Coordination of Overcurrent and Distance Relays Using Hybrid Particle Swarm Optimization

Javad Sadeh[1], Vahid Amintojjar[2], Mohsen Bashir[3]

[1] *Associate Professor, Islamic Azad University, Gonabad Branch, Gonabad , Iran;*
[2] *M.Sc. Student, Islamic Azad University, Gonabad Branch, Gonabad, Iran;*
[3] *M.Sc. Student, Ferdowsi University of Mashhad, Mashhad, Iran*

Abstract: Protection of power transmission has an important role in power systems. To have a better protection it is common to combine difference types of relays, which combination of overcurrent and distance relays is a well-known protection scheme in transmission lines. Another thing, which should be considered is defining a backup protection system that clear fault when main protection clear the fault. To achieve this aim, coordination between primary and backup protection systems should be performed. Speed, selectivity and stability are constraints, which must be satisfied by performing coordination, and sometimes it is so hard by conventional methods. Therefore, considering coordination of relays as an optimization problem and solving this problem by intelligent methods can be effective. Many intelligent methods have been suggested performing coordination between overcurrent and distance relays. In this paper, an optimal coordination of overcurrent and distance relays is proposed, which uses a hybrid Particle Swarm Optimization (PSO) with a new assumption that satisfies all constraints.

Keywords: power system protection, overcurrent and distance relay coordination, particle swarm optimization.

1 Introduction

To achieve comprehensive protection in power networks it is common to use primary and back up protection. Due to importance of transmission systems, a higher quality of protection should be considered. Therefore, in transmission systems, a combination of distance and overcurrent relays is used. In this protection scheme, both types of relays can have a role as a primary and backup protection. For better protection, it is common to protect a line with these two types as a primary and local backup. To have a better protection, primary and backup system should be coordinated. To coordinate the relays, a coordination time interval (*CTI*) is added to back up operating time to assure back up would not operate sooner than primary protection.

To obtain a 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].

As mentioned, for better protection, it is common to use overcurrent and distance relays in a protection scheme. In this structure, overcurrent and first zone of distance relays are used as primary and second zone of distance and delayed overcurrent relays treat as a backup protection.

Although a primary and backup protection scheme has some advantages, complexity of coordination by conventional methods is one of the major subjects. The coordination of relays could be considered as an optimization problem, which its aim is to minimize the operation time of relays and satisfying coordination constraints. If time multiplies setting (TMS) of the overcurrent relays and the second zone time (T_{z2}) of distance relays considered as variables in problem, performing coordination can be done by linear programming methods. By this assumption, in [2] problem is expressed as a linear one and coordination of second zone of distance relays and overcurrent relays is performed by linear programming. In this situation, pickup current of overcurrent relays are considered as predetermined values. 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 0.3 or 0.4s.

To have a comprehensive coordination it is better to consider pickup currents as variables. In this case, an effective nonlinear method should be applied to perform coordination. In [3] Genetic Algorithm (GA) is applied as a nonlinear method to obtain pickup current of overcurrent relays and new objective function is used to fulfill coordination. Objective function in [3] is modified in [4] and coordination is performed by considering various characteristics for overcurrent relays. In this method, GA is used to obtain desirable setting of overcurrent relays such as TMS and pickup current. Distance relay parameters such as second and third zone times are assumed predetermined. In suggested algorithm, GA finds the best characteristic for each overcurrent relays. Another intelligent method, which is used for performing coordination between relays is PSO. In [5] coordination of overcurrent relays has been done by PSO and in [6] it is fulfilled by hybrid PSO. In these papers, PSO is applied to perform coordination between overcurrent relays.

*Corresponding author (email: commoncat@163.com)

978-1-4244-9620-4/11/$26.00 ©2011 IEEE

In this paper, a modified hybrid PSO is proposed to find the global optimal point in coordination of overcurrent and distance relays, which is highly constraint optimization. A novelty of this paper is considering T_{z2} as new variables that makes convergence of the problem harder. To overcome this complexity, a modified hybrid PSO is applied. This algorithm is divided in two parts, linear and nonlinear. For performing nonlinear part, PSO is used to obtain pickup current for overcurrent relays and after that, linear programming is applied to determine optimal *TMS* and T_{z2} of the relays in linear part.

