Optimal Coordination of Directional Overcurrent Relays Using PSO-TVAC Considering Series Compensation

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Abstract. *The integration of system compensation such as Series Compensator (SC) into the transmission line makes the coordination of directional overcurrent in a practical power system important and complex. This article presents an efficient variant of Particle Swarm Optimization (PSO) algorithm based on Time-Varying Acceleration Coefficients (PSO-TVAC) for optimal coordination of directional overcurrent relays (DOCRs) considering the integration of series compensation. Simulation results are compared to other methods to confirm the efficiency of the proposed variant PSO in solving the optimal coordination of directional overcurrent relay in the presence of series compensation.*

Keywords

Directional overcurrent relay coordination, particle swarm optimization (PSO), power system protection, series compensation, time varying acceleration coefficients (PSO-TVAC).

1. Introduction

Overcurrent protection could be used as the primary protection in distribution or sub-transmission networks. Directional overcurrent relays (OCRS) have been commonly used as an economic alternative for the protection of sub-transmission and distribution system or as a secondary protection of the transmission system [1]. Directional OCR coordination in power distribution network is a major concern of protection engineer to assure service continuity.

Many attempts and strategies based on conventional and computerized methods have been made in the past to coordinate overcurrent relays. A simplex method is proposed to solve the optimum coordination of overcurrent relay timing. A linear programming is proposed in [2],[3],[4]. In [5], the optimum coordination has been obtained considering the configuration changes of the network into account. Authors in [6] present a review of the major contributions in this area.

The difficulties associated with using the mathematical optimization of complex engineering problems have contributed to the development of alternative solutions. In the literature, many standard optimization methods and hybrid variants based on metaheuristic algorithms have been proposed and applied with success for solving many complex problems related to power system protection coordination [7]. Authors in [8] proposed a Hybrid GA-NLP Approach for solving the optimal coordination of direction overcurrent. A seeker optimization method is adapted and applied to solving the optimal coordination of directional overcurrent relays DOCRs [9].

The problem of relays coordination becomes more complex with the presence of series compensation. Series capacitor (SC) is commonly installed on long transmission lines to increase loadability of the line, enhance system stability and reduce line losses [10]. The presence of SC in transmission lines affects the voltage and current signals at the relaying point and it can disturb selectivity the coordination between different relays, this affects greatly the service continuity and power quality delivered to consumers. Therefore it is necessary to carefully carry out a study to determine new setting of DOCRs and distance relays [1]. Many papers have been proposed to solve the optimal coordination of directional relay considering the series compensation. In the literature many variants based on PSO have been proposed to enhance the performance of the standard PSO algorithm to solve the power system protection coordination. Authors in [10] proposed an optimal coordination of distance and overcurrent relays in series compensated systems based on MAPSO, a standard PSO and modified particle swarm optimization for optimal coordination of overcurrent relays are proposed in [11], [12], [13], [14], [15], [16], [17], [18].

Particle swarm optimization (PSO) is one of the best global optimization methods firstly proposed in [19]. Its development was based on observations of the social behavior of animals such as bird flocking, fish schooling and swarm theory. Compared with GA, PSO has some attractive characteristics. It has a memory, so knowledge of good solutions is stored by all particles; whereas in GA, previous knowledge of the problem is destroyed once the population changes. It has constructive cooperation between particles, particles in the swarm share information among themselves [20], [21], [22].

In this paper an adaptive variant of PSO named PSO-TVAC is proposed and adapted to solve the optimal coordination of directional overcurrent relays (DOCRs) considering the impact of series compensation (SC). The main objective of this study is the minimization of the total time of primary relays by determining the optimum values of time dial setting (TDS) (continuous parameter) and pickup tap setting (PTS) (discrete parameter).

2. Problem Formulation

In the relay coordination problem of DOCRs, the main objective is to minimize the total time of operation of primary relays, through two types of tap settings, namely the time dial setting TDS and pickup tap setting PTS. The objective function can be defined as follows [9]:

$$\min(J) = \sum_{i=1}^{n} w_i T_{ik}, \tag{1}$$

where n the number of is relays and w_i depends upon the probability of a given fault occurring in each protection zone and is usually set to one and T_{ik} is the operating time of the i_{th} relay

2.1. Relay Characteristics

The operating time of the operating time of the overcurrent (please correct the statement before) relay is a non-linear function consisting of pickup current setting (Ip) and time dial setting (TDS). Various formulations have been applied for overcurrent relays characteristics simulation. In this work we will use approximate mathematical formula for a relay characteristic suggested in [3], [4], [5] and given by:

$$T_{ik} = TDS_i \left(\frac{0.14}{(\frac{I_i}{Ip_i})^{0.02} - 1} \right), \tag{2}$$

where TDS_i and Ip_i are time dial setting and primary pickup current setting of the i_{th} relay respectively and I_i is the fault current passing through i_{th} relay. The concept of relay pickup tap setting (PTS) could be formulated by [9]:

$$PTS_i = \frac{Ip_i}{RC_i}, \tag{3}$$

where RC_i is the the transformer turns ratio.

2.2. Standard I.D.M.T. Overcurrent Relays

The current/time tripping characteristics of IDMT relays may need to be varied according to the tripping time required and the characteristics of other protection devices used in the network. For these purposes, IEC 60255 defines a number of standard characteristics as follows [23]:

- Standard Inverse (SI).
- Very Inverse (VI).
- Extremely Inverse (EI).
- Definite Time (DT).

The tripping characteristics for different TMS settings using the SI curve ar illustrated in Fig. 1.

2.3. Constraint

The coordination problem has two types of constraints. Firstly, it is the constraint of the relay characteristic and secondly it is coordination constraint. Relay constraints include limits of relay operating time and settings. Coordination constraints are related to the coordination of primary and backup relays .

