 \\ a_3 &= 0.0364465 \\ a_4 &= -0.000319901 \end{aligned} \quad (5)$$

It is also assumed that TSMs of the relays are discrete. TSMs overcurrent relays vary from 0.05 to 1 in steps of 0.05 and TSMs earth fault relays vary from 0.1 to 0.4 in steps of 0.1.

The control parameters of GA are listed in Table IV. To compose OF, the values of $\alpha_1, \alpha_2, \beta_1, \beta_2, \gamma_1, \gamma_2$ are mentioned as below:

$$\alpha_1 = 1, \alpha_2 = 1, \beta_1 = 100, \beta_2 = 100, \gamma_1 = 100, \gamma_2 = 100 \quad (6)$$

TABLE IV
CONTROL PARAMETERS OF GA

GA Parameters	Value
Number of Generations	4000
Size of population	200
Initial Population	Random
Mutation	1

By applying the GA with selected values, the output results for TSMs and operating times of overcurrent and earth fault relays are obtained. These TSMs and operatring times are given in Table V.

From the second and third columns 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 for overcurrent relays and between 0.1 and 0.4 for earth fault relays.

In the forth column of Table V, the operating times of overcurrent relays for the three phase fault close to the relays are given. In the fifth column of Table V, the operating times of earth fault relays for the one phase to ground fault close to the relays are given. It can be seen that most of the operating times have small values.

The discrimination times between M/B overcurrent and earth fault relays are given in Table VI. The type of mai and backup relays are shown in third column.

From the forth column of Table VI, it can be seen that all of the Δt_{mb} are positive and most of them are small. That means, the relay settings are accurate, fit and have not any miscoordination. For example, for the main overcurrent relay number 4 and backup overcurrent relay number 3, Δt_{mb} is equal to 0.0009 (sec). As CTI' is assumed 0.3 (sec), relay number 3 will operates 0.3009 (sec) later than relay number 4 for the fault close to the main relay.

In Table VI, only in 4 cases of 33, the operating times of backup relays are 0.6(sec) to 0.7(sec) more than the operating times of main relays. In the other cases, the discrimination times between M/B relays are about 0.3(sec).

VI. CONCLUSION

A new computer program for overcurrent and earth fault relays coordination based on GA has been developed. In the proposed method, the OF has been modified by adding some new terms which presents the constraint for overcurrent and earth fault relays coordination in the networks with different levels of voltage. The computer program has been tested on a sample power network. From the obtained results, it has been shown that the new method is successful and accurate.

TABLE V
TSMS OF OVERCURRENT AND EARTH FAULT RELAYS

Relay numbers	TSMs of overcurrent relays	TSMs of earth fault relays	Operating times of overcurrent relays(sec)	Operating times of earth fault relays(sec)
1	0.05	0.1	0.2010	0.1064
2	0.2	0.4	0.6879	0.8068
3	0.15	0.3	0.4851	0.5863
4	0.05	0.2	0.3463	0.3491
5	0.05	0.1	0.4039	0.1170
6	0.15	0.2	0.4299	0.2908
7	0.1	0.2	0.2855	0.3428
8	0.15	0.2	0.4507	0.3888
9	0.05	0.1	0.3646	0.1155
10	0.1	0.2	0.4206	0.3500
11	0.15	0.3	0.5371	0.5766
12	0.25	0.4	0.7719	0.8011
13	0.05	0.1	0.2466	0.1086
14	0.05	0.2	0.3037	0.3274
15	0.05	0.1	0.1741	0.1035
16	0.05	0.1	0.2049	0.1049
17	0.1	0.4	0.2403	1.0355
18	0.1	0.4	0.2254	1.0446

TABLE VI
DISCRIMINATION TIME OF OVERCURRENT AND EARTH FAULT RELAYS

Main relay	Backup relay	Type of main and backup relays	Δt_{mb} (sec)
16	1	O/C-O/C	0.3683
3	2	O/C-O/C	0.0028
4	3	O/C-O/C	0.0009
5	4	O/C-O/C	0.0352
2	7	O/C-O/C	0.0010
16	7	O/C-O/C	0.3650
13	8	O/C-O/C	0.0035
9	10	O/C-O/C	0.0018
10	11	O/C-O/C	0.0015
11	12	O/C-O/C	0.0007
15	14	O/C-O/C	0.0020
6	17	O/C-O/C	0.1403
7	17	O/C-O/C	0.0035
12	17	O/C-O/C	0.0007
2	18	O/C-O/C	0.0083
8	18	O/C-O/C	0.0156
14	18	O/C-O/C	0.0084
3	2	E/F-E/F	0.0006
4	3	E/F-E/F	0.0431
5	4	E/F-E/F	0.0393
1	6	E/F-E/F	0.0353
16	7	E/F-E/F	0.0008
13	8	E/F-E/F	0.0030
9	10	E/F-E/F	0.0008
10	11	E/F-E/F	0.0447
11	12	E/F-E/F	0.0492
15	14	E/F-E/F	0.0527
6	17	E/F-O/C	0.0001
7	17	E/F-O/C	0.3663
12	17	E/F-O/C	0.4176
2	18	E/F-O/C	0.0505
8	18	E/F-O/C	0.0377
14	18	E/F-O/C	0.0395

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