PARTICLE SWARM OPTIMIZATION BASED OPTIMAL OPERATING TIME OF DIRECTIONAL OVERCURRENT RELAYS IN INTERCONNECTED NETWORK

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Abstract—*Particle Swarm Optimization PSO method is used to coordinate directional over current relays (DOCRs) in an interconnected power system network. The essential feature of the PSO technique that the total operating time of all primary relays is minimized. A cost function is developed in terms of summation of operating times of the power system primary over current relays. The proposed cost function has some Constraints such as value of coordination time interval CTI (difference between operating times of back up and primary relays), the range of the time dial setting of the relay TDS and range of Pick up current of the relays. MATLAB code program is built to minimize the cost function under its constraints of standard IEEE 8-bus. The operating times of relays obtained by using the proposed PSO is compared with using Linear programming method. The validation of the results obtained from implementing PSO is done by running the ETAP program under same fault conditions to get the operating time of primary and backup relays .The results prove that the powerful and effectiveness of proposed PSO to get the minimum operating times of primary relays of power system.*

Index Terms-- *directional over current relays Optimization- Particle Swarm Optimization (PSO) - power system protection.*

1. INTRODUCTION

Due to the rapid development of huge industrial systems, stability and security issues of power systems have recently acquired more attention. The basic function of protection systems is to detect and remove the faulty parts as fast and selectively as possible [1, 2]. Coordination of protection is defined as the process of choosing settings or time delay characteristics of protective devices such that the operation of the devices will occur in a specified order to minimize customer service interruption, reduce equipment damage, or personal injury [3].

The aim of relay coordination in power systems is to quickly isolate fault areas to preserve service throughout most of the power systems [1]. Each protection relay needs to be coordinated with the relays protecting adjacent equipment. Hence, relays should not only be correctly operated, but also properly coordinated with each other by finding optimum relay settings [2]. Over current relay is one of the commonly used protective devices in power systems, and their coordination is the main aspect of the protection system design [4],[3]. In large interconnected networks, the coordination between all protective devices, without any violation, is very complicated and sometimes impossible [4]. When a fault occurs in most radial feeders, the fault current will be greater than the load current with no reverse fault current. As a result, these types of radial feeders can be protected using non directional over current relays If the protected line is installed with power supplies at both ends, such as in the case of loop networks, the fault current may be fed from the left or right in the event of reverse external failure. In this case, relay malfunctions may occur only if non directional over current relays are used for protection, as these relays cannot be coordinated.

Directional over current relay (DOCR) is a method to improve protection. DOCR is designed to function only in the event of a unidirectional fault current [5]. Most work on protection coordination is geared toward determining the values of time dial setting (TDS) and plug setting (PS) values according to the coordination relationship of the primary/backup (P/B) pairs to fully secure protection for the entire system [1]. In protection coordination problem, the total operating time of all primary relays is minimized [2].Over the past seven decades, several studies on optimal coordination of over current relays has been carried out using ,Trial and error method, Structural analysis method, and Optimization method [6]. In optimization method, nonlinear programming is used in order to calculate the values of plug settings PS and time setting multiply TSM in relays while in linear programming the coefficients of TSM are determined by considering the values of PS in a default mode [6]. Optimum coordination of digital over current relays in a standard 33-bus radial distribution system was described [7]. The feasibility of applying a Nelder-Mead simplex search method and a particle swarm optimization (NMPSO) methodology to address the coordination optimization of a DOCR distribution system based on IEEE 8- and 14-bus test systems was proposed [5]. In addition to near-end faults, the far-end faults incorporated into the objective function and it takes into account a large number of coordination constraints in the optimal coordination problem [2]. a hybrid optimization technique namely IA-PSO is proposed to select the optimal values of relay settings and present a solution for the coordination problem between primary and backup relays [2]. IA, PSO and IA-PSO algorithms are applied to IEEE 4-bus and IEEE 6-bus systems [4]. The optimization problem is solved by genetic algorithm (GA) [3].The problem of determining the optimal time dial setting TD and pickup PU values of each DOCR is formulated as a nonlinear programming problem and a hybrid PSO–LP approach is used to find the optimal solution, making use of the advantages of PSO and LP techniques and, at the same time, overcoming their drawbacks [8].Optimal Coordination of Over current Relays Based on Modified Bat Optimization Algorithm was proposed [6].

