Optimal Coordination of Overcurrent and Distance Relays with Hybrid Genetic Algorithm

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Abstract: **To achieve better protection, it is common to use both distance and overcurrent relays as main and backup relays respectively, in power transmission protection scheme. In this situation it is necessary to coordinate these two types of relays simultaneously that makes the problem harder to find a global optimal point. To overcome the complexity, it is a good idea to use an optimization algorithm like (GA) to perform coordination between distance and overcurrent relays. In this paper, a hybrid algorithm based on GA and linear programming (LP) is proposed to obtain the relay settings which are Time Multiplier Setting (*TMS*) and I_{set} for overcurrent relays and Second Zone Time (T_{z2}) for distance relays. By this assumption, new variables are added to the problem and size of search space will become bigger, thus finding the global optimal point will be harder. It is shown that the proposed hybrid GA can find a better solution in comparing to the conventional methods.**

***Keywords: Genetic algorithm, Overcurrent and distance relay coordination, Power system protection*.**

I. INTRODUCTION

In a power network, many abnormal conditions may have occurred, which could make an interruption in power transmission lines. To avoid such situations, a reliable protective system should be provided. For providing reliability, backup and primary protections are used that means if the primary protection does not work, backup protection will clear the fault. To prevent miscoordination, a Coordination Time Interval (CTI) is added to backup operation time to ensure backup protection would not operate sooner than primary protection. To obtain mentioned reliable protection, suitable setting of relays should have been selected. Also the protection system should have some features such as sensitivity, selectivity and speed [1].

To provide a better protection, in many transmission lines it is common to use both overcurrent and distance relays, while delayed second zone time of distance relay plays an important role as a backup and instantaneous for the first zone as main protection.

Studying of coordination of relays as an optimal problem at first was performed for overcurrent relays. This problem has been formulated and solved by linear and nonlinear methods. By assuming *TMS* as a variable and pick up currents as predetermined values, problem becomes linear. By this assumption, problem can be formulated as a linear optimization problem and usually solved using linear programming method [2-3].

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In [4] pick up current is considered as a discreet variable and formulated as a Mixed Integer Nonlinear Programming (MINLP) and is solved using DICOPT in GAMS. A nonlinear method is applied in [5] in which pick up current was assumed to be continues variable and discreet solution is obtained by rounding-off to the nearest discreet value. Another nonlinear method as well as intelligent methods are applied to perform coordination between overcurrent relays like Genetic Algorithm GA [6], Particle Swarm Optimization (PSO) [7] and Evolutionary Algorithm (EA) [8].

To achieve a better protection it is common to use both overcurrent and distance relays in power system protection scheme. In this protection scheme, second zone of distance relay is a backup of the next transmission line while the first zone of distance relay and overcurrent relay are primary relays. By adding the distance relay to a protection scheme to improve reliability, the optimal coordination problem will be changed, and new methods should be considered. To find a global optimal point of a coordination problem which is composed of distance and overcurrent relays, some methods has been suggested [9]-[12].

A method to determine second zone timing of distance relay in a composed scheme with overcurrent relay has been proposed in [9] and [10], the relay coordination problem is formulated as a linear programming and TMS and T_{z2} are considered as variables of the problem. It has been resulted when a protection scheme is composed of these relays, both relay settings should be considered in computation, and it is shown in practical cases T_{z2} could be larger than conventional setting, which is 0.3s.

By considering I_{set} as a new variable, problem will become a nonlinear one and in this situation nonlinear methods should be applied. In [11] a GA method is suggested to overcome nonlinearity and obtain desirable setting of overcurrent relays such as TMS and I_{set}, which satisfy coordination constraints between overcurrent and distance relays. Mentioned problem in [11] is stated in [12] and coordination is performed by modifying Objective Function (OF). Various characteristics for overcurrent relay are considered and the best characteristic for each relay is selected by GA to fulfil optimal coordination.

In this paper, a hybrid GA is proposed to perform coordination in the protection scheme which is composed of distance and overcurrent relays. Unlike the references mentioned above, to achieve a better protection, each second zone time of distance relay is considered as a new variable and problem divided into two parts. Part 1 is nonlinear part of the problem and is performed by GA. In this part GA returns I_{set}. Part 2 is linear part, and it returns TMS and T_{z2}. The performance of the proposed method is evaluated by obtained results from an 8-bus power system.

