Chapter 3

Particle Swarm Optimization Solution for Power System Operation Problems

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Additional information is available at the end of the chapter

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Abstract

Application of particle swarm optimization (PSO) algorithm on power system operation is studied in this chapter. Relay protection coordination in distribution networks and economic dispatch of generators in the grid are defined as two of power system-related optimization problems where they are solved using PSO. Two case study systems are conducted. The first case study system investigates applicability of PSO on providing proper overcurrent relay settings in the grid, while in the second case study system, the economic dispatch of a 15-unit system is solved where PSO successfully provides the optimum power output of generators with minimum fuel costs to satisfy the load demands and operation constraints. The simulation results in comparison with other methods show the effectiveness of PSO against other algorithms with higher quality of solution and less fuel costs on the same test system.

Keywords: power system, economic dispatch, relay coordination, particle swarm optimization

1. Introduction

Electric power system is the most complex man-made system, and the modern society depends heavily on continuous and reliable operation of this system to supply electricity to commercial, residential and industrial consumers. Operation of the power grid involves a balanced platform in generation, transmission and distribution, which costs billions of dollars to run. The reliable and continuous availability of electricity with minimum costs is the major objective of utility grids and energy providers. Two of the important complex problems in power system are economic dispatch and power system protection.

The power plants and utility grids need to allocate the available generation units in an efficient and economical way to respond to the load demand in order to provide continuous power supply in stable conditions and with minimum power production costs. This is addressed as economic dispatch (ED) [1, 2]. With the practical constraints on the generators, finding optimum power outputs with minimum fuel costs is challenging.

In addition, as the occurrence of failures and faults in the power grid is inevitable, the entire power system must be protected. The relay protection scheme is designed to detect faults and isolate the faulty parts of the grid from the healthy sections in order to mitigate the consequences of the faults and maintain continuity of service. If a fault occurs, the nearest corresponding relays must operate as fast as possible to clear the fault. If due to any reason these primary relays fail to react, their backup relays must operate and accomplish the task. Directional overcurrent relays (DOCRs) are a suitable and economical protection scheme for distribution systems [3]. The protection design of DOCRs is based on two parameters, time multiplier setting (TMS) and plug setting (PS). Proper settings of TMS and PS allow a primary relay to clear the faults in its protection zone as fast as possible and in case of failure, its backup relay operates immediately after a time interval to clear the fault. TMS and PS values of each relay must be coordinated with other backup relays, where again relays act with different current settings, which make the coordination a complex task. Each pairs of relays include four variables (TMS, PS) and the complexity of coordination will be intense in bigger systems with more relays and constraints. Due to the complex interconnection of the distribution systems and also nonlinear characteristics of operation time of relays, finding best relay settings could be very difficult.

Considering the non-convex and nonlinear nature of these problems, traditional methods fail to feasibly or optimally solve them. Therefore, evolutionary algorithms have gained more attentions as solutions to such optimization problems. Some of the recent related works on ED problem have been studied with the metaheuristic methods such as Genetic Algorithm (GA) [4], Particle Swarm Optimization (PSO) [4], Imperialist Competitive Algorithm (ICA) [5], Artificial Bee Colony (ABC) [6], Bacterial Foraging Optimization (BF) [7], Hybrid Harmony Search with Arithmetic Crossover (ACHS) [8], GA with a special class of ant colony optimization (GAAPI) [9] and so on. The modified and hybrid models of PSO such as Modified PSO (MPSO) [10], guaranteed convergence PSO (GCPSO) [10], Species-based Quantum Particle Swarm Optimization (SQPSO) [11], Iteration PSO (IPSO) [12], Parallel PSO with Modified Stochastic Acceleration Factors (PSO-MSAF) [13], Distributed Sobol PSO and Tabu Search Algorithm (DSPSO-TSA) [14], Self-Organizing Hierarchical PSO (SOH-PSO) [15], Passive Congregation-based PSO (PC-PSO) [15] and Simple PSO (SPSO) [15] have also been employed to address the ED problem.

Application of metaheuristic algorithms on power system protection and particularly, DOCR coordination in distribution networks has been introduced in literature such as PSO [3, 16], Harmony Search Algorithm (HSA) [17], Cuckoo Algorithm [18], chaotic firefly algorithm [19], differential evolution [20] and so on.

