A New Genetic Algorithm Method for Overcurrent Relays and Fuses Coordination

H. Askarian, R. Mohammadi, F. Razavi, M.Khoddami, H.Torkaman

Abstract— **For optimal co-ordination of overcurrent relays (O/C), linear programming techniques such as simplex, two-phase simplex and dual simplex are used. Another way of optimal coordination program is using artificial intelligent system such as GA (Genetic Algorithm). In this paper, a powerful optimal coordination method based on GA is problems of miscoordination and continuous or discrete TSM (Time Setting Multiplier) or TDS (Time Dial Setting).**

The way of including the fuses in coordination process is given. In other words a parameter which specified the type and size of fuses curves are taken into account in the GA.

The new approach is applied to a sample power system network and from the results it is revealed that the method is capable to solve the problem of miscoordination and consider both different types of O/C and different arrangements of fuses.

Index Terms— **Protection, Optimal Coordination, Relay Settings, Overcurrent Relays, Genetic Algorithm.**

I. Introduction

Directional overcurrent relays and fuses are the main components of power distribution system protection and are extensively used as an economical means for protecting the systems. The selection of fuses and relays appropriate settings of relays under various systems conditions play an important role in timely removal of the faulty section of power systems. The coordination of the protection devices is an important problem and includes: relay-relay, relay-fuse and fuse-fuse coordination.

Researchers have described various optimization methods to find the directional overcurrent relay settings [1], [2], [3], [4] and [5]. The traditional optimal coordination of overcurrent relays are commonly performed by linear programming techniques, including the simplex [2], [3], [6], two-phase simplex [7] and dual simplex methods [8] and some new method [9]. The traditional optimization techniques are based on an initial guess and may be trapped in the local minimum [10]. Since the problem of coordination has multi-optimum points, ordinary mathematical based optimization technique will fail. Intelligent optimization techniques such as Genetic Algorithm (GA) have come up which can adjust the settings of relays without such limitation.

C.W.So et. al. developed a method based on GA for optimal coordination [11]. C.W.So et. al. also developed Evolutionary Algorithm [12], [13] and [14]. These methods have two problems. One of them is miscoordination and another is discrete or continues TSM.

In references [15], [16] and [17] the coordination rules for fuses-fuse, fuse-relay, relay-fuse are discussed. However the combination of them in the whole network using optimization techniques is given.

In this paper, the existing GA is improved by adding a new expression the OF already exists in the mentioned literature, such that the miscoordination problems is solved. Also the new algorithm can handle both continues and discrete TSM's or TDS's. Fuses as small as overcurrent relays are taken into account. Because of the different size of fuses, it can be assumed the fuses to be similar to relays with discrete TSM.

II. Review of GA to Relay Coordination Application

This section is devoted to the review of the notation and concept of GA application to overcurrent relays coordination presented in references [11] to give a better understanding and coherency to this paper.

The flow diagram of the GA application to relay coordination is shown in Fig. 1.

The description of the flowchart is given below:

A. Initialization

The first “Parents“ chromosome pool should be generated by creating several sets of relay settings randomly such that all sets of the relay settings totally satisfy all the constraints. Each set of relays setting is packed into a chromosome. The key variable in the GA is the chromosome and it consists of all relay TSM's or TDS's. In other words some TSM’s sets i.e. (TSM1, TSM2, TSM3,…, TSMn) , (TSM1’, TSM2’, TSM3’,…, TSMn’),… belong to relay set ($R_1, R_2, R_3, \ldots, R_n$) are initially randomly selected. The number of TSM’s sets are referred as to population size. Then after each iteration the

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new TSM's belong to relays R_1 to R_2 are given to the algorithm.

Regarding the chromosomes of fuses, it consists of the fuse indices of all fuses.

