Optimal Coordination of DOCR for Radial Distribution Systems in Presence of TCSC

Lazhar Bougouffa, Abdelaziz Chaghi
LSP-IE Laboratory Research Laboratory, Faculty of Technology, Department of Electrical of Engineering,
University of Batna, Algeria

Article Info

Article history:

Received Dec 2, 2015
Revised Mar 19, 2015
Accepted Apr 4, 2016

Keyword:

Distribution system
DOCRs
Optimal coordination
PSO
TCSC

ABSTRACT

Protective relays coordination is the process of determining the exact relay settings such that the relay closes to the fault would operates faster than other relays. The operating time of each relay depends on two independent variables called Pickup current (Ip) and Time Dial Setting (TDS). In this paper, a PSO algorithm has been presented to determine the coordination of Directional Over-Current Relays (DOCRs) in presence of multi-system FACTS devises. From the simulation result and analysis, the impact of TCSC location in the in 33-bus distribution system on Directional Over-Current Relays has been observed on the optimal relays settings as well as the effectiveness of the proposed algorithm in finding optimal coordination of directional over-current relays.

Corresponding Author:

Lazhar Bougouffa,
LSP-IE Laboratory Research Laboratory, Faculty of Technology,
Department of Electrical of Engineering,
University of Batna, Street El Hadi Boukhlouf, 05000, Batna - Algeria
Email: blazhar2010@gmail.com

1. INTRODUCTION

The equipments of electric power systems represent some of the oldest industrial machinery still in general use today. Another dimension of automation in the case of transmission systems is the direct modification of the grid's properties with the aid of solid-state technology essentially; various types of transistors scaled up and combined to handle large power applications in a new category of equipments called flexible A.C. transmission systems (FACTS). Transmission lines generally have physically fixed parameters such length and impedance that become firm constraints in modeling and analysis. Other components such as transformers and capacitors may have variable states or settings, but conventionally these settings are discrete and require mechanical switching. FACTS technology offers ways to modify the electrical characteristics of transmission components much more rapidly, even in real time, so as to increase operating efficiency and relieve constraints without the need for adding major equipments. FACTS devices include various types of reactive compensation, phase shifting, and power flow control [1].

The basic task of the Over-Current relays (OCR) is to sense faults on the lines and to rapidly isolate these faults by opening all the current paths. This sensing and switching must occur as fast as possible to minimize damage. However, it should be very selective so no more of the network is removed from service than is necessary. In order to increase reliability, this need has led to the practice of providing both "primary" protections with "backup" protection which should function only if one of the primary devices fails. Over-current relays are classified on the basis of their operation time, in the following three categories: Instantaneous Over-current Relay (IOR), Definite Time Over-current Relay (DTOC) and Inverse Definite Minimum Time (IDMT) Over-current Relay; this relay has an inverse time characteristic. This means that the relay operating time is inversely proportional to the fault current [2].

2. DIRECTIONAL OVERCURRENT RELAYS

Directional Over-Current Relays (DOCR) coordination problem is a parametric optimization problem, where different constraints have to be considered in solving the objective function [3]-[4]. Here the objective function to be minimized is the sum of the operating times of the relays connected to the system, subject to constraints. A typical inverse time directional over-current relay has two units, an instantaneous unit (time independent) and an inverse over-current unit (time dependent). The instantaneous unit operates with no intentional time-delay when current is above a predefined threshold value, known as the instantaneous current setting. Time-delay unit is used for current, which is below the instantaneous current setting but exceeds the normal flow due to a fault. This unit operates at the occurrence of a fault with an intentional time-delay [5]. Two settings are associated with the time-delay unit, which are the Time dial setting (TDS) and Backup current setting (I_P).

The pickup value is the minimum value of current for which the relay operates. The time dial setting defines the operating time (T) of the relay for each current value.

The operating time (T) of a DOCR is a non-linear function of the relay settings (Time Dial Settings (TDS) and pickup current (I_P) and the fault current (I_F) seen by the relay. Thus, the relay operating time equation for a DOCR is given by [6]:

$$t = TDS \times \frac{0.14}{\left(\frac{I_f}{KCT \times I_p}\right)^{0.02} - 1} \tag{1}$$

Where

KCT is the current transformer ratio.