2.4. Constraint of Operating Time and Bounds on the Relay Settings

1) The Bounds on Operating Time

The limits are expressed by:

$$T_{ik}^{\min} \leq T_{ik} \leq T_{ik}^{\max}, i = 1, ..., m, \tag{4}$$

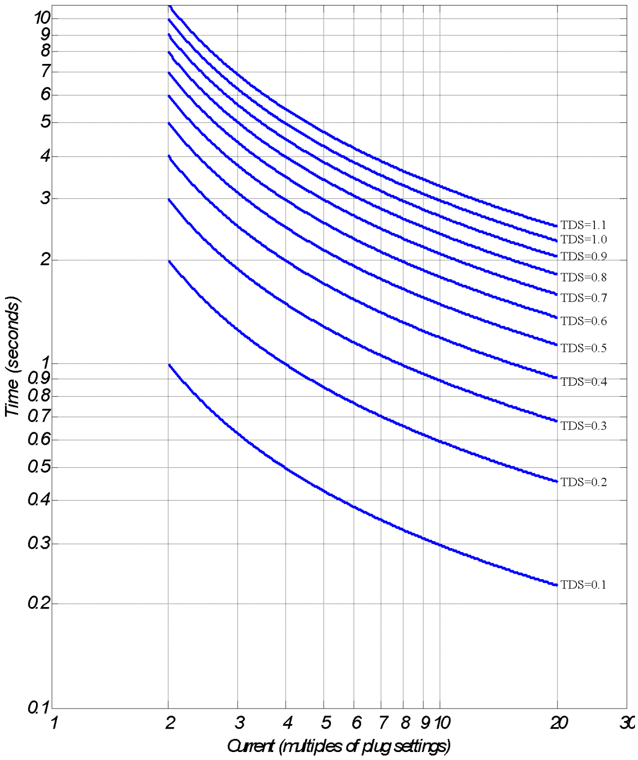

Fig. 1: Typical time/current characteristics of standard IDMT relay.

where $T_{ik}^{\min}$ and $T_{ik}^{\max}$ are the minimum and maximum operating times of the i_{th} relay at the k_{th} location.

2) The Constraint of Time and Current Settings

The limits on TDS and PTS are expressed by:

$$TDS_{ik}^{\min} \leq TDS_{ik} \leq TDS_{ik}^{\max}, \quad i = 1, ..., m, \tag{5}$$

$$PTS_{ik}^{\min} \leq PTS_{ik} \leq PTS_{ik}^{\max}, \quad i = 1, ..., m, \tag{6}$$

where $TDS_i^{\min}$, $PTS_i^{\min}$ are the minimum value of TDS and PTS of the relay i_{th} location. $TDS_i^{\max}$, $PTS_i^{\max}$ are the maximum value of TDS and PTS of the relay i_{th} location.

2.5. Coordination Criteria

The coordination of directional overcurrent relays involves a choice of relay settings such that for every fault in the system, there is a specified minimum coordination interval or time delay between the operation of the primary relay and that of the backup relay, this interval ensures that the backup relay operates only when the primary relay fails to perform its assigned task [2]. The value time coordination interval (CTI) is usually selected between 0.2 and 0.5 s. In this work the CTI is taken as 0.2.

$$T_{jk} \geq T_{ik} + CTI, \quad CTI = 0.2, \tag{7}$$

where T_{jk} operating time of the primary relay R_j, for fault at k, T_{ik} operating time of the backup relay R_i, for the same fault at k and the violation in the coordination criteria can be defined as follows:

$$Viol\_CC = T_{OP-Ba} - (T_{OP-Pr} + CTI), \tag{8}$$

where $Viol\_CC$ violation in the coordination criteria, T_{OP-Ba}, T_{OP-Pr} are the operating time of the primary relay and backup relay respectively.

3. Series Compensated Systems

As it is well known, the operating time of DCORs depends on fault current through it. It is evident that due to the presence of SC in the line, the short circuit current passing through the main and backup relays for near-end fault will be changed. To take the series compensation in consideration, the short circuit analysis is performed. Figure 2 shows the single line of a simplified compensated system, in which the SC is considered in the middle of a line 1-6. The new total impedance of the transmission line becomes $Z_L - jX_{SC}$, in this study the degree of compensation taken is 65 %($C = 65$ %).

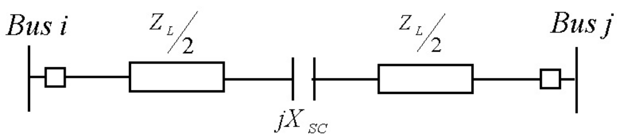

Fig. 2: The single line of a simplified series compensated system.

4. Optimization Algorithm (PSO-TVAC)

Particle Swarm Optimization, is a basic modern heuristic search method inspired by the behavior of social systems, firstly introduced by Kennedy and Eberhart 1995 [19], [20], [21]. The PSO algorithm begins by creating a random population of particles with random positions marked by $X(t)$ vectors and random velocities $V(t)$. The modified velocity and position of each particle can be calculated using the current velocity and the distance from $Pbest_m$, $Gbest_m$ shown in the following formulas equations:

$$\begin{cases} V(t+1) = w \cdot V(t) + C_1 rand_1 \cdot (Pbest_m - \\ \qquad X(t)) + C_2 rand_2 \cdot (Gbest_m - X(t)) \\ X(t+1) = X(t) + (t+1), \end{cases} \tag{9}$$

where $V(t+1)$, $V(t)$ is the current and modified velocity respectively, $rand_1$ and $rand_2$ are the random numbers between 0 and 1, $Pbest_m$, is the best value found by particle m, and $Gbest_m$ is the best found in the group, $X(t)$ is the current position $X(t+1)$ is the modified position, C_1; C_2 are cognitive and social coefficients. The concept of time varying inertial weight was introduced in [21] is suggested to decrease linearly from 0.9 to 0.4 during the run .the inertial weights formulated as in Eq. (10) where $iter$ is the current iteration number while $ter_{\max}$ is the maximum number of iterations.

$$w = (w_{\max} - w_{\min}) \cdot \frac{(iter_{\max} - iter_{\min})}{iter_{\max}} + w_{\min}. \quad (10)$$

In this work a new variant named particle swarm optimization based Time Varying Acceleration Coefficients ($PSO-TVAC$) [12] is proposed to improve the performances of the standard PSO algorithm. The idea behind $PSO-TVAC$ is to enhance the global search in the early part of the optimization and to encourage the particles to converge towards the global optima at the end of the search [22]. This is achieved by changing the acceleration coefficients C_1 and C_2 with time in such a manner that the cognitive component is reduced while the social component is increased as the search proceeds. The acceleration coefficients are expressed as:

$$\begin{cases} c_1 = (c_{1f} - c_{1m})\dfrac{iter}{iter_{\max}} + c_{1m} \\ \\ c_2 = (c_{2f} - c_{2m})\dfrac{iter}{iter_{\max}} + c_{2m} \end{cases}, \quad (11)$$

where C_{1f}, C_{1m}, C_{2f} and C_{2m} are social acceleration factors, initial and final values of cognitive respectively. The value of this coefficients taken from Ref [24],[25] reports 2.5 for C_{1m} and C_{2f} and 0.5 each for C_{2m} and C_{1f} as the most effective values. the population size and max- generations are taken 200, 500 respectively.

