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Considering the Effect of Series Capacitor in Optimal Coordination of Directional Over-current Relays

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ABSTRACT

Proper coordination between the Directional Over-Current Relays (DOCRs) in sub-transmission and distribution systems is one of the important conditions for the system security. The problem of setting DOCRs and their coordination is a highly constrained optimization problem that has been stated and solved as a nonlinear programming problem. The integration of the Series Capacitor (SC) into the transmission line makes the coordination problem more complex. In this study, a new problem formulation is proposed to calculate the optimal relay settings of Directional Over-Current Relays (DOCRs) in series compensated systems. In this study, the Modified Adaptive Particle Swarm Optimization (MAPSO) is employed to calculate the optimal relay settings. The proposed method is tested on a case study and optimal results are compared between compensated and uncompensated systems.

Key words: Directional over-current relay, optimal relay coordination, series capacitor, particle swarm optimization

INTRODUCTION

Protective systems continuously monitor the electrical status of power system components and de-energize them (for instance by tripping a circuit breaker) as speedily as possible when they are the site of a serious disturbance such as a short-circuit fault. Directional over-current relays (DOCRs) are used as the main protection and or back-up for the protection of transmission lines. The main reason for applying back-up protection is to ensure in the event of failure or non-availability of the main protection the fault will be cleared after a certain time delay known as Coordination Time Interval (CTI). Therefore all of the protective relays must be coordinated well with each other. The problem of coordinating protective relays is the process of finding suitable relay settings such that the relay closest to the fault would operates faster than other relays (Al-Odienat, 2006; Tumay *et al.*, 2002).

In systems that are protected by DOCRs, Time Dial Setting (TDS) and the pickup current (Ip) setting for directional over-current relays, must be calculated exactly such that the coordination all relays with each other is met (Zeineldin *et al.*, 2006; El-Arroudi *et al.*, 2005).

There are different factors that may affect on protective relay settings and disturb the selectivity and coordination of these relays. An important one of these factors is transmission line series compensation. Series capacitor (SC) is commonly installed on transmission line to increase loadability of the line, enhance system stability, improve load sharing on parallel paths and reduce line losses (Jazaeri *et al.*, 2011; Moravej *et al.*, 2011; Sidhu and Khederzadeh, 2006; Samimi and

Golkar, 2012). Despite the beneficial effects of SCs, their presence in the fault loop affects the voltage and current signals at the relaying point and it can disturb the selectivity and original coordination of relays. Therefore it is necessary to carefully carry out a study to determine new setting of DOCRs. Basically, to determine the settings of DOCRs, two different approaches are used; conventional approach such as trial and error approach (Abdelaziz *et al.*, 2002) and optimization techniques. But nowadays because of the complexity of power systems, the optimization techniques, with respect to their inherent advantages, has higher accuracy than conventional methods of relay coordination.

In literature at first, in uncompensated systems, for optimal coordination of over-current relays, due to the complexity of nonlinear optimization technique the traditional optimal coordination has been performed using linear programming approach including simplex, two phase simplex methods (Urdaneta *et al.*, 1988; Chattopadhyay *et al.*, 1996). It should be noted that due to simplification of these methods the solution obtained in this way would not be optimal.

Recently, the optimization methods are used to solve the DOCRs coordination problem as a complex and non-convex optimization problem. Genetic Algorithm (GA) and Evolutionary Algorithm (EA) are proposed to calculate the optimal solution for relay setting (Razavi *et al.*, 2008; So and Li, 2000). Noghabi *et al.* (2009) and Bedekar and Bhide (2011) reported the problem of determining the optimum settings of DOCRs is formulated as a Nonlinear Programming Problem (NLPP) and hybrid GA approach is proposed to find the optimum solution.

PSO algorithm which is one of the capable heuristic techniques to solve constrained optimization problems, has been recently adopted due to its superiority over other Evolutionary Algorithm (EA) regarding its memory and computational time requirements as it relies on very simple mathematical operations, also it requires very few lines of computer code to implement (Kennedy and Eberhart, 1995; Yap *et al.*, 2011; Gao *et al.*, 2009; Minhat *et al.*, 2008). The optimal coordination of over current relays (Zeineldin *et al.*, 2006; Mansour *et al.*, 2007) has been done by methods based on PSO Algorithm.

It should be noted that all of the aforementioned references in above have presented some methods for optimal relays coordination in uncompensated systems. In literature only different problems faced by protective relays in series compensated lines and some of the solution to these problems are researched and published but the relays coordination problem is not discussed (Marttila, 1992; Jena and Pradhan, 2010). Moravej *et al.* (2011) have proposed a new approach for optimal coordination of distance relays in compensated systems which have a combined protection scheme with over-current relays.