In present study a proposed PSO optimization technique is used to achieve the coordination optimization of a DOCR distribution system, IEEE 8-bus test system was utilized to verify the feasibility of the proposed algorithm. Moreover, the obtained results when using these algorithms is compared with the published results obtained of Linprog (linear programming) obtained using the MATLAB optimization toolbox. Also the obtained result of TDS and the value of pickup and fault currents are used in Etap software to get the operating time of relay and it is compared with those of a proposed PSO optimization technique.

2. DESCRIPTION OF PRIMARY AND BACK UP OVER CURRENT RELAY PROTECTION

The operating time of inverse definite minimum time relay IDMT is inversely proportional to the fault current. Hence, over current relay will operate fast after sensing a high current. However, IDMT relays are categorized into standard inverse, very inverse and extremely inverse types. Relay characteristics depend on the type of standards selected for its operation. These standards can be ANSI, IEEE, IEC or user defined. Typically, there are over current relays for protection against inter phase faults and phase to earth faults on the line [9].Relays may not work for different reasons in a protection system. Therefore, it is usual that the primary protection system synchronizes with other relays (back up) to minimize the possibility of errors in protection system as shown Figure (1). It is necessary that backup relay operates slower than primary relay. In the distribution networks, a remote backup protection with time delay is used. The backup relay time delay is described by coordination constrains interval CTI. Ideally, the backup protection systems need to be completely independent [11].

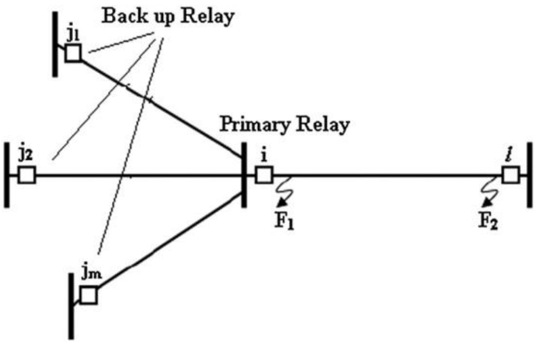

Figure 1. Primary and backup relays of distribution system

3. PROBLEM STATEMENT

The present work aims to determine the minimum operating time of all power system primary over current relays. Therefore the power system equipments and stability are protected and achieved respectively. To estimate the minimum operating time of all relays, an object function for relays operating times is developed under some constrains.

3.1 Object function for over current relays operating times

The directional over current relays coordination strategy in power system protection is to minimize the total operating times of all power system relays .to achieve this object the following object function (J) is developed and given by [8]:-

$$object\ function\ (J) = \sum_{i=1}^{n} w_i t_i \qquad \textbf{(1)}$$

where n is the number of relays, t_i is the operating time OT of the relay (i), and W_i is portability of occurrence of faults in protection area and usually equal to 1 for all relays [4]. The operating time of each relay t_i can be defined by the following equations according to IEEE standard C37.112-1996:-

$$t_i = TDS_i \times \left(\frac{28.2}{(\frac{I_{fi}}{I_{pi}})^2 - 1} + 0.1217 \right) \qquad (2)$$

Where TDS_i and Ip_i are the time dial setting and the pickup current setting of the i_{th} relay, respectively. The I_{fi} is the short-circuit fault current passing through the i_{th} relay

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3.2 Object function constrains

It is well known that there is a time coordination between primary and back up over current relay protection. The coordination constrains between the primary relay i and and it's back up relay j for object function is given by:-

$$t_j - t_i \geq CTI \qquad (3)$$

Where CTI is the coordination time interval; its value ranges from 0.2 to 0.5 s. In this study, a CTI of 0.2 s is chosen [5]. Furthermore the time dial setting TDS_i of relay i is ranged from 0.1000 to 1.1000:-

$$0.1000 \leq TDS^i \leq 1.1000 \qquad (4)$$

Also the pickup current of each relay must be greater than twice value of minimum load current and less than half of minimum value of fault current. The object function given in equation (1) with it's constrains given in equation (3) and (4) must be minimized to determine the required TDS_i whereupon the operating times of power system relays is determined .To minimize object function the particular swarm optimization method is employed.

4. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization, abbreviated as PSO, is based on the behavior of a colony or swarm of insects, such as ants, termites, bees, and wasps; a flock of birds; or a school of fish. The particle swarm optimization algorithm mimics the behavior of these social organisms. The word *particle* denotes, for example, a bee in a colony or a bird in a flock. Each individual or particle in a swarm behaves in a distributed way using its own intelligence and the collective or group intelligence of the swarm. As such, if one particle discovers a good path to *food*, the rest of the swarm will also be able to follow the good path instantly even if their location is far away in the swarm. Optimization methods based on swarm intelligence are called behaviorally inspired algorithms as opposed to the genetic algorithms, which are called evolution-based procedures. The PSO algorithm was originally proposed by Kennedy and Eberhart in 1995 [12].

In the past several years, PSO has been successfully applied in many fields. It has been demonstrated that the results of PSO are superior to other methods. The PSO procedure is reviewed below.

(1) *Initialization*. It randomly generates a swarm of potential solutions called “particles” and assigns a random velocity to each.

(2) *Velocity Update*. The particles are then “flown” through hyperspace by updating their own velocity. The velocity update of a particle is dynamically adjusted, subject to its own past flight and those of its companions. The velocity and position of the particles are updated by the following equations:-

$$V_{id}^{new}(t+1) = c_o \times V_{id}^{old}(t) + c_1 \times rand() \times \left(P_{id}(t) - x_{id}^{old}(t)\right) + c_2 \times rand() \times \left(P_{gd}(t) - x_{gd}^{old}(t)\right) \qquad (5)$$

$$x_{id}^{new}(t+1) = x_{id}^{old}(t) + V_{id}^{new}(t+1) \qquad (6)$$

$$c_o = 0.5 + \frac{rand()}{3} \qquad (7)$$

Where $c1$ and $c2$ are two positive constants; $c0$ is an inertia weight, and rand() is a random value between (0, 1).Equation (5) illustrates the calculation of a new velocity for each individual. The velocity of each particle is updated according to its previous velocity (V_{id}), the particle's previous best location P_{id} , and the global best location (P_{gd}). Particle velocities for each dimension are clamped to a maximum velocity Vmax. Equation (6), shows how each particle's position is updated in the search space [5]. Using MATLAB code ,the equations (5) ,(6) ,(7) and taking into consideration the constrains given in equations (3),(4) and the value of relay pickup I_p based on system loads .The MATLAB code is implemented to find control variables TDS_i whereupon relays operating times t_i which yield the minimum value of object function of equation (2).

5. DESCRIPTION OF PROTECTION SYSTEM UNDER STUDY

An IEEE 8-bus test system shown in fig. (2) is used to test and demonstrate the proposed method for solving a new problem formulated. The system consists of 9 lines, 2 transformers, and 14 DOCRs. All the DOCRs have the IEEE standard inverse-time characteristics mentioned in equation (2) system parameters are taken from [5]. At bus 4, there is a link to another network modeled by a short-circuit capacity of 400MVA. There are 20 inequality constraints corresponding to each relay pair. Table [1] illustrates the fault currents of the DOCR coordination pairs of primary/backup relays P/B in the event of a close-in three-phase short fault of the system. Also, the pickup current of each relay of system under study shown in fig.(1) is tabulated in table [2].

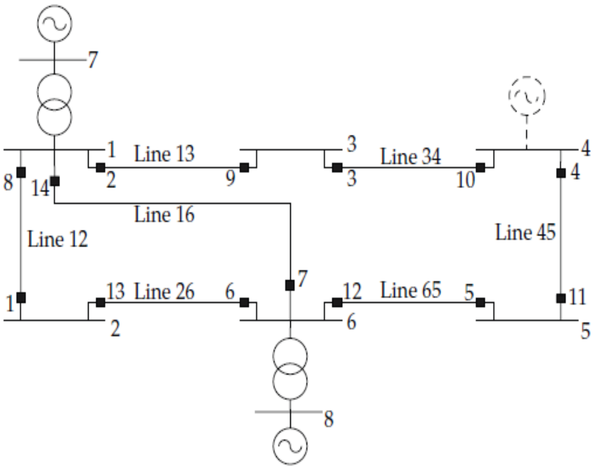


Figure 2: One-line diagram for an IEEE 8-bus test system.

