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OVERCURRENT RELAYS COORDINATION AND PROPOSING AN ADAPTIVE METHOD OF COORDINATION OF RELAYS CONSIDERING OF NETWORK CHANGES

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Abstract- The networks are changing continually and these changes can be the result of a permanent fault, DG entrance, or omission of a set of loads, etc. We know that the overcurrent relays will work properly when they have accurate coordination between operating time when a fault occurs in network and other relays. For applying this coordination on relays, we have to now the network's topology and Current through the relays. While that it is true that the network is work stable and unchanged. However, some of these changes with implementation of new conditions will result in a miscoordination of the settings of overcurrent relays. Therefore, there is a need for new coordination. In this article a sample network in a stable mode and the resulting changes that are because of DG entrance and also their effect on relay coordination before and after the change, are investigated.

Keywords: Overcurrent Relay Coordination, PSO, TSM, Overcurrent Relay Online Coordination, Optimal Method, DG.

I. INTRODUCTION

One of the major impacts of the short circuit faults on a power system is the emergence of the sudden flow. Therefore, it is very common that the flow range is used as the major sign of identifying a fault. Thus, protection of the overflow is one of the protective methods that is widely used in power systems. This kind of protection that is named protection of the nondirective over flow relies on flow range. However, we often need to know that whether fault has happened in front of breaker or in the back of it.

This is possible if there is a circumstance that not only do we consider the flow range, but also the amount (value) of its phase according to the voltage of the place of relay, consequently, the direction of the fault in regards to the position of the radar can be identified. This kind of protection is called directive overflow protection and with more consideration one can find out that, the directive overflow protection has much more selection and identification power in comparison with nondirective overflow protection.

Another issue worthing attention is that these relays need to program in a way that no interference in their performance occur. This programming will lead to the cooperation of the high-current relays. In cooperation of the high-current relays, two factors have to be regulated. One is time regulation and the other is current regulation. Time regulation is responsible for operation time of the relay, and the current regulation identifies the needed current for relay operation.

However, these setting are not possible in a widespread network using a manual method and by use of the common mathematical rules, so these settings should done through an artificial intelligence computer method that leads to optimization of relay coordination. For an optimized coordination, these items should be considered [2]:

- Optimal method
- OF
- Network type
- Nonlinear or linear relay characteristic proportional to TSM

However, the point is that the networks temporarily or permanently experience severe changes and this means that short circuit levels and load currents will change. Therefore, it is necessary that after every change, prior coordination is conducted and if needed, new coordination's are implemented. In reference [3], optimal solution is made by constraints only. Minimization is inherently included by setting the time dials to minimum and then increasing their values gradually. The protection relay coordination problem, which is highly constrained discrete optimization problem is difficult to solve by conventional optimization techniques [4].

II. OVERCURRENT RELAYS COORDINATION PROBLEM

Overcurrent relays are devices, which have ability to interrupt electricity supply service due to some severe fault. In a modem electrical power system, network interconnection is very complicated. This affects difficulty of key parameter setting of protective relaying devices.

When a total number of overcurrent relays to be coordinated is increased according to a complex transmission network, relay coordination setting is more difficult and cannot be performed by a simple hand calculation. The following is to propose a scheme of digital overcurrent relay coordination based on genetic algorithms. The relay coordination task described in this paper is in form of constrained optimization problems. Before solving such a problem, its objective function and constraints must be defined, accordingly.

A. Overcurrent Relay Characteristics

An overcurrent relay is a typical protective relay that allows a protected load operating within a preset value of the load current. The overcurrent relay is placed at the secondary side of the current transformer. The operating time of the overcurrent relay can vary due to relay type, TMS and magnitude of fault currents. For the inverse time overcurrent relay which corresponds to the ANSI device number of 51, the operating time of the overcurrent relay can be expressed as shown in Equation (1) according to the IEC standard 255-4 [5].

$$t = \frac{k}{\left(\frac{I_{sc}}{I_0}\right)^m - 1} \times TMS \tag{1}$$

$$PSM = I / CT \tag{2}$$

where, α and β are arbitrary constant, PSM is plug setting multiplier, CT is the current tap setting of the relay, I is the actual current seen by the relay α and β are constant.