The requirement of selectivity dictates that when a fault occurs, the area isolated by the protective relay must be as small as possible, with only the primary protection relay operating. In addition, the failure possibility of a protective relay must be considered. In this situation, another relay must operate as backup protection. In order to satisfy the requirement of selectivity, the following constraint must be added [7]-[8]:

$$T_{back\text{-}up}^{F1} - T_{primary}^{F1} \leq CTI \tag{2}$$

$$T_j^{F1} - T_i^{F1} \leq CTI \tag{3}$$

Where T_j^{F1}-T_i^{F1} are the operating times of ith primary relay T_i^{F1} and jth backup relay T_j^{F1} respectively for the near-end fault F_1 as shown in Figure 2.

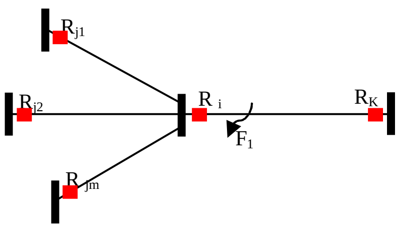

Figure 1. Primary and backup relays

The Coordination Time Interval (CTI) is the minimum time gap in operation between the primary and its backup relay. CTI depends upon type of relays, speed of the circuit breaker and a safety margin which is usually selected between 0.2 s and 0.5 s [5].

The limits on the relay parameter can be presented as follows:

$$TDS_i^{min} \leq TDS_i \leq TDS_i^{max} \tag{4}$$

$$I_{Pi}^{min} \leq I_{Pi} \leq I_{Pi}^{max} \tag{5}$$

The minimum pickup current setting of the relay (I_{Pi}^{min}) is the maximum value between the minimum available current setting and the maximum load current max (I_{loadi}^{max}, I_{Pi}^{min}). In similar, the maximum pickup current setting (I_{Pi}^{max}) is chosen as the minimum value between the maximum available current setting of the relay and the minimum measured fault current max (I_{Faulti}^{min}, I_{Pi}^{max}) [9].

The TDS is assumed to vary between a minimum value of 0.05 and maximum value of 1.2. The pickup current setting Ip is assumed to vary between a minimum value 0.25 and maximum value of 2.5 with step of 0.25.

3. OPERATION OF THYRISTOR CONTROLLED SERIES CAPACITOR

The TCSC installed in the systemisconsisted as a series compensating capacitor (C) shunted by a thyristor controlled reactor (TCR) as shown in Figure 2 and is placed in series on a transmission line [10].

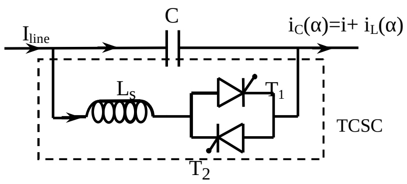

Figure 2. Basic TCSC scheme

TCSC has four operation modes: Blocking, Bypass, Capacitive and Inductive mode. The four operation modes are made by the firing angle (α) of thyristors [11].

In blocking mode the firing angle of the thyristors is 90°. The TCSC impedance will be equal to capacitance reactance X_C.

When two anti-parallel thyristors are on in all time that they have turning on condition, the TCSC will operate in Bypass mode. The thyristors conduct 180° degree in each cycle.

If the firing angle of the thyristors is greater than zero and smaller than 90 degree, the impedance of TCR branch in fundamental frequency will be given by equation (6) in wich α is the firing delay angle with respect to zero crossing of the line current [10].

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - Sin2\alpha}, \quad X_L \leq X_L(\alpha) \leq \infty \tag{6}$$

4. PARTICLE SWARM OPTIMISATION

The Particle Swarm Optimization (PSO), which has gained rapid popularity as an efficient optimization technique, is relatively a recent heuristic method introduced by Eberhart and Kennedy [12]. PSO has a flexible and well-balanced mechanism to enhance and adapt the global and local exploration and exploitation abilities within a short calculation time. The main advantages of PSO algorithm are summarized as: simple concept, easy implementation, robustness to control parameters. In PSO algorithm: the individual best (p^{best}) and the global best (g^{best}) are used. As a particle moves through the search space, it compares its fitness value at the current position to the best fitness value it has ever attained previously. The best position that is associated with the best fitness encountered so far is called the p^{best}. The g^{best}, is the best position among all of the individual's best positions achieved so far.