5. Simulation Results

The proposed algorithm is applied to 8-bus network shown in Fig. 3 to solve the coordination problem. In this paper the coordination time interval CTI is taken as 0.2 s, and the TDS values can change continuously from 0.1 to 1.1 while pickup tap setting PTS values can change continuously from 0.5 to 2.5 are considered [10].The ratio current transformer of relays (1, 2, 4, 5, 6, 8, 10, 11, 12, 13) and (3, 7, 9, 14) are assumed as (1200/5) and (800/5) respectively. The short-circuit current for near-end 3-ph short circuit faults is given in Tab. 1 and Tab. 2 .

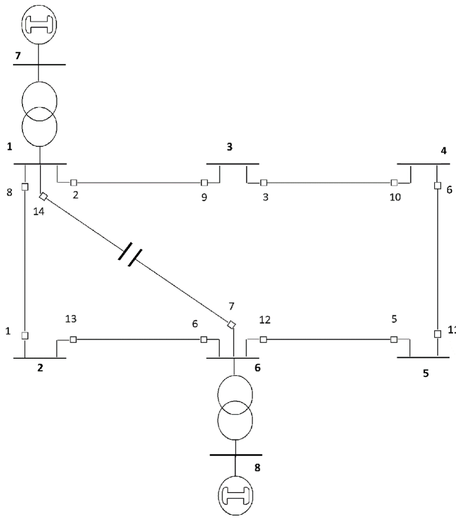

Fig. 3: Single line diagram of 8-bus system.

5.1. Case Studies

In this study three cases are considered to demonstrate and improve solution of optimal relay coordination considering series compensation:

- **Case 1**: The PSO-TVAC algorithm is applied for optimal relay coordination problem without considering series capacitor (SC).
- **Case 2**: In this case, the best solution found in the first case (without series compensation) is considered to show its effect on the presence of series compensation on the relay coordination.
- **Case 3**: In this case, the PSO-TVAC algorithm is applied for optimal coordination of DOCR considering series compensation (SC).

Table 1 shows the optimal setting of control variables found using PSO-TVAC. The best operation time is 5.8646 s without considering SC which is better than the result found in [10], it is important to note that all constraints are satisfied and within their admissible limits and the value coordination time interval (CTI) is also within the specified value (0.2 s). In order to show the impact of the series compensation on relay coordination, the optimal variable controls found in the first case are considered in the presence of SC. The main task of this test is to demonstrate the impact of SC installed at a specified branch on the efficiency of the power system protection (relay coordination). As we can see from Tab. 2, the fault current at different branches associated to primary and backup relays are changed. Results depicted in Tab. 3 shows clearly the constraints violation on the value time coordination interval (CTI), which affect the relay coordination, this proves the necessity to find new optimal vector control

Tab. 1: Optimal relay settings in 8-Bus system without compensation.

Scenario A without compensation									
Primary/Backup pairs			**Fault Current (KA)**		**Optimal Relay setting without compensation**				
(No)	***Pr-Re***	***Ba-Re***	***Pr-Re***	***Ba-Re***	***No-Re***	**MAPSO [10]**		**PSO-TVAC Case 1**	
1	1	6	3.260	3.260		TDS	$Ip(A)$	TDS	$Ip(A)$
2	2	1	6.113	1.001	1	0.101	368.76	0.1000	378.984
3	2	7	6.113	1.900	2	0.118	995.86	0.1744	600.000
4	3	2	3.060	3.060	3	0.102	805.74	0.1593	400.000
5	4	3	3.833	2.324	4	0.100	865.94	0.1141	600.000
6	5	4	2.410	2.410	5	0.193	153.15	0.1000	369.456
7	6	5	6.215	1.060	6	0.100	856.06	0.1275	600.000
8	6	14	6.215	1.780	7	0.260	122.99	0.1614	400.000
9	7	5	5.228	1.112	8	0.100	811.08	0.1242	600.000
10	7	13	5.228	0.834	9	0.165	180.96	0.1000	400.000
11	8	7	6.134	1.890	10	0.100	726.34	0.1106	600.000
12	8	9	6.134	1.126	11	0.100	780.72	0.1226	600.000
13	9	10	2.060	2.060	12	0.127	964.58	0.1770	600.000
14	10	11	3.949	2.439	13	0.100	367.83	0.1000	377.472
15	11	12	3.893	3.893	14	0.197	238.03	0.1560	400.000
16	12	13	6.140	0.988	**Best solution found (OF)**			$\sum(T_{ik})$	
17	12	14	6.140	1.780					
18	13	8	3.017	3.017					
19	14	1	5.172	0.857	**MAPSO [10]**			**5.9118**	
20	14	9	5.172	1.087	**PSO-TVAC Case 1**			**5.8646**	

Tab. 2: Optimal relay settings in 8-Bus system without compensation.