In this paper, a type of inverse time overcurrent relay is used. Therefore, α and β can be specified according to the IEC standard as follows.

Table 1. Characteristic of overcurrent relay [5]

Type	m	k
Normal Inverse	0.02	0.14
Very Inverse	1	13.5
Extremely Inverse	2	80
Long-time Inverse	1	120

B. Primary and Backup Relaying Constraints

A primary or main protective device is a relay that is in the nearest position to the fault and must respond to the fault as fast as possible. To achieve a reliable protection system backup, relays are devices, which will be initiated within a certain amount of time after the main relay fails to break the fault. An amount of delay time, called time grading margin, must be add to the main relay operating time. Figure 1 can explain this. Relay m and b are the main and the backup relays, respectively. F_1 and F_2 are two fault cases seen by both relays. The operating time of the backup relay must be at least the operating time of the main relay plus the time grading margin for every fault case [6].

To generalize backup relaying constraint, Equation (3) is defined as follows:

$$\Delta t_{mb} = t_b(F_i) - t_m(F_i) - TGM \geq 0, \quad i \in FC \tag{3}$$

where, $t_b(F_i)$ is the operating time of the backup relay due to fault F_i, $t_m(F_i)$ is the operating time of main relay due to Fault F_i, TGM is the time grading margin, 0.3-0.5 sec, and FC denotes a set of fault cases.

Table 2. Line information

Line	R (pu)	X (pu)
1	0.0018	0.0222
2	0.0018	0.0222
3	0.0018	0.02
4	0.0022	0.02
5	0.0022	0.02
6	0.0018	0.02
7	0.0022	0.0222
8	0.0018	0.0222

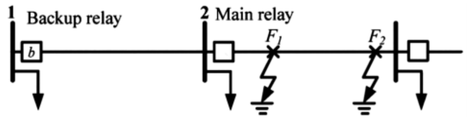

Figure 1. Simple feeder for overcurrent protection [5]

C. Objective Function

To coordinate the protective relaying devices, the operating time of the main relay is minimized. As mentioned in previous subsection, the operating time of backup relay is set as inequality constraints. The objective function used in this paper is given as follows [8, 9].

$$OF = \alpha_1 \sum \left(t_i\right)^2 + \alpha_2 \sum \left(\Delta t_{mb} - \beta_2 \left(\Delta t_{mb} - |\Delta t_{mb}|\right)\right)^2 \tag{4}$$

where, α_1 and α_2 are values between 1-2 and β has a value between100-200.

Table 3. Generator information

Generator	R (pu)	X (pu)	V (kV)
1	0.000001	0.1	10
2	0.000001	0.1	10
3	0.000001	0.1	10

III. AN INTRODUCTION TO PSO ALGORITHM

A. PSO Algorithm

The Particle Swarm Optimization (PSO) algorithm is an efficient algorithm and developed in recent years. PSO is one of the new algorithms invented by Kennedy and Eberhart in 1995 [11]. This algorithm inspired from social behavior of animals such as bird flocking or fish schooling. In comparison with other optimization algorithms, PSO has considerable search for complex optimization problems with faster convergence rate.

Table 4. Transformer information

Transformer	R (pu)	X (pu)
1	0.000001	0.026666
2	0.000001	0.026666
3	0.000001	0.026666

As an advantage in programming, PSO requires fewer parameters for regulation than other optimization algorithms. Implementation steps of this algorithm are as follows [12, 15]:

1- Random generating of primary population.

2- Particles fitness calculation respect to their current positions.

