An Efficient Minimum Break-Points Determination Algorithm Using Expert System and Genetic Algorithm

H. Sharifian, H. A. Abyaneh, R. Mohammadi, F. Razavi

Abstract--**Interconnected power systems are multi-loop structured. In such networks, the determination of settings for all overcurrent relays can be done in different forms and may be quite complicated. The main problem for coordination is the determination of starting points, i.e. the location of starting relays in the procedure for settings, which is referred to as break-points (BP). In the recent developed algorithm an approach based on expert system is applied to consider the effects of pilot protection, fault levels, etc. This paper introduces a new method which not only contains the characteristics of the previous method, but also it can generate new BP after each coordination process. Finally the minimum break-points set (MBPS) that leads to a minimum miscoordination is obtained. The method is applied to the 6 buses network for case study. From the obtained results, it is reviled that the new method is accurate and contains no miscoordination.**

Index Terms-- **Coordination, Minimum Break Point Set (MBPS), Protection, Relay settings**

I. INTRODUCTION

MANY attempts have been made in the past to coordinate overcurrent relays using conventional and computerized methods. Coordination algorithms consider different techniques, both for interconnected and industrial networks [1]-[3], [12]. The selection of appropriate settings by the coordination procedures leads to disconnection of the minimum parts of the network under consideration [4], [13]. The complexity of the problem increases with the number of the loops presented in the system. A basic difficulty in setting overcurrent relays results when the setting of the last relay in a sequence is carried out; which closes a loop, it must be coordinated with the one set initially 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 the break-points (BP), (2) an efficient sequence for setting the remaining relays, i.e. the determination of efficient primary and back up relay sets. Therefore, finding the starting points, which are called break-points, is the basic requirement in this technique.

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Feipeng and Huaqiang developed a method based on graph theory for determination of BP, directed loop matrix and relative sequence matrix [5], [6]. In this method neither the network parameters (like the location of power generation) are not considered nor are the obtained break-points set (BPS) of the minimum one. In addition because of the large matrices, it is useless for large power networks.

Bapeswara Rao and Sankara Rao [7] proposed a method for determining the minimum break-points set (MBPS) of a power system network and manipulation of matrix L'. However, determination of the complete loop matrix L' can be time consuming for large power networks.

Prasad et al. suggested a faster method for BPS determination based on simple loops matrix. Although, this method has a good advantage compared to 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 as well as the network parameters which were not considered [8].

Madani et al. and Jamali et al. have presented the graph-theoretical approach for composition of minimum or near to minimum BPS and again only the network topology is considered [14], [15], however the second one can consider the three terminal transmission lines and three winding transformers.

Askarian Abyaneh et al. developed an efficient computer program for the determination of BPS based on graph theory [9]. 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 [9]. 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.

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 use of genetic algorithm (GA) [16]. In this method although the MBPS is obtained but it is not considered the parameters such as fault level, pilot protection, important load and etc.

Reference [10] again which is written by [9]'s authors, do not consider the system configurations for finding BP only, in contrast with what the previous methods had been done. It shows that many other parameters have influence on the BP. The kinds and location of protection devices, the location of power generation and short circuit level can affect BP. As an example, if a pilot system is used, the BP is different in comparison with the case in which such protection does not exist. So the authors developed a new method, which is based on expert system. But the used expert system has some problems. The method gives weights to the expert rules and compares them with each other, the relays 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 BP is fulfilled.

In this paper, a new method with the use of GA is introduced that not only considers network simplification and the parameters of the expert system, but also the MBPS will be obtained. Then the obtained MBPS are delivered to the Overcurrent Relays Coordination Program (ORCP). Finally the results of relays coordination are evaluated by obtaining the Δt (the time difference between the operation of primary and backup relays and the time 0.3 sec). As a result if coordination was not fulfilled by the given weights, the weights are change until the coordination is fulfilled.

II. New Method

In order to determine the MBPS, the following stages should be done as follow:

<u>Step1. Calculating the PV vectors for each rule</u>

PV vector is a $1\times n$ matrix, which n is the number of relays. The elements of this matrix are the value of expert rules. Reference [10] introduced 8 expert rules namely:

a) Close up and far away feeders from the source
b) Fault level
c) Higher speed protection
d) Relays of common loop
e) Loops with lower relays
f) Pilot protection
g) Number of feeders
h) Important loads

Each rule allocates a weight which is called a Point Value (PV). For example the third rule says "the feeders on which the higher speed protections are installed can be considered as break-points." [10]. So the PV vector for the third rule can contain 1 and 0 which 1 refers to a relay with higher speed protection (for example overcurrent relays with extremely inverse characteristics or high set instantaneous element) and 0 refers to the relay which do not have any higher speed protection. The other PV vectors should be calculated by the methods which are developed in [10]. So PV vectors (eight vectors) will be obtained at the end of this stage. Simplifying the network is done before due to the 4th and 5th rules.)