Each particle updates its position based upon its own best position, global best position among particles and its previous velocity vector according to the following equations:

$$\begin{aligned} v_i^{k+1} &= w \times v_i^k + c_1 \times r_1 \times (p^{best} - s_i^k) \\ &+ c_2 \times r_2 \times (g^{best}{}_i - s_i^k) \end{aligned} \tag{7}$$

$$s_i^{k+1} = s_i^k + ¡ \times v_i^{k+1} \tag{8}$$

Where,

v_i^{k+1} : The velocity of i^{th} particle at $(k+1)^{th}$ iteration

w : Inertia weight of the particle
v_i^k : The velocity of i^{th} particle at k^{th} iteration
$c_{1,}c_2$: Positive constants having values between [0, 2.5]
r_1, r_2 : Randomly generated numbers between [0, 1]
p_{best_i} : The best position of the i^{th} particle obtained based upon its own experience
g_{best} : Global best position of the particle in the population
s_i^{k+1} : The position of i^{th} particle at $(k+1)^{th}$ iteration
x_i^k : The position of i^{th} particle at k^{th} iteration
¡ : Constriction factor. It may help insure convergence.

Suitable selection of inertia weight w provides good balance between global and local explorations.

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \quad (9)$$

Where, $w_{\max}$ is the value of inertia weight at the beginning of iterations, $w_{\min}$ is the value of inertia weight at the end of iterations, the value of $\omega^{\max}$ and $\omega^{\min}$ are taken to be equal to 0.9 and 0.5 respectively, *iter* is the current iteration number and $iter_{\max}$ is the maximum number of iterations.

5. IMPLEMENTATION OF PROPOSED PROGRAM

Conventionally, objective function in coordination studies is constituted as the summation of operating times of all primary relays. Specific to directional over-current relays, the optimal coordination problem determines two parameters, that is, the pickup current setting I_P and the time dial setting TDS. The objective function represented by *L* is given by:

$$L = \min \sum_{i=1}^{N} t_{il} \quad (10)$$

where *L* is the objective function in sec, t_i is the operating time of the ith relay, and N is the total DOCRs in the system.

The two variables in the objective function are the TDS and $I_{P.}$ By minimizing both the TDS and I_P we can able to minimize the operating time of the primary relays and satisfying the coordination between the primary and backup relays. The set of the constraints are also framed as per the constraints conditions mentioned above. The range of TDS's is from 0.01 to 1.0 and for I_P from 0.5 to 2.5. The CTI is set to a desired value of 0.3 sec.

The various steps involved in the implementation of PSO to the DOCRs problem with 64 decisions variables are:

Step 1. Input the data of 33 IEEE distribution test system to calculate the power flow and current,
Step 2. Define population size (50), no of iteration (=500), assume suitable values of PSO parameters.
Step 3. Initial searching points and velocities are randomly generated within their limits. P^{best} is set to each initial searching point. The best-evaluated values among P^{best} is set to g^{best}.
Step 4. New velocities are calculated using the equation (7).
Step 5. Evaluate the fitness values for new searching point. If evaluated values of each agent is better than previous P^{best} then set to P^{best}. If the best P^{best} is better than best g^{best} then set to g^{best}.
Step 6. If the maximum iteration is reached stop the process otherwise go to step3.

6. CASE STUDIES

A developed Matlab program is implemented to a modified 33-bus (IEEE 12.66 kV, 100 MVA) [13] in order to calculate the optimal coordination of DOCRs using PSO under system changes. This change is the varying mode of the TCSC. The program is implemented for different firing angle alpha of the TCSC and two angles for each mode are selected. Three phase Faults are generated on each bus. The calculation of fault current seen by each primary and backup relays is carried out, however no backup relay exists for relays R1.

Directional over-current relays are used in the system to protect the feeder in case of three phase faults. The single line diagram of the IEEE 33-bus system is shown in Figure 3.