Scenario A with compensation									
Primary/Backup pairs			**Fault Current (KA)**		**Optimal Relay setting without compensation**				
(No)	***Pr-Re***	***Ba-Re***	***Pr-Re***	***Ba-Re***	***(No-Re)***	**Case 2**		**Case 3**	
1	1	6	3.382	3.382		TDS	$Ip(A)$	TDS	$Ip(A)$
2	2	1	6.600	0.683	1	0.1000	378.984	0.1000	267.12
3	2	7	6.600	2.660	2	0.1744	600.000	0.1889	600.00
4	3	2	3.895	3.895	3	0.1593	400.000	0.1643	400.00
5	4	3	3.912	2.388	4	0.1141	600.000	0.1179	600.00
6	5	4	2.396	2.396	5	0.1000	369.456	0.1000	407.16
7	6	5	6.897	1.032	6	0.1275	600.000	0.1178	600.00
8	6	14	6.897	2.546	7	0.1614	400.000	0.2037	400.00
9	7	5	5.000	1.025	8	0.1242	600.000	0.1133	600.00
10	7	13	5.000	0.623	9	0.1000	400.000	0.1000	400.00
11	12	13	6.845	2.587	10	0.1106	600.000	0.1188	600.00
12	12	14	6.845	1.000	11	0.1226	600.000	0.1302	600.00
13	13	8	2.492	2.492	12	0.1770	600.000	0.1860	600.00
14	14	1	4.033	2.509	13	0.1000	377.472	0.1000	259.176
15	14	9	4.074	4.074	14	0.1560	400.000	0.1995	400.00
16	12	13	6.602	0.670	**Best solution found (OF)**			$\sum(T_{ik})$	
17	12	14	6.602	2.613					
18	13	8	3.098	3.098					
19	14	1	4.929	0.638	**Case 2** $(PSO-TVAC)$			**5.6833**	
20	14	9	4.929	0.996	**Case 3** $(PSO-TVAC)$			**5.9369**	

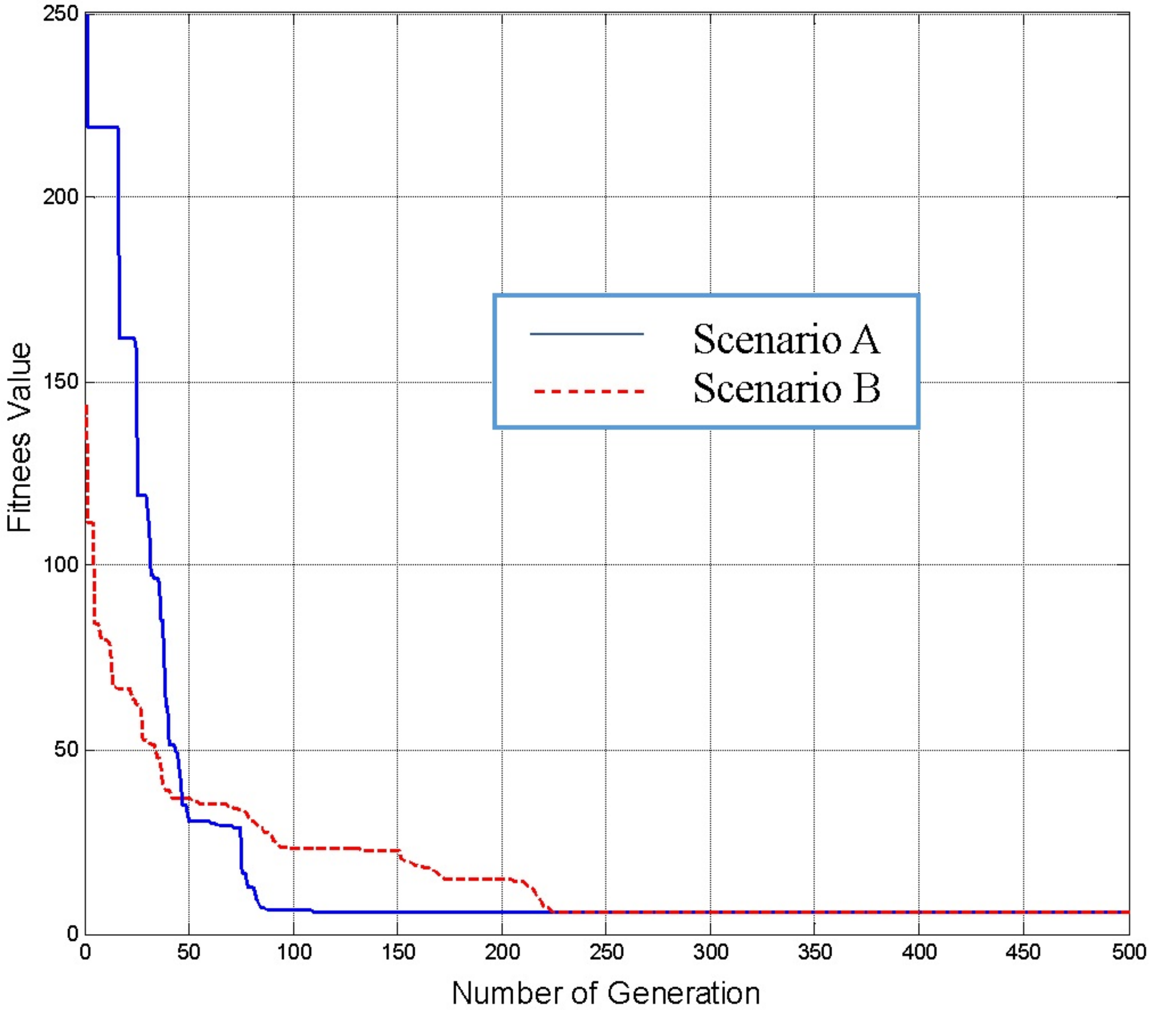

Fig. 4: Convergence characteristic for PSO-TVAC.

Tab. 3: The violation of the associated constraints for three cases.