3- Comparison current fitness of particles with their best experience:

$$\text{if} \quad F(P_i) \geq pbest_i \xrightarrow{\text{then}} \begin{cases} pbest_i = F(P_i) \\ xbest_i = x(t) \end{cases} \tag{5}$$

4- Comparison of the current fitness of particles with the best experience of all particles.

$$\text{if} \quad F(P_i) \geq gbest_i \xrightarrow{\text{then}} \begin{cases} gbest_i = F(P_i) \\ xgbest_i = x_i(t) \end{cases} \tag{6}$$

5- Change the velocity of each particle according to Equation (7):

$$\begin{aligned} & v_i(t) = v_i(t-1) + \rho_1(xpbest_i - x_i(t)) + \\ & + \rho_2(xgbest - x_i(t)) \end{aligned} \tag{7}$$

6- The particle position change to new position according to Equation (8):

$$x_i(t) = x_i(t-1) + v_i(t) \tag{8}$$

7- Algorithm is iterated from step 2 until the convergence is obtained.

Parameters used in the above algorithm are defined as, $F_i(P_i)$ is fitness of the ith particle, $x_i(t)$ is position of the ith particle, $pbest_i$ is best fitness of the ith particle. $xpbest_i$ is position of the ith particle related to $pbest_i$, $gbest_i$ is best fitness of all particle in the population, $xgbest_i$ is position of the particle with the best fitness.

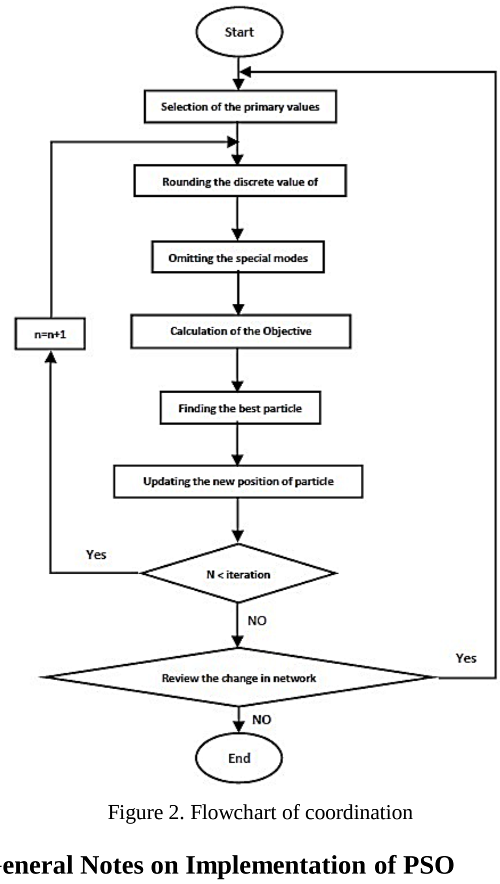

Figure 2. Flowchart of coordination

B. General Notes on Implementation of PSO

B.1. Number of Particles

Number of particles in search space is chosen by trial and error method to get better convergence. Since PSO application is relatively based on swarm intelligence, more particles lead to a better response. On the other hand, more particles require more calculations and therefore the method will be time consuming.

B.2. Velocity Limitation

One higher limit for velocity prevents that particles jump with high speed in searching region. Consequently, Space is searched to reach better region accurately. Additionally, this limitation prevents algorithm divergence due to high velocities of particles. After updating velocity vector, following conditions are checked:

$$\text{if} \quad V_i(t) \geq V_{\max} \xrightarrow{\text{then}} V_i(t) = V_{\max} \tag{9}$$

$$\text{if} \quad V_i(t) \leq -V_{\max} \xrightarrow{\text{then}} V_i(t) = -V_{\max} \tag{10}$$

The maximum value of velocity is selected with respect to change of position vector parameters. However, researches have shown that if the Equation (11) is applied for updating velocity vector, it doesn't require checking previous conditions [10, 13, 14].

$$\begin{aligned} & v_i(t) = kv_i(t-1) + \rho_1(xpbest_i - x_i(t)) + \\ & + \rho_2(xgbest - x_i(t)) \end{aligned} \tag{11}$$

$$k = 2 / \left| 2 - \rho - \sqrt{\rho^2 - 4\rho} \right|, \quad \rho = (\rho_1 - \rho_2) > 4 \tag{12}$$

B.3. Inertia Weight

This parameters controls effect of previous velocity on current velocity. Its large certainly causes wide search space and vice versa. Implementation of inertia weight can be done by using of Equation (13):

$$\begin{aligned} & v_i(t) = \phi v_i(t-1) + \rho_1(xpbest_i - x_i(t)) + \\ & + \rho_2(xgbest - x_i(t)) \end{aligned} \tag{13}$$

Preliminarily inertia weight is initialized by 1 value and reduce along algorithm [14, 16, 17].

