Determination of the Minimum Break Point Set Using Expert System and Genetic Algorithm

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***Abstract*—Determination of the minimum break point set (MBPS) in interconnected networks is the key step during calculation and setting of overcurrent relays protection values. Recently, two separate approaches based on expert system and MBPS have been developed respectively. The first one considers the effects of fault level, network configuration, pilot protection and other protection systems. The second one defines protection relay dependency dimension (PRDD) for finding MBPS. By comparison of PRDD in a multi-loop network, the MBPS can be determined, and the process of comparison will not stop until the MBPS of the network is discovered. This paper introduces a new method which takes into account expert rules as well as MBPS simultaneously in the frame of the new objective function of genetic algorithm. It can also generate a new MBPS after each coordination process. The method is applied to the 8-buses and the IEEE 30-buses networks. The obtained results have revealed that the new method is accurate and capable of reducing miscoordinations.**

***Index Terms*—Coordination, minimum break point set (MBPS), protection, protective relaying, relay settings.**

I. Introduction

PROTECTION systems must react fast, be reliable, and selective to faulty network conditions. Overcurrent protection, one of the basic protective relaying principles, is the common system for distribution and transmission networks protection as the main and for the backup, respectively. However, in the majority of cases, selectivity can only be achieved by time grading [1]–[3]. The selection of appropriate settings by the coordination procedures leads to disconnection of the minimum parts of the network under consideration [4], [5].

Setting and coordinating of protective devices in an interconnected network is virtually complicated. The complexity of the problem increases with the increment of the number of loops presented in the system. A basic difficulty in setting overcurrent relays is encountered when the setting of the last relay in a sequence, which closes a loop, is carried out. It must be coordinated with the one initially set in that loop. If it does not, one must proceed around the loop again. Of course, a given relay usually participates in more than one loop, so this procedure needs some organization. Indeed, for a given network it is required to select: 1) a minimum set of relays to begin the process with break points and 2) an efficient sequence for setting the remaining relays (i.e., determination of efficient primary and back up relays sets [6]). Therefore, finding the starting points (i.e., the location of starting relays in the procedure) for settings which are called break points is the basic requirement. The proper set of relays to start the coordination procedure is termed a break point set (BPS) and each relay in a BPS is termed a break point (BP).

Several ordinary and optimum methods using linear programming (LP) techniques, genetic algorithm (GA) methods have been developed [7]–[11]. The sympathy trips include a classification which can be summarized as follows: a) Before the operation of any backup relay, some other relays operate; and b) Before the operation of a primary relay, either its backup or any other relay operates. This classification is very important in relay coordination as given in [12]. The constraints related to the sympathy trips are included in the coordination process of the mentioned reference. Break points have been included in some coordination methods. Solving relays coordination using break points for large networks makes the relays TSMs to be lower and therefore the relative operating times are decreased. This advantage is shown in Section IV by comparing the results of coordination program using both break points and without break points.

It should be noted that finding break points in small networks with limited number of buses and loops is not much complex. However, with the increase of the number of buses and loops in the system, the problem of finding the suitable BPS is virtually complicated [13]. Feipeng and Huaqiang developed depth-first-search and retrospect method for determination of BPS. A new means that found out all the simple loops by searching the relays protection coordination set was advanced in these papers. But there is much redundancy calculation time because the method has not optimized the sequence of searching relays protection coordination set. If the scale of networks is large, the process of searching cannot converge [14], [15]. Bapeswara Rao and Sankara Rao proposed a method for determining the minimum break point set (MBPS) of a power system network and manipulation of the complete loop matrix (L’). Complete loop matrix includes both simple loops and the other loops (i.e., composite loops). However, determination of the complete loop matrix L’ can be time-consuming for large power networks [13]. Prasad *et al.* suggested a faster method for BPS determination based on simple loops matrix. Although, this method is better

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than the previous ones; it needs to consider the whole system at the beginning stage to compose a simple loops matrix and it cannot determine the minimum set [16]. Madani and Jamali have presented the graph-theoretical approach for composition of minimum or near to minimum BPS and again only the network topology is considered [17], [18]; however, the second one can also consider the three terminal transmission lines and three winding transformers. H.A.Abyaneh *et al.* developed an efficient computer program for the determination of BPS based on graph theory [19]. In this method, network reduction is made first, and then the appropriate loops are composed, while in the traditional graph theory approach the composition of the matrices loops are made on the original network [19]. Here, simplifying the network yields to reduce the mass of equations but the obtained BPS is not the minimum one and the network parameters such as pilot protection or important loads are not considered.

The work in [6] does not consider system configuration only when finding BPS. It shows that many other parameters have influence on the BPS. These include type and location of protection devices, location of power generation and short-circuit level. As an example, if a pilot system is used, the BPS can be different compared to the case where such protection does not exist. Thus, the authors developed a new method, which is based on expert system. The method gives weights to the expert rules and compares them with each other; the relay with higher weight is the first break point and continues until no loop remains in the network. The BPS which is found by this method is not the minimum one and there is no guaranty that the relays coordination with the obtained BPS is fulfilled. In the method, 8 rules have been introduced. For each rule a specific weight is allocated. Also for each relay of the network a score is related to each rule. In other words, as an example for relay no.1, 8 scores related to rules 1 to 8 are obtained. The weight of each rule is multiplied to point value (PV) of the relay under consideration. The summation of obtained values from eight rules for each relay is considered as final score of the relay. Finally, the relay with largest score value is selected as first break point. Descriptions of PV and weights are given in the Appendix A and [6].

Yue *et al.* published a paper in which the new concepts of the relay protection dependency dimension (RPDD) and the relay protection dependency set (RPDS) are put forward with the use of genetic algorithm (GA) [20], [21]. If in a network two relays are needed to be coordinated with the relay number 1, these two relays are RPDS of this relay. PRDD of protection is 2 (i.e., the dimensions of PRDS). In this method, although the MBPS can be obtained, it does not consider network and protection parameters such as fault level, pilot protection, important load, etc.

In this paper, a new method using GA is introduced that not only considers network simplification and the parameters of the expert system, but also leads to finding the MBPS. Justification for using GA, with respect to other efficient optimization techniques is provided as follows:

1) Nonlinear optimal programming techniques are complex. In all linear programming techniques such as simplex, two-phase simplex and dual-simplex methods, the auxiliary variables are introduced. The variables should be equal to the number of constraints. Hence, the use of these methods has limitations in terms of low number of constraints [3].
2) The traditional optimization techniques are based on an initial guess and may be trapped in the local minimum. Since the problem of coordination has multi-optimum points, ordinary mathematical-based optimization technique will fail. New optimization techniques such as evolutionary programming (EP) and genetic algorithm (GA) have come up which can be used to adjust the settings of relays. Genetic algorithm is an optimization method to overcome the problems of classical optimization methods. GA uses synchronously many points for searching in the surface. This method (GA) has been chosen because of lower probability of trapping in local minimum. It means that the convergence probability in GA is more than other traditional optimization methods. Larger number of generations and population size produce better results while using genetic algorithm [7].

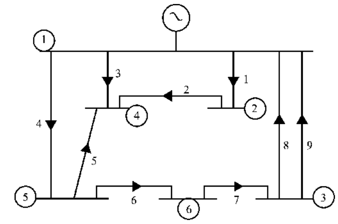

Fig. 1. Example network.

The obtained MBPS are then delivered to the Overcurrent Relays Coordination Program (ORCP) [11]. In the coordination program six current pairs (SCP) [22] are included. SCP are described in Appendix A. More information is given in Section III part C. Finally the results of the relays coordination are evaluated by obtaining the time difference between the operations of primary and backup relays. As a result, if the coordination has not been fulfilled by the given weights defined in the objective function, the weights are changed until the coordination is fulfilled. Also, a new expression called miscoordination criterion is introduced for evaluating the relays coordination.