6. RESULTS AND DISCUSSION

The Particle Swarm Optimization PSO technique is applied to minimize the object function given in equation (1). The parameters of PSO chosen for this problem are: C_1= 1.2, C_2= 0.012, W =.0004, population size =50, and maximum iterations = 5000. The object function values versus number of iterations of the tested system is shown in fig. (3). The Control variables TDSs of each relay results by using Particle Swarm Optimization (PSO) algorithm and Linear Programming optimization technique [5] for comparison to get the optimum coordination of over current relays of the tested system are depicted in table [3]. Therefore using equation (2), the optimum relays operating times t_i (primary/backup time) , coordination time interval CTI_i can be obtained based on optimum TDS_i (using proposed PSO).

Table [1]: P/B relays and the close-in fault currents for an IEEE 8-bus test system.

Primary relay		Backup relay	
Relay NO.	Fault current	Relay NO.	Fault current
1	3230	6	3230
8	6080	9	1160
8	6080	7	1880
2	5910	1	993
9	2480	10	2480
2	5910	7	1880
3	3550	2	3550
10	3880	11	2340
6	6100	5	1200
6	6100	14	1870
13	2980	8	2980
14	5190	9	1160
7	5210	5	1200
14	5190	1	993
7	5210	13	985
4	3780	3	2240
11	3700	12	3700
5	2400	4	2400
12	5890	13	985
12	5890	14	1870

Therefore using equation (2), the optimum relays operating times t_i (primary/backup time) , coordination time interval CTI_i can be obtained based on optimum TDS_i (using proposed PSO).The result is illustrated in Table [4]. The results show that the CTI of all cases are more than 0.2 s, which satisfy our constraints. The comparison results between using PSO and Linear programming approach show that the operating times are nearly agreed, however the PSO is simple and faster.

Table 2: pickup current of relays for an IEEE 8-bus test

Relay no.	Pickup current
1	600
2	800
3	500
4	800
5	600
6	500
7	600
8	500
9	600
10	500
11	600
12	500
13	600
14	500

Table 3. Results of Particle Swarm and Linprog Optimization (PSO) Algorithms

Relay no.	TDS using Linprog [5]	TDS using PSO
1	0.1007	0.1
2	0.2485	0.2177918
3	0.2294	0.2239791
4	0.1115	0.1097349
5	0.1003	0.1
6	0.3858	0.3844485
7	0.1103	0.1027608
8	0.3575	0.3530007
9	0.1001	0.1
10	0.2947	0.2943295
11	0.1794	0.1785108
12	0.5591	0.5534621
13	0.1007	0.1
14	0.1094	0.1
Object function	1.964	1.964

7. VALIDATION OF THE PROPOSED PSO RESULTS USING ETAP PROGRAM

To confirm the validity of the PSO results of operating time of relays, Etap software is used for simulating over current relay working in a simple power network at same condition of fault current values of primary and backup cases as in table [1]. Input data to Etap are pick up current from table [2], and TDS_i values from table [3]. The outputs of running Etap program are fault currents, and circuit breaker clearing time.

The operating time of the working relay is obtained by subtracting the value of standard circuit breaker opening time delay (Min delay) of .01s value shown in fig.(4) from the circuit breaker clearing time .