Pr-Re	***Ba-Re***	**Case 1**			**Case 2**			**Case 3**		
		T_{OP-Pr}	T_{OP-Ba}	$Viol\_CC$	T_{OP-Pr}	T_{OP-Ba}	$Viol\_CC$	T_{OP-Pr}	T_{OP-Ba}	$Viol\_CC$
1	1	0.3183	0.5184	0.2001	**0.3129**	**0.5072**	**0.1944**	0.2688	0.4686	0.1998
2	2	0.5138	0.7137	0.1999	**0.4970**	**1.1815**	**0.6845**	0.5383	0.7387	0.2003
2	3	0.5138	0.7139	0.2000	**0.4970**	**0.5851**	**0.0881**	0.5383	0.7384	0.2001
3	4	0.5370	0.7372	0.2002	**0.4789**	**0.6405**	**0.1616**	0.4939	0.6938	0.1999
4	5	0.4228	0.6226	0.1999	**0.4181**	**0.6130**	**0.1949**	0.4320	0.6323	0.2003
5	6	0.3663	0.5665	0.2002	0.3675	0.5689	0.2014	0.3880	0.5878	0.1998
6	7	0.3729	0.6572	0.2843	0.3566	0.6745	0.3178	0.3295	0.7457	0.4162
6	8	0.3729	0.7206	0.2477	0.3566	0.5792	0.2225	0.3295	0.7407	0.4111
7	9	0.4284	0.6283	0.1999	0.4361	0.6790	0.2429	0.5504	0.7512	0.2008
7	10	0.4284	0.8760	0.4477	0.4361	1.3901	0.9540	0.5504	0.7912	0.2407
8	11	0.3654	0.7163	0.3510	0.3485	0.5940	0.2455	0.3179	0.7497	0.4317
8	12	0.3654	0.6694	0.3040	0.3485	0.7570	0.4085	0.3179	0.7570	0.4390
9	13	0.4201	0.6199	0.1998	**0.3757**	**0.5360**	**0.1603**	0.3757	0.5757	0.2001
10	14	0.4032	0.6034	0.2002	**0.3986**	**0.5913**	**0.1927**	0.4282	0.6280	0.1998
11	15	0.4504	0.6503	0.1999	**0.4395**	**0.6345**	**0.1950**	0.4668	0.6668	0.2000
12	16	0.5205	0.7205	0.2001	0.5043	1.2130	0.7086	0.5300	0.7300	0.2001
12	17	0.5205	0.7206	0.2001	**0.5043**	**0.5710**	**0.0666**	0.5300	0.7302	0.2002
13	18	0.3298	0.5297	0.1998	**0.3256**	**0.5210**	**0.1954**	0.2752	0.4752	0.2000
14	19	0.4158	0.8509	0.4351	0.4240	1.3370	0.9130	0.5422	0.7970	0.2548
14	20	0.4158	0.6932	0.2774	0.4240	0.7603	0.3363	0.5422	0.7603	0.2181

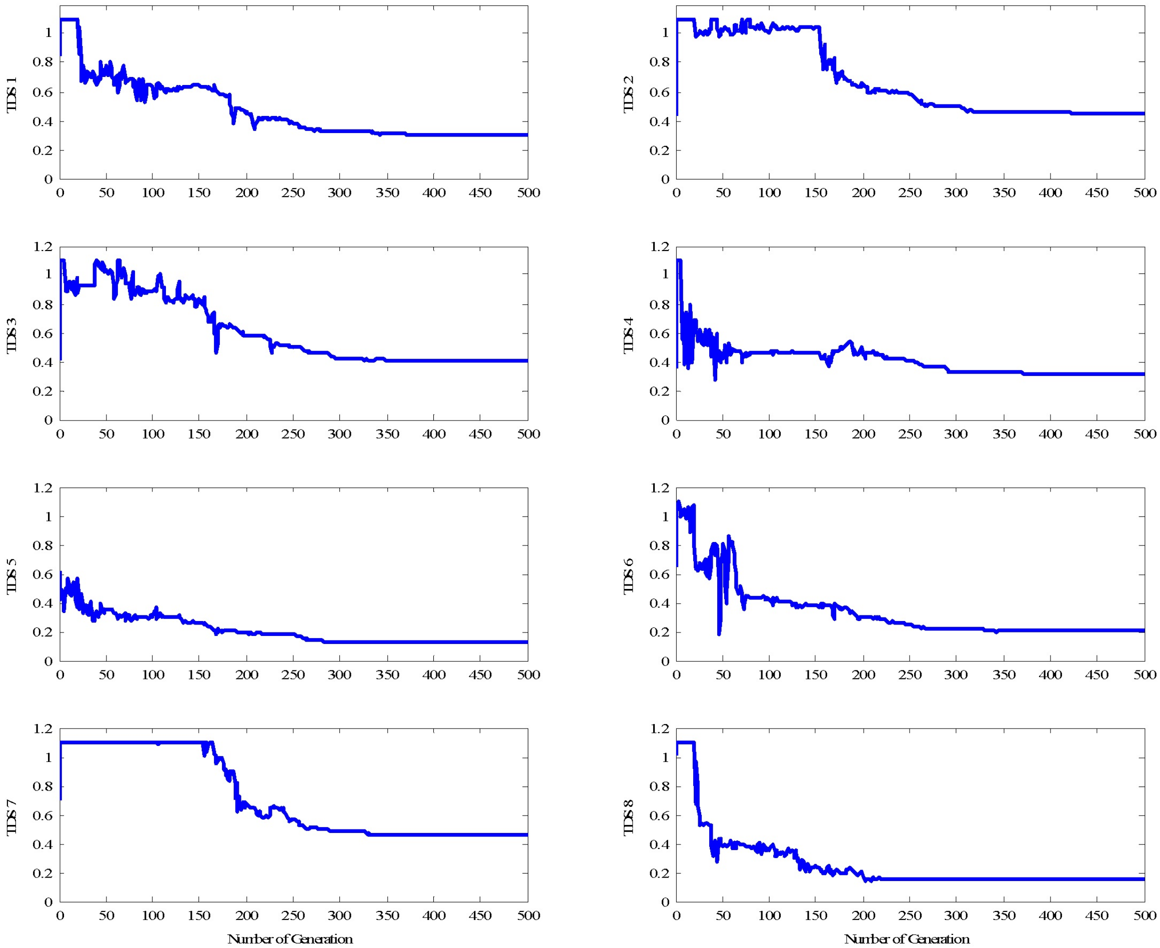

Fig. 5: Convergence evolution of control variable TDS associated to relays 1-8 during search process.