II. REVIEW OF COORDINATION PROBLEM

A. Problem statement

Optimal coordination of overcurrent relays in the power network is a problem that could be stated as an optimization problem and depends on considering a variable. it could be linear or nonlinear. The general form of the problem is defined as follows:

$$obj = min \sum_{i=1}^{n} t_i \quad (1)$$

$$Subject\ to : T_b - T_m \geq CTI \quad (2)$$

Where n is the number of relays, and t_i is the operating time of ith relay. T_b is operating time of backup relay, and T_m is operating time of primary relay. *CTI* is the coordination time interval. The main aim of this optimization problem is to minimize the objective function (*obj*) which is subjected to coordination constraints and all of constraints should be satisfied [3].

B. Relay characteristic

For overcurrent relays many characteristic formulations are proposed that define the operation time of relays versus fault current passed through it. One of the nonlinear formulations which is used widely, is standard inverse time and stated as follows:

$$t_i = \frac{0.14*TMS_i}{\left(\frac{I_{sc_i}}{I_{set_i}}\right)^{0.02} - 1} \quad (3)$$

Where I_{sc_i}, I_{set_i} are short circuit current and pickup current respectively and TMS_i is time multiplier setting of ith overcurrent relay. If I_{set_i} is considered as a decision variable in (1), problem becomes a nonlinear one because this equation is a nonlinear function of I_{set_i}, but if I_{set_i} is considered as a predetermined variable, the problem will be a linear because equation (3) is a linear function of TMS_i and could be solved by linear programming [12].

C. Coordination constraints

The coordination constraints are expressed as below:

$$T_b - T_m \geq CTI \quad (4)$$

When the protection scheme is composed of overcurrent and distance relays inequality (4) is shown as:

$$T_{z2\ backup} - T_{oc\ main} \geq CTI' \quad (5)$$

$$T_{oc\ backup} - T_{z2\ main} \geq CTI' \quad (6)$$

It means when both types of relays are considered, size of coordination constraints would be third time bigger than the condition which only overcurrent is used. In this condition, a new coordination time interval (*CTI'*) between distance and overcurrent relays should be defined, which does not have to be the same value as *CTI* that is used in coordination of overcurrent relay pairs.

III. PROPOSED HYBRID GA

In nonlinear optimization problems, using intelligent methods are common to find the global optimum point. Nonlinearity and vast search space are good reasons to use the stochastic search algorithm.

As mentioned, by considering *TMS* or I_{set} as decision variables, linearity or nonlinearity of the problem will be determined.

To achieve comprehensive coordination, determining of these two types of parameters are so important, therefore by dividing the problem into linear and nonlinear subroutines, finding these parameters and achieving to comprehensive coordination will be easier. If the linear subroutine is performed by liner programming, the search space will become smaller for nonlinear part, which is solved by GA.

A. Genetic algorithm subroutine

One of the most powerful stochastic search methods for solving optimization problems is GA, which is based on evolutionary theory. One of the most important individuals of this method is simplicity. To solve the problems, a suitable coding method should be applied for chromosomes in GA. In this paper length of chromosomes are depends on the number of relays that is used in coordination problem (Fig. 1).

I_{set1}	I_{set2}	I_{set3}	…	I_{setn}

Figure 1. Chromosome string

The simplest form of the genetic algorithm involves three types of operators: selection, crossover (single point), and mutation.

- **Selection**: This operator selects chromosomes in the population for reproduction. The fitter the chromosome, the more times it is likely to be selected to reproduce.
- **Crossover**: This operator randomly chooses a locus and exchanges the sub-sequences before and after that locus between two chromosomes to create two off-springs. The crossover operator roughly mimics biological recombination between two single-chromosome (haploid) organisms.
- **Mutation**: This operator randomly flips some of the bits in a chromosome. Mutation can occur at each bit position in a string with some probability, usually very small [13].

In this paper nonlinear subroutine is performed by GA, and its aim is to find desirable current settings for over current relays (I_{set}). Length of chromosomes is equal the number of relays, which is coded by binary string. This type of coding is more suitable for crossover and mutation. Fitness function is another important object, which has a major role in converging of GA. Despite the linear programming, in GA fitness function includes coordination constraints. It means fitness function is the same as (1) except that some statements are added to it and expressed as:

$$Fitness\ function = \min\left(\alpha \sum_{i=1}^{n} t_i + \beta \sum_{i=1}^{n} \left|T_{DIOC_i} - \left|T_{DIOC_i}\right|\right| + \lambda \sum_{i=1}^{n} \left|T_{OCDI_i} - \left|T_{OCDI_i}\right|\right| + \delta \sum_{i=1}^{n} \left|T_{OC_i} - \left|T_{OC_i}\right|\right|\right) \quad (7)$$

Where:

$$T_{OC_i} = T_{oc\ backup\ i} - T_{oc\ main\ i} - CTI' \quad (8)$$

$$T_{DIOC_i} = T_{oci} - T_{z2\ i} - CTI' \quad (9)$$

$$T_{OCDI_i} = T_{z2i} - T_{oc\ i} - CTI' \quad (10)$$

In (7)-(10) T_{oc} and T_{z2} are operating time of overcurrent and second zone of distance relays, respectively and α, β, λ and δ are penalty factors.