II. Problem Statement

The existing expert system method [6] suffers from three drawbacks:

1) The obtained BPS does not represent the minimum set.
2) There is no feedback from coordination program's results to find the new BPS.
3) The expert rules are not complete.

To show the mentioned weaknesses of the [6]'s method, the following description and example is given.

Obviously, different BPS can be obtained by using the [6]'s methods, but it is not clear which of them is the suitable one. To illustrate that consider the network of Fig. 1. There is pilot protection in lines 2 and 6 and also important loads are connected to buses 3 and 6. With the use of [6]'s method the relays 2, 5, 7, 2', 5', 7', 8' and 9' have been obtained when the weight of rules pilot protection and important load is higher than the other rules. Relay 2 is the one which is in the direction of line 2, and 2' is in the opposite direction of line 2. As a result, these relays have been selected as BPS, so their TSMs should be the minimum one (i.e., 0.05). For instance, relay 2' is one of the BPS member with $\mathrm{TSM} = 0.05$. Its backups are relays 3 and 5 whose TSMs will be obtained by considering the required time difference 0.3 sec. However, relay 5 is another break point with $\mathrm{TSM} = 0.05$ and the coordination between relays 2' and 5 may not be fulfilled. Therefore by changing the weights of expert rules (for example, increasing the weight of close up and far away feeders from the source rule) the new BPS should be chosen. This manner should be continued until the coordination is fulfilled. This problem also exists between pairs 2 and 5', 8' and 7', 9' and 7'. This example showed that the suitable BPS should be obtained in the way that the coordination becomes fulfilled. Hence, it is necessary to get a feedback from the coordination program results to identify the correct BPS.

Fourth and fifth rules of this system are related to the graph theory. In the fourth rule, after choosing a relay, by using NRT (Number of Relays in the Total Simple Loops), the loops on which the selected relay is installed are specified. In the fifth rule, by using NRT and NRL (Number of Relays in a loop), the loops with lower relays are recognized. By considering the procedure, it is understood that the rule tries to give the possible lower number of the break points. However, it will be shown in Section III part B and Section IV that the absolute MBPS is given using new GA application. Therefore, including graph theory (fourth and fifth rules) cannot help the new method based on GA, because it (GA application) inherently finds MBPS.

In this part, the reason of considering six current pairs as a new rule to complete expert rules is given below:

The six current pairs is a technique for coordination of overcurrent relays [22]. In fact, the fault currents of the primary and backup relays are calculated for six situations. The six current pairs are described in Appendix C. Some of the situations are, nevertheless, ignored because the condition $\mathrm{I}/\mathrm{I_b} > 1.3$ is not fulfilled (I is the fault current and $\mathrm{I_b}$ is the pickup current). It means that the backup fault current is not enough compared to the pickup current. In other words, the threshold of $\mathrm{I}/\mathrm{I_b}$ in expert system modification as 1.3 is chosen because the value of $\mathrm{I}/\mathrm{I_b}$ lower or equal to 1.3 causes the relative relay operating time (as backup) to be very long and there is no effect on coordination. Therefore, it should not be considered in finding BPS determination process. The remaining states are the constraints which the coordination inequality should be solved for them [22]. Thus, some of the six current pairs are not taken into account. As an example, for a relays pair (A, B) where B is the backup of A, three current pairs may be effective; however, for another relays pair (C, D), six current pairs can be involved. Because the TSM of relay B should satisfy less inequality than the TSM of relay D, the B's TSM is most probably less than the TSM of relay D. Since the relays with smaller TSM are the suitable candidates to be BPS members, therefore the numbers of effective current pairs are considered as a base for the rule. It is possible to complete the expert rules of [6] by adding the six current pairs rule to the exiting one. Regarding the method presented in [21], although it can obtain the MBPS using genetic algorithm, it does not consider protection system parameters. Therefore, there is a need to combine both expert system and GA methods to find efficient MBPS.

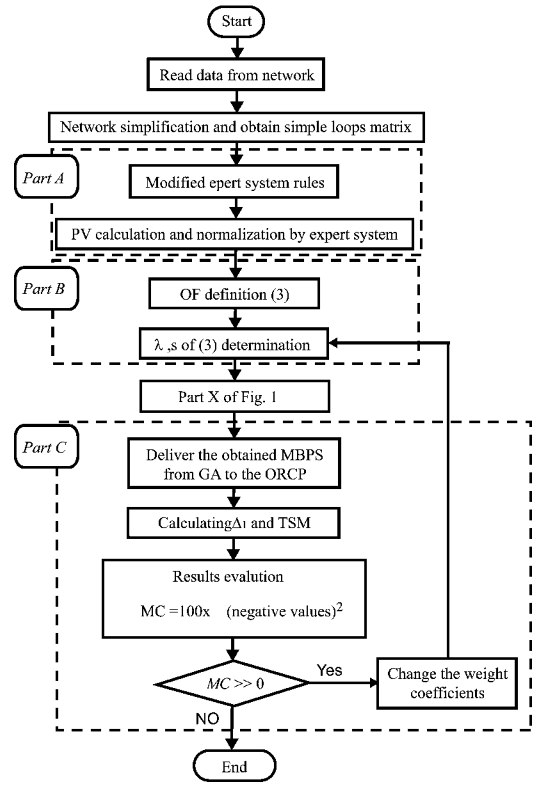

Fig. 2. Flowchart of the new method.

III. New Method

Fig. 2 shows the flowchart of the new method. As can be Seen from the figure, part X of Fig. 5 of Appendix A is exactly repeated. Parts A, B and C of the flowchart are the novelties of the paper. They are described as follows.

A. Expert System Modifications

As described in Section II, the fourth and the fifth rules must be removed from the expert system. Therefore, the new expert system has 7 rules including 6 rules of the previous method (i.e., the rules 1–3 and 6–8 of Appendix A) plus a new rule. The new rule is the effective number of six current pairs. Thus, the new expert system has the following rules:

1) close up and far away feeders from the source;
2) fault level;
3) higher speed protection;
4) pilot protection;
5) number of feeders;
6) important loads;
7) six current pairs.

As described in Appendix A, a PV vector must be allocated to each rule. The procedure for calculating the PV of the first six mentioned rules has been given in [6]; however, for the recent rule (the seventh rule), this procedure is as follows.

1) The six current pairs should be calculated for all relay pairs.
2) Those that do not satisfy the condition $\mathrm{I}/\mathrm{I_b} > 1.3$ must be eliminated. This is because the relative operating times related to $\mathrm{I} \leq 1.3\mathrm{I_b}$ is very high and does not affect on coordination. Eliminating the relevant pairs causes much

simplification of the method and keeping the accuracy is achieved. The threshold is selected by trial and error.

3) The number of times each relay is in the backup situation is calculated and the greatest one is chosen.
4) The number of times which each relay is in the backup situation subtracted from the greatest one (chosen in the third stage) is assumed to be the PV of that relay.

For clarification, consider Fig. 1. For example, relay 5 is the backup of relays 2' and 3'. As such, 12 current pairs should be written for pairs (2', 5) and (3', 5). But, only four of them are remained and the other ones are eliminated due to the condition $\mathrm{I/I_b} > 1.3$. Therefore, relay 5 is in the backup situation for four times. However, all the six current pairs of (2, 1) are remained. It means that relay 1 is in the backup situation for six times which is the greatest number among the relays of this network. Hence, the PV of relay 5 is equal to $2(6-4=2)$ and for relay 1 is equal to $0(6-6=0)$. Relay 5 has a higher score than the relay 1 to be a break point.