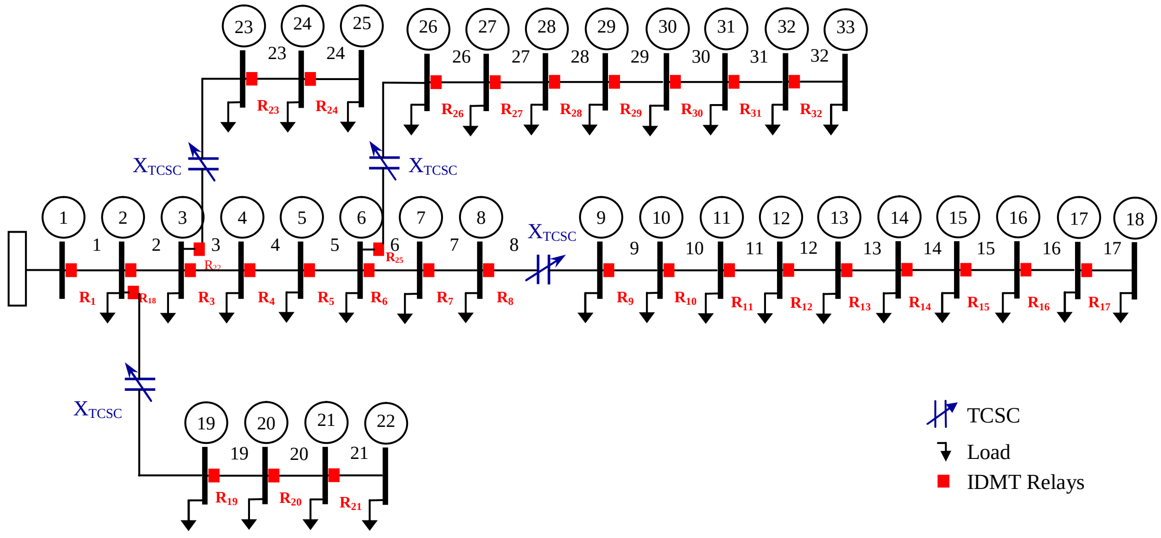

Figure 3. System diagram of IEEE 33 bus for the case study

The system consists of 32 electromechanical IDMT Directional over-current relays. The value of KCT ratio is given in Table 1.

Table 1. The KCT ratio for relays

IDMT Directional Over-Current Relays No.	KCT
R_1, R_2	1200/5
R_3, R_{18}, R_{19},R_{30},	1000/5
R_{23}, R_{24}	800/5
R_4, R_5, R_6, R_7, R_8, R_9, R_{20}, R_{21}, R_{22}, R_{29}, R_{31},	300/1
R_{10}, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, R_{16}, R_{17}, R_{25}, R_{26}, R_{27}, R_{28}, R_{32},	200/1

The TCSC can be installed anywhere in the distribution circuit in order to control the power flow. Since it is essentially a variable reactance, its impedance will be added arithmetically to the system impedance and result in a reduction of the fault currents. The system is modified for four locations of the TCSC compensators added to the system. The location of the integrated TCSC is branch8, branch18, branch22 and branch25. The selected location of the TCSC is taken arbitrary in the system.

The rated value of TCSC is a function of the reactance where the TCSC is installed and expressed as:

$$X_{Total} = X_{line} + X_{TCSC} \tag{11}$$

Where

$$X_{TCSC} = K_{TCSC} \cdot X_{line} \tag{12}$$

X_{Total} is the overall line reactance with the TCSC installed. X_{TCSC} is the reactance of the TCSC and K_{TCSC} is the coefficient which represents the compensation level of the TCSC (-0.7 ≤ K_{TCSC} ≤ 0.2). The working range of reactance of TCSC is fixed between -0.7(capacitive) X_{line} and 0.2(inductive) X_{line} [14].

The apparent reactance injected by the TCSC in the system in the case study is presented in Figure 4.

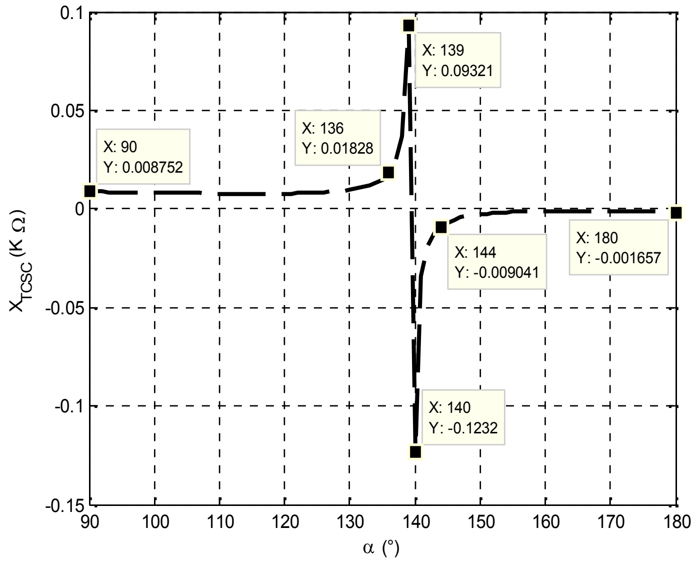

Figure 4. Characteristic Curve of TCSC study $X_{TCSC}(\alpha)$.