B. *Linear* subroutine

In each iteration, linear subroutine computes *TMS* and T_{z2} and makes a penalty factor (α) which is used by GA. It means if linear programming converges for a chromosome, the penalty factor would be 1 (α=1), else it is set to a high value (α=1000). This part is done by linprog function of MATLAB® Toolbox™. Flowchart of algorithm is shown in Fig. 2.

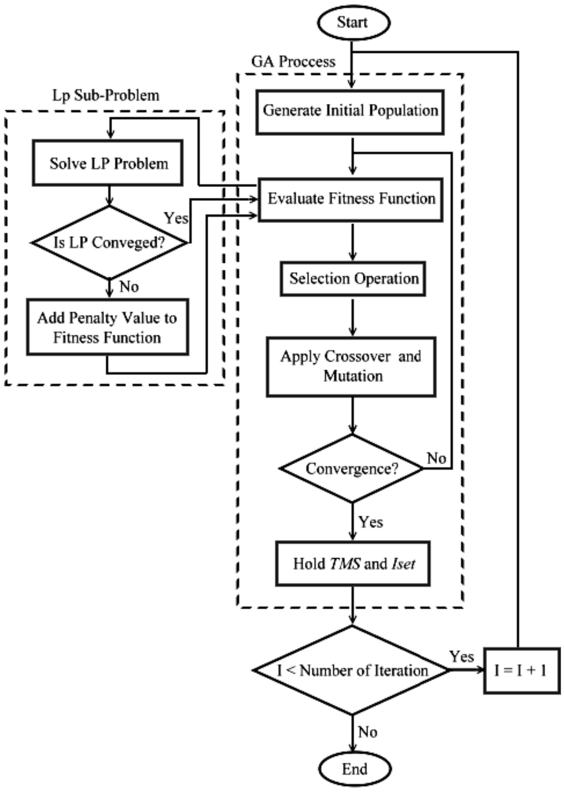

Figure 2. Flowchart of Hybrid GA

IV. CASE STUDY

The case study is an 8-bus network with two 150MVA generators and 7 transmission lines. Bus 4 linked to another network with 400MVA short circuit capacity. The network consists of 28 relays (14 overcurrent and 14 distance relays) which are placed in 1–14 as shown in Fig. 3. All of overcurrent relays have standard inverse time characteristics and their pickup currents are considered as eight values (0.5, 0.75, 1, 1.25, 1.5, 2, 2.25, 2.5). *TMS* is considered to be continues and can change between 0.05 and 1.1. *CTI* and *CTI'* assumed to be 0.3s and 0.25s, respectively. Table I shows load data consists of active and reactive power.

TABLE I. LOAD DATA

Node	P (MW)	Q (MVAr)
2	80	50
3	80	70
4	90	70
5	90	70

The following tables contain data, which is used in the network. Table II is about line data, which includes resistances and reactances. These parameters are per unit length of lines. In Table III ratio of current transformers are presented that are connected to relays, which is shown in Fig. 3. The other data like transformer data, generator data, backup and primary relays are given in [14].

Population of GA and the number of iteration are selected to be 100 and 2000, respectively. The other parameters like crossover and mutation are assumed to be 0.8 and 0.08 respectively and these parameters are obtained by try and error procedure.

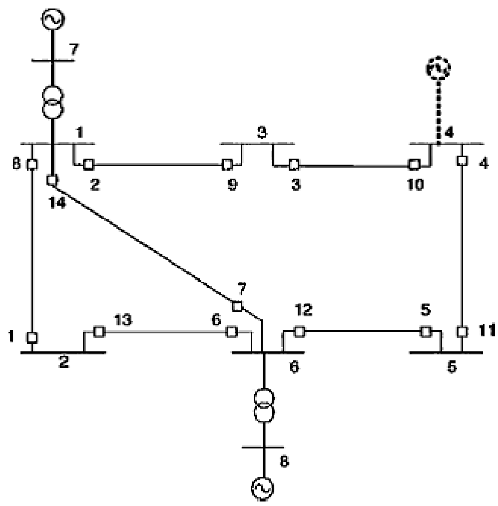

Figure 3. Single line diagram of 8-bus network

Results are shown in Tables IV to VI. In Table IV, the T_{z2} is assumed to be the same for all distance relays and two methods are applied to perform coordination.