In this chapter, PSO is applied as a solution to the introduced power system operation problems, namely ED and DOCR coordination. The rest of the chapter is organized as follows: in Section 2, these power system problems are defined and formulated as optimization problems. PSO algorithm is explained in Section 3. In Section 4, PSO is applied in two case study systems to conduct the performance and feasibility of this method. Finally, Section 5 concludes the chapter with the results in pervious sections.

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2. Problem formulation

In this section, overcurrent relay coordination and economic dispatch problems are formulated separately as optimization problems.

2.1. Relay coordination problem

In a protection scheme, each primary relay should operate as fast as possible to clear the fault in a system. If the operation time of the relay takes longer than an acceptable time, the damage on the faulty equipment would be severe with serious consequences. In other words, minimizing the total operation time of relays decreases the risk and stress on the protected apparatus, which can be depicted as an optimization objective function:

$$OF = \min \sum_{i=1}^{n} w_i t_i \tag{1}$$

where t_i is the operation time of relay R_i, w_i is the probability of the occurrence of fault on transmission line in the zone of protection, and it is normally set to 1; n is the total number of relays in the system.

Generally, the operation time of DOCRs is defined in (2):

$$t_i = \frac{\lambda \times TMS_i}{\left(\frac{I_{Fi}}{PS_i}\right)^{\eta} - 1} + L \tag{2}$$

where I_{Fi} is the fault current seen by the appropriate relay R_i after being transformed through the secondary winding of corresponding current transformer (CT). Depending on the type of relays, the characteristic constants λ, L and η are selected [16]. In this chapter, continuous form of TMS and PS is considered with relay type of standard inverse definite minimum time (IDMT). Based on that, all the relays in the system are assumed identical with a common characteristic function approximated by:

$$t_i = \frac{0.14 \times TMS_i}{\left(\frac{I_i}{PS_i}\right)^{0.02} - 1} \tag{3}$$

To ensure that the operation time of an individual relay is proper enough to mitigate the damage impact of faults on the apparatus, the time must be within an acceptable range:

$$t_{i\min} \le t_i \le t_{i\max}; i = 1, \ldots, n \tag{4}$$

where, respectively, $t_{i\min}$ and $t_{i\max}$ are the minimum and maximum operating time of the relay R_i. Each overcurrent relay has a manufactured TMS range to provide controllability of response to faults with different speeds. As shown in (3), t_i is proportional to TMS values. Also, the PS has nonlinear effect on the operating time. Within a security margin and to avoid maloperation of an individual relay with normal load or slight overload current, the minimum pickup current setting is selected bigger than the maximum load current. The maximum plug setting is chosen not greater than the minimum fault current [19]. Therefore, there are constraints on TMS and PS as follows:

$$TMS_{i\min} \le TMS_i \le TMS_{i\max};\ i = 1, \ldots, n \quad (5)$$

$$PS_{i\min} \le PS_i \le PS_{i\max};\ i = 1, \ldots, n \quad (6)$$

where $TMS_{i\max}$, $PS_{i\max}$, $TMS_{i\min}$ and $PS_{i\min}$ are the maximum and minimum values of TMS and PS of relay R_i. Although the constraints in Eqs. (4)–(6) seem to provide satisfactory limits on performance of each relay, they are not enough to guarantee correct performance of the protection scheme as the coordination between primary-backup relays has not been considered.

The constraints can only ensure the operation of an individual relay not a primary-backup pair. To coordinate adjacent relays as primary and backup relays, the primary relay should operate as fast as possible within its acceptable boundaries. If it fails to act, its backup relay needs to take over the tripping action with a minimum time. The minimum operating time of the backup relay must be small but yet bigger than the operating time of primary relay. Therefore, a coordination time interval (CTI) is added to the constraints to satisfy the proper coordination scheme.

$$t_{j\ backup} - t_{i\ primary} \ge CTI \quad (7)$$

where t_i and t_j are the operation time of primary and backup relays, respectively. CTI depends upon the relay type, circuit breaker speed, relay over-travel time and the safety factor time for CT saturation, setting errors, contact gaps and so on. According to the IEEE standard [21], CTI is set to 0.2 s for the digital relays. **Figure 1** shows the backup-primary pair of relays in a radial network.

2.2. Economic dispatch

How to allocate the available generators in the grid to respond to the load demand with minimum fuel costs is an economical aspect of power dispatch in the electric power system that annually costs millions of dollars to operate.