In this study a new approach for the optimal coordination of directional over-current relays in series compensated system, as a constrained nonlinear optimization problem, is proposed. In other word, a systematic method for formulation of the problem of determining optimum settings of DOCRs is presented.

The Modified Adaptive Particle Swarm Optimization (MAPSO) is employed to solve the proposed optimization problem that has low sensitivity with respect to both its adjustable parameters and initial point.

FORMULATION OF THE PROBLEM

A typical inverse time over-current relay consists of two units: (i) an instantaneous unit and (ii) a time-delay unit. The time-delay unit has two values to be set, the pickup current value (Ip) and the Time Dial Setting (TDS). The pickup current value (Ip), is the minimum current value for which the relay operates and the TDS adjusts time-delay before a relay whenever the fault current reaches a value equal to or greater than the pickup current (Ip). This section presents the over-current relays coordination problem.

DOCRs coordination problem: In the coordination problem of DOCRs, the aim is to determine the TDS and Ip of each relays, so that the overall operating time of the primary relays is minimized. Therefore the objective function can be stated as follows:

$$\mathrm{Min}\sum_{i}^{n} W_i T_{ik} \tag{1}$$

where, T_{ik} indicates the operation time of DOCRi for a fault in zone K and W_i is a coefficient which depends upon the probability of a given fault occurring in each protection zone. Since the lines are of approximately equal length W_i is usually set to 1 (Urdaneta *et al*., 1996).

Relay characteristics: The over-current relays employed in this paper are considered as digital (numerical) and directional with standard IDMT characteristics (Inverse Definite Minimum Time) that comply with the IEC255-3 standard and have their tripping direction away from the bus:

$$T_{ik} = \frac{0.14 \times TDS_i}{\left[\left(\frac{I_i}{I_{Pi}}\right)^{0.02} - 1\right]} \tag{2}$$

where, TDS_i and I_{pi} are the time dial setting and pickup current setting of the ith relay, respectively and I_i is the short circuit current passing through ith relay. However it can be shown that the proposed method can be easily applied to a system with combination of DOCRs with different characteristics (e.g., Very inverse, extremely inverse, etc.).

The constraints, that make the optimization problem infeasible, can be stated as follows:

Selectivity constraints for primary-backup relays: 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:

$$T^{F_i}_{\text{back-up}} - T^{F_i}_{\text{primary}} \leq CTI \tag{3}$$

or:

$$T_j^{F_i} - T_i^{F_i} \leq CTI \tag{4}$$

where,T_i^{Fi}, T_j^{Fi} are the operating time of ith primary relay ($T^{i}_{primary}$) and jth back-up relay ($T^{Fi}_{back\text{-}up}$) respectively for the near-end fault F_i as shown in Fig. 1.

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 and 0.5 sec.

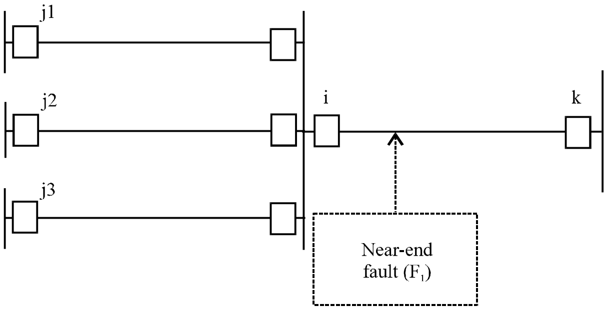

Fig. 1: Primary and backup relays

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

$$\mathrm{TDS}_{i_{\min}} \leq \mathrm{TDS}_i \leq \mathrm{TDS}_{i_{\max}} \tag{5}$$

$$\max(I^{\max}_{\mathrm{load}_i}, I^{\min}_{p_i}) \leq Ip_i \leq \min(I^{\min}_{\mathrm{fault}_i}, I^{\max}_{p_i}) \tag{6}$$

The minimum pickup current setting of the relay is the maximum value between the minimum available current setting ($I^{\min}_p$) and maximum local current ($I^{\max}_{\mathrm{load}}$) passes through it. In similar, the maximum pickup current setting is chosen minimum value between ($I^{\max}_p$) on the relay and minimum fault current ($I^{\min}_{\mathrm{fault}}$) which passes through it (Noghabi *et al.*, 2009).