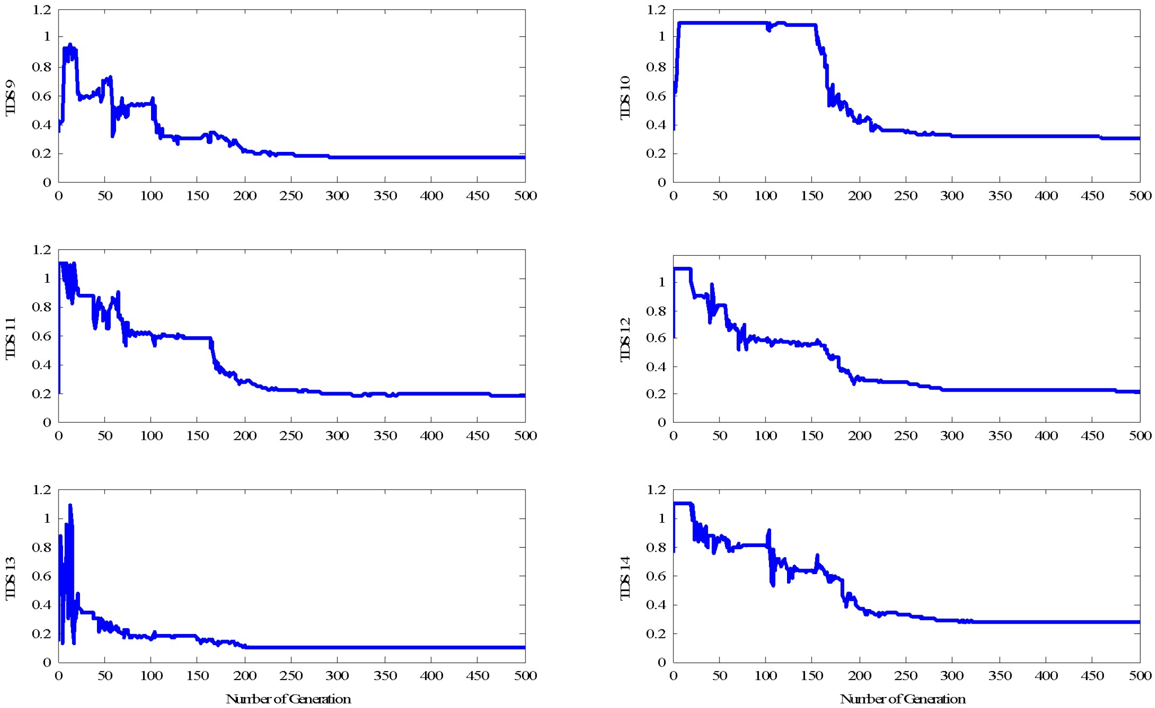

Fig. 6: Convergence evolution of control variable TDS associated to relays 9-14 during search process.

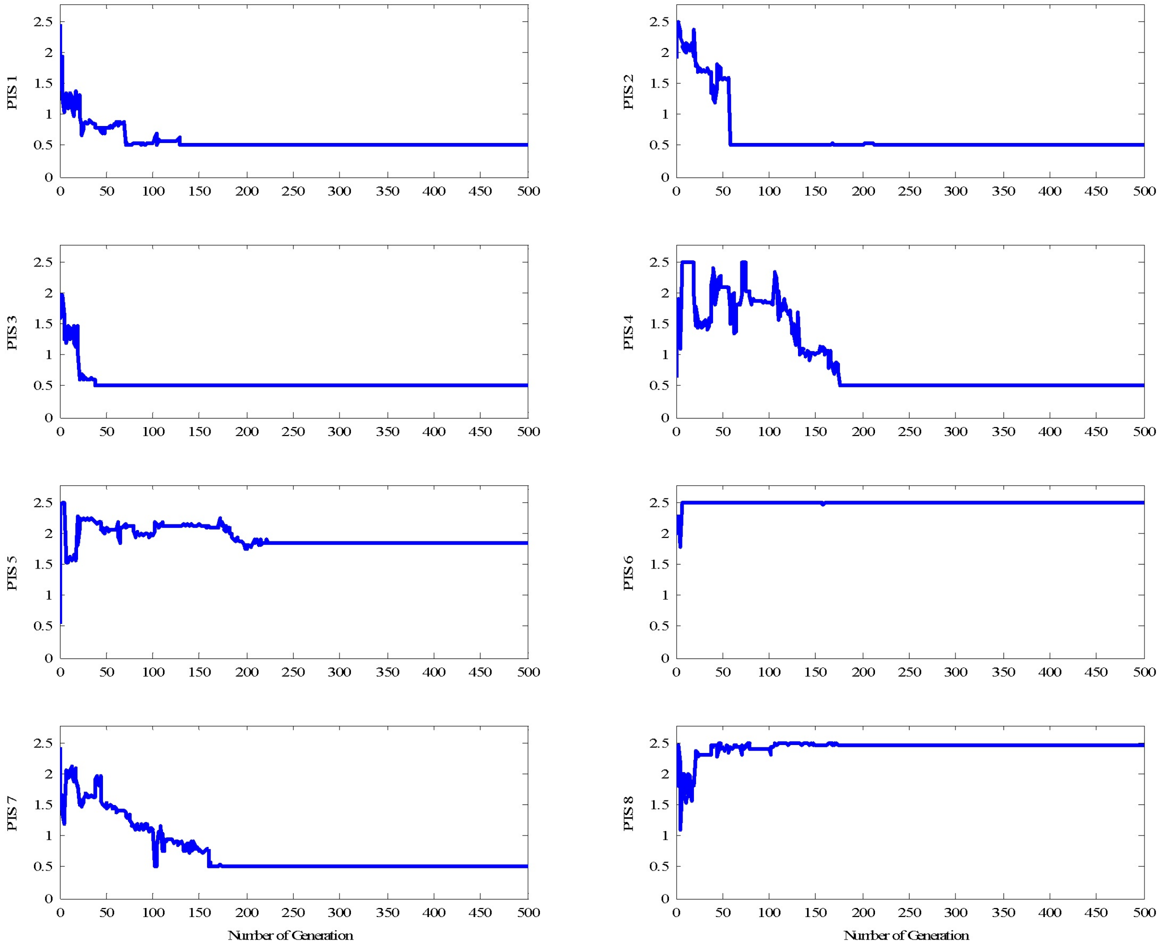

Fig. 7: Convergence evolution of control variable PTS associated to relays 1-8 during search process.