Table 4: Operating time of P/B relays and CTI values

Primary relay		Backup relay		CTI
Relay no.	Operating Time	Relay no.	Operating time	
1	0.11296	6	0.31296	0.2000
8	0.11074	9	1.04220	0.9315
8	0.11074	7	0.34114	0.2304
2	0.14114	1	1.63377	1.4926
9	0.18749	10	0.38750	0.2000
2	0.14114	7	0.34114	0.2000
3	0.15509	2	0.35509	0.2000
10	0.17598	11	0.37598	0.2000
6	0.12012	5	0.95217	0.8320
6	0.12012	14	0.64390	0.5238
13	0.13132	8	0.33132	0.2000
14	0.08080	9	1.04220	0.9614
7	0.05146	5	0.95217	0.9007
14	0.08080	1	1.63377	1.5529
7	0.05145	13	1.67582	1.6244
4	0.15840	3	0.35846	0.2000
11	0.15768	12	0.35768	0.2000
5	0.20017	4	0.40017	0.2000
12	0.18064	13	1.67582	1.4951
12	0.18064	14	0.64390	0.4632

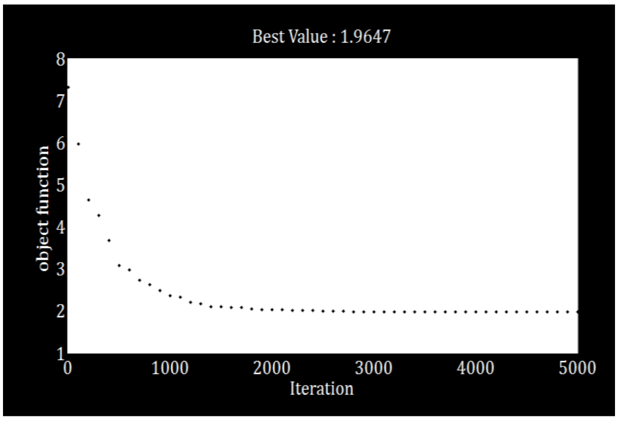
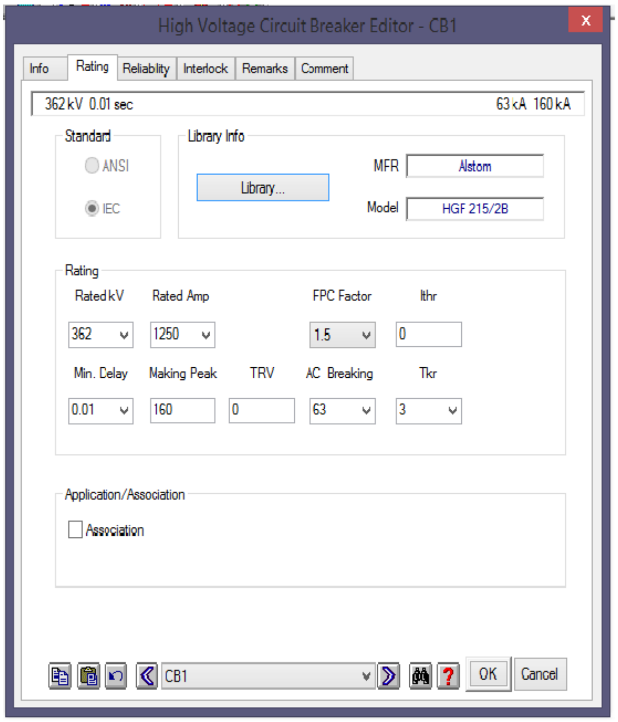


Figure 3: Object function versus number of iterations of PS

The simulated over current relay in Etap software is 7SR11 over current relay developed by Siemens. To change the fault current passing through the relay, the rated MW of generation in power system is changed.