2 Review of coordination problem

A. Problem statement

Coordination of overcurrent relays in a power network could be expressed as an optimization problem in general form of (1) which the main objective is calculating setting of relays that minimize total operation time of overcurrent relays subject to coordination constraints. Linearity or nonlinearity of the problem depends on considering the pickup current (I_{set}) as a variable or not. The general form of the problem can be stated as follows:

$$\mathrm{obj} = \min \sum_{i=1}^{n} k_i x_i \tag{1}$$

$$Subject\ to: Ax \leq b \tag{2}$$

where n is the number of relays, x_i and k_i are two component of *i*th relay which is shown in two parts in (3). Backup and primary constraints could be defined like (2). *CTI* is the coordination time interval which will appear in (2) instead of *b*. 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.

B. Overcurrent relay characteristic

Overcurrent relays have many types, which are used in transmission and distribution systems. These relays are categorized by their characteristics that define the operation time of relays versus fault current passed through it. Standard inverse time is one of the common types of relays, which are used widely and its formulation is defined as expressed in (3).

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

where I_{sc_i}, I_{set_i} are short circuit current and pickup current respectively, and TMS_i is time multiplier setting of *i*th 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 [7].

C. Coordination constraints

The coordination constraints are expressed as below:

$$T_b - T_m \geq CTI \tag{4}$$

where T_b and T_m are operating time of backup and primary relays respectively. When the protection scheme is composed of overcurrent and distance relays, inequalities (5) and (6) should be considered in constraints.

$$T_{z2\ backup} - T_{oc\ main} \geq CTI' \tag{5}$$

$$T_{oc\ backup} - T_{z2\ main} \geq CTI' \tag{6}$$

In (5) and (6) T_{oc} is operating time of overcurrent relay and T_{z2} is operating time of the second zone of distance relay. It means that when both types of relays are considered, size of coordination constraints would be third times bigger than the condition which only overcurrent relays are used. In this condition, a new coordination time interval (*CTI'*) between distance and overcurrent relays should be defined, which does not have the same value as *CTI* that is used in coordination of overcurrent relay pairs. In the proposed formulation, all second zone time of the distance relays are considered as independent variables, Therefore new form of a problem should be redefined as follows:

$$obj = \min\left(\sum_{i=1}^{n} t_i + \sum_{i=1}^{n} T_{z2_i}\right) \tag{7}$$

Subject to :

$$T_{oc\,backup} - T_{oc\,main} \geq CTI \tag{8}$$

$$T_{z2\,backup} - T_{oc\,main} \geq CTI' \tag{9}$$

$$T_{oc\,backup} - T_{z2\,main} \geq CTI' \tag{10}$$

Constraints (8-10) show if a fault occurs in a line the primary protection should operate sooner than backup, but there is a chance for backup protection to operate. In Fig.1, if primary protection (second zone of the main distance relay or main overcurrent relay) could not clear the fault at F2, backup overcurrent relay should operate after a determined coordination time interval (*CTI'*), if it is necessary, and in F_1 if the first zone of distance relay or main overcurrent relay are unable to operate and clear the fault, second zone of backup distance relay or back up overcurrent relay should clear the fault after a coordination time interval.

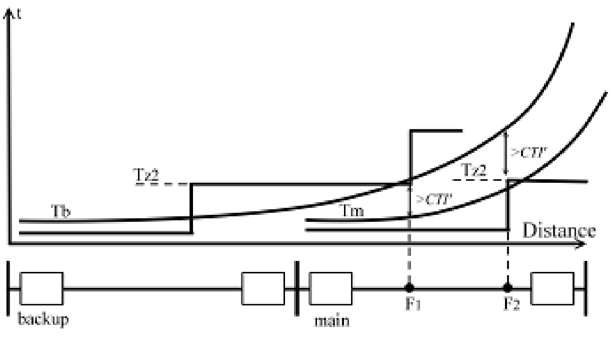

Figure 1 Coordination between overcurrent and distance relays

3 Proposed hybrid PSO

In this paper *TMS*, I_{set} and T_{z2} are considered as decision variables, which by this assumption, the problem is a nonlinear one. To perform optimal nonlinear problem, hybrid PSO is applied to overcome nonlinearity and complexity. Hybrid PSO is composed of two part, which are PSO and linear programming. As linear programming obtains T_{z2} and *TMS*, the search space will become smaller for PSO algorithm to find suitable I_{set}.