B. OF Definition

The proper OF not only must minimize the number of BP, but also should consider the expert rules. So, the 7 rules of the new expert system should be included to (A2) of Appendix A. The new OF is given

$$\begin{aligned} f(X) = & \sum_{i=1}^{l} \frac{1}{\sum_{j=1}^{n} L_{ij}X_j + \lambda} + \lambda_0 \sum_{j=1}^{n} X_j \\ & + \frac{\lambda_1}{\sum_{j=1}^{n} PV1_j X_j + \delta} + \frac{\lambda_2}{\sum_{j=1}^{n} PV2_j X_j + \delta} \\ & + \frac{\lambda_3}{\sum_{j=1}^{n} PV3_j X_j + \delta} + \frac{\lambda_4}{\sum_{j=1}^{n} PV4_j X_j + \delta} \\ & + \frac{\lambda_5}{\sum_{j=1}^{n} PV5_j X_j + \delta} + \frac{\lambda_6}{\sum_{j=1}^{n} PV6_j X_j + \delta} \\ & + \frac{\lambda_7}{\sum_{j=1}^{n} PV7_j X_j + \delta}. \end{aligned} \tag{1}$$

where

n	relays number;
l	simple loops number;
X	variables vector (BPS representation);
L	simple loops matrix;
δ	constant to avoid the relevant term being undefined;
PV_i	PV vector i;
λ_i	weight coefficients;
λ	a constant to avoid the relevant term being undefined.

The first term of this function is related to the main constraint (i.e., the inequality of (A1) of Appendix A). Therefore, having a very small value for λ yields having a large value for the first term if $\sum_{j=1}^{n} L_{ij}X_j = 0$. In order to minimize the OF, those answers (i.e., vector X) which do not satisfy it, are omitted. The second term is related to the minimum set and its weight λ_0 specifies an importance degree.

It should be noted that the initial guess is selected to be any value between 0 and 1. The variable vector X which is BPS is obtained after many repetitions to reach the global minimum; otherwise it will be trapped in the local minimum. Finally, the results between 0 and 0.5 are considered as zero and the variables greater than 0.5 are taken into account to be 1. In other words, 1 indicates that it is BP and 0 means that it is not BP.

The other terms have come due to the expert rules. PV_1 to PV_7 are the vectors related to expert rules respectively. For example, PV_1 is a vector that shows the value of close up and far away feeders from the source rule for each relay. In fact, the relay with high PV is more suitable to be a BP, so the PVs are placed in the denominators of the fractions to obtain the small values for large values of PV. A small value should be assigned to δ in order to avoid the fraction being undefined if the summation is zero. λ_1 to λ_7 are the weight coefficients of rules one to seven. If one of the λ coefficients is zero, the relevant term of OF will be zero and that rule is not taken into account. In fact, the weight of each rule or λ coefficient shows how much the rule affects on the BP. For example, it is possible to give a zero weight to all the rules except the fourth rule which is related to the pilot protection. Therefore, the BPS will be obtained just due to it without considering any other rules. The weights are the controllable variables. Different weights lead to different BPS.

Although for adjusting the weights of λ_i, trial and error method has been used, some criteria and ranges have been considered. If it is intended to have lower effect of a rule, the value of 1 is given as coefficient. For higher effect, the value of 10 is taken into account. Finally, to have the most effect, the value of 100 as a weight is considered. Of course $\lambda_0 = 1000$ (i.e., the weight of being minimum value is extremely large). Compared to this value, the values of λ_1 to λ_7, 0, 1, 10, and 100 have been given to the rules as weights. It will be shown in the eight-bus network that in the second and the third iterations, λ_1 is allocated 100. Using GA as described in part X of Fig. 5 of Appendix A, the MBPS of the network is obtained.

C. ORCP Evaluation

Now, the obtained MBPS are delivered to the coordination program [11], [22]. The way of including MBPS, is to set the TSMs of the backup relays whose primary relays are MBPS members as minimum value (i.e., 0.05). This makes the coordination process to become easier and the average of TSMs lower. It will be shown in Section IV that the optimal coordination program developed in [11] called ORCP is used. The ORCP is based on GA and OF is the summation of square operating times and the square time difference between backup and the primary relays times. The detailed description of OF has been given in [11]. Six current pairs are included in OF to consider the fault to be close to the CB of the primary relay or the far end bus or a place where causes the high set instantaneous current passes through the primary relay. For example, for the first current pair (CP#1), the fault is on the far end bus or line-end

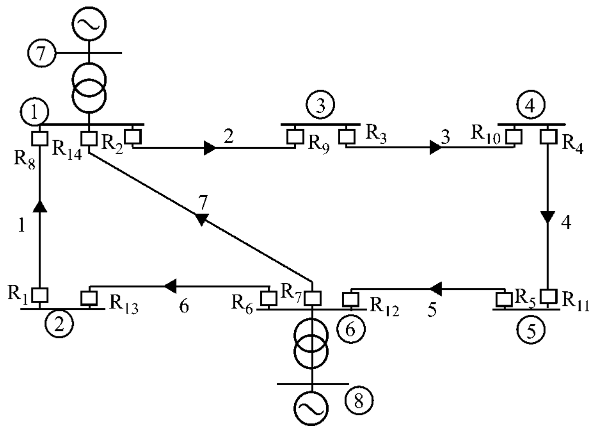

Fig. 3. Eight-bus case study network.

fault and lines outages are such that the current flowing through the backup relay is maximum [22]. In the OF of the coordination program, the current pairs in which the backup relays are break points must be deleted. This is because when one relay is a break point, there is no need to be the backup for its primary relay and it gets the lower TSM (i.e., 0.05).

Δt which will be shown in the output tables, are defined by

$$\Delta t = t_b - t_p - CTI. \quad (2)$$

where t_p and t_b are the operation times of the primary and backup relays for the six fault current pairs. CTI is the suitable time difference; here it is 0.3 sec. Obviously, as shown in (2), if Δt is negative, the miscoordination occurs.

The results of ORCP (i.e., Δt and TSMs) are evaluated at this stage. If the value of Δt is negative, the miscoordination exists between the primary and the backup relays. Thus, a kind of criterion is defined as

$$\text{Miscoordination Criterion (MC)} = 100 \times \sum (\text{negative values})^2.$$

This is one of the novelties of this paper. Here, the square of the negative values are used; as such, greater miscoordinations (more negative ones) have more effects on MC. Usually the summation is a small number, as a result, it is multiplied by 100 for easier working.

Therefore, the amount of MC shows the value of miscoordination. If MBPS yields to miscoordination, it is not a proper one and another MBPS should be determined by varying the weights of the expert rules. If the high value for MC is obtained, the method will change the weights of the expert rules to correct the MBPS and reduce the miscoordinations. In fact, by looking at the results of coordination program, it can be found that how much the weights should be changed. Trial and error manner can be useful.

IV. Test Results

A. Eight-Buses Network

1) Network and Parameters Information: The eight-bus network of Fig. 3 is chosen for testing the new method. This network has been used in papers [2], [3] for testing the relays coordination and it is possible to check the output results. The relays 2, 6, 7, 8, 12, and 14 are placed near generator buses and considered to be with high set protections. There is not any important load, so the weight of the sixth rule (important loads) will be zero $(\lambda_6 = 0)$. The relays 5 and 12 have pilot protection.