Table 5. PSO parameters

PSO parameters	Value	PSO parameters	Value
α_1	1	iteration	100
α_2	2	particle	200
β	150		

IV. IMPLEMENTION OF PSO ALGORITHM

When an error occurs both the primary and backup relays sense it. In this case, the main relay will operate faster backup relay, because the Main relay operating time is less than backup relays. Therefore, the purpose is that calculating the operating time of relays in backup and main mode. The difference this time is that the standard should be the main relay and backup relay is about 0.3-0.5. Therefore, objective function is proposed in Equation (4).

In Equation (1) k and m will depend on the type of Relay. Therefore, finding the suitable TMS and acquiring the smaller t for gaining the minimum amount of will be the objective of implementing the simulation by PSO. It is apparent that the information acquired will be valid unit the values of I_0, I_{sc} in network remain constant [7].

Accordingly, for any change in amount of parameters of the network, new calculations for any relay should be conducted. This means that network should continuously be reviewed and analyzed and in case of a need, new setting are implemented [18]. As a solution to this problem the problem dimension will be equal to the number of relay, accordingly number of TMS, relay will be calculated and after each implementation, changes will again be checked by pattern that is being shown in Figure 2.

Table 6. Generator information

Main relay	Backup relay	Primary relay SC current	Backup relay current
1	6	2665	2665
2	7	5352	1522
2	1	5352	800
3	2	3118	3318
4	3	2215	2215
5	4	1335	1335
6	14	4953	1518
6	5	4953	404
7	13	4221	709
7	5	4221	400
8	7	4949	1512
8	9	4949	404
9	10	1425	1425
10	11	2321	2316
11	12	3465	3465
12	14	5355	1524
12	13	5355	801
13	8	2473	2473
14	1	4221	789
14	9	4221	400

V. SIMULATION RESULTS

A. Network and Protection Information

Figure 3 consists of 7 lines, 9 buses and 3 transformer and 3 generator. It is assumed that all the lines are protected by overcurrent relays and the overcurrent relays are normal inverse type. It is also assumed that TSM's of the relays are discrete and TSM's varies from 0 to 1 in steps of 0.05. The information data of the network is given in Tables 2 to 4, R (pu) and X (pu) are based on 100 MVA and 150 kV. For acquiring the short circuit current, we have to implement the short circuit for all the possible modes for primary and backup relays.

Table 7. The PSO output

Relay	Value
TMS_1	0.1
TMS_2	0.15
TMS_3	0.5
TMS_4	0.25
TMS_5	0.05
TMS_6	0.1
TMS_7	0.1
TMS_8	0.25
TMS_9	0.1
TMS_{10}	0.5
TMS_{11}	0.25
TMS_{12}	0.05
TMS_{13}	0.35
TMS_{14}	0.1

B. PSO Information

The control parameters of PSO are listed in Table 5.

C. Results and Discussion

The results of the case study and simulation that are not based DG connected to bus 4. In Table 6 measurement units for both the primary and backup relays current are Amperes. After applying PSO, results obtained in Table 7. Then entered the DG and the results are shown in Table 8. It can be seen that there are large variations in network.

Now if we assume that the network fault occurs with prior setting, as an example the currents of relays will be changed. So for doing this, we have to review the relays coordination for the new simulation, it is investigated that whether the amount of changes can transform the relay coordination or not. In this case, it is completely true, so the coordination is calculated with PSO again and is implemented. Finally, the function is as Equation (4).