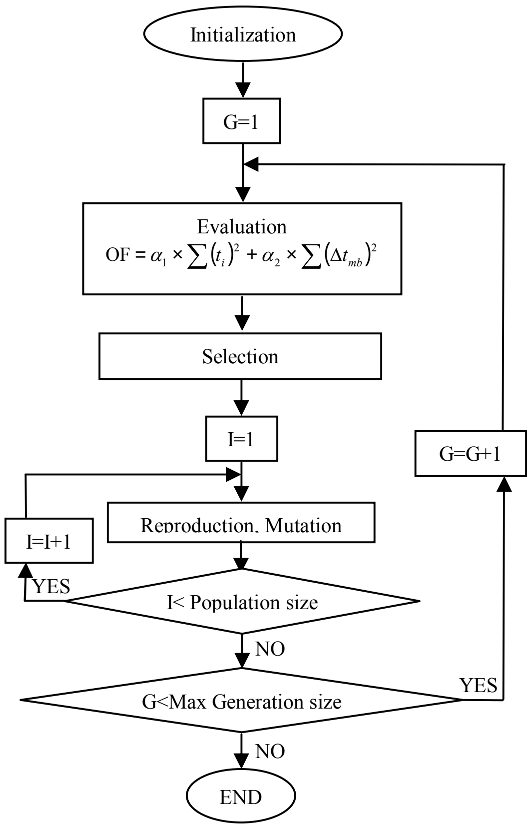

Fig. 1. Flow diagram of GA application to relay coordination.

B. Evaluation

To evaluate the goodness of each chromosome regarding the user preferences on the relay grading method, the OF value which is shown in the flowchart and will be described at the beginning of the next section is calculated to evaluate the effectiveness of the grading.

C. Selection, Reproduction and Mutation

In this part of the flowchart, the minimum value of OF in each stage is chosen.

The reproduction is responsible for producing offspring by the genetic operation crossover and mutation. Checking and evaluating of each new offspring satisfaction is required in order to form the "Children" chromosome pool. The new offspring indicate the new TSM's of relays.

The detail description of these parts of the flowchart is given in [11].

D. Selection from "Children" and "Parents" for next generation

It is common in optimization methods including GA to find that the OF value is extremely sensitive to one parameter, whilst large changes are still needed in another parameter to cause significant changes. To deal with such inequities, the OF value of each chromosome, i.e a set of relays TSM's of the "Parents" will be converted to a raw fitness, and then to a scaled fitness and finally to the expected frequency of selection as a parent.

E. Termination

The process will be terminated after a fixed number of generations. The required number of generations varies from system to system depending on the system complexity and the size of population.

III. Problem Statement

As mentioned in section 1, the existing intelligent method including GA can not solve two main problems. The problems are miscoordination and discrete or continuous TSM or TDS plus fuse consideration. The detail description of the problems is given below.

A. Miscoordination problem

The O.F. according to the existing method can be described as follow:

$$O.F = \alpha_1 \times \sum (t_{op})^2 + \alpha_2 \times \sum (\Delta t)^2 \tag{1}$$

Where α_1 is used to control the weighting of t_{op}, α_2 is used to control the weighting of Δt, t_{op} is relay operating time and Δt is the operation time difference for each pair of relays that is obtained from (2):

$$\Delta t = t_m - t_b - CTI \tag{2}$$

To describe this, Fig. 2 which is part of an interconnected network with three relays (R_1, R_2, R_3) is taken into account.

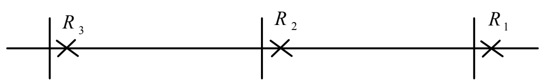

Fig. 2. A sample network.

R_2 and R_3 must be coordinated with R_1 and R_2 respectively. It is assumed that among many cases of the chromosome being processed, two following cases also exist;

Case 1) $\Delta t_{12} = -0.12, \Delta t_{23} = 0.14, \mathrm{OF} = 0.73$

Case 2) $\Delta t_{12} = +0.16, \Delta t_{23} = 0.22, \mathrm{OF} = 0.82$

Δt_{12} and Δt_{23} have been found from (2) for the relay pairs (1&2) and (2&3) respectively.

Obviously values 0.73s and 0.82s for OF are found from (2) with the given Δt_{12} and Δt_{23}. The existing GA methods select Case 1 as more optimal than the second, because of having lower value for OF, however by accurate consideration Case 2 must be selected. If Case 1 is chosen, because $\Delta t_{12} = -0.12$, miscoordination between relays 1 and 2 will exist. Therefore, (1) must be reformulated to a new formula in which this important factor to be inherently included. The detail of the new method will be described in section 4.

B. Discrete or continuous TSM or TDS

The ways of TSM or TDS consideration in the existing articles are described below:

1) For continuous TSM or TDS method, the solution finds the relays optimal coordination settings based on continuous consideration of TSM's or TDS's [12], [13] and [14]. However, if TSM's or TDS's of the relays are discrete, the final computer output of the coordination program for each relay is rounded to the next upper allowable discrete value of the relevant relay. Now if both TSM's or TDS's of a pair of P/B relays are rounded and the calculated TSM or TDS result of the computer program for a primary relay is far from the next allowable discrete value of TSM or TDS and the TSM or TDS of the backup is very close to the existing value on the relay, then it is more probable that miscoordination occurs.