High Voltage Circuit Breaker Editor - CB1

Info | Rating | Reliablity | Interlock | Remarks | Comment

362 kV 0.01 sec 63 kA 160 kA

Standard: ○ ANSI ● IEC

Library Info: MFR: Alstom; Model: HGF 215/2B

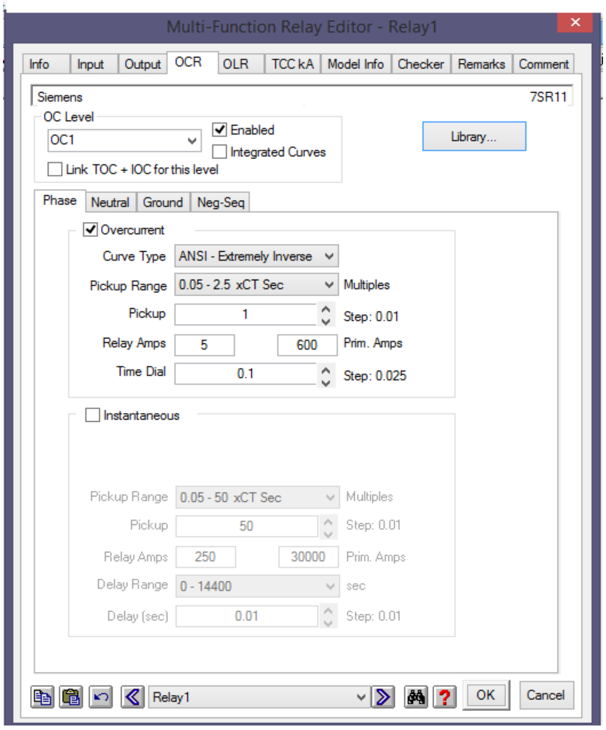
Rating:

Rated kV: 362
Rated Amp: 1250
FPC Factor: 1.5
Ithr: 0
Min. Delay: 0.01
Making Peak: 160
TRV: 0
AC Breaking: 63
Tkr: 3

Application/Association: ☐ Association

CB1

Figure 4: C.B opening time delay in Etap


Multi-Function Relay Editor - Relay1

Info | Input | Output | OCR | OLR | TCC kA | Model Info | Checker | Remarks | Comment

Siemens 7SR11

OC Level: OC1
☑ Enabled
☐ Integrated Curves
☐ Link TOC + IOC for this level

Phase | Neutral | Ground | Neg-Seq

☑ Overcurrent
Curve Type: ANSI - Extremely Inverse
Pickup Range: 0.05 - 2.5 xCT Sec Multiples
Pickup: 1 Step: 0.01
Relay Amps: 5 600 Prim. Amps
Time Dial: 0.1 Step: 0.025

☐ Instantaneous
Pickup Range: 0.05 - 50 xCT Sec Multiples
Pickup: 50 Step: 0.01
Relay Amps: 250 30000 Prim. Amps
Delay Range: 0 - 14400 sec
Delay (sec): 0.01 Step: 0.01

Relay1

Figure 5: primary relay no.1 setting in Etap

7.1 Primary Relay Validation

The data of primary relay number 1 used in Etap program validation are fault current , pick up current of 600A and TDS value of 0.1s (using PSO) are obtained from tables [1,2,3] and input to Etap program shown in fig.(5). The distribution network having primary relay is built to apply Etap program as shown in fig.(6). The output results of Etap program are fault current of 3230 amps and fault clearing time FCT of 0.123s as shown in fig.(6). The operating time of the relay is obtained by subtracting the FCT of 0.123s value minus the opening time delay of standard circuit breaker of .01s resulting 0.113 s. The above results agreed with the value of relay operating time given in table [4] using PSO method.