The branch number, sending bus and receiving bus numbers are given in columns 1 to 3 of Table I. The short-circuit level of each bus calculated due to rule 2 is given in column 4. The short-circuit level (SCL) has been calculated by applying three-phase faults close to the relays.

TABLE I
Network Data

Branch No.	Sending bus	Receiving bus	SCL of sending relay (1000 MVA)	SCL of receiving relay (1000 MVA)
1	2	1	2.68	4.96
2	1	3	5.36	1.44
3	3	4	3.33	2.33
4	4	5	2.23	3.48
5	5	6	1.35	5.37
6	6	2	4.97	2.49
7	6	1	4.23	4.23

TABLE II
GA Parameters

GA Parameters	Value
Generation number	1000
Population size	100
Initial population	Random
Mutation Function	Gaussian

As described in Section III, relays coordination is made in 2 stages. At the first stage the MBPS are obtained using parts A and B of Fig. 2 and at the next stage the obtained MBPS are entered as the input of the coordination program. If miscoordination exists, the new MBPS is calculated by using the new rules' weights. This is continued until the coordination is fulfilled.

The control parameters of GA are listed in Table II.

The generation size is considered to be 1000. Because the size of the test network is not very large, smaller value can lead to the minimum answer but, the value of 1000 is chosen to make sure that the minimum set is obtained. The population size is chosen to be 100. It is directly related to the chromosome length, for longer lengths more chromosomes should be produced. Of course, it is found by trial and error. The initial values (the genes of chromosome) can be simply chosen by random in this algorithm.

Let $\lambda_0 = 1000$ to obtain the minimum set. As described in Section III, λ and δ should be very small values, so $\lambda = 0.00001$ and $\delta = 0.0001$. The other λ coefficients will be determined in the repetitive procedure to reach the MBPS which leads to minimum miscoordination.

As mentioned in Section I, to avoid GA to trap in local minimum, the suitable adjustment of parameters are selected. The probabilities of mutation $(\mathrm{P_m})$ and crossover $(\mathrm{P_c})$ are chosen to be 0.01 and 0.8 for both networks of this part and part B.

TABLE III
Δt FOR DIFFERENT BREAK POINTS IN THREE ITERATIONS AND FOR THE PREVIOUS METHODS

Pairs	Main Relay Number	Backup Relay Number	Break Points 5,8,14	1,7,9	5,13, 14	3,13, 14	6,7,10	1,4,8,14
			1st iteration	2nd iteration	3rd iteration	[21]'s method	[21]'s method	[19]'s method
			Δt					
3	2	1	0.003	-0.026	-0.026	-0.026	0.003	-0.026
3	14	1	0.328	0.270	0.270	0.270	0.328	0.270
1	3	2	0.173	0.173	0.176	0.145	0.180	0.173
2	3	2	0.173	0.173	0.176	0.145	0.180	0.173
3	3	2	-0.001	-0.001	0.001	0.001	0.004	-0.001
5	3	2	0.062	0.062	0.064	0.053	0.067	0.062
6	3	2	0.173	0.173	0.176	0.145	0.180	0.173
1	4	3	0.082	0.082	0.085	-0.554	0.082	0.082
2	4	3	0.082	0.082	0.085	-0.554	0.082	0.082
3	4	3	-0.002	-0.002	0.001	-0.385	-0.002	-0.002
5	4	3	0.036	0.036	0.039	-0.429	0.036	0.036
6	4	3	0.082	0.082	0.085	-0.554	0.082	0.082
3	5	4	-0.006	-0.006	0.008	0.008	-0.006	-0.006
3	1	6	0.001	0.000	0.000	0.000	-0.308	0.000
5	1	6	0.279	0.275	0.275	0.275	-0.294	0.275
3	2	7	0.002	-0.021	-0.021	-0.004	-0.021	0.002
3	8	7	0.060	0.033	0.033	0.053	0.033	0.060
3	13	8	-0.314	0.001	0.001	0.001	0.001	-0.314
5	13	8	-0.355	0.258	0.258	0.258	0.258	-0.355
3	9	10	-0.002	-0.002	-0.002	-0.002	-0.293	-0.002
1	10	11	0.238	0.238	0.247	0.238	0.216	0.238
2	10	11	0.238	0.238	0.247	0.238	0.216	0.238
3	10	11	-0.001	-0.001	0.004	-0.001	-0.001	-0.001
5	10	11	0.075	0.075	0.082	0.075	0.069	0.075
6	10	11	0.238	0.238	0.247	0.238	0.216	0.238
1	11	12	0.060	0.056	0.060	0.051	0.060	0.051
2	11	12	0.060	0.056	0.060	0.051	0.060	0.051
3	11	12	0.003	-0.001	0.002	-0.004	-0.002	-0.004
5	11	12	0.026	0.022	0.025	0.018	0.022	0.018
6	11	12	0.060	0.056	0.060	0.051	0.060	0.051
3	12	13	0.031	0.031	0.031	0.031	0.031	0.031
3	6	14	0.130	0.130	0.130	0.130	0.130	0.130
3	12	14	0.048	0.048	0.048	0.048	0.048	0.048
MC			22.44	0.114	0.110	125.2	26.74	22.51

2) Procedure Application: The first iteration of the procedure application to the test network will be given.

First Iteration: In the first step the network is simplified and the simple loop matrix (L) is obtained. Then the PV vectors should be found at the next step. The PV vector of the new rule (seventh rule) is $\mathrm{PV}_7 = \{3,0,0,4,5,3,3,3,5,4,0,0,4,3\}$.

Now the weights should be assigned to the expert rules. Choosing the weight coefficients is completely optional at the beginning. The higher weight is assigned to the higher speed protection, so $\lambda_3 = 10$, $\lambda_1 = \lambda_2 = \lambda_5 = 1$ and $\lambda_4 = \lambda_6 = \lambda_7 = 0$. The pilot protection has not been considered in this case. After entering these coefficients to (1), GA starts. The answer is {5, 8, and 14} as the first MBPS. As it can be seen, two relays of the MBPS (relays 8 and 14) have higher speed protection. It should not be forgotten that the main condition to determine a BP is the relay can open the network in the direction of its operation and no loop remains in the network. The third break point (relay 5) without high set protection has been selected because of the first and the second rules.

TABLE IV
TSM FOR DIFFERENT BREAK POINTS IN THREE ITERATIONS AND FOR THE PREVIOUS METHODS.

Relay number	Break Points 5,8,14	1,7,9	5,13,14	3,13,14	6,7,10	1,4,8,14
	1st iteration	2nd iteration	3rd iteration	[21]'s method	[21]'s method	[19]'s method
	TSM					
1	0.055	0.05	0.05	0.05	0.055	0.05
2	0.167	0.167	0.169	0.106	0.168	0.167
3	0.124	0.124	0.126	0.05	0.124	0.124
4	0.05	0.05	0.051	0.051	0.05	0.05
5	0.05	0.05	0.05	0.05	0.05	0.05
6	0.124	0.119	0.119	0.119	0.05	0.119
7	0.054	0.05	0.05	0.053	0.05	0.054
8	0.05	0.122	0.122	0.122	0.122	0.05
9	0.05	0.05	0.05	0.05	0.05	0.05
10	0.091	0.091	0.091	0.091	0.05	0.091
11	0.137	0.137	0.138	0.137	0.101	0.137
12	0.235	0.234	0.236	0.233	0.194	0.233
13	0.05	0.05	0.05	0.05	0.05	0.05
14	0.05	0.05	0.05	0.05	0.05	0.05
Average	0.092	0.096	0.097	0.087	0.083	0.091

In the next step, the obtained MBPS should be delivered to the ORCP. The results of this program are given in Tables III and IV. In the first column of Table III, there are the current pairs for which the coordination inequalities are written. The other pairs which are not written in the table are deleted because the condition $\mathrm{I/Ib} > 1.3$ has not been fulfilled. The second column is the number of primary relays, the third for backup relays. The amounts of (2) relative to the effective pairs are given in columns 4 to 9. The values of the fourth column of Table III are the Δt which are obtained through the BPS of the first iteration. For example, in the fourth column, the second row of Table III, there is 0.328 sec. time difference between the primary and the backup relays operation for the third current pair, when relay 1 is backup of relay 14. The negative numbers show miscoordinations because the time difference between their operations is less than 0.3 sec. In the last row of Table III the amounts of MCs defined in the part C of Section III, are given and for first iteration it is equal to 22.44236. In fact, this is a large number and shows that there is some miscoordination. The suitable value for MC is between 0 and 1. Thus, the procedure should return to step 3 to give other weights to the expert rules.