The three-phase fault applied at bus-9. Figure 5 represents the variation of the fault current at branch 8 and branch 7 respectively as a function of alpha varied from 90° to 180°in inductive and capacitive modes.

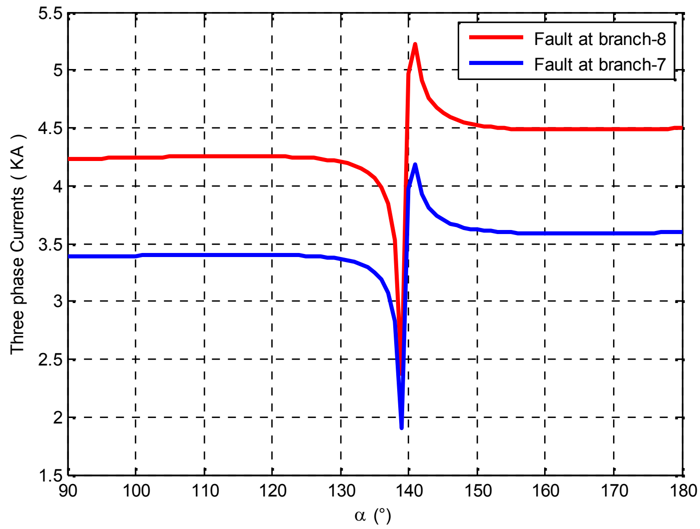

Figure 5. The variation of the fault current at branch 8 and branch 7

It is clear from Figure 5, that there is an effect of the injected reactance of the TCSC on the fault current seen by the relays when varying reactance of the TCSC with respect to firing angle alpha. The operating time of relays is varied because the value of fault current is also a function of TCSC injected reactance.

Figure 6 shows that the operating times of primary R_8 and back-up relays $R_{7.}$ As can be seen the operating times of primary relays without TCSC is less than the operating times of primary relays in both inductive and capacitive mode, where the fault occurs at any bus of the network in the presence of the TCSC.

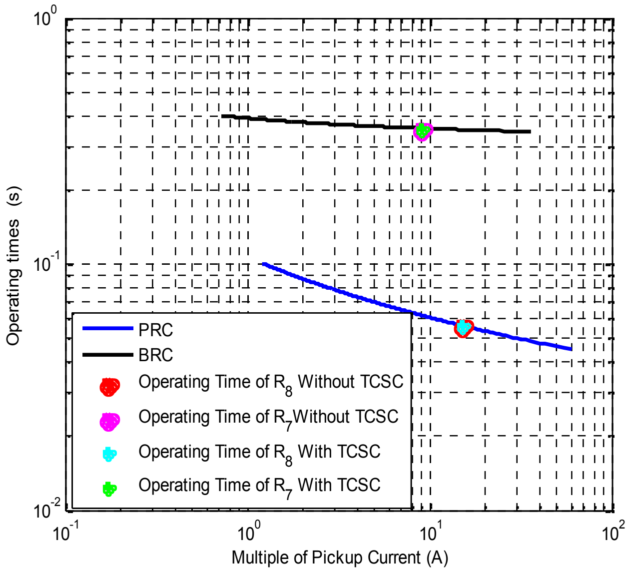

Figure 6. Operating time's characteristics of R_8 and R_7 for fault at bus-9 without and with TCSC

7. RESULTS AND DISCUSSION

In order to illustrate the effects of the TCSC insertion in the distribution system on the setting of DOCRs, different locations are chosen for the TCSC. For this purpose, branches 8 18, 22 and 25 of the most important feeder of the distribution system are selected to compensated.

The network used for the relay coordination study is shown in Figure3.The relay coordination is carried out using PSO with the process of coordination described before. Table II shows the optimum setting values of relays' TDSs found by using PSO. The effect of the TCSC on the relays settings can be shown by comparing the results with and without integration the compensator in the system for different penetration. The optimum values of TDS and I_P of all relays obtained in this process was repeated for all possible values of firing angle alpha of TCSC. As can be see each relay have a constant operating time for two selected different angles in each mode in case of three-phase faults and the coordination time interval is always at a minimum.

Table 2 shows the optimal results of TDSs in presence of TCSC installation in four locations of 33-bus distribution system. Table 3 shows comparative results between the optimal pickup current I_P without and with TCSC for different firing angle in the inductive and capacitive mode. As can be seen there is an effect of the TCSC compensator on the setting of pickup current.