Limits on primary operation time:

$$T_{i\min} \leq T_i \leq T_{i\max} \tag{7}$$

This constraint imposes constraint on each term of objective function to lie between 0.05 and 1 sec.

MODIFIED ADAPTIVE PARTICLE SWARM OPTIMIZATION (MAPSO)

Particle swarm optimization (PSO) is a population based search method that introduced by Kennedy and Eberhart as a modern heuristic optimizer (Kennedy and Eberhart, 1995).

During last decade many studies focused on this method and almost all of them strongly confirmed the abilities of this newly proposed optimization technique, abilities such as fast convergence, finding global optimum, simple programming and adaptability with constrained problems (Kennedy and Eberhart, 1995; Gao *et al.*, 2011; Yap *et al.*, 2011).

In PSO, the feasible solution, called particles, share their information with each other and run toward best trajectory to find optimum solution in an iterative process. A velocity vector is defined for each particle and particle position depends on this velocity. In each iteration, the velocity and position of particles are updated:

$$V_{i,iter+1} = wV_{i,iter} + c_1 r_1 (P^{best}_{i,iter} - X_{i,iter}) + c_2 r_2 (G^{best}_{iter} - X_{i,iter}) \tag{8}$$

$$X_{i,iter+1} = X_{i,iter} + V_{i,iter+1} \tag{9}$$

where, $V_{i,\,iter}$ and $X_{i,\,iter}$ represent the velocity vector and the position vector of ith particle at each iteration, respectively $P^{best}_{i,iter}$ and $G^{best}_{i,iter}$ are personal best position of ith particle and global best position of swarm until iteration iter, respectively w is inertia weight factor which controls the global and local exploration capabilities of particles; the constants c_1, c_2 represent the learning rate or the acceleration term that pulls each particle towards P_{best} and G_{best} positions. r_1 and r_1 are two random numbers between 0 and 1. In this study, a specific kind of tree topology for the PSO is used that each level of the tree has only one node or one particle. In this topology, each particle can move up and down by any number of levels in each iteration and so the hierarchy is updated in one iteration (Amjady and Soleymanpour, 2010; Sutha and Kamaraj, 2008).

To enhance the efficiency of the PSO and to control the local search and convergence to the global optimum solution, some modifications are proposed by Chaturvedi *et al.* (2008) and Ratnaweera *et al.* (2004).

In this study, to deal with the complicated problem of relays coordination, the Modified Adaptive Particle Swarm Optimization (MAPSO) is employed which has presented by Amjady and Soleymanpour (2010) and has the following new modification.

- The split-up of the cognitive part into the best and not-best components
- Personal best position exchanging
- New velocity limiter

Therefore, in this study, due to some advantages of the MAPSO such as robustness, good exploration capability and convergence behavior, the proposed coordination problem is solved using MAPSO.

DOCRs COORDINATION IN THE SERIES COMPENSATED SYSTEMS

Series compensation increases power transfer capability and improves power system stability. Figure 2 shows the single line of a simplified compensated system which the SC is considered in the middle of a line. The capacitive reactance X_{SC} is typically from 25 to 75% of the line inductive reactance XL. On the other hand the degree of compensation of the line, C, is stated as:

$$C = ({}^{X_{SC}}\!/_{X_L}) \times 100 \tag{10}$$

The typical protective bypass system consists of a metal oxide varistor (MOV), bypass gap, damping reactor and bypass circuit breaker. The varistor provides overvoltage protection of the series capacitor during power system faults. The bypass gap is controlled to spark over in the event of excess varistor energy. The bypass breaker closes automatically in the case of prolonged gap conduction or other platform contingencies. The breaker also allows the operator to insert or bypass the series capacitor. The damping reactor limits the capacitor discharge resulting from gap flashover or bypass breaker closure (Fig. 3) (IEEE, 2004).