Second Iteration: By looking at the results of the ORCP in the fourth column of Table III, it is found that the miscoordination exists when relay 8 is a backup for relay 13. Therefore, this relay should not be selected as a break point. By increasing the weight of the first rule (close up and far away feeders from the source), it is possible to avoid this relay be a break point. In this case, the weight coefficients are$\lambda_1 = 100$, $\lambda_3 = 10$, $\lambda_2 = \lambda_5 = 1$, and $\lambda_4 = \lambda_6 = \lambda_7 = 0$. GA gives the MBPS {1, 7 and 9} using these coefficients. Because the weight of the first rule is greater than the others, relays 1 and 9 have been selected as MBPS members which are more far from the source. This MBPS is also delivered to the ORCP. The results of the coordination program are given in the fifth column of the Table III. The amount of MC in this case is equal to 0.11425 and shows that the negative values are very low. This is in the acceptable range (between 0 and 1). So this MBPS is the one which leads to almost no miscoordination. Now, let us examine the third iteration, where a better answer would be obtained.

Third Iteration: In both previous cases, the pilot protection (fourth rule) and the recent rule (seventh rule) have not been considered. Thus, in this case the weight coefficients are $\lambda_1 = 100$, $\lambda_3 = 10$, $\lambda_2 = \lambda_4 = \lambda_5 = \lambda_7 = 1$ and λ_6 is considered to be zero.

The MBPS in this case is {5, 13, and 14}. Relays 13 and 14 are the backup relays of relay 12. Because the relay 12 has pilot protection, it does not need the backup. Therefore, its backups (Relays 13 and 14) are chosen as break points. Relay 5 is also selected because it is more far from the source compared to relay 4. Relay 4 is the backup of relay 5 which has pilot protection. If the weight of the pilot protection is higher than the first rule (i.e., $\lambda_1 = 1$ and $\lambda_4 = 100$), then relay 4 would be selected instead of relay 5. By considering the relay numbers in the third column of Table III, it is revealed that there is no relay 5 in the column of backup relays. It means that all SCP, related to the cases in which relay 5 is the backup of relays 6 and 7, are deleted. Also, the fifth element of the PV7 vector is equal to 5 and shows that it has high score to be one of the BP. So, adding the seventh rule is another reason for selecting relay 5 in the MBPS. The MBPS {5, 13 and 14} is delivered to the ORCP. The results are given in the sixth column of the Table III. As it can be seen in the last row, the amount of MC is also very low in this case $(\mathrm{MC} = 0.11026)$. It is nearly equal to the previous one (up to two decimal digits). It means that the procedure has converged to 0.11 and there is no need to continue once more.

For all the above cases the same results will be obtained, if the fourth and the fifth rules of [6]'s expert system (related to the graph theory) are considered. Therefore, the removal of the fourth and the fifth rules described in Appendix A is verified.

3) Compared to the Other Methods: To show the advantages of this new method, it is compared to the two previous ones (i.e., [21] and [6]) and when BPS has not been considered.

Using the method in [21], different BPS are obtained such as {3, 13, 14}, {6, 7, 10} and {1, 7, 10}. They are also delivered to the ORCP and their results (two of them because of space limitation) are given in the columns 7 to 9 of Table III. It can be seen that the amounts of MCs are very high for both sets. There is no way to obtain a set with lower miscoordination.

By using [6]'s method, the 4 break points {1, 4, 8, and 14} have been obtained. The important load rule is not considered, the higher weight is allocated to the high set protection rule which is equal to 2 and equal weights (equal to 1) are allocated to the others. As it is described in the Appendix A, the method of [6] cannot give the MBPS. It gives 4 break points for the network of Fig. 3; however, it is possible to open the loops of this network with 3 relays. The MBPS which are obtained by [6] are delivered to the ORCP. The values of the ninth column of Table III show Δt. The high value of MC obviously shows that there is miscoordination between primary and backup relays. Because there is no feedback from the outputs in this method, there is not any way to change the rules' weights. Consequently it is not possible to correct the output in order to obtain less miscoordinations.

In Table IV, there are TSMs of relays in different cases. The TSM varies with step of 0.001, in the program. By considering again the MC of the new method and [6]'s paper, it is revealed that the miscoordinations are reduced over 200 times whilst the TSMs of the third iteration are almost equal to the TSMs of the [19]'s method except for relay 8 which is increased about two times. The similar comparison between results shown in Table IV of [21]'s paper with the new method verify the same conclusion. As mentioned in Section I, solving relays coordination using MBPS for large networks make the relays TSMs to be lower. Therefore, for the eight-bus network under consideration, the results of coordination process for both with and without MBPS have been almost the same. As a result, the relative TSMs without MBPS are not given here. For large network of part B where MBPS is affected on TSMs, the relative description will be fully described. The relative computational time of the new method (MBPS finding) is 10 seconds.

B. IEEE 30-Buses Network

1) Network and Parameters Information: The IEEE 30-buses network of Fig. 4 is another selected system to verify the method. The information of the network is given in [23]. In this network for relays 34 and 77 pilot protections are considered. It is assumed that all source buses are equipped with the high set protection and an important load has been located on bus 18.

The short-circuit currents (SCC) are given in Table V. The SCC of the relative buses (11 and 26) of relays 57 and 79 are considered to be zero. Because of existing only static loads and not induction motors, there is no need to install relays on these buses.

Since the network under consideration is much larger than the previous one, that is, it includes 30 buses, 86 relays, the length of chromosomes set is 86, population size is considered to be greater than previous example (i.e., 200). Obviously, for this network, the number of loops are more, therefore, the number of constraints are more than the previous example. Consequently, the generation number of 2000 is taken into account. The same as before, λ_0 is considered to be given a larger value than the other coefficients (i.e., 1000). Allocating the weights of 1 and 10 for the rules gives suitable results.