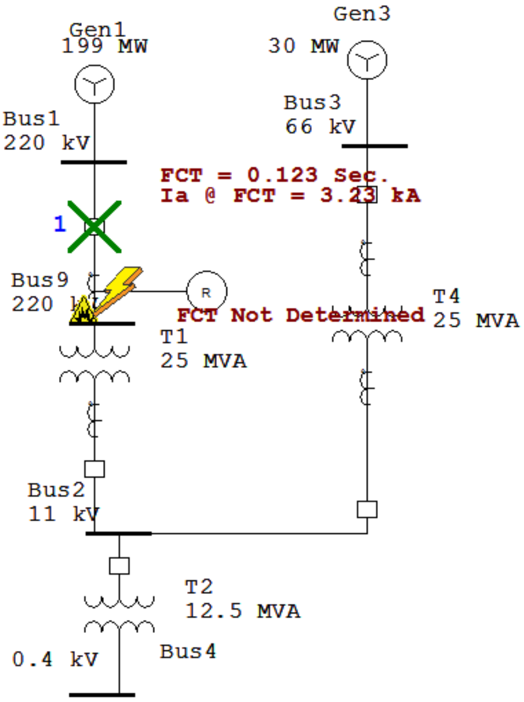
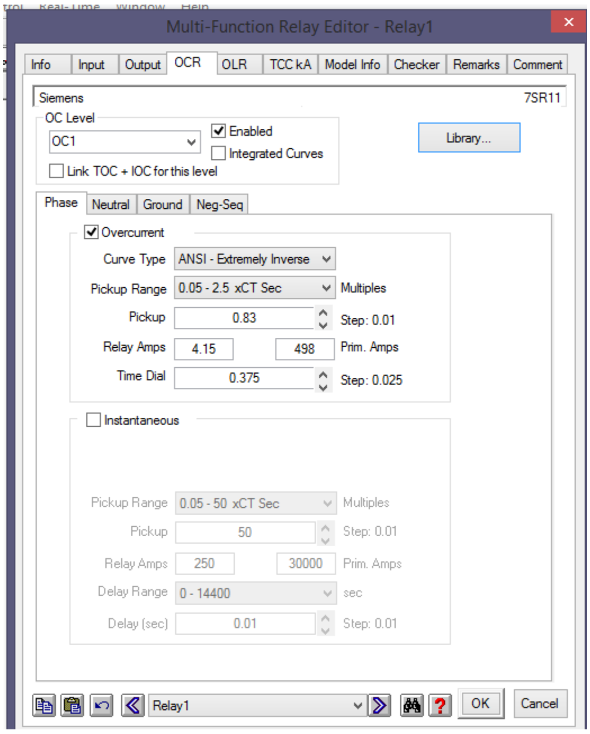


Figure 6: fault clearing time for primary relay no.1 in Etap

7.2 Backup Relay Validation

The data of back up relay number 6 used in Etap program validation are fault current, approximately pick up current of 500A and approximately TDS value of 0.384s (using PSO) are obtained from tables [1, 2, 3] and input to Etap program shown in fig. (7). the distribution network having backup relay is built to apply Etap program as shown in fig. (8). The output results of Etap program are fault current of 3230 amps and fault clearing time FCT of 0.313s as shown in fig.(8). The operating time of the relay is obtained by subtracting the FCT of 0.313s value minus the opening time delay of standard circuit breaking of .01s resulting 0.303 s. The above results agreed approximately with the value of relay operating time given in table [4] using PSO method.