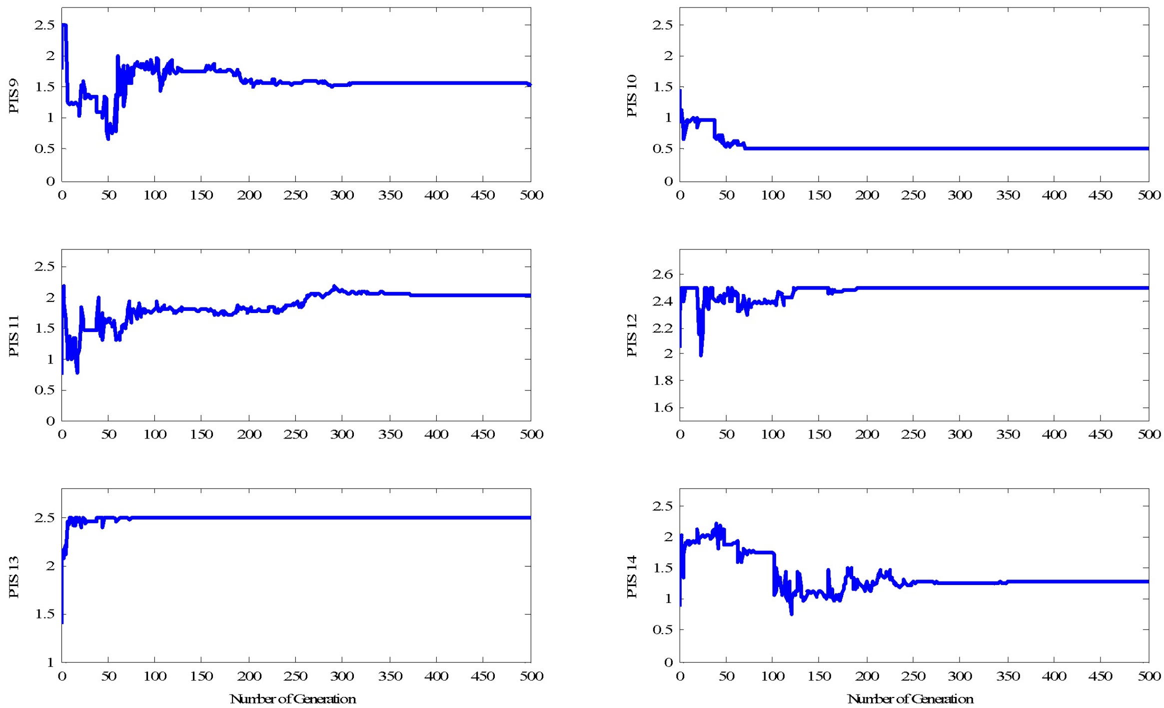

Fig. 8: Convergence evolution of control variable PTS associated to relays 9-14 during search process.

(TDS, IP) adapted to the new configuration (with series compensation). The convergence of the proposed variant$PSO - TVAC$ for the first case and the third case is well shown in Fig. 4, the convergence evolution of the two control variables TDS and PTS during the search process corresponding to all relays are shown in Fig. 5, Fig. 6, Fig. 7, Fig. 8.

6. Conclusion

This work proposed an optimal coordination for directional overcurrent relays considering series compensation using modified variant of PSO named PSO-TVAC algorithm. The main objective of this study is first to demonstrate the effect of series compensation on the performance of relays coordination to ensure service continuity. In the second stage the efficiency of the proposed PSO-TVAC to solve the relays coordination problem is demonstrated on a practical test system (8-Bus) considering the effect of series compensation. Simulation results compared with other optimization methods prove the efficiency of the proposed variant in term of solution quality and convergence.

References

[1] URDANETA, A. J., R. NADIRA and L. G. P. JIMENEZ. Optimal coordination of directional overcurrent relays in interconnected power systems. *IEEE Transactions on Power Delivery*. 1988, vol. 3, iss. 3, pp. 903–911. ISSN 0885-8977. DOI: 10.1109/61.193867.

[2] BEDEKAR, P. P., S. R. BHIDE and V. S. KALE. Optimum coordination of overcurrent relay timing using simplex method. *Electric Power Components and Systems*. 2010, vol. 38, iss. 10, pp. 1175–1193. ISSN 1532-5008. DOI: 10.1080/15325001003652900.

[3] URDANETA, A. J., H. RESTREPO, S. MARQUEZ and J. SANCHEZ. Coordination of directional overcurrent relay timing using linear programming. *IEEE Transactions on Power Delivery*. 1996, vol. 11, iss. 1, pp. 122–129. ISSN 0885-8977. DOI: 10.1109/61.484008.

[4] CHATTOPADHYAY, B., M. S. SACHDEV and T. S. SIDHU. An on-line relay coordination algorithm for adaptive protection using linear programming technique. *IEEE Transactions on Power Delivery*. 1996, vol. 11, iss. 1, pp. 165–173. ISSN 0885-8977. DOI: 10.1109/61.484013.

[5] NOGHABI, A. S., J. SADEH and H. R. MASHHADI. Considering Different Network Topologies in Optimal Overcurrent Relay Coordination Using a Hybrid GA. *IEEE Transactions on Power Delivery*. 2009, vol. 24, iss. 4, pp. 1857–1863. ISSN 0885-8977. DOI: 10.1109/tpwrd.2009.2029057.

[6] HUSSAIN, M. H., S. R. A. RAHIM and I. MUSIRIN. Optimal Overcurrent Relay Coordination: A Review. *Procedia Engineering*. 2013, vol. 53, iss. 1, pp. 332–336. ISSN 1877-7058. DOI: 10.1016/j.proeng.2013.02.043.

[7] MAHDAD, B., K. SRAIRI and T. BOUKTIR. Interactive DE for solving combined security environmental economic dispatch considering FACTS technology. *Frontiers in Energy* . 2013, vol. 7, iss. 4, pp. 429–447. ISSN 2095-1698. DOI: 10.1007/s11708-013-0270-x.