<u>Step2. Giving weights to the expert rules</u>

The weight of each rule shows how much the rule affects on the BP. For example it is possible to give zero weight to all the rules except the 4th and 5th rules which is related to the graph theory. So the BP will be obtained just due to the graph theory without considering any other of them. In fact the weights are the controllable variables. Different weights leads to the different set of BP. However the PVs are the constant values that are related to the relay position in network or special characteristic such as having higher speed protection.

<u>step3. Objective Function (OF) Definition</u>

Because one of the aim of this paper is to minimize the number of BP, the proper OF should be defined. This OF not only must minimize the number of BP, but also it should consider the expert rules. There is a main constraint that should be satisfied which dictates the BP to open all loops in the network. Reference [16] has developed a method that considers this constraint as follow;

$$\sum_{j=1}^{n} L_{ij} X_j \geq 1 \qquad i = 1,2,\ldots, M \tag{1}$$

Where:
L is the simple loops matrix,
M is the number of simple loops,
n is the number of relays, and
$X = \{x_1, x_2, \ldots, x_n\} \in \{0,1\}$ 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 it must be at least one break-point in each directional simple loop in order to satisfy (1) and convert the directional multi-loop network to the radial network.

The new OF that considers expert rules is given in (2). In this method the constraints are included as part of OF.

$$f(X) = \sum_{i=1}^{l} \frac{1}{\sum_{j=1}^{n} L_{ij} X_j + \lambda} + \lambda_0 \sum_{j=1}^{n} X_j + \frac{\lambda_1}{\sum_{j=1}^{n} PV1_j X_j + \delta} + \frac{\lambda_2}{\sum_{j=1}^{n} PV2_j X_j + \delta} + \frac{\lambda_3}{\sum_{j=1}^{n} PV3_j X_j + \delta} + \frac{\lambda_4}{\sum_{j=1}^{n} PV4_j X_j + \delta} + \frac{\lambda_5}{\sum_{j=1}^{n} PV5_j X_j + \delta} + \frac{\lambda_6}{\sum_{j=1}^{n} PV6_j X_j + \delta} + \frac{\lambda_7}{\sum_{j=1}^{n} PV7_j X_j + \delta} + \frac{\lambda_8}{\sum_{j=1}^{n} PV8_j X_j + \delta} \tag{2}$$

Where:
n = relays number
l = simple loops number
X = variables vector (break-point set representation)
L = simple loops matrix
δ = a constant to avoid the relevant term being undefined
PV_i = PV vectors
λ_i = weight coefficients.

The first term in this function is related to the main constraint. So having a very small value for λ yields to have 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 are not satisfying it, are omitted. The second term is related to the minimum set and its weight λ_0 specifies importance degree. The other terms have come due to the expert rules. *PV1* to *PV8* are the vectors for expert rules respectively. For example *PV1* 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 break-point, so the PVs are placed in the denominator of the fractions to obtain the small value for large value of PV. A small value should be assigned to δ in order to avoid the fraction being undefined if the summation were zero. λ_1 to λ_8 are the weight coefficients of rules one to eight. If one of the λ coefficients is zero, the relevant term of OF will be zero and the relative rule is not taken into account.

step4. GA Application

Now the proper algorithm is needed in order to minimize the defined 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 preliminary problem could approach to optimal solution [16].

i) Evolution operator (genes)

Every gene represents the state of relay. If the relay is a break-point, its gene will be 1, otherwise it will be zero.

ii) Chromosome

It is a character set composed of a serial of 0 or 1, which have special physical meanings. Chromosome *A* represents all the states of the network relays. In this case the vector *X* is the Chromosome which contains a series of 0 and 1, which 1 refers to the BP relays and 0 to the others.

iii) Fitness function

Fitness function is the goal function of gene evolution algorithm which is given by (2).

The initial values (the genes of chromosome) can be chosen by random in this algorithm and the population size is 100 in this case. Also generations is chosen to be 1000 in order to be sure that the minimum set will be obtained.

So by running GA the MBPS will be discovered at the end of this stage.

step5. Delivering the MBPS to the ORCP

Now the discovered BP are delivered to the coordination program. It is sufficient to omit those inequalities which are written for the case that one break-point relay is backup for another relay. When one relay is a break-point relay, there is no need to be the backup for its primary relay and it gets the lower TSM (discrete time setting multiplier), e.g. 0.05.