A. Proposed hybrid PSO

PSO was developed by Eberhart and Kennedy in 1995 [8]. This algorithm is a particles (population) based stochastic optimization technique, and each particle associate with a velocity. Velocity is one of the effective parameters that have a major affection for converging problems, and it is used for updating particles. Unlike the GA, PSO does not have crossover and mutation operators, and it works by function, which updates particles. In standard form of PSO, every particle intends to move to their best location (P_{best}) and the best position of the group (G_{best}) and it is performed by velocity. Particles could be n-dimensional variable and the position of *i*th particles is expressed as below:

$$x_i = [x_{i1}, x_{i2}, x_{i3,...,} x_{in}] \tag{11}$$

Each particle tries to modify its position using the current velocity and its distance from P_{best} and G_{best}. The modification can be represented by the concept of velocity and can be calculated as shown in the following formulas:

$$v_i^{t+1} = w.v_i^t + c_1.rand()(P_{best\,i} - x_i) + c_2.rand()\,(G_{best\,i} - x_i) \tag{12}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{13}$$

$$|\ v_i^{t+1}| \le kV_{max} \tag{14}$$

The first term in (12) represents the inertia of the particle, while the second and third terms represent the memory and the cooperation between particles, respectively. The parameter V_{max} represents the resolution with which regions within the feasible search space are to be searched. Choosing a high number for V_{max}, can make the particles fly past the optimal solutions. On the contrary, by setting small value for V_{max}, particles may not explore sufficiently and, the particle becomes trapped in a local optimal solution. The constants c_1 and c_2 represent the learning rate or the acceleration term that pulls each particle towards P_{best} and G_{best} positions. High values of c_1 and c_2 could cause the particle to move past the optimal solution. While low values could cause the particle to get trapped in a feasible solution before being pulled toward to the optimal solution. Inertia weight w governs how much of the previous velocity should be retained from the previous time step.

B. Modified PSO subroutine

It is common to use conventional PSO methods for unconstraint problem. Coordination of overcurrent and distance relays is highly constraint problem and performing this coordination by conventional PSO is difficult, if not impossible. To overcome such difficulty PSO algorithm should be modified. Modification includes: updating and initializing population procedures [9].

The main aim of this modification is to hold all particles in feasible space. By this way, to initialize population, particles should be selected from feasible space. To assure all particles will be maintained in feasible space, new updating method should be applied. In this new updating method, particle is updated by (12) at the first time and after that algorithm checks constraints, if constraints are not satisfied, update will be reset and particle will be renewed by (15), if this update does not work again, (16) is the last step of updating procedure and particle will back to its last best position (P_{best}). This modified updating method guarantees all particles satisfy constraints and if the first population was selected from feasible space, all particles will fly through the feasible search space from the first iteration.

$$\begin{cases} v_i^{t+1} = c_2.rand(G_{best\,i} + x_i) \\ x_i^{t+1} = x_i^t + v_i^{t+1} \end{cases} \tag{15}$$

If constraints are not satisfied for the second time update will be:

$$\begin{cases} v_i^{t+1} = 0 \\ x_i^{t+1} = P_{best\,i} \end{cases} \tag{16}$$

In nonlinear part, modified PSO is applied to obtain pickup current of overcurrent relays. Unlike linear programming, to satisfy constraints in stochastic search algorithm like GA and PSO, objective function includes constraints and for showing their effect on objective function, new formulate should be considered. In this paper, an objective function is suggested, which is similar to (7) except that constraints are added to it, which is expressed as:

$$\text{Fitness function} = \min(\alpha \sum_{i=1}^{n} t_i + \beta \sum_{i=1}^{n} \left|T_{DIOC_i} - |T_{DIOC_i}|\right| + \lambda \sum_{i=1}^{n} \left|T_{OCDI_i} - |T_{OCDI_i}|\right| + \delta \sum_{i=1}^{n} \left|T_{OC_i} - |T_{OC_i}|\right|) \tag{17}$$

Where:

$$T_{OC_i} = T_{oc\,backup\,i} - T_{oc\,main\,i} - CTI \tag{18}$$

$$T_{DIOC_i} = T_{oc\,i} - T_{z2\,i} - CTI' \tag{19}$$

$$T_{OCDI_i} = T_{z2\,i} - T_{oc\,i} - CTI' \tag{20}$$

In (17)-(20) T_{oc} and T_{z2} are operating time of overcurrent and second zone of distance relays, respectively and α, β and λ are penalty factors. In (17) if some of the constraints are not satisfied for a particle, values of T_{OC}, T_{DIOC} *or* T_{OCDI} will be negative, and it causes terms like (21) has a positive value that multiple to penalty factor, and the result is increasing in the objective function. If constraints are satisfied, values of T_{OC}, T_{DIOC} and T_{OCDI} will be positive, and in this condition all terms except total operation time of relays will be zero.