[8] BEDEKAR, P. P. and S. R. BHIDE. Optimum Coordination of Directional Overcurrent Relays Using the Hybrid GA-NLP Approach. *IEEE Transactions on Power Delivery*. 2011, vol. 26, iss. 1, pp. 109–119. ISSN 0885-8977. DOI: 10.1109/tpwrd.2010.2080289.

[9] AMRAEE, T. Coordination of Directional Overcurrent Relays Using Seeker Algorithm. *IEEE Transactions on Power Delivery*. 2012, vol. 27, iss. 3, pp. 1415–1422. ISSN 0885-8977 DOI: 10.1109/tpwrd.2012.2190107.

[10] MORAVEJ, Z., M. JAZAERI and M. GHOLAMZADEH. Optimal coordination of distance and over-current relays in series compensated systems based on MAPSO. *Energy Conversion and Management*. 2012, vol. 56, iss. 1, pp. 140–151. ISSN 0196-8904. DOI: 10.1016/j.enconman.2011.11.024.

[11] ZEINELDIN, H. H., E. F. EL-SAADANY and M. M. A. SALAMA. Optimal coordination of overcurrent relays using a modified particle swarm optimization. *Electric Power Systems Research*. 2006, vol. 76, iss. 11, pp. 988–995. ISSN 0378-7796. DOI: 10.1016/j.epsr.2005.12.001.

[12] MANSOUR, M. M., S. F. MEKHAMER and N. EL-KHARBAWE. A Modified Particle Swarm Optimizer for the Coordination of Directional Overcurrent Relays. *IEEE Transactions on Power Delivery*. 2007, vol. 22, iss. 3, pp. 1400–1410. ISSN 0885-8977. DOI: 10.1109/tpwrd.2007.899259.

[13] LIU, A. and M. YANG. Optimal Coordination of Directional Overcurrent Relays Using NM-PSO Technique. In: *Proc. International Symposium on Computer, Consumer and Control*. Taichung: IEEE, 2012, pp. 678–681. ISBN 978-1-4673-0767-3. DOI: 10.1109/is3c.2012.176.

[14] FARZINFAR, M., M.JAZAERI and F. RAZAVI. A new approach for optimal coordination of distance and directional over-current relays using multiple embedded crossover PSO. *International Journal of Electrical Power & Energy Systems*. 2014, vol. 61, iss. 1, pp. 620–628. ISSN 0142-0615. DOI: 10.1016/j.ijepes.2014.04.001.

[15] MANDAL, K. K., S. MANDAL, B. BHATTACHARYA and N. CHAKRABORTY. Nonconvex emission constrained economic dispatch using a new self-adaptive particle swarm optimization technique. *Applied Soft Computing*. 2015, vol. 28, iss. 1, pp. 188–195. ISSN 1568-4946. DOI: 10.1016/j.asoc.2014.11.033.

[16] HUSSAIN, M. H., I. MUSIRIN, A. F. ABIDIN and S. R. A. RAHIM. Directional overcurrent relay coordination problem using Modified Swarm Firefly Algorithm considering the effect of population size. In: *IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014)*. Langkawi: IEEE, 2014, pp. 591–596. ISBN 978-1-4799-2421-9. DOI: 10.1109/peoco.2014.6814497.

[17] HOSSEINNEZHAD, V., M. RAFIEE, M. AHMADIAN and M. T. AMELI. Species-based Quantum Particle Swarm Optimization for economic load dispatch. *International Journal of Electrical Power & Energy Systems*. 2014, vol. 63, iss. 1, pp. 311–322. ISSN 0142-0615. DOI: 10.1016/j.ijepes.2014.05.066.

[18] JORDEHI, A. R. Enhanced leader PSO (ELPSO): A new PSO variant for solving global optimisation problems. *Applied Soft Computing*. 2015, vol. 26, iss. 1, pp. 401–417. ISSN 1568-4946. DOI: 10.1016/j.asoc.2014.10.026.

[19] KENNEDY, J. and R. EBERHART. Particle swarm optimization. In: *Proc. of ICNN'95 - International Conference on Neural Networks*. Perth, WA: IEEE, 1995, pp. 1942–1948. ISBN 0-7803-2768-3. DOI: 10.1109/icnn.1995.488968.

[20] SHI, Y. and R. C. EBERHART. Empirical study of particle swarm optimization. In: *Proc. of the Congress on Evolutionary Computation-CEC99*. Washington, DC: IEEE, 1999, pp. 1945–1950. ISBN 0-7803-5536-9. DOI: 10.1109/cec.1999.785511.

[21] EBERHART, R. C. and Y. SHI. Comparing inertia weights and constriction factors in particle swarm optimization. In: *Proc. of the Congress on Evolutionary Computation*. La Jolla, CA: IEEE, 2000, pp. 84–88. ISBN 0-7803-6375-2. DOI: 10.1109/cec.2000.870279.

[22] CHATURVEDI, K. T., M. PANDIT and L. SRIVASTAVA. Particle swarm optimization with time varying acceleration coefficients for non-convex economic power dispatch. *International Journal of Electrical Power & Energy Systems*. 2009, vol. 31, iss. 6, pp. 249–257. ISSN 0142-0615. DOI: 10.1016/j.ijepes.2009.01.010.

[23] RICHARDS, S., S. POTTS, E. GRAHAM, M. BERQSTROM and M. BAMBER. *Network protection & automation guide: protective relays, measurement & control*. 2nd ed. Levallois-Perret: Alstom Grid. 2011. ISBN 9780956867803.

[24] MANCER, N., B. MAHDAD, K. SRAIRI and M. HAMED. Multi Objective For Optimal Reactive Power Flow Using Modified PSO Considering TCSC. *International Journal of Energy Engineering*. 2012, vol. 2, iss. 4, pp. 165–170. ISSN 0142-0615. DOI: 10.5923/j.ijee.20120204.08.

[25] MANCER, N., B. MAHDAD, K. SRAIRI and M. HAMED. Multi objective ORPF using PSO with time varying acceleration considering TCSC. In: *11th International Conference on Environment and Electrical Engineering*. Venice: IEEE, 2012, pp. 802–807. ISBN 978-1-4577-1830-4. DOI: 10.1109/eeeic.2012.6221485.

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