In the available coordination program [11], the inequalities are written for all of the primary and backup states as the six pair rules. Here the OF is the summation of the operation times that should be minimized and the minimum time differences with 0.3 sec (Δt) for all backup and primary relays are constraints Δt is entered in OF and the results show the TSMs that satisfy minimum OF.

Δt is also shown in output tables are defined by

$$\Delta t = t_b - t_p - CTI \tag{3}$$

Where:

t_p and t_b are the operation time of the primary and backup relay for fault in front of the circuit breaker.

CTI is the suitable time difference, here it is 0.3 sec.

As shown in (3), it is obvious the miscoordination will be occurred if Δt is negative. So the TSMs and Δt will be known at the end of this stage.

step6. Evaluating the results

The results of ORCP i.e. TSMs and Δt should be evaluated at this stage. If the value of Δt is negative, the miscoordination exists between the primary and backup relays. So a kind of criterion can be defined as follow:

miscoordination criterion (MC) = $100 \times \sum (\textit{negative values})^2$

Therefore the amount of MC shows the value of miscoordination. So 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 high value for MC is obtained, the method will return to step 2 to change the weights of the expert rules to correct the MBPS and reduce the miscoordination. In fact by looking carefully at the results of coordination program, it can be found that how much the weights should be changed. Sometimes trial and error manner can be useful.

III. Test Results

The 6 bus test network is shown in Fig. 1.

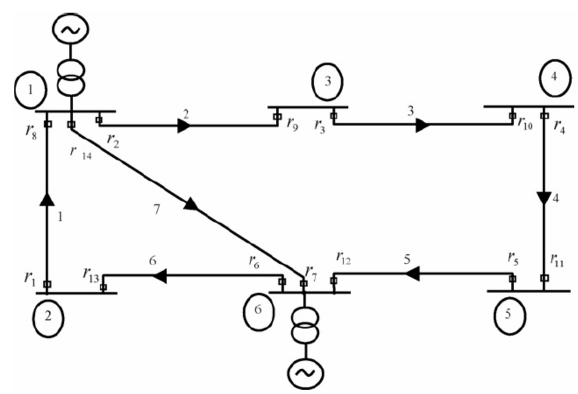

Fig. 1. The 6 bus case study network

TABLE I
NETWORK DATA

Branch No.	Sending bus	Receiving bus	S.C.L of sending relay (1000 MVA)	S.C.L of receiving relay (1000 MVA)
1	2	1	0.71	1.30
2	1	3	1.41	0.38
3	3	4	0.87	0.61
4	4	5	0.58	0.91
5	5	6	0.35	1.40
6	6	2	1.30	0.65
7	6	1	1.11	1.11

The branch number, sending and receiving bus numbers are given at column 1 to 3. The short circuit level of each bus calculated due to rule 2 is given in column 4. Three phase faults in front of each relay have been made to calculate the S.C.L (Short Circuit Level).

The relays 2, 6, 7, 8, 12, 14 are considered to be with high set protections and there is not any important load, so the weight of the 8th rule (important loads) will be zero (λ_8=0).

Relays coordination is made in 2 stages. At the first step the MBPS are obtained by (2) and at the next step the BP are entered in coordination program. If miscoordination occurred by using the obtained MBPS, the new one are calculated using the new rules' weights. These steps are continued until the coordination is fulfilled.

Stage 1

To show the advantages of the new method and find the suitable weights, two stages i.e. BP finding and coordination for different cases are given bellow.

Different cases are considered for the network which their related outputs are given in Tables 2 and 3. Let λ_0=1000 in all cases.

a) First of all by using [10]'s method the 4 BP, {1,4,8,14} have been obtained. The important load rule is not considered and the higher weight, 2, is allocated to high set protection rule and equal weights (equal to 1) are allocated to the other rules.

b) The MBPS will be obtained using GA with graph rules consideration. These are 4th and 5th rules of OF, so the weights of λ_1 to λ_8 except λ_4 and λ_5 are considered to be zero and let λ_4=λ_5=1. Different sets are obtained by running GA each time, {6,7,10} , {3,8,14} , {2,13,14} and {6,7,11} are resulted.

c) The weights of rules 3 and 6 (rules of pilot protection and having high set protection) are zero, i.e. the location of high set and pilot protection are not considered (λ_3=λ_6=λ_8=0, λ_1=λ_2=λ_4=λ_5=λ_7=1). The set of relays {5,8,14} have been obtained. The main condition to determine the BP is that the relay can open the network in the direction of its operation and no loop can remain in the network, so the relays 8 and 14 in which both of them are placed at a source bus and are determined as BP, however the more far away relays are more proper to be the BP [10]. Because of this fact with increasing the weight of the close up and far away feeders from the source rule, the sets of relays {1,7,9} with λ_1=10, or {5,13,14} with λ_1=1000, have been obtained that only one of the 3 relays is placed at the source bus.