Both GA and linear programming obtain the same value for T_{z2} but fitness of GA is smaller than linear programming. In Tables V and VI, T_{z2} is considered as a variable for each distance relay, in this condition size of variables will be two times bigger. Table V includes setting of relays, which is performed by linear programming and in Table IV results are obtained by GA. As indicated, the GA reaches to the better point compared to the obtained result in Table IV and V.

TABLE II. LINE PARAMETERS

Extreme Node	R (Ω/m)	X (Ω/m)	Length
1 2	0.004	0.05	100
1 3	0.0057	0.0714	70
3 4	0.005	0.0562	80
4 5	0.005	0.045	100
5 6	0.0045	0.0409	110
2 6	0.0044	0.05	90
1 6	0.005	0.05	100

TABLE III. CT RATIO

Relay no	CT ratio	Relay no	CT ratio
1	240	8	240
2	240	9	160
3	160	10	240
4	160	11	240
5	240	12	240
6	240	13	240
7	160	14	160

In [15] it has been stated in some systems, second zone time of distance relay should be set on high value. In the system under study the second zone of distance relay in the first condition, is obtained 0.88s which is higher than conventional setting. By considering T_{z2} as an independent variable for each distance relay, size of variable will be twice larger than before, but the results are better.

TABLE IV. LINEAR PROGRAMMING AND HYBRID GA RESULT

	LP		Hybrid GA	
relay	*TMS*	*TAP*	*TMS*	*TAP*
1	0.140563	1	0.07424	1.5
2	0.196716	2.25	0.17931	2.5
3	0.186545	2	0.14977	2.5
4	0.195304	2.5	0.1953	2.5
5	0.120664	1.25	0.12066	1.25
6	0.15829	2.25	0.14097	2.5
7	0.184872	2.25	0.18487	2.25
8	0.212039	1.25	0.098	2.5
9	0.093162	2.5	0.09316	2.5
10	0.160012	2.25	0.14269	2.5
11	0.151187	2	0.11457	2.5
12	0.196716	2.5	0.19672	2.5
13	0.167934	1	0.13124	1.25
14	0.345112	0.5	0.34511	0.5
	T_{z2}	0.880007	T_{z2}	0.88001
	Fitness	19.54542	**Fitness**	18.9196

TABLE V. LINEAR PROGRAMMING WITH 28 VARIABLES

Linear programming				
overcurrent	*TMS*	*TAP*	*Distance*	T_{z2}
1	0.1115	1	15	0.8005
2	0.1760	2.25	16	0.6464
3	0.1310	2	17	0.7611
4	0.1616	2	18	0.5436
5	0.0855	1.25	19	0.6848
6	0.1472	2.25	20	0.5502
7	0.1467	2.25	21	0.8005
8	0.1977	1.25	22	0.7043
9	0.0787	2.5	23	0.7285
10	0.1386	2.25	24	0.5515
11	0.1072	2	25	0.7433
12	0.1729	2.5	26	0.6271
13	0.1561	1	27	0.8038
14	0.2679	0.5	28	0.8038
Fitness	15.7385		*Average* T_{z2}	0.7

TABLE VI. HYBRID GA WITH 28 VARIABLES

Hybrid GA				
overcurrent	*TMS*	*TAP*	*Distance*	T_{z2}
1	0.05476	1.5	15	0.76568
2	0.15679	2.5	16	0.583574
3	0.09915	2.5	17	0.738059
4	0.15429	2.5	18	0.498105
5	0.07221	1.25	19	0.642702
6	0.1267	2.5	20	0.42626
7	0.12355	2.5	21	0.76568
8	0.08884	2.5	22	0.630168
9	0.07256	2.5	23	0.675475
10	0.11686	2.5	24	0.528048
11	0.07889	2.5	25	0.690537
12	0.16373	2.5	26	0.563891
13	0.11797	1.25	27	0.774373
14	0.24857	0.5	28	0.774373
Fitness	14.20024		*Average* T_{z2}	0.65

V. CONCLUSION

In this paper, a hybrid GA method is proposed to perform optimal coordination between distance and overcurrent relays. The proposed method uses two linear and nonlinear subroutines. In the nonlinear part (finding pick up current) GA is applied and in the linear part (finding *TMS* and T_{z2}) linear programming is used. To obtain better results, pick up currents are considered as discreet values and *TMSs* are considered as continuous.

The novelty of this paper is, considering T_{z2} as an independent variable for each distance relay. Suggested method successfully is applied and obtaining results are better than a condition which one T_{z2} is considered (as a variable or predetermined value).

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