2) For discrete TSM or TDS method, the results of the computer program are discrete directly. In these methods TSM's or TDS's are considered to be discrete inherently. In other words, each TSM or TDS is shown by a binary code [11]. Using binary codes for continuous TSM's or TDS's make many binary numbers which is obviously difficult to carry out the mathematical calculation even with the new advanced computers. Therefore, almost there is no solution for the relays inherently their TSM or TDS are continuous.

C. Lack of fuses

The existing optimal coordination programs have not considered fuses. The characteristics of different fuses are nonlinear. Therefore the optimal coordination of both relays and fuses installed on a network must be solved by non linear technique.

IV. New Method

The flow diagram of the new method is given in Fig. 3. As can be seen the OF is shown as the third step. The novelty of the new method is in this step and discrete or continuous TSM which will be described below.

A. OF

In this paper an OF of (1) for relay-relay coordination is replaced to (3). New OF is defined as:

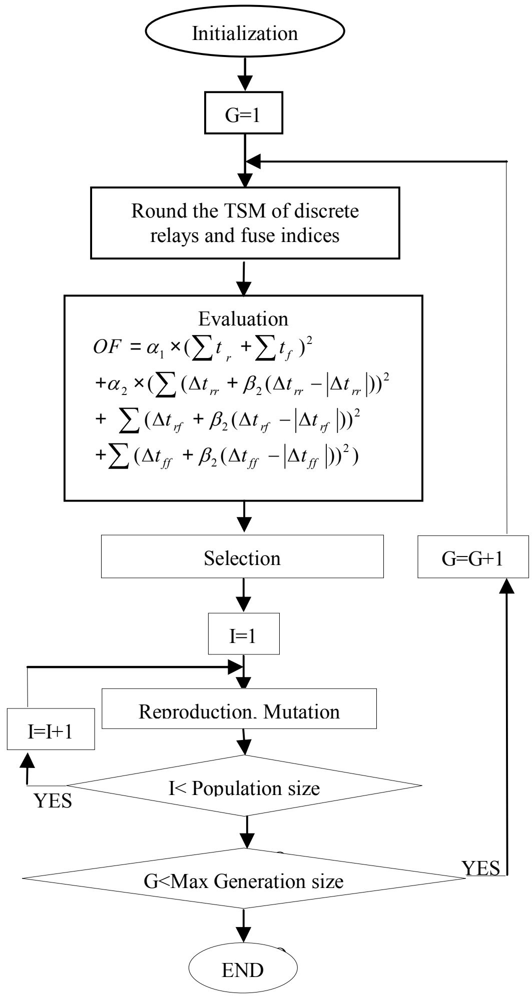

Fig. 3. Flowchart of the New Method.

In this equation β_2 is the new parameter to consider the miscoordination, α_1 and α_2 are defined in (1).

As can be seen in the new equation, the expression $\left(\Delta t_{mb} + \beta_2 \times \left(\Delta t_{mb} - |\Delta t_{mb}|\right)\right)$ is used instead of Δt_{mb}. Now consider Δt_{mb} to be positive, then the relative expression $\left(\Delta t_{mb} + \beta_2 \times \left(\Delta t_{mb} - |\Delta t_{mb}|\right)\right)$ will be equal to Δt_{mb}, i.e. exactly the previous equation, however if Δt_{mb} is negative the mentioned expression will be:

$$\left(\Delta t_{mb} + \beta_2 \times \left(\Delta t_{mb} - |\Delta t_{mb}|\right)\right) = \left(1 + 2\beta_2\right)\left(\Delta t_{mb}\right) \tag{4}$$

Clearly for positive values of β_2, the value of (4) is greater than the previous case and is not selected with the evaluation part of GA.

Regarding the next problem i.e. the way of TSM consideration in the existing articles, the following description is given;

Considering all possibilities of P/B (Primary and Backup

Relay) relays and fuses the OF for GA is completed as below:

$$
\begin{aligned}
OF &= \alpha_1 \times (\sum t_r + \sum t_f)^2 \\
&+ \alpha_2 \times (\sum (\Delta t_{rr} + \beta_2 (\Delta t_{rr} - |\Delta t_{rr}|))^2 \\
&+ \sum (\Delta t_{rf} + \beta_2 (\Delta t_{rf} - |\Delta t_{rf}|))^2 \\
&+ \sum (\Delta t_{ff} + \beta_2 (\Delta t_{ff} - |\Delta t_{ff}|))^2)
\end{aligned} \tag{5}
$$