As it seems just 3 relays have been obtained for the network of Fig. 1 in all of the cases, however 4 relays have been obtained by the method of [10].

Stage 2

At this stage the obtained sets are delivered to the coordination program. As the BP are the relays that coordination starts from these, the minimum TSM shall be assigned to them and there is no need to be the backup for their front relays. So the inequalities that relates to coordination the break-point relay to its front relay will be omitted from the OF, it means that the mass of inequalities that should be solved decreases.

The BP which are obtained by [10] are delivered to the ORCP. The 4th column of Table 2 is the Δt that obtained with these BP. By choosing each of MBPS in the new method, different results have been obtained from the coordination program. For instance the results of coordination program are come in the 5th column of Table 2 if the MBPS was {6,7,10} in case *b*. It should be noted from the four sets of case *b* the set {6,7,10} is selected arbitrary. The results of case *c* are given in the 6th and 7th columns of Table 2.

Results Analyzes

The results of coordination program are given in Tables 2 and 3 for different cases. In the first column of Table 2, there are the current pairs, which the coordination inequalities are written for them. The other pairs which are not written in the table are omitted because the condition I/I_b>1.6 is not fulfilled. The second column is the number of primary relays, the third for backup relays. Δt of (3) are given in columns 4 to 7. For example in the 4th column of Table 2, there is 0.36 sec time difference between the primary and backup relay operation when relay 7 is backup for relay 8 for third current pair. The negative numbers shows miscoordination, because of the time difference between their operations are less than 0.3 sec.

It is obvious that there is miscoordination between primary and backup relay operations with the obtained BP of [10]'s method, and because there is no feedback of outputs in this method there is not any way to change the rules weights and correction the output in order to have less miscoordination. The numbers of column 5 are the outputs of ORCP when the BP is obtained just due to graph theory. For instance in the numbers of 5th column, consider when relay 6 is backup for relay 1. The values of Δt for both of the pairs are negative. Obviously the relay 6 operates about 0.64 sec (0.3-(-0.34) =0.64) faster than primary relay 1. Therefore the set {6,7,10} is not the proper set. In fact when these relays are chosen as BP, their TSM are 0.05 and they operate fast. So the graph rule is not sufficient to have proper BP. It can be seen that two of these BP are close to the sources and they yields to miscoordination. Then by returning to the first step and changing the weights, the new MBPS will be obtained. Columns 6 and 7 are related to the cases in which the weights of close up and far away feeders from the source rule is greater than the previous case. As a result the miscoordination is less than before. In fact the results of these columns, especially 6th column, show that the optimum MBPS with the lowest miscoordination are obtained and the TSMs which refer to this MBPS can be chosen for time setting of the relays.

TABLE II
Δt FOR DIFFERENT BREAK-POINTS DUE TO DIFFERENT CASES a AND b AND c

Pairs	Primary relay No.	Backup relay No.	Break-Points 1,4,8,14 Case *a*	6,7,10 Case *b*	5,13,14 Case *c*	1,7,9 Case *c*
			Δt			
3	8	7	0.0599	0.0325	0.0599	0.0325
3	2	7	0.0022	-0.0209	0.0022	-0.0209
3	2	1	-0.0257	0.0482	0.0482	-0.0257
1	3	2	0.1731	0.1731	0.1797	0.1731
2	3	2	0.1731	0.1731	0.1797	0.1731
3	3	2	-0.0005	-0.0005	0.0042	-0.0005
5	3	2	0.0616	0.0616	0.0669	0.0616
6	3	2	0.1731	0.1731	0.1797	0.1731
1	4	3	0.0818	0.0818	0.0818	0.0818
2	4	3	0.0818	0.0818	0.0818	0.0818
3	4	3	-0.0022	-0.0022	-0.0022	-0.0022
5	4	3	0.0357	0.0357	0.0357	0.0357
6	4	3	0.0818	0.0818	0.0818	0.0818
3	5	4	-0.0058	-0.0058	-0.0058	-0.0058
3	6	14	0.1302	0.1302	0.1302	0.1302
1	14	1	-0.1472	0.0036	0.0036	-0.1472
2	14	1	-0.1472	0.0036	0.0036	-0.1472
3	14	1	0.2700	0.4208	0.4208	0.2700
6	14	1	-0.1472	0.0036	0.0036	-0.1472
3	1	6	-0.0002	-0.3390	-0.0012	-0.0002
5	1	6	0.1243	-0.3455	0.1247	0.1243
3	9	10	-0.0016	-0.2928	-0.0016	-0.0016
5	9	10	0.2715	-0.2770	0.2715	0.2715
1	10	11	0.2382	0.2165	0.2382	0.2382
2	10	11	0.2382	0.2165	0.2382	0.2382
3	10	11	-0.0009	-0.0011	-0.0009	-0.0009
5	10	11	0.0753	0.0692	0.0753	0.0753
6	10	11	0.2382	0.2165	0.2382	0.2382
1	11	12	0.0556	0.0602	0.0511	0.0556
2	11	12	0.0556	0.0602	0.0511	0.0556
3	11	12	-0.0008	-0.0025	-0.0044	-0.0008
5	11	12	0.0216	0.0221	0.0177	0.0216
6	11	12	0.0556	0.0602	0.0511	0.0556
3	12	14	0.0475	0.0475	0.0475	0.0475
3	12	13	0.0307	0.0307	0.0307	0.0307
3	13	8	-0.3141	0.0015	0.0015	0.0015
5	13	8	-0.3286	0.1127	0.1127	0.1127