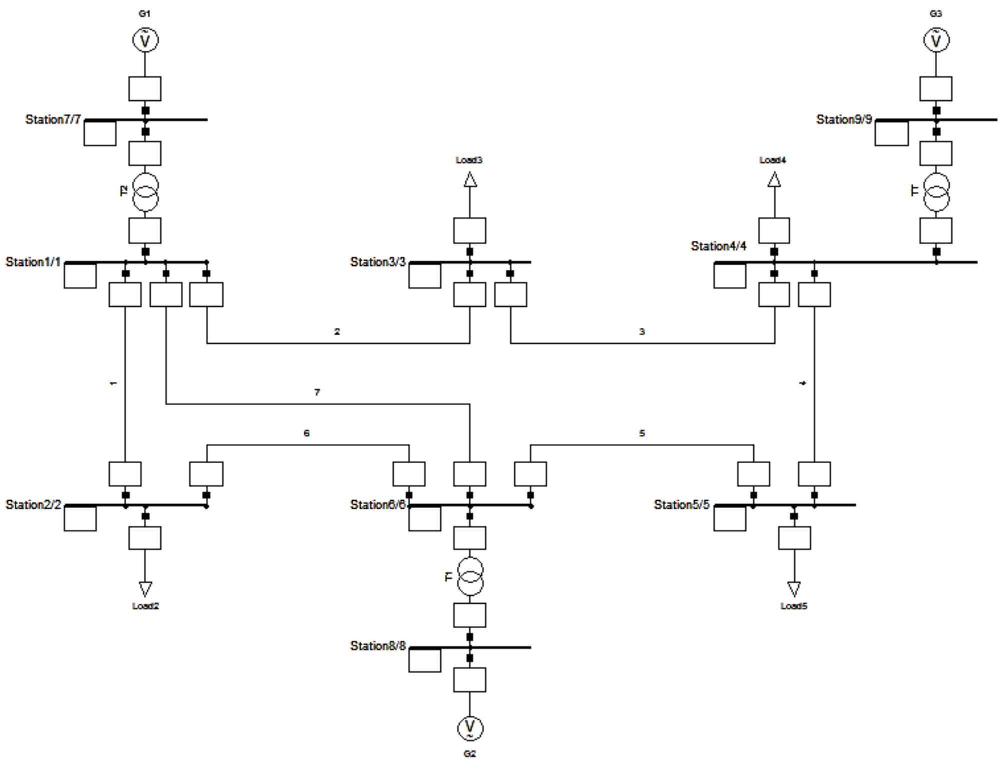

Figure 3. Sample network contains 9 buses

Table 8. Generator information

Main relay	Backup relay	Primary relay SC current	Backup relay current
1	6	3590	3595
2	7	6303	2147
2	1	6303	1129
3	2	3700	3700
4	3	5238	2208
5	4	3262	3262
6	14	6045	2109
6	5	6945	1809
7	13	5930	1098
7	5	5930	1804
8	7	6908	2134
8	9	6908	1747
9	10	3335	3335
10	11	5338	2309
11	12	3854	3854
12	14	6263	2120
12	13	6263	1115
13	8	3322	3322
14	1	5885	1113
14	9	5885	1744

Table 9. PSO Output

Relay	Value
*TMS*1	0.1
*TMS*2	0.1
*TMS*3	0.15
*TMS*4	0.05
*TMS*5	0.3
*TMS*6	0.15
*TMS*7	0.2
*TMS*8	0.3
*TMS*9	0.25
*TMS*10	0.1
*TMS*11	0.25
*TMS*12	0.05
*TMS*13	0.25
*TMS*14	0.15

VII. CONCLUSIONS

This paper described the use of the PSO search method to coordinate the overcurrent relaying system. In this paper, a 9-bus test power system with fourteen relays is tested. The results show that the overcurrent coordination is correct while the network has not changed. However, after each main change in network like DG entrance, or omission of a set of loads, etc. As it was mentioned, the changes in network can change all the settings of the relays and accordingly the network should be reviewed so that if needed new settings in relays are implemented. This review should be done by equipment such as PMU so that the network is analyzed online.