Δt_{rf} , Δt_{ff} and Δt_{rr} are obtained by;

$$\Delta t_{rf} = (t_{Br} - 0.75 t_{Pf}) \tag{6}$$

$$\Delta t_{ff} = (t_{Bf} - t_{Pf} - .35) \tag{7}$$

$$\Delta t_{rr} = (t_{Br} - t_{\mathrm{Pr}} - 0.3) \tag{8}$$

Where:

t_r and t_f are backup relay and main fuse operating time for the fault close to the main fuse.

t_{Bf} and t_{Pf} are backup and main fuse operating time for fault close to the main fuse.

t_{Br} and t_{Pr} are backup relay and main relay operating time for fault close to the main relay.

B. Discrete and continuous TSM or TDS

For continues TSM method, solution finds relays optimal coordination settings directly. However, for discrete TSM after final coordination process, the answers are rounded to the upper steps. This method is not accurate, because this process may disturb the optimal solution [12], [13] and [14].

For discrete TSM method, there is no solution for the relays inherently their TSM are continues [11].

The idea of the new method for discrete values of TSM's is to solve the problem by considering that TSM's are continuous, initially. But, after compliment of each iteration and before starting the evaluation part of the algorithm, the obtained TSM's or are rounded to the next allowable discrete value marked on the relays. Of course for relays with continuous TSM, the inversion of TSM to discrete values is not made.

Because of the different size of fuses, it can be assumed the fuses to be similar to relays with discrete TSM. In reality fuses do not have TSM, but to consider them in the GA, parameter Fn (Fuse number) which specifies the type and size of fuses curve are taken into account as chromosome.

C. Relays and Fuses Modeling

It should be noted that for finding the relays operating times, a more common formula for approximating the relay characteristics is used:

$$\frac{t}{\mathrm{TSM}} = a_1 + \frac{a_2}{(M-1)} + \frac{a_3}{(M-1)^2} + \frac{a_4}{(M-1)^3} + \frac{a_5}{(M-1)^4} \tag{9}$$

Where:

M is the ratio of relay current to the pickup current $\left(M = \dfrac{I_{sc}}{I_b} \right)$.

I_b is relay setting and I_{sc} is short circuit current.

a_1, a_2, a_3, a_4 and a_5 are scalar quantities which characterize the particular device being simulated. t is relay operating time.

The fuses characteristics are similar to O/C relays but with different slopes. The relays modeling are not suitable for fuses. Fig. 4. shows a sample type of fuses characteristics. From Fig. 4, it can be seen that the curve characteristics can be divided in to three parts and the relative equations are given as:

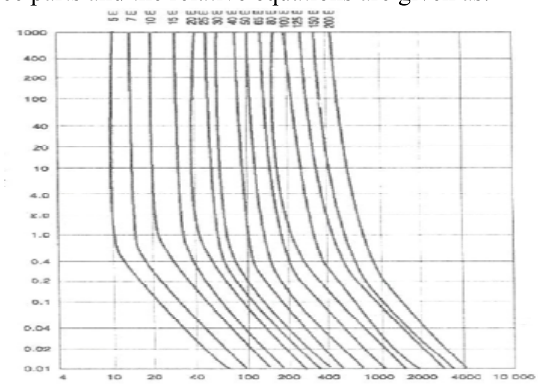

Fig. 4. Fuses typical current characteristics

$$
\begin{cases}
\log T = A_0 + A_1(\log I / I_0) & \mathrm{I} < (\mathrm{I}_2 \times I_0) \\
\log T = B_0 + B_1(\log I / I_0) & (\mathrm{I}_2 \times I_0) < \mathrm{I} < (\mathrm{I}_1 \times I_0) \\
\log T = C_0 + C_1(\log I / I_0) & (\mathrm{I}_1 \times I_0) < \mathrm{I}
\end{cases} \tag{10}
$$

In (10) $A_0, A_1, B_0, B_1, C_0, C_1$ are constant coefficients. If $F = \{F_{I1}, F_{I2}, F_{I3}, F_{I4}, ..., F_{I_n}\}$ are a group of fuses for nominal currents $I_1, I_2, I_3, ..., I_n$ and the fuse characteristic F_{I_k} is given, the characteristic for fuse F_{I_h} with nominal current I_h is obtained using (10). In this equation I_0 is found by;

$$I_0 = I_h / I_k \tag{11}$$

V. Test Result

A. Network and Protection Information

Fig. 5. consists of 8 lines, 8 buses and 1 transformer. It is assumed that all the lines are protected by overcurrent relays or fuses. The overcurrent relays are normal inverse type and the relay characteristic is formulated by (9).

a_1, a_2, a_3, a_4, a_5 for the particular overcurrent device (normal inverse) is given below:

$$
\begin{cases}
a_1 = 1.98,\ a_2 = 8.57,\ a_3 = \text{-}0.46 \\
a_4 = 0.036,\ a_5 = \text{-}0.0003
\end{cases} \tag{12}
$$

It is also assumed that TSM's of the relays are discrete and TSM's varies from 0 to 1 in steps of 0.05.