Therefore in normal operation, the overvoltage protection does not operate and the SC equivalent impedance is a pure capacitive reactance. In this case MOVs will be untriggered and the equivalent impedance of SC bank is equal to:

$$Z_{SC} = -jX_{SC} \tag{11}$$

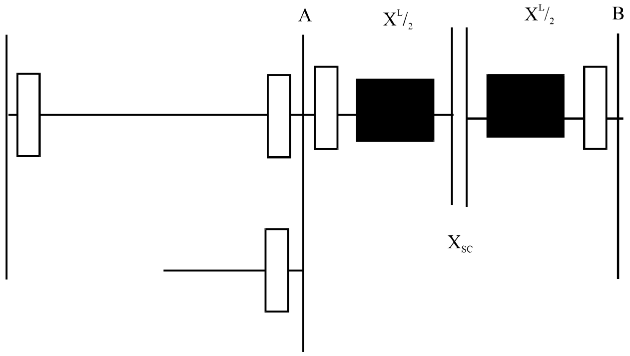

Fig. 2: The single line of a simplified series compensated system

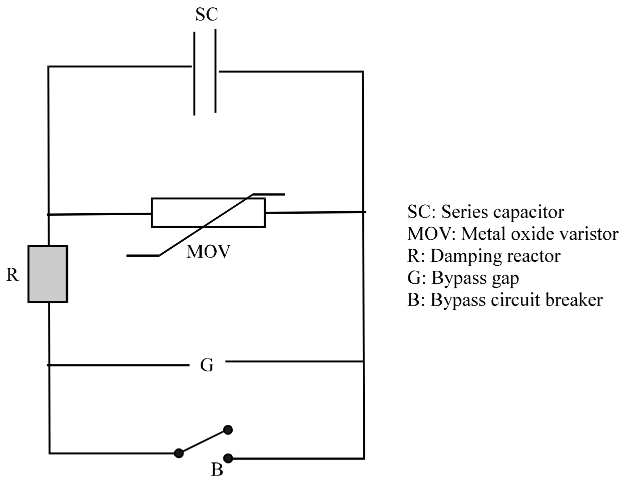

Fig. 3: Configuration of a series capacitor

During high fault current, the conduction of MOVs increase and the equivalent impedance of SC according to Goldsworthy model (Goldsworthy, 1987) is obtained as:

$$Z_{SC} = R_{MOV} - jX_{SC} \tag{12}$$

where, R_{MOV} is related to conduction of the MOV. The bypass gap operates when the energy absorbed by the MOV is greater than the preset value. In the bypass gap operation mode, the equivalent impedance of SC bank is the inductive reactance of the damping reactor (Sidhu and Khederzadeh, 2006).

Series Capacitors (SCs) and their protective bypass systems, in spite of their beneficial effects on the power system performance, cause some problems for protective relays and may leads to mis-coordination. Therefore the relays coordination in series compensated systems is considered to be one of the most difficult tasks.

In this study a critical phenomenon of compensated system that influence the performance of DOCRs, is described in the following:

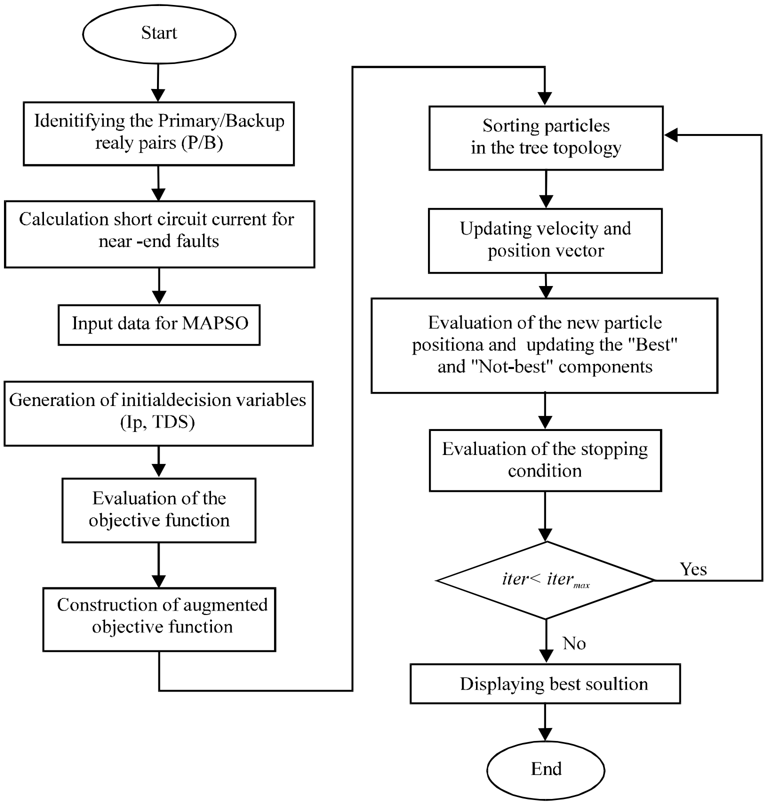

Fig. 4: Flowchart of the proposed method for optimal relay coordination

- This phenomenon should be considered in the relay coordination problem

As stated earlier, the coordination problem of DOCRs is a function of short circuit current level. In other words, the operating time of DOCRs depend on fault current through it. It is apparent that due to presence of SC in the line, the short circuit current passing through the main and backup relays for near-end fault (F_1) will be changed. Therefore in this paper with considering the series compensation the Short circuit analyses are performed and new coordination problem is solved for computing the related optimum setting of the relays.