In system protection the main goal of relays coordination is the setting of relays such that minimum relay operating time is achieved and the whole of system are under primary and backup protection. Also the Coordination Time Interval (CTI) between primary and backup relays is satisfied (i.e., CTI ≥ 0.3) as shown in Table 4.

Table 2. Settings Values of Relay's TDSs Using PSO

Relays	Without TCSC	Setting of TDS			
		Inductive mode		Capacitive mode	
		α=90°	α=135°	α=136°	α=180°
R_1	0.5000	0.5000	0.5000	0.5000	0.5000
R_2	0.3500	0.3500	0.3500	0.3500	0.3500
R_3	0.3400	0.3400	0.3400	0.3400	0.3400
R_4	0.3300	0.3300	0.3300	0.3300	0.3300
R_5	0.3400	0.3400	0.3400	0.3400	0.3400
R_6	0.3500	0.3500	0.3500	0.3500	0.3500
R_7	0.2700	0.2700	0.2700	0.2700	0.2700
R_8	0.2400	0.1700	0.0500	0.1200	0.3300
R_9	0.3100	0.5700	0.3800	0.4100	0.3100
R_{10}	0.4600	0.4800	0.5700	0.5100	0.4500
R_{11}	0.4200	0.4400	0.5200	0.4500	0.4200
R_{12}	0.3000	0.3200	0.4000	0.3300	0.3100
R_{13}	0.3400	0.3600	0.4500	0.3900	0.3400
R_{14}	0.3700	0.3300	0.4100	0.3300	0.3100
R_{15}	0.3600	0.3800	0.4500	0.3700	0.3600
R_{16}	0.3000	0.3100	0.3900	0.3100	0.2900
R_{17}	0.3200	0.3700	0.4500	0.3700	0.3500
R_{18}	0.4000	0.2400	0.0700	0.0800	0.4000
R_{19}	0.2600	0.2200	0.1700	0.1700	0.2700
R_{20}	0.3500	0.3300	0.3700	0.3500	0.2600
R_{21}	0.3200	0.3100	0.3300	0.3000	0.3000
R_{22}	0.3300	0.2400	0.0900	0.0900	0.3400
R_{23}	0.2900	0.2500	0.0500	0.0500	0.3000
R_{24}	0.2800	0.3000	0.3200	0.3100	0.2800
R_{25}	0.4300	0.3900	0.2600	0.2700	0.4300
R_{26}	0.4400	0.4400	0.3800	0.4400	0.4400
R_{27}	0.3200	0.3200	0.2600	0.3000	0.3300
R_{28}	0.3300	0.3200	0.2700	0.3500	0.3300
R_{29}	0.3400	0.3400	0.3700	0.3100	0.3400
R_{30}	0.2600	0.2600	0.2800	0.2300	0.2600
R_{31}	0.3300	0.3300	0.3500	0.3000	0.3300
R_{32}	0.4200	0.4200	0.4400	0.4000	0.4200

Table 3. Settings Values of Relay's Ip Using PSO

Relays	Setting of I_P				
	Without TCSC	Inductive mode		Capacitive mode	
		α=90°	α=135°	α=136°	α=180°
R_1	0.7300	0.7300	0.7300	0.7300	0.7300
R_2	0.7500	0.7500	0.7500	0.7500	0.7500
R_3	1.0400	1.0400	1.0400	1.0400	1.0400
R_4	0.8100	0.8100	0.8100	0.8100	0.8100
R_5	0.3500	0.3500	0.3500	0.3500	0.3500
R_6	0.3500	0.3500	0.3500	0.3500	0.3500
R_7	1.0700	1.0700	1.0700	1.0700	1.0700
R_8	1.0100	1.0800	1.0100	0.3600	0.3700
R_9	0.3600	0.3600	0.3800	0.3400	0.3800
R_{10}	0.5200	0.5200	0.5400	0.5300	0.5600
R_{11}	0.5600	0.5300	0.5400	0.5400	0.5400
R_{12}	0.5400	0.5100	0.5100	0.5100	0.5100
R_{13}	0.5600	0.5500	0.5500	0.5100	0.5300
R_{14}	0.5200	1.0500	1.0600	1.1400	1.0800
R_{15}	0.5300	0.5000	0.5600	0.5600	0.5100
R_{16}	0.5000	0.5300	0.5100	0.5100	0.5500
R_{17}	0.8300	0.5300	0.5400	0.5600	0.5400
R_{18}	1.2200	1.2300	1.2400	1.1100	1.1500
R_{19}	1.0300	0.9500	0.9600	1.0400	1.0400
R_{20}	0.5000	0.5200	0.5600	0.5700	0.5200
R_{21}	0.5500	0.5100	0.5200	0.5500	0.5300
R_{22}	0.9800	1.0300	1.0600	0.9800	0.9400
R_{23}	1.0200	1.0200	0.9600	0.9500	1.0300
R_{24}	1.0100	0.9800	0.9600	1.0700	1.0400
R_{25}	0.5200	0.5300	0.5600	0.5400	0.5600
R_{26}	0.5500	0.5200	0.5400	0.5200	0.5500
R_{27}	0.5700	0.5100	0.5100	0.5700	0.5100
R_{28}	0.5200	0.5600	0.5300	0.5300	0.5200
R_{29}	0.7200	0.7400	0.6800	0.7100	0.7100
R_{30}	1.5600	1.6000	1.5700	1.6300	1.5500
R_{31}	1.0900	1.1300	1.1300	1.1400	1.0900
R_{32}	0.5100	0.5200	0.5000	0.5000	0.5100