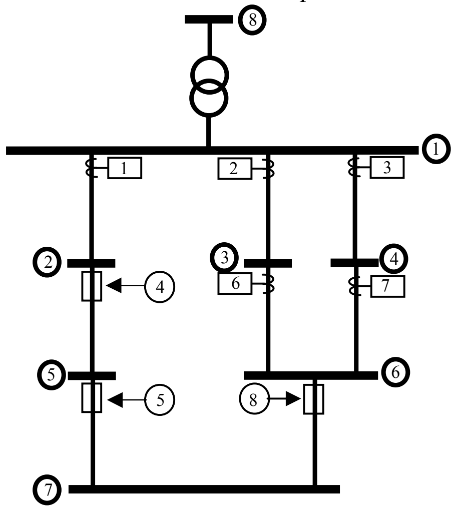

Fig. 5. Sample network (8 buses)

Also the fuses are as below:

$$F = \{ F_1, F_2, F_3, F_6, F_{10}, F_{16}, F_{20}, F_{25}, F_{36}, F_{50}, F_{63}, F_{80}, F_{100}, F_{125}, F_{160}, F_{200}, F_{224}, F_{250}, F_{300}, F_{355}, F_{400}, F_{425}, F_{500}, F_{600}, F_{800}, F_{1000} \} \tag{13}$$

Where the coefficients of fuse $Fn = 6$ is given as below:

$$\begin{cases} A_0 = 11.45, B_0 = 0.95, C_0 = 0.157 \\ A_1 = -7.15, B_1 = -0.59, C_1 = -0.3 \end{cases} \tag{14}$$

The information data of the network is given in TABLE I, TABLE II and TABLE III.

TABLE I
LINE INFORMATION

LINE	R (PU)	X (PU)	V (KV)
1	0.40	0.20	10
2	0.28	0.19	10
3	0.24	0.13	10
4	0.38	0.19	10
5	0.40	0.23	10
6	0.30	0.17	10
7	0.26	0.15	10
8	0.50	0.22	10

TABLE II
GENERATOR INFORMATION

GENERATOR	R (PU)	X (PU)	V (KV)
1	0.10	0.30	10

TABLE III
TRANSFORMER INFORMATION

TRANSFORMER	R (PU)	X (PU)
1	0.01	0.30

R (pu) and X (pu) are based on 100MVA and 150kV.

To obtain the OF, SC (short circuit) current of backup and primary relays or fuses must be calculated for the fault close to the CB of the primary relay or fuse of each P/B. The relevant information including P/B relays or fuses numbers and SC current flowing is given in TABLE IX.

TABLE IX
P/B PAIR INFORMATION

MAIN RELAY OR FUSE	BACKUP RELAY OR FUSE	PRIMARY RELAY OR FUSE SC CURRENT	BACKUP RELAY OR FUSE CURRENT
4	1	524.2	524.2
6	2	507.7	507.7
7	3	567.0	567.0
8	6	608.3	277.7
5	4	339.9	339.9
8	7	608.3	330.8

In the TABLE IX measurement units for both the primary and backup relays current is amp.

B. *GA Information*

The control parameters of GA are as follow:

TABLE X
GA PARAMETERS

GA PARAMETERS	VALUE
Number of generation	300
Size of population	100
Initial population	random
Mutation	1.0

As described in the previous section, to compose OF, determination of $\alpha_1, \alpha_2, \beta_2$ is essential. For testing the effectiveness of GA for coordinating overcurrent relays, several trials with different values of $\alpha_1, \alpha_2, \beta_2$ are tested. The variations of $\alpha_1, \alpha_2, \beta_2$ values is listed in TABLE XI.