Figure 4 shows the summary of the proposed method to solve the coordination problem of DOCRs using MAPSO. This method is used for both uncompensated and compensated systems. At first, in order to consideration of related constraints, the short circuit currents for the faults close to the circuit breaker of the main over-current relays are calculated. Short circuit analyses are performed for different fault impedances to find the worst case. In the last resort the MAPSO algorithm is run and the optimum relay settings are obtained.

SIMULATION AND RESULTS

In order to consider the impact of series compensation on the protective relay settings, the coordination formulation corresponding to the compensated and uncompensated systems was tested successfully for various systems, out of which one is presented in this study and effectiveness of used MAPSO is evaluated. For this purpose, two scenarios are examined for related test case as follows:

- **Scenario A:** optimal relay coordination in the uncompensated system

This scenario is considered as the base original system without series capacitor (SC) and the optimal settings of DOCRs is calculated.

- **Scenario B:** optimal relay coordination in the compensated system

In this scenario, test case is compensated by series capacitor. Then the optimal coordination problem is solved and the obtained results are compared with those obtained from Scenarios A.

The selected test system is the 8-bus study network. For obtaining the optimum results, at first, the Primary /Backup (P/B) relay pairs are identified which in two scenarios are the same. After that, for each P/B relay pairs, the short circuit current passing through the relays for near-end fault is calculated. The three phase faults, as worst fault, are applied at the near-end of each relay. It should be noted that the short circuit analysis are done for each scenario. The best solution of the MAPSO algorithm, among 25 trail runs is calculated, since the MAPSO begins from a random initial point (step 1 of the step by step algorithm). Also the parameters of the MAPSO, according to Amjady and Soleymanpour (2010), have been set based on trial and error and the best values are selected.

Test case: 8- bus system: The proposed method for optimal coordination directional over-current relays, in compensated and uncompensated systems, is applied to this test case separately. The 8-bus system, as shown in Fig. 5, is compensated with series capacitor located at middle of the line 1-6. The degree of compensation is assumed to be 65 percent (C = 65%). The system data are given in Table 1-4 (Zeineldin *et al*., 2006). The 8-bus system has a link to another network, modeled by a short circuit power of 400 MVA. The transmission network consist of 14 DOCRs with IEC standard inverse type characteristic which their location are indicated in Fig. 5.

Table 1: Line characteristics of 8-buses system

Bus-Bus	Voltage level (kV)	R (O km)	X (O km)	Y (S km)	Length (km)	Degree of compensation (C%)
1-2	150	0.0040	0.0500	0	100	0
1-3	150	0.0057	0.0714	0	70	0
3-4-	150	0.0050	0.0563	0	80	0
4-5	150	0.0050	0.0450	0	100	0
5-6	150	0.0045	0.0409	0	110	0
2-6	150	0.0044	0.0500	0	90	0
1-6	150	0.0040	0.0500	0	100	65

Table 2: Generators data of 8-buses system

Bus	Sn (MVA)	V_n (kV)	X (%)
7	150	10	15
8	150	10	15

Table 3: Transformers data of 8-buses system

Bus-Bus	S_n (MVA)	V_n (kV)	V_s (kV)	X (%)
1-7	150	10	150	4
8-6	150	10	150	4

Table 4: Loads data of 8-buses system

Bus	P (MW)	Q (MVAR)
2	40	20
3	60	40
4	70	40
5	70	50

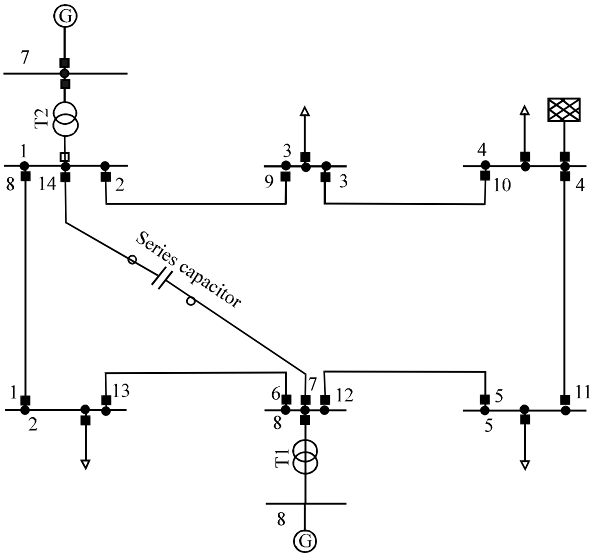

Fig. 5: Single line diagram of series compensated 8-bus system

In both scenarios A and B, for DOCRs, TDS values can range continuously from 0.1 to 1.1 and C_{TI} is assumed to be 0.2 sec.