Algorithm Application: The same as previous example, first the relative simple loop matrix (L) is obtained. The number of simple loops is 402 in both clockwise and counter clockwise directions. Then, the PV vectors are calculated and normalized. For example, for rule 7, PV7 is given below:

$$\begin{aligned}\mathrm{PV7} = \{&14,\ 14,\ 17,\ 16,\ 16,\ 17,\ 4,\ 0,\ 17,\ 13,\\ &16,\ 17,\ 5,\ 18,\ 13,\ 17,\ 18,\ 17,\ 15,\ 17,\\ &16,\ 17,\ 17,\ 13,\ 13,\ 13,\ 16,\ 18,\ 18,\ 17,\\ &16,\ 17,\ 16,\ 16,\ 18,\ 18,\ 16,\ 18,\ 18,\ 18,\\ &17,\ 17,\ 16,\ 16,\ 16,\ 18,\ 15,\ 16,\ 18,\ 15,\\ &9,\ 17,\ 0,\ 11,\ 13,\ 4,\ 18,\ 18,\ 18,\ 15,\ 15,\\ &18,\ 18,\ 18,\ 17,\ 15,\ 17,\ 13,\ 12,\ 12,\ 13,\\ &16,\ 12,\ 8,\ 15,\ 15,\ 17,\ 12,\ 18,\ 16,\ 18,\\ &18,\ 18,\ 18,\ 17,\ 14\}.\end{aligned}$$

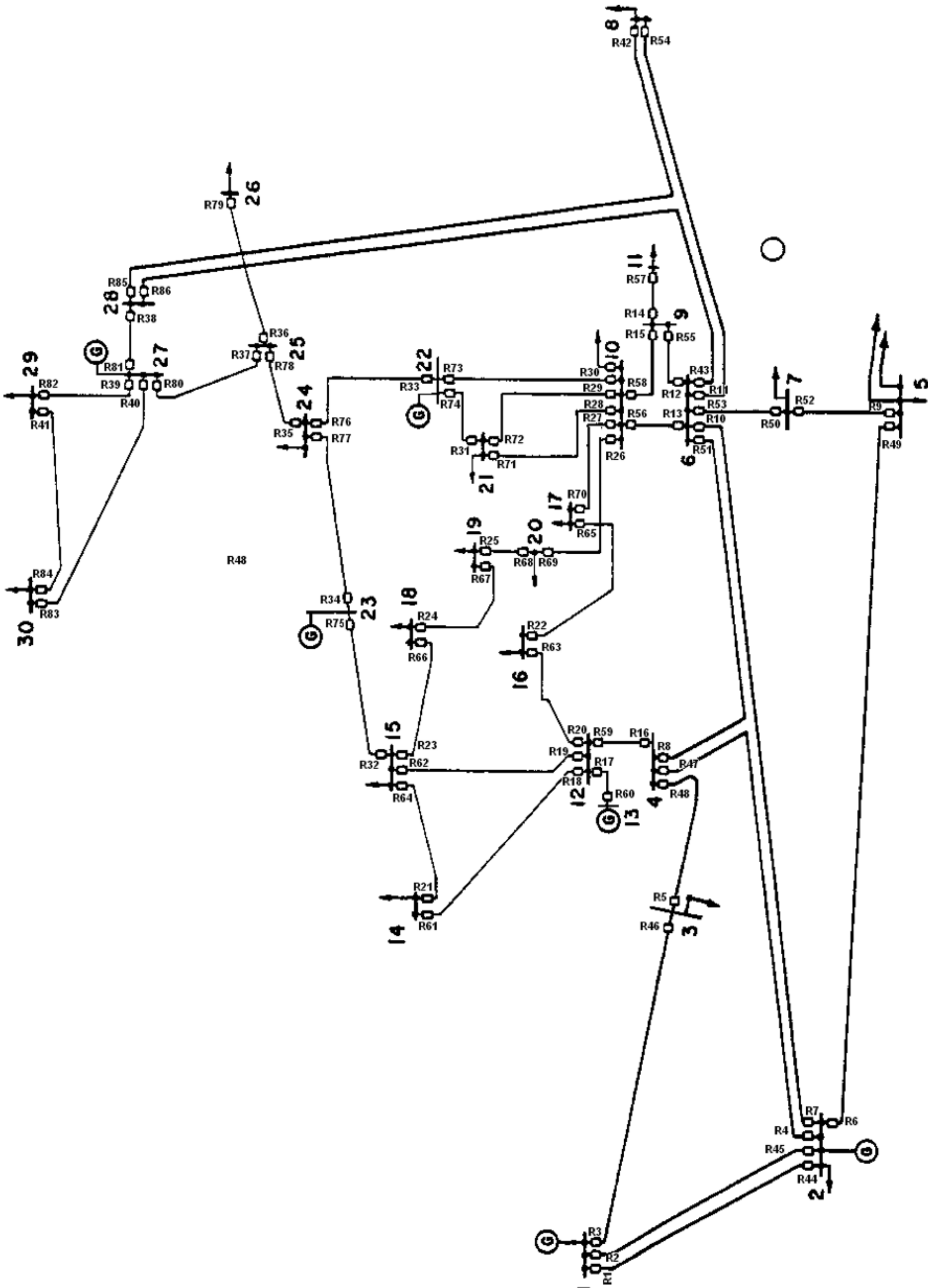

Fig. 4. IEEE 30 buses.

The related weights of the expert rules in the first iteration of the example are considered to be all the same as previous one except the important load. The important load coefficient here is set to 1, whilst in the previous network it has not been considered. GA procedure is again made by using (1) as OF with the mentioned coefficients. The MBPS result is {4, 7, 12, 13, 16, 19, 26, 28, 29, 39, 40, 44, 45, 53, 73, 74, 85, 86}. In other words, 18 relays out of 86 are selected as breakpoints. Relays 4, 7, 39, 40, 44,

TABLE V
SHORT-CIRCUIT CURRENTS

Relay Number	SCC (A)	Relay Number	SCC (A)
1	6616.216782	44	7749.451852
2	6616.216782	45	7749.451852
3	7078.259817	46	3412.724617
4	8039.946054	47	5105.519759
5	1468.365901	48	5414.057937
6	8465.105153	49	1409.682427
7	7986.77291	50	5970.801056
8	3457.731332	51	5136.065004
9	1553.945178	52	2764.955559
10	6743.35018	53	947.8514916
11	7192.614332	54	719.4170964
12	6761.406755	55	2144.894674
13	5165.32268	56	4246.644255
14	3388.6364	57	0
15	1264.36366	58	6278.130361
16	5455.383399	59	3435.854887
17	2882.485201	60	4217.621953
18	4297.833208	61	894.9947941
19	3694.620381	62	2235.246405
20	3975.547557	63	1130.048892
21	1009.664133	64	3237.460635
22	1269.655124	65	2714.789938
23	3122.654081	66	798.4612259
24	1095.906677	67	1122.929019
25	785.9637984	68	1422.898167
26	6249.762941	69	675.5598176
27	6255.463367	70	720.2510227
28	5775.890525	71	5256.486805
29	5775.890525	72	5256.486805
30	5604.351536	73	6428.353448
31	2079.917403	74	5964.380044
32	2257.68618	75	4917.498601
33	6521.091975	76	1712.598665
34	5060.694674	77	2114.261103
35	2597.317986	78	1339.501617
36	2088.406807	79	0
37	780.3003858	80	4966.908579
38	3602.302079	81	4547.417617
39	5255.31323	82	295.685966
40	5131.127807	83	366.8866125
41	738.7794582	84	531.0987618
42	3852.431947	85	3728.524392
43	6714.102827	86	1595.096177

45, 73 and 74 (8 relays) have instantaneous elements. Other relays are selected as BPS members because of SCC (relays 12, 13, 16, 19, 28, 29, 85, and 86) and far from important loads (relay 26 and 53). After that, similar to previous procedure application, the MBPS are delivered to ORCP and the results of primary and backup (P/B) pairs Δt are obtained. Because the relative table of all Δt is too large, only the summarized one is given as Table VI. Of course, the relative obtained break points which are in the position of backup for P/B pairs are not considered as entering data to ORCP. The second row is related to the first iteration of new BPS. From the third column of Table VI the relative MC amount which is equal to 600.84 is shown. This indicates that there are many miscoordinations. From the Table, it can be seen that there are 71 miscoordinations that exist between P/B relays.