TABLE XI
PARAMETER VARIATIONS

CASE NUMBER	α_1	α_2	β_2	TSM
Case 1	1	2	100	Discrete TSM
Case 2	20	1	10	Discrete TSM
Case 3	1	2	0	Discrete TSM
Case 4	1	2	100	Continuous TSM

C. *Results and discussion*

By applying the GA with selected values, the output results for TSM's are obtained. Four different cases have been considered. Case 1 and 2 belong to the new GA method and Case 3 is for the traditional GA method. In Case 4 OF of the new method is applied, but the way of using TSM is traditional. To make the comparison of the different cases easily, the operating times of the relays and fuses as well as TSM's and Fn's are included in TABLE XII.

TABLE XII
GA OUTPUT

CASE	CASE1 $\alpha_1=1$ $\alpha_2=2$ $\beta_2=100$	CASE2 $\alpha_1=20$ $\alpha_2=1$ $\beta_2=10$	CASE3 $\alpha_1=1$ $\alpha_2=2$ $\beta_2=0$	CASE4 $\alpha_1=1$ $\alpha_2=2$ $\beta_2=100$
GENERATION	300	300	1000	1000
TSM_1	0.25	0.25	0.15	0.30
TSM_2	0.35	0.30	0.05	0.35
TSM_3	0.3	0.30	0.15	0.30
Fn_4	15	14	13	5
Fn_5	10	10	10	10
TSM_6	0.2	0.15	0.05	0.20
TSM_7	0.2	0.15	0.01	0.20
Fn_8	12	12	12	12
t_1	0.6820	0.6820	0.3702	0.8183
t_2	0.8639	0.7405	0.1172	0.8639
t_3	0.7786	0.7786	0.3701	0.7786
t_4	0.2742	0.2145	0.2887	0.2742
t_5	0.3131	0.3131	0.3131	0.3131
t_6	0.5839	0.4379	0.1335	0.5839
t_7	0.6087	0.4565	0.2813	0.6087
t_8	0.2187	0.2187	0.2187	0.2187
Δt_{41}	+0.0984	-0.0593	-0.2556	-0.0593
Δt_{62}	+0.1008	+0.0379	-0.4000	+0.0379
Δt_{73}	+0.0193	+0.0565	-0.2593	-0.0956
Δt_{86}	0.0964	-0.0314	-0.3935	+0.1611
Δt_{54}	+0.0038	+0.0381	-0.2273	+0.2571
Δt_{87}	+0.1335	-0.0146	-0.2092	+0.1835

From the second column of TABLE XII (Case 1), it can be seen:

-The values of TSM's are small and they are in the valid range i.e. between 0.05 and 1.

-Obviously, the operating times of the fuses are the lowest.

-All Δt values are small and positive. The largest Δt is 0.1335. That means, the relays settings and fuses selections are accurate, fit and haven't any miscoordination.

In third column of TABLE XII (Case 2), α_1 is considered to be greater than Case 1 and α_2 and β_2 less than the previous case. In other words, more weight is given to the summation of the operating times and less weight for Δt. In this case, decrement of the summation of the operating times is expected. Comparison between the information of columns 2 and 3 shows that, the results of both cases are approximately to be the same. However, although the operating times of the relays and the fuses are either lower or equal to the previous case, but in Case 2, 3 miscoordinations are seen.

In forth column of the output (Case 3) because β_2 is taken into account to be zero, the traditional GA is considered. This time, 6 miscoordinations were found.

In fifth column i.e. (Case 4) of TABLE XII, the new GA method is applied with continuous consideration of TSM's. In this case although the new OF is used but during the whole process, the TSM's are kept continuous and after all results have been obtained, they are rounded to the next upper discrete values of TSM's. Here, also 2 miscoordinations were found. Therefore it can be resulted that to prevent miscoordination for networks with discrete relays, both new OF and new discrete TSM's consideration solution must be taken into account.

It should be noted that the fuses are considered to be discrete and obviously the discrete process described in section IV.B is applied.

From, the whole computer output, it can be concluded that Case 1 in which the full new procedure including new OF and inversion of TSM's or fuses indices to the next allowable discrete values on the relays and fuses after each stage with suitable parameters of α_1, α_2 and β_2 have been considered is the successful method.

VI. CONCLUSION

A new algorithm for O/C relays and fuses coordination based on the GA has been developed. In the proposed method, the special OF is introduced.

For testing the effectiveness of GA for coordinating overcurrent relays and fuses by using new approach the method was applied to a sample power system network and from the results it is reviled that the presented OF is capable to solve the problem of both discrete and continuous TSM'S in one hand, and different arrangements of fuses and relays as P/B's in the other hand, as well as being able to handle the miscoordination problem.

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