Siemens 7SR11

OC Level: OC1

☑ Enabled

☐ Integrated Curves

☐ Link TOC + IOC for this level

☑ Overcurrent

Curve Type: ANSI - Extremely Inverse

Pickup Range: 0.05 - 2.5 xCT Sec Multiples

Pickup: 0.83 Step: 0.01

Relay Amps: 4.15 498 Prim. Amps

Time Dial: 0.375 Step: 0.025

☐ Instantaneous

Pickup Range: 0.05 - 50 xCT Sec Multiples

Pickup: 50 Step: 0.01

Relay Amps: 250 30000 Prim. Amps

Delay Range: 0 - 14400 sec

Delay (sec): 0.01 Step: 0.01

Figure 7: backup relay no.6 setting in Etap

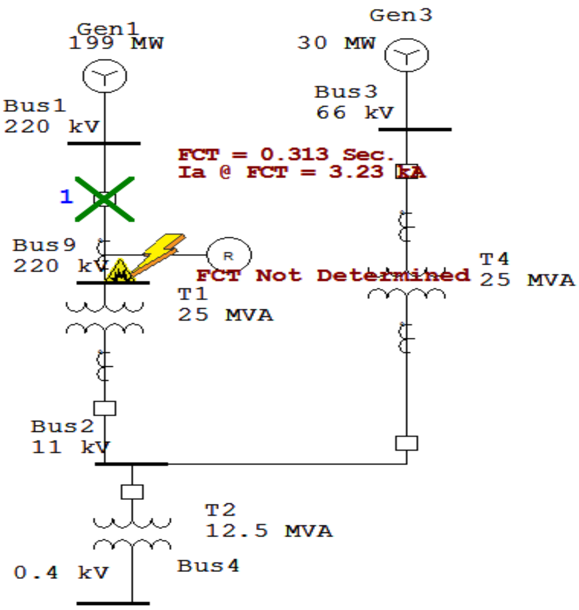


Figure 8: fault clearing time for backup relay no.6 in Etap

8. CONCLUSIONS

In this paper, the directional overcurrent relays DOCR coordination is optimized using PSO optimization method. The reduction of the total operating time of the DOCR is the goal. An object function is developed for optimization in terms of summation of operating times of primary relays in interconnected networks. Some constraints are subjected on proposed object function such as relay time dial setting TDS and Coordination time intervals CTI. The PSO method is applied on standard IEEE-9-bus system. The results of PSO are relay TDS, CTI and operating times. The PSO results are compared with using Linear programming optimization method. The comparison results show the nearly agreement between them. However The PSO is simple and it is working faster than Linear programming method. Validation of PSO results is evaluated using Etap program. The result of validation of primary and back up relays are powerful.

References

[1] *Ming-Ta Yang and An Liu "Applying Hybrid PSO to Optimize Directional Over current Relay Coordination in Variable Network Topologies" Hindawi Publishing Corporation ,Volume 2013, Article ID 879078.*

[2] *M. ZELLAGUI and H. AHMED HASSAN "A Hybrid Optimization Algorithm (IA-PSO) for Optimal Coordination of Directional Over current Relays in Meshed Power Systems" WSEAS TRANSACTIONS on POWER SYSTEMS.*

[3] *N. M. Stenane and K. A. Folly "Application of Evolutionary Algorithm for Optimal Directional Over current Relay Coordination" Journal of Computer and Communications, 2014, 2, 103-111 Published Online July 2014 in SciRes.*

[4] *F.Adelnia1, Z .Moravej and M. Farzinfar "A new formulation for coordination of directional Over current relays in interconnected networks" INTERNATIONAL TRANSACTIONS ON ELECTRICAL ENERGY SYSTEMS Int. Trans. Electr. Energ. Syst. 2015; 25:120–137 Published online 6 November 2013 in Wiley Online Library.*

[5] *An Liu and Ming-Ta Yang "A New Hybrid Nelder-Mead Particle Swarm Optimization for Coordination Optimization of Directional Over current Relays "Hindawi Publishing Corporation, Volume 2012, Article ID 456047.*

[6] *R. Kheirollahi and F.Namdari "Optimal Coordination of Over current Relays Based on Modified Bat Optimization Algorithm" . International Electrical*

Engineering Journal (IEEJ) Vol. 5 (2014) No.2, pp. 1273-1279 ISSN 2078-2365.

[7] N. Ghaffarzadeh and S. Heydari "Optimal Coordination of Digital Over current Relays using Black Hole Algorithm" World appl. programming, Vol(5), No (2), February, 2015. pp. 50-55.

[8] V. Papaspiliotopoulos, T. Kurashvili and G. Korres, " Optimal Coordination of Directional Over current Relays for Distribution Systems with Distributed Generation based on a Hybrid PSO-LP Algorithm" the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 308755 – the SuSTAINABLE project, funded under the EC call "ENERGY.2012.7.1.1".

[9] M. Zellagui and A.Abdelaziz "Optimal Coordination of Directional Over current Relays using Hybrid PSO-DE Algorithm" International Electrical Engineering Journal (IEEJ) Vol. 6 (2015) No. 4, pp. 1841-1849 ISSN 2078-2365.

[10] Azari and M.Akhbari "Optimal coordination of directional Over current relays in distribution systems based on network splitting" INTERNATIONAL TRANSACTIONS ON ELECTRICAL ENERGY SYSTEMS Int. Trans. Electr. Energ. Syst. (2014) Published online in Wiley Online Library.

[11] S. Mohammad Ali Mosavi ,T. Kejani and H. Javadi "Optimal setting of directional over-current relays in distribution networks considering transient stability" INTERNATIONAL TRANSACTIONS ON ELECTRICAL ENERGY SYSTEMS Int. Trans. Electr. Energ. Syst. (2015) Published online in Wiley Online Library.

[12] Singiresu S. Rao "Engineering Optimization Theory and Practice" Engineering Optimization: Theory and Practice, Fourth Edition Singiresu S. Rao Copyright © 2009 by John Wiley & Sons,