In Table 3, there are TSMs of relays in different cases. The TSM varies with step of 0.001, in the program. The numbers which are given in the last row of Table 3 referred to MC. By comparing this criterion in all of the cases, it is revealed that the coordination will be fulfilled in the case that the MC is the minimum. So the MBPS {5,13,14} is the optimum set which yields to the lowest miscoordination.

TABLE III
TSM FOR DIFFERENT BREAK-POINTS DUE TO DIFFERENT STATES a AND b AND c

Relay No.	Break-Points 1,4,8,14 Case *a*	6,7,10 Case *b*	5,13,14 Case *c*	1,7,9 Case *c*
	TSM			
1	0.05	0.063	0.063	0.05
2	0.167	0.167	0.168	0.167
3	0.124	0.124	0.124	0.124
4	0.05	0.05	0.05	0.05
5	0.05	0.05	0.05	0.05
6	0.119	0.05	0.131	0.119
7	0.054	0.05	0.054	0.05
8	0.05	0.122	0.122	0.122
9	0.05	0.05	0.05	0.05
10	0.091	0.05	0.091	0.091
11	0.137	0.101	0.137	0.137
12	0.234	0.194	0.233	0.234
13	0.05	0.05	0.05	0.05
14	0.05	0.05	0.05	0.05
MC	27.2356	39.7295	0.0062	6.6141

IV. CONCLUSION

In this paper the minimum break-point set based on GA application with considering the expert rules was determined. In this method the OF of GA considers all of the expert rules and determine the MBPS. By applying this method to a 6 bus network the MBPS was obtained. After delivering the obtained MBPS to the coordination program (ORCP), the results are evaluated. The method has been tested for different cases and the optimum MBPS which yields to the lowest miscoordination has been obtained.

V. ACKNOWLEDGMENT

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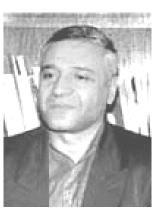
VII. Biographies

Hoda Sharifian was born in Tehran, Iran, on October 29, 1985. She graduated from National Organization for Development of Special Talent (NODET), and studied at the Amirkabir University of Technology (Tehran Polytechnic). She received the B.S. degree in electrical engineering in 2006. Currently, she is studying M.S. in power electrical engineering at the same university. Her fields of interest include power system protection and electrical software.



Hossein Askarian Abyaneh received the B.S. degree from Iran University of Science and Technology in Tehran in 1976, and he received the M.S. degree and Ph.D. from UMIST, Manchester, U.K. in 1985 and 1988 respectively, all in electrical power system engineering.

Currently, he is a Professor with the Department of Electrical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Iran, working in the area of the relay protection and power quality.

Reza Mohammadi was born in Tabrib, Iran, on September 22, 1981. He received the B.S. degree from Iran University of Science and Technology in electrical engineering in 2004 and He received M.S. degree from Amirkabir University of Technology in electrical engineering in 2007. Currently, He is studying P.h.D in power electrical engineering at the same university. Her fields of interest include power system protection and electrical software.

Farzad Razavi received the B.S, M.S. and Ph.D. degrees from the Amirkabir University of Technology (Tehran Polytechnic), Iran, in 1998, 2000 and 2007 respectively, all in power electrical engineering.

His employment experience included R&D Counselor and R&D Manager in Pars Tableau Company, Project Manager in Sepehr Company.

His fields of interest included power system protection, mathematic, FACTS and power electronics.