The three columns of Table VI consist of the number of $\Delta t < 0$ (miscoordination), the values of MC, and the average of TSMs of all relays, respectively. The values related to the second column for each case are the number of P/B relays with $\Delta t < 0$. It should be noted that $-0.05 \leq \Delta t \leq 0$ is considered to be zero since compared to 0.3 sec, the mentioned small values can be ignored. The values in Table VI are obtained from the Table of the Appendix B and the Table of Δt of P/B relays.

TABLE VI
SUMMARY OF RESULTS FOR THE IEEE 30-BUS NETWORK

	Number of Δt<0	MC	Average of TSM
1st iteration	71	600.841	0.078
2nd iteration	30	299.706	0.083
3rd iteration	1	0.473	0.086
[21]'s method	34	252.749	0.080
[19]'s method	48	281.756	0.083
No BP	0	0	0.754

Therefore, the procedure returns to give different weights to the expert rules. To select the new weights, it is necessary to analyze the BPS of the first iteration. By considering again the original information of Δt, it can be seen that being the relays 7, 13, 26, 53, 73, and 74 as break points causes the miscoordinations for the P/B relays in which one of the mentioned relays has been the backup of the relevant P/B ones. The relays 7, 73, and 74 have instantaneous elements and because of their large coefficient values, they are chosen as break points. On the other hand, these relays are installed on the feeders of the source buses and according to the first rule they should not be selected. Other relays (i.e., 13, 26, and 53) are also only far from the sources by 1, 2 and 2 feeders; therefore, they also must not be included as BPS members.

It can be understood that by increasing the first rule weights, the relevant relays are not selected as BPS members.

As a result for the second iteration, the weight of the first rule is changed to 10. Therefore, both first and third rules will have the same effects on the BPS result. The results of second iteration give the BPS as {4, 12, 16, 19, 28, 29, 32, 39, 40, 42, 44, 45, 49, 53, 58, 62, 73, 78}. By applying the new PBS to ORCP and evaluating the result, it can be seen that the MC for the second iteration is decreased to 299.706. It means that miscoordination is less than the first iteration result, but still the significant miscoordinations exist. Again, from the 6 mentioned undesired break points, still two relays (i.e., 53 and 73) are included. Also two relays 32 and 78 are selected. This is because the role of pilot protection of relays 34 and 77 which are the primary relays of the selected BPS are affected.

Again, by considering the miscoordination related to P/B relays from the original information of Δt, it can be seen that relays 53, 73, and 78 must be deleted from BPS for micoordinations reduction. By considering the values of PV7 (i.e., SCP vector in deep), it can be understood that relay 53 has not gained any point and the two relays 73 and 78 gained lower points compared to the others. Therefore, by increasing high weight to this rule (SCP), better results can be obtained. Therefore, by changing λ_7 to 10, the new BPS for the third iteration becomes {4, 9, 12, 16, 19, 28, 29, 30, 32, 39, 40, 42, 43, 44, 45, 49, 58, 62}. Again, the BPS is given to ORCP and the relevant MC at the fourth row of the third column of Table VI becomes 0.473 which is extremely reduced.

To compare the advantages of the new method with the methods of [6] and [21], the following description is given. For the application of [21], two different BPS, that is, {1, 2, 28, 29, 30, 32, 39, 40, 47, 49, 50, 55, 56, 61, 62, 69, 85, 86} and {10, 28, 29, 30, 32, 39, 40, 43, 44, 45, 50, 56, 58, 62, 63, 64, 85, 86} are obtained. Due to space limitations, only the results of the first BPS application to ORCP have been shown. The relevant MC is 252.75, which is very large and can be seen from Table VI, 48 miscoordination numbers exist. For the method [6] with the weight of 2 for the fault level and higher speed protection rules and equal weights (equal to 1) for the other 23 BPS members {4, 6, 7, 11, 15, 21, 22, 27, 28, 29, 30, 33, 34, 39, 40, 43, 44, 45, 58, 64, 73, 74, 80} have been the result. The MC result of Table VI is 281.76 and a lot of miscoordination numbers can be seen. From the analysis given here, it can be revealed that the final result of BPS, third iteration is the best solution compared to the results of other methods.

To compare the final results when MBPS (third iteration) is used and no break points used, the fourth and the seventh rows of Table VI are taken into account. Although in the fourth column, the number of miscoordination is 1; however, the value of the relative $\Delta t = 0.067$ (i.e., the operating time difference between the backup and primary relays is still 0.233 sec). In other words, it can be said that the miscoordinations of the final iteration with MBPS and no BPS are almost the same, while the average values of the TSMs of coordination method with and without MBPS are 0.086 and 0.754, respectively. In other words, using MBPS for large network causes lower TSMs and relays operating times and, as a result, lower damages to the power system during faults occurrence.

For 8- and IEEE 30-buses networks, different GA important parameters have been considered to avoid the suboptimal solution. Some of the related parameters are given in Table II and second paragraph of part B1. Also, to escape from trapping in local minimum, the parameters of GA, such as mutation and crossover function which have been selected, are the same for both networks and given in the last paragraph of Section IV part A1. The value of this parameters have been determined with trial and error for many times; also, the algorithm has permitted continuing until the convergence to global optimum is obtained. Since the network is larger than the example of part A, the taken computational time to converge the program is 80 sec.

V. Conclusion

In this paper, a new method for finding MBPS based on GA using the expert rules has been described. Some redundant rules of expert system have been removed and a new rule related to SCP has been added. Another advantage of the new method is receiving feedback from the coordination program when the MBPS has been applied. Therefore, the suitable MBPS with minimum miscoordination has been found. The new method has been tested by applying it to two different interconnected networks, namely 8- and IEEE 30-buses networks. The final results have been compared with the existing GA and expert system methods. From the coordination evaluation of the final obtained MBPS, it has been revealed that the approach described in this paper is successful.

Appendix A
Review of Recent Existing Methods

For the continuity of the discussion, the recently developed method in [6], which forms the basis of the proposed method, will be summarized below.

The proposed method in [6], after simplifying the network to form the simple loops matrix, considers system configuration as well as system and protection parameters, and finally introduces 8 expert rules namely:

1) close up and far away feeders from the source;
2) fault level
3) higher speed protection;
4) relays of common loop;
5) loops with lower relays;
6) pilot protection;
7) number of feeders;
8) important loads.

As mentioned in Section I of this paper, each rule allocates the score to the relays (i.e., PV). The PVs are the constant values that are related to the relay position in the network or a special characteristic such as having higher speed protection. PV calculation has been described in [6]; therefore, only a brief description of it is given here. The PV vector is a $1 \times n$ matrix, in which n is the number of relays. The elements of this matrix are the values of expert rules. For example, the third rule says: "The feeders on which the higher speed protections are installed can be considered as break points". Therefore, the PV vector for the third rule can contain 1 and 0, where 1 refers to a relay with higher speed protection (for instance, overcurrent relays with extremely inverse characteristics or high set instantaneous element) and 0 refers to the relay without any higher speed protection. Another example is related to fault level rule, the feeders with lower fault level have more chance to be break points.

The way of considering this in the developed computer program is given below:

1) fault is chosen adjacent to each relay;
2) fault current is calculated;
3) for each fault, a PV is given; for a higher fault current, lower PV is given;

The other PV vectors should be calculated by the methods developed in [6].