$$\left|T_{OCDI_i} - |T_{OCDI_i}|\right| \tag{21}$$

C. Linear subroutine

In every iteration, PSO computes I_{set} of overcurrent relays and after that linear subroutine takes these parameters to obtain *TMS* and T_{z2}. Computation in this part will be done by linear programming. Another thing which should be checked in linear subroutine is whether the problem converges for particle or not. If the problem does not converge, the penalty factor would be 1(α=1), but if this part is not able to converge, it means that the particle is not in feasible space and in this case, penalty factor will set on high value (α=1000) which increase the objective function. This part is done by linprog function of MATLAB® Toolbox™.

4 Case study

The study system 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. 2. All of overcurrent relays have standard inverse time characteristics and their pickup currents are considered as nine values (0.5, 0.75, 1, 1.25, 1.5, 1.75, 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 1 shows load data consists of active and reactive power.

Table 1 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 2 is about line data, which includes resistances and reactances. These parameters are per unit length of lines. The other data like transformer data, generator data, backup and primary relays are given in [10].

Population of PSO and the number of iteration are 20 and 50, respectively. The best value of c1, c2 and w in (12) are selected by try and error procedure. Both pickup currents and TMSs are considered as continuous values but in the end of each iteration, pickup currents are rounded to the nearest allowable number.

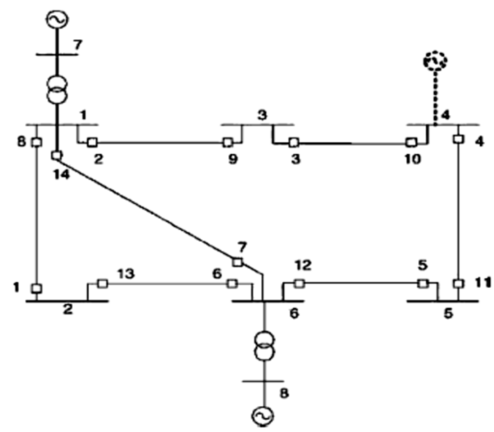

Figure 2 Single line diagram of 8-bus network

Results are shown in Tables 3 to 6. In Table 3, it is assumed that T_{z2} is the same for all distance relays and two methods are applied to perform coordination.

In Table 3, it is shown that both PSO and linear programming obtain the same value for T_{z2}, but fitness of PSO is smaller than linear programming one. In this case, it is assumed that all of distance relays have the same T_{z2}. In this condition, to have a better comparison with the result in Tables 4 and 5, number of distance relays is multiplied to T_{z2} and after that, it is added to total operating time of overcurrent relays.

Table 2 Line parameters

Extreme Node		R (Ω/km)	X (Ω/km)	Length(Km)
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

In Tables 4 and 5, T_{z2} is considered as a variable for each distance relay, in this condition size of variables will be two times bigger. Table 4 includes setting of relays, which is performed by linear programming and in Table 5 results are obtained by PSO. As indicated, the PSO reaches to the better point compared to the obtained results in Tables 5 and 4.

Table 3 Linear programming and hybrid PSO

	LP		Hybrid PSO	
relay	*TMS*	*TAP*	*TMS*	*TAP*
1	0.140563	1	0.074238	1.5
2	0.196716	2.25	0.179311	2.5
3	0.186545	2	0.149773	2.5
4	0.195304	2.5	0.195304	2.5
5	0.120664	1.25	0.120664	1.25
6	0.15829	2.25	0.140966	2.5
7	0.184872	2.25	0.167492	2.5
8	0.212039	1.25	0.097997	2.5
9	0.093162	2.5	0.093162	2.5
10	0.160012	2.25	0.142685	2.5
11	0.151187	2	0.114572	2.5
12	0.196716	2.5	0.196716	2.5
13	0.167934	1	0.131245	1.25
14	0.345112	0.5	0.345112	0.5
	T_{z2}	0.880007 Sec	T_{z2}	0.880007 Sec
	Fitness	19.54542 Sec	**Fitness**	18.89305 Sec

In [11] it is mentioned that 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.