Table 5 corresponding to scenario A, shows the primary/backup (P/B) pairs and corresponding fault currents for the faults exactly close to the circuit breaker of the main over-current relays.

Similarly, due to presence of the SC in scenario B, the short circuit analyses are performed and the obtained results are shown in Table 5.

It is apparent from Table 5 that the fault current passing through the main relays is increased in scenario B in comparison to scenario A. Due to the presence of SC in scenario B, the net fault impedance for all faults behind SC is reduced and the fault current is increased. In other word the presence of SC in a system will change the normal power flow as well as the short circuit current all over the relays.

The relays 7 and 14 are located in the series compensated line 1-6 and have a contrary manner than other relays (Fig. 5).

Table 6 shows the obtained optimal values of the decision variables in both scenarios (i.e. Ip_i, TDS_i).

It can be observed from the results presented in Table 6 that, the optimal values of Ip_i and TDS_i are the typical setting used in DOCRs protection scheme. The objective function value has been calculated as the sum of the operating time of each relay for the fault in its primary zone of protection. As noted earlier, the operating time of DOCRs is a function of fault current level. Therefore due to increase in fault current in the presence of SC, the optimal value of objective function in scenario B is less than scenario A.

Table 5: P/B Relay pairs and the near-end fault currents in 8-buses system (scenario A and B).

	P/B pairs		Near-end fault currents (KA)-scenario A		Near-end fault currents (KA) scenario B	
P/B No.	Primary relay No.	Backup relay No.	Primary relay	Backup relay	Primary relay	Backup relay
1	1	6	3.260	3.260	3.382	3.38222
	2	1	6.113	1.001	6.600	0.683
3	2	7	6.113	1.900	6.600	2.660
4	3	2	3.060	3.060	3.895	3.895
5	4	3	3.833	2.324	3.912	2.388
6	5	4	2.410	2.410	2.396	2.396
7	6	5	6.215	1.060	6.897	1.032
8	6	14	6.215	1.780	6.897	2.546
9	7	5	5.228	1.112	5.000	1.025
10	7	13	5.228	0.834	5.000	0.623
11	8	7	6.134	1.890	6.845	2.587
12	8	9	6.134	1.126	6.845	1.000
13	9	10	2.060	2.060	2.492	2.492
14	10	11	3.949	2.439	4.033	2.509
15	11	12	3.893	3.893	4.074	4.074
16	12	13	6.140	0.988	6.602	0.670
17	12	14	6.140	1.780	6.602	2.613
18	13	8	3.017	3.017	3.098	3.09819
	14	1	5.172	0.857	4.929	0.638
20	14	9	5.172	1.087	4.929	0.996

Table 6: Optimal relay settings in 8-buses system using MAPSO

Relay No.	Time dial setting (TDS)		Pickup current setting (A) (Ip)	
Scenario	A	B	A	B
1	0.127	0.100	447.76	536.75
2	0.324	0.395	692.14	689.37
3	0.167	0.127	559.96	759.69
4	0.131	0.144	812.44	813.97
5	0.100	0.106	183.76	361.62
6	0.261	0.228	298.65	339.81
7	0.246	0.198	404.93	371.09
8	0.191	0.212	479.48	568.18
9	0.180	0.100	246.86	432.53
10	0.111	0.103	806.34	858.65
11	0.137	0.121	771.12	797.23
12	0.272	0.289	481.58	497.96
13	0.101	0.199	528.45	436.98
14	0.164	0.158	438.93	365.21
Best Solution Found (OF)		Scenario A (Feasible)		7.958
		Scenario B (Feasible)		6.92

The operating time of the primary and backup relays for both scenarios, corresponding to primary/backup (P/B) pairs, is shown in Table 7. It can be seen that the coordination between relays (with respect to related constraints and minimum CTI of 0.2 s) is maintained in all cases. The following observation can be found in Table 7 for two scenarios A and B.