NOMENCLATURES

I: The actual current seen by the relay
α and β: The arbitrary constant
PSM: The plug setting multiplier
CT: The current tap setting of the relay
$t_b(F_i)$: The operating time of the backup relay
$t_m(F_i)$: The operating time of the main relay
$F(P_i)$: Fitness of the ith particle
$x_i(t)$: Position of the ith particle
$pbest_i$: Best fitness of the ith particle
$xpbest_i$: Position of the ith particle related to $pbest_i$
$gbest_i$: Best fitness of all particle in the population
$xgbest_i$: Position of the particle with the best fitness

REFERENCES

[1] H.K. Kargar, H.A. Abyaneh, V. Ohis, M. Meshkin, "Pre-Processing of the Optimal Coordination of Overcurrent Relays", Elsevier, Elect. Power Res., Vol. 75, pp. 134-141, June 2005.
[2] D. Birla, R.P. Maheshwari, H.O. Gupta, "Time Overcurrent Relay Coordination - A Review", Int. Jour. Emerg. Electr. Power Syst., Vol. 2, No. 2, 2005.
[3] H.A. Abyaneh, et al., "A New Optimal Approach for Coordination of Overcurrent Relays in Interconnected Power Systems", IEEE Trans. Power Deliv., Vol. 18, No. 2, pp. 430-435, April 2003.
[4] C.W. So, K.K. Li, "Overcurrent Relay Coordination by Evolutionary Programming", Electr. Power Syst. Res., Vol. 53, pp. 83-90, 2000.
[5] IEC Standard 255-4.
[6] C.W. So, K.K. Li, K.T. Lai, K.Y. Fung, "Application of Genetic Algorithm for Overcurrent Relay Coordination", IEEE Conf. Developments in Power System Protection, pp. 66-69, 1997.
[7] C.W. So, K.K. Li, "Time Coordination Method for Power System Protection by Evolutionary Algorithm", IEEE Trans. Ind. Appl., Vol. 36, pp. 1235-1240, 2000.
[8] C.W. So, K.K. Li, "Intelligent Method for Protection Coordination", IEEE International Conference of Electric Utility Deregulation Restructuring and Power Technology, Hong Kong, pp. 378-382, April 2004.
[9] B. Chattopadhyay, M.S. Sachdev, T.S. Sidhu, "An Online Relay Coordination Algorithm for Adaptive Protection Using Linear Programming Technique", IEEE Trans. Power Deliv., Vol. 11, pp. 165-173, January 1996.
[10] H.A. Abyaneh, R. Keyhani, "Optimal Coordination of Overcurrent Relays in Power System by Dual Simplex Method", AUPEC Conf., Vol. 3, pp. 440-445, Perth, Australia, 1995.
[11] M. Bigdeli, E. Rahimpour, "Estimation of Simplified Transient Model Parameters Using Genetic Algorithm", IEEE Conference, ICEE, Iran, May 2010.
[12] J. Kennedy, R. Eberhart "Particle Swarm Optimization", IEEE International Conf. on Neural Networks, Perth, Australia. Vol. 4, pp. 1942-1948, 1995.
[13] Y. Shi, R. Eberhart "Empirical Study of Particle Swarm Optimization", Congress on Evolutionary Computation, CEC 99, Vol. 3, pp. 1945-1950, 1999.
[14] M. Clerc, J. Kenndy, "The Particle Swarm-Explosion, Stability, and Convergence in an Ulti-Dimensional Complex Space", IEEE Trans. Evol. Comput., Vol. 6, pp. 58-73, 2002.
[15] R. C. Eberhart, Y. Shi, "Comparing Inertia Weights and Constriction Factors in Particle Swarm Optimization", Congr. Evol. Comput, pp. 84-88, 2000.
[16] I. Trelea, "The Particle Swarm Optimization Algorithm, Convergence Analysis and Parameter Selection", Inf. Process Lett., Vol. 85, No. 6, pp. 17-325, 2003.

[17] Y. Zheng, L. Ma, L. Zhang, I. Qian, "On the Convergence Analysis and Parameter Selection in Particle Swarm Optimization", Conf. Machine Learning Cybern., pp.1802-1807, 2003.
[18] M. Valii, E. Bigdeli, F. Hojjatiparast "Transient Model Parameters Identification of Transformer Based on PSO Algorithm", 3rd International Conference on Electric Power and Energy Conversion Systems (EPECS), pp. 479-483, Istanbul, 2-4 Oct. 2013.

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