In Table 6, coordination is performed by GA and it is shown that the obtained results by GA and PSO are equal. But GA can achieve the optimal coordination in 1000 iterations with 100 population [12] but PSO uses just 50 and 20 iteration and population respectively.

Table 4 Linear programming with 28 variables

Linear programming				
overcurrent	*TMS*	*TAP*	*Distance*	T_{z2} (Sec)
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 Sec			*Average* T_{z2} 0.7 Sec	

Table 5 Hybrid PSO with 28 variables

Hybrid PSO				
overcurrent	*TMS*	*TAP*	*Distance*	T_{z2} (Sec)
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 Sec			*Average* T_{z2} 0.65 Sec	

5 Conclusion

In this paper, a new method is proposed to perform optimal coordination between distance and overcurrent relays. The proposed method for every second zone of distance relays, a variable is considered. Finding *TMS* and T_{z2} for each relay is fulfilled by linear programming, and computing of I_{set} is done by using PSO. Proposed hybrid PSO was successful in achieving a better coordination than linear programming. Obtained results of PSO and GA for a sample network, are equal, but PSO performs coordination with less population and iteration that makes this algorithm faster. Suggested method successfully applied and obtained results are better than a condition which one T_{z2} is considered (as a variable or predetermined value).

Table 6 Hybrid GA with 28 variables

Hybrid GA				
overcurrent	*TMS*	*TAP*	*Distance*	T_{z2} (Sec)
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 Sec			*Average* T_{z2} 0.65 Sec	

1 P. M. Anderson, Power System Protection. New York: McGraw-Hill, 1999.

2 L. G. Perez, and A. J. Urdaneta. Optimal Computation of Distance Relays Second Zone Timing in a Mixed Protection Scheme with Directional Overcurrent Relays. IEEE Trans. on Power Delivery,2001, Vol. 16, No. 3.

3 R. M. Chabanloo, H. A. Abyaneh, S. S. H. Kamangar, and F. Razavi. A New Genetic Algorithm Method for Optimal Coordination of Overcurrent relays in a Mixed Protection Scheme with Distance Relays. IEEE Universities Power Engineering Conference, 2008, pp. 1-5.

4 R. M. Chabanloo, H. A. Abyaneh, S. S. H. Kamangar, and F. Razavi. A New Genetic Algorithm Method for Optimal Coordination of Overcurrent and Distance Relays Considering Various Characteristics for Overcurrent Relays. 2nd IEEE International Conference on Power and Energy (PECon 08), 2008.

5 M. R. Asadi, and S. M. Kouhsari. Optimal Overcurrent Relays Coordination Using Particle Swarm Optimization Algorithm. IEEE Power Systems Conference and Exposition, 2009 pp. 1-7.

6 M. Bashir, M. Taghizadeh, J. Sadeh, and H. Rajabimashadi. A New Hybrid Particle Swarm Optimization for Optimal Coordination of Overcurrent relays. IEEE Power System Technology (POWERCON), International Conference on, 2010, pp.1-6.

7 H. H. Zeineldin, E. F. El-Saadany, and M. M. A. Salama. Optimal Coordination of Overcurrent Relays Using a Modified Particle Swarm Optimization. Electric Power System Research, 2005, Vol. 76, pp. 995-998.

8 J. Kennedy, and R. Eberhart. Particle Swarm Optimization. Neural Networks, 1995, Vol. 4, pp. 1942-1948.

9 M. M. Mansour, S. F. Mekhamer, and N. E. Elkharbawe. A Modified Particle Swarm Optimizer for the Coordination of Directional overcurrent relays. IEEE Trans on Power Delivery, 2007, Vol. 22. No. 3.

10 A. S. Braga, and J. T. Savaria. Coordination of Overcurrent Directional Relays in Meshed Networks Using the Simplex Method. IEEE Electrotechnical Conference, 1996, Vol. 3.

11 L. G. Perez, A. J. Urdaneta, E. Sorrentino, F. Garayar, A. Urizar, J. C. Ledezma, G. D. Alcala, N. Carrion, C. Canache, J. Fernandez, O. Sanz, and F. Guevara. Comparison of Time Coordination Feasibility Criteria for a Subtransmission System Protection Scheme. IEEE Conference on Devices, Circuits and System, 1998.

12 J. Sadeh, V. Amintojari, M. Bashir. Optimal Coordination of Overcurrent and Distance Relays With Hybrid Genetic Algorithm. IEEE Environment and Electrical Engineering. 2011.