Table 4. Coordination Time Interval of Each P/B Pair of Relays

P/B		Without TCSC	α=90°	α=135°	α=136°	α=180°
		Coordination Time Interval (CTI) (sec)				
R_{32}	R_{31}	0.3206	0.3002	0.3199	0.2991	0.3009
R_{31}	R_{30}	0.2999	0.3009	0.3522	0.3002	0.3012
R_{30}	R_{29}	0.3011	0.2994	0.2994	0.3222	0.3017
R_{29}	R_{28}	0.3008	0.3174	0.2991	0.3003	0.3182
R_{28}	R_{27}	0.3007	0.3008	0.3009	0.3002	0.3223
R_{27}	R_{26}	0.3005	0.3010	0.3282	0.3010	0.2990
R_{26}	R_{25}	0.3115	0.3015	0.3004	0.3001	0.2995
R_{25}	R_5	0.3022	0.3017	0.2998	0.3172	0.2990
R_{24}	R_{23}	0.3002	0.2998	0.2994	0.2998	0.3007
R_{23}	R_{22}	0.3001	0.3005	0.2996	0.3508	0.2999
R_{22}	R_2	0.3159	0.3003	0.3010	0.3009	0.3007
R_{21}	R_{20}	0.2996	0.3184	0.3017	0.2992	0.2998
R_{20}	R_{19}	0.3011	0.3004	0.3002	0.3002	0.3011
R_{19}	R_{18}	0.2999	0.3003	0.3002	0.3015	0.2996
R_{18}	R_1	0.2994	0.2995	0.3652	0.3655	0.3005
R_{17}	R_{16}	0.3021	0.3014	0.3367	0.3686	0.3383
R_{16}	R_{15}	0.3877	0.3036	0.4547	0.3590	0.3036
R_{15}	R_{14}	0.2991	0.3011	0.3476	0.2998	0.3597
R_{14}	R_{13}	0.3011	0.2991	0.3187	0.3001	0.2996
R_{13}	R_{12}	0.3001	0.2999	0.3298	0.2994	0.2993
R_{12}	R_{11}	0.3002	0.3002	0.3042	0.2995	0.3373
R_{11}	R_{10}	0.2994	0.2991	0.2999	0.3008	0.3005
R_{10}	R_9	0.3033	0.3016	0.2990	0.3015	0.3215
R_9	R_8	0.3003	0.3000	0.3025	0.3001	0.3005
R_8	R_7	0.3036	0.2997	0.3011	0.2998	0.3001
R_7	R_6	0.3003	0.3003	0.3003	0.3003	0.3003
R_6	R_5	0.3184	0.3184	0.3184	0.3184	0.3184
R_5	R_4	0.3005	0.3005	0.3005	0.3005	0.3005
R_4	R_3	0.2994	0.2994	0.2994	0.2994	0.2994
R_3	R_2	0.2997	0.2997	0.2997	0.2997	0.2997
R_2	R_1	0.3002	0.3002	0.3002	0.3002	0.3002

The coordination time interval of some combination of relays is verified for a 33 bus system. When a fault occurs in zone of R16 there is sufficient CTI margin (0.4547 s at α=135°) for backup relay R15 to operate.