Table 7: Operating time of primary and backup relays

			Operating time (second)			
	P/B pairs		Scenario A		Scenario B	
P/B No.	Primary relay No	Backup relay No.	Primary relay	Backup relay	Primary relay	Backup relay
1	1	6	0.439	0.746	0.384	0.686
2	2	1	0.783	1.098	0.695	1.107
3	2	7	0.783	0.911	0.695	0.1.087
4	3	2	0.726	1.013	0.702	1.000
5	4	3	0.544	0.851	0.515	0.904
6	5	4	0.483	0.788	0.541	0.771
7	6	5	0.583	1.549	0.530	1.023
8	6	14	0.583	1.062	0.530	0.836
9	7	5	0.651	0.978	0.670	0.876
10	7	13	0.651	1.015	0.670	1.178
11	8	7	0.512	0.814	0.617	0.823
12	8	9	0.512	1.107	0.617	0.967
13	9	10	0.582	0.891	0.516	0.821
14	10	11	0.506	0.827	0.467	0.787
15	11	12	0.486	0.894	0.469	0.587
16	12	13	0.731	1.276	0.704	1.027
17	12	14	0.731	1.054	0.704	1.023
18	13	8	0.400	0.721	0.409	0.915
19	14	1	0.525	1.368	0.459	1.502
20	14	9	0.525	0.796	0.459	0.992

In scenario A, the relay 1 will take 0.439 s to operate for fault corresponding to P/B No. 1, whereas it will operate in 1.098 s and 1.368 s for faults corresponding to P/B No. 2, 19, respectively. The similar description can be derived from Table 7 for scenario B.

This is desirable, because for fault corresponding to P/B No. 1, relay 1 is primary relay and hence it is first to operate, whereas for fault P/B No. 2 and 19, relay 1 is backup relay and should operate after related primary relays. Similar description can be given for operating time of each relay for different fault points.

The comparison of two scenarios shows that, due to presence of SC and increase in the fault current level in the section B, the operating time of each P/B relays in this scenario is lower than those in the scenario A. But the operating time of primary relays 7 and 14, that are located in series compensated line, are become less in scenario B.

Also it can be seen from Table 7 that, in scenario A, the time taken by relay 1 (backup for relay 14) to operate for fault corresponding to P/B No. 19 is 1.368 seconds. It is because small amount of fault current flows through relay 1 and major amount of fault current flows through relay 9 (other backup for relay 14). Similar description can be given for operating time of other relays not only in scenario A but also in scenario B.

CONCLUSIONS

In this study, the optimal coordination problem of directional over-current relays has been presented firstly. Then with considering the effect of series capacitor on the relays setting, a new method for optimal coordination of directional over-current relays, in series compensated systems, has been proposed.

In this study the presented coordination problems as nonlinear problems have been solved using the MAPSO and the optimum results are obtained. As expected, on comparison, the best solution found in series compensated systems, due to increase in the fault currents level is computed lower than that in uncompensated systems.

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REFERENCES

Abdelaziz, A.Y., H.E.A. Talaat, A.L. Nosseir and A.A. Hajjar, 2002. An adaptive protection scheme for optimal coordination of overcurrent relays. Electr. Power Syst. Res., 61: 1-9.

Al-Odienat, A.I., 2006. Power system blackouts: Analysis and simulation of August 9, 2004 blackout in Jordan power system. Inform. Technol. J., 5: 1078-1082.

Amjady, N. and H.R. Soleymanpour, 2010. Daily hydrothermal generation scheduling by a new modified adaptive particle swarm optimization technique. Electric Power Syst. Res., 80: 723-732.

Bedekar, P.P. and S.R. Bhide, 2011. Optimum coordination of directional overcurrent relays using the hybrid GA-NLP approach. IEEE Trans. Power Delivery, 26: 109-119.

Chattopadhyay, B., M.S. Sachdev and T.S. Sidhu, 1996. An on-line relay coordination algorithm for adaptive protection using linear programming technique. IEEE Trans. Power Delivery, 11: 165-173.

Chaturvedi, K.T., M. Pandit and L. Srivastava, 2008. Self-organizing hierarchical particle swarm optimization for nonconvex economic dispatch. IEEE Trans. Power Syst., 23: 1079-1087.

El-Arroudi, K., G. Joos, D.T. McGillis and R. Brearley, 2005. Comprehensive transmission distance protection settings using an intelligent-based analysis of events and consequences. IEEE Trans. Power Delivery, 20: 1817-1824.