Also, the summarized description of second MBPS determination method (i.e., the recent developed intelligent algorithm [21]) is devoted to review to give a better understanding of this paper. The model of gene evolution method for determining MBPS has been described in [21] as follows:

The directional simple loops matrix is $L = C_i[l_{ij}^r]_{M\times N}$. Where, M and N are the number of simple loops and relays respectively. C_i is the loop i and r is the directional edge, namely directional relay in loops. If the loop C_i contains edge r, l_{ij} is 1, contrarily if r is not owned to loop C_i then l_{ij} equals 0. Let variable $X = \{x_1, x_2, \ldots, x_n\} \in \{0, 1\}$ or X can be a $1 \times n$ vector. x_j will be 1 if it belongs to the MBPS, otherwise it will be zero. So the problem of MBPS results in the following inequality:

$$\begin{cases} \sum_{j=1}^{N} X_j = |MBPS| \\ \sum_{j=1}^{N} L_{ij} X_j \geq 1 \qquad i = 1, 2, \ldots, M. \end{cases} \tag{A1}$$

where

L simple loops matrix;

M N having been defined before.

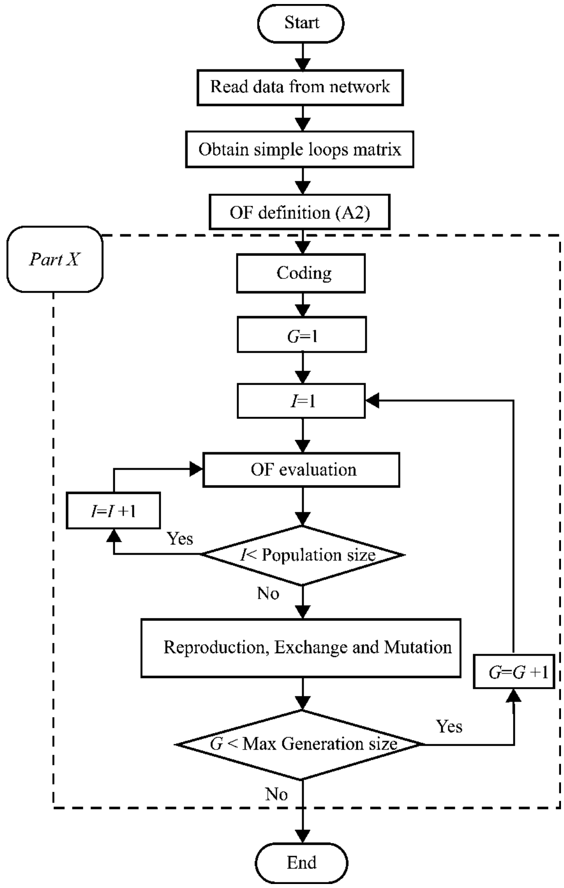

Fig. 5. Flowchart of the existing GA.

It must be at least one break point in each directional simple loop in order to satisfy the inequality of (A1) and convert the directional multi-loop network to the radial network. The fitness function of this problem is as (A2) which is the amount of break points of relays in loops on the condition of the inequality of (A1). Theoretically $f(X)$ is smaller, the solution is better.

$$f(X) = \sum_{j=1}^{N} X_j. \tag{A2}$$

Now the suitable algorithm is needed in order to minimize the defined fitness or objective function (OF). As it can be seen, it is a kind of 0–1 integer quadratic programming problem and GA is very applicable to this kind of problems. GA is a searching and optimization method based on the mechanism of natural selection and colony inheritance. In term of the principle of survive competition and by virtue of operations of replication, exchange and mutation, the problem could approach to optimal solution [21]. Fig. 5 shows the flowchart of the approach. As can be seen from the flowchart after the composition of simple loops matrix, OF is defined according to (A2).

Then the GA procedure being coding, evaluation, reproduction, exchange and mutation are made one after the other. Part X is shaded because it has been used in Section III.

Appendix B
TSMs Values for IEEE 30-Buses Network

See Table VII.

TABLE VII
TSM For Different Break Points in Three Iterations and for the Previous Methods (IEEE 30 Buses)

Relay Number	TMS					
	1st iteration	2nd iteration	3rd iteration	[21]'s method	[19]'s method	No BPS
1	0.067	0.067	0.067	0.067	0.05	0.085
2	0.055	0.055	0.055	0.055	0.05	0.07
3	0.077	0.077	0.077	0.077	0.077	0.611
4	0.05	0.05	0.05	0.05	0.071	0.206
4	0.05	0.05	0.05	0.05	0.071	0.206
5	0.095	0.095	0.095	0.095	0.095	0.619
6	0.088	0.088	0.088	0.05	0.088	0.465
7	0.05	0.141	0.141	0.05	0.141	0.903
8	0.22	0.22	0.22	0.22	0.22	1.182
9	0.078	0.078	0.05	0.078	0.078	0.597
10	0.168	0.168	0.168	0.168	0.168	0.812
11	0.092	0.092	0.092	0.05	0.092	1.411
12	0.05	0.05	0.05	0.082	0.082	1.401
13	0.05	0.168	0.168	0.168	0.168	1.62
14	0.05	0.05	0.05	0.05	0.05	0.05
15	0.102	0.102	0.102	0.05	0.102	1.106
16	0.05	0.05	0.05	0.05	0.05	0.385
17	0.05	0.05	0.05	0.05	0.05	2
18	0.084	0.084	0.084	0.084	0.084	0.375
19	0.05	0.05	0.05	0.089	0.089	0.649
20	0.083	0.083	0.083	0.083	0.083	0.821
21	0.089	0.089	0.089	0.05	0.089	0.602
22	0.085	0.085	0.085	0.05	0.085	0.704
23	0.086	0.086	0.086	0.086	0.086	0.669
24	0.155	0.155	0.155	0.155	0.155	0.664
25	0.221	0.221	0.221	0.221	0.221	1.643
26	0.05	0.166	0.166	0.166	0.166	1.159
27	0.086	0.086	0.086	0.05	0.086	1.526
28	0.05	0.05	0.05	0.05	0.05	2
29	0.05	0.05	0.05	0.05	0.05	1.375
30	0.05	0.05	0.05	0.05	0.05	1.131
31	0.05	0.05	0.05	0.05	0.05	0.082
32	0.05	0.05	0.05	0.05	0.05	0.515
33	0.08	0.08	0.08	0.05	0.08	1.61
34	0.077	0.077	0.077	0.05	0.077	1.446
35	0.05	0.05	0.05	0.05	0.05	2
36	0.05	0.05	0.05	0.05	0.05	0.744
37	0.05	0.05	0.05	0.05	0.05	0.05
38	0.05	0.05	0.05	0.05	0.05	0.05
39	0.05	0.05	0.05	0.05	0.05	0.05
40	0.05	0.05	0.05	0.05	0.05	0.05
41	0.05	0.05	0.05	0.05	0.05	0.305
42	0.084	0.05	0.05	0.084	0.084	0.945
43	0.082	0.082	0.05	0.05	0.082	1.977

Appendix C
Six Current Pairs

SCP (i.e., the relative currents of primary and backup relays [22]) is added in the coordination process. The SCP will be summarized.

CP#1 represents current pair No. 1 which means the fault is on the far end bus or line-end fault and lines outages are such that the current flowing through backup relay is maximum. The fault location of CP#2 (current pair no. 2) is similar to CP#1 but the current through the primary relay is minimum. CP#3 considers close in fault but the lines outages are such that the current of backup relay is maximum. CP#4 considers the fault to be at a point such that the current of the primary relay be equal to the highest instantaneous element current setting. If the high set instantaneous element exists, the relevant current of each P/B relay is the mean of current pairs 2 and 4. CP#5 represents that. However, if high set instantaneous element does not exist, then the mean of current pairs 2 and 3 is considered. For CP#6, the fault point is the same as cases 1 and 2 but, the ratio of the backup relay current to the primary relay current is minimum.

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