8. CONCLUSION

In this paper, a PSO algorithm has been presented to determine the coordination of directional over-current relays in presence of FACTS devises. From the simulation results and analysis, the impact of the TCSC on over-current protection relay is observed on the optimal relays settings. Moreover the relays settings depend on the system location as well as on which mode is operating at the time of fault. Therefore care must be taken in order to ensure successfull protected zone. The performance of the proposed PSO based algorithm is evaluated. The results show the effectiveness of the proposed algorithm in finding optimal coordination of directional over-current relays.

REFERENCES

[1] A. V. Meier, *Electric power systems*, ISBN-13: 978-0-471-17859-0, by John Wiley & Sons. 2006.

[2] D. Birla, R.P. Maheshwari, H.O. Gupta, "Time-over-current relay coordination: a review," *International Journal Emerging Electrical Power System (IJEEPS)*, Vol. 2, 2005.

[3] A. Rathinam, D. Sattianadan and K.Vijayakumar. "Optimal Coordination of Directional Over-current Relays using Particle Swarm Optimization Technique," *International Journal of Computer Applications* (*IJCA*). Vol 10, No.2, pp 43-47, 2010.

[4] P. P. Bedekar, S. R. Bhide. "Optimum coordination of over-current relay timing using continuous genetic algorithm," *Expert Systems with Applications* Vol.38. pp 11286–11292. 2011.

[5] P. M. Anderson, "Power System Protection," McGraw-Hill, New York, 1999.

[6] A. S. Noghabi, H. R. Mashhadi, J. Sadeh, "Optimal Coordination of Directional Over-current Relays Considering Different Network Topologies using Interval Linear Programming," *IEEE Transactions on Power Delivery*. Vol.25 No 3. pp. 1348-1354. 2010.

[7] Q. Yue, F. Lu, W. Yu, and J. Wang. "A Novel Algorithm to Determine Minimum Break Point Set for Optimum Cooperation of Directional Protection Relays in Multiloop Networks," *IEEE Transactions on power delivery*, Vol. 21, pp.1114-1119, July 2006.

[8] T. Amraee. "Coordination of Directional Overcur-rent Relays Using Seeker Algorithm," *IEEE Trans-actions on Power Delivery*, vol. 27, No. 3, pp. 1415–1422. 2012.

[9] M. Jazaeri and M. Gholamzadeh. "Considering the Effect of Series Capacitor in Optimal Coordination of Directional Over-currant Relays," *Trends in Applied Sciences Research*, Vol.7, No. 6, Pp421-433, 2012.

[10] M. Nayeripour and M. M. Mansouri, "Analyze of Real Switching Angle Limits in TCSC on Capacitor and Inductor Values and their Selection Factors," *International Journal of Advanced Science and Technology (IJAST)*, Vol. 57, August 2013.

[11] M. Zellagui, R. Benabid, A. Chaghi, M. Boudour. "Impact of GCSC on IDMT Directional Overcurrent Relay in the Presence of Phase to Earth Fault," *Serbian Journal of Electrical Engineering (SJEE)*, Vol.10, No. 3, pp. 381-398, 2013.

[12] R. Eberhart, J. Kennedy, "Particle Swarm Optimization," *in Proceeding of IEEE International Conference on Neural Networks*, Vol. 4, pp. 1942–1948, 1995.

[13] A. K. Sarma and K. M. Rafi. "Optimal Selection of Capacitors for Radial Distribution Systems Using Plant Growth Simulation Algorithm," *International Journal of Advanced Science and Technology (IJAST)*, Vol. 30.Pp43-54. May 2011.

[14] P. K. Tiwari, Y. R. Sood. "An Efficient Approach for Optimal Placement of TCSC in Double Auction Power Market," *International Journal of Electronics and Electrical Engineering (IJEEE).* pp 321-326, 2012.

BIOGRAPHIES OF AUTHORS

Lazhar Bougouffa was born in Batna, Algeria, 1986. He received his MASTER degree in Electrical Engineering from department of Electrical Engineering at University of Batna, Algeria, 2011. He is currently doing PHD in Electrical power system

Prof. Abdelaziz Chaghi was born in Batna, Algeria, 1954. He received his BS degree from the University of Oran, Algeria 1980, and MS from the Manchester University, En gland 1984, and received his PhD from Batna University, Algeria 2004. He is currently a Professor at department of Faculty of Technology, Electrical Engineering and member LSP-IE research laboratory at faculty of technology-University of Batna. His areas of interest include power systems optimization, power system protection, renewable energy sources, harmonic, power quality and FACTS devices