Gao, X.Y., L.Q. Sun and D.S. Sun, 2009. An enhanced particle swarm optimization algorithm. Inform. Technol. J., 8: 1263-1268.

Gao, H., J. Cao and M. Diao, 2011. A simple quantum-inspired particle swarm optimization and its application. Inform. Technol. J., 10: 2315-2321.

Goldsworthy, D.L., 1987. Linearized model for MOV-protected series capacitors. IEEE Trans. Power Syst., 2: 953-957.

IEEE, 2004. IEEE Std 824-2004 IEEE standard for series capacitor banks in power systems. Transmission and Distribution Committee of the IEEE Power Engineering Society. http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1488515

Jazaeri, M., M. Gholamzadeh and M. Pazoki, 2011. Analysis of over/under-reaching of distance relay on transmission line in presence of UPFC. Trends Applied Sci. Res., 6: 580-594.

Jena, P. and A.K. Pradhan, 2010. A positive-sequence directional relaying algorithm for series-compensated line. IEEE Trans. Power Delivery, 25: 2288-2298.

Kennedy, J. and R. Eberhart, 1995. Particle swarm optimization. Proc. IEEE Int. Conf. Neural Networks, 4: 1942-1948.

Mansour, M.M., S.F. Mekhamer and N.E.S. El-Kharbawe, 2007. A modified particle swarm optimizer for the coordination of directional overcurrent relays. IEEE Trans. Power Deliv., 22: 1400-1410.

Marttila, R.J., 1992. Performance of distance relay mho elements on MOV-protected series-compensated transmission lines. IEEE Trans. Power Delivery, 7: 1167-1178.

Minhat, A.R., I. Musirin and M.M. Othman, 2008. Evolutionary programming based technique for secure operating point identification in static voltage stability assessment. J. Artif. Intell., 1: 12-20.

Moravej, Z., M. Jazaeri and M. Gholamzadeh, 2011. Optimal coordination of distance and over-current relays in series compensated systems based on MAPSO. Energy Convers. Manage., 56: 140-151.

Noghabi, A.S., J. Sadeh and H.R. Mashhadi, 2009. Considering different network topologies in optimal overcurrent relay coordination using a hybrid GA. IEEE Trans. Power Delivery, 24: 1857-1863.

Ratnaweera, A., S.K. Halgamuge and H.C. Watson, 2004. Self-organizing hierarchical particle swarm optimizer with time varying acceleration coefficients. IEEE. Trans. Evol. Comput., 8: 240-255.

Razavi, F., H.A. Abyaneh, M. Al-Dabbagh, R. Mohammadi and H. Torkman, 2008. A new comprehensive genetic algorithm method for optimal overcurrent relays coordination. Elect. Power Syst. Res. J., 78: 713-720.

Samimi, A. and M.A. Golkar, 2012. A novel method for optimal placement of FACTS based on sensitivity analysis for enhancing power system static security. Asian J. Appl. Sci., 5 : 1-19.

Sidhu, T.S. and M. Khederzadeh, 2006. Series compensated line protection enhancement by modified pilot relaying schemes. IEEE Trans. Power Delivery, 21: 1191-1198.

So, C.W. and K.K. Li, 2000. Time coordination method for power system protection by evolutionary algorithm. IEEE Transa. Ind. Appl., 36: 1235-1240.

Sutha, S. and N. Kamaraj, 2008. Particle swarm optimization applications to static security enhancement using multi type facts devices. J. Artif. Intell., 1: 34-43.

Tumay, M., I. Eker, V.K.E. Ercelebi and M.U. Unver, 2002. Modelling of power system protection signalling. J. Applied Sci., 2: 502-517.

Urdaneta, A.J., H. Resterbo, J. Sanchez and S. Marquez, 1996. Coordination of directional overcurrent relays timing using linear programming. IEEE Trans. Power Delivery, 11: 122-129.

Urdaneta, A.J., R. Nadira and L. Perez, 1988. Optimal coordination of directional overcurrent relay in interconnected power systems. IEEE Trans. Power Delivery, 3: 903-911.

Yap, D.F.W., S.P. Koh, S.K. Tiong and S.K. Prajindra, 2011. Particle swarm based artificial immune system for multimodal function optimization and engineering application problem. Trends Applied Sci. Res., 6: 282-293.

Zeineldin, H.H., E.F. El-Saadany and M.M.A. Salama, 2006. Optimal coordination of overcurrent relays using a modified particle swarm optimization. Elect. Power Syst. Res. J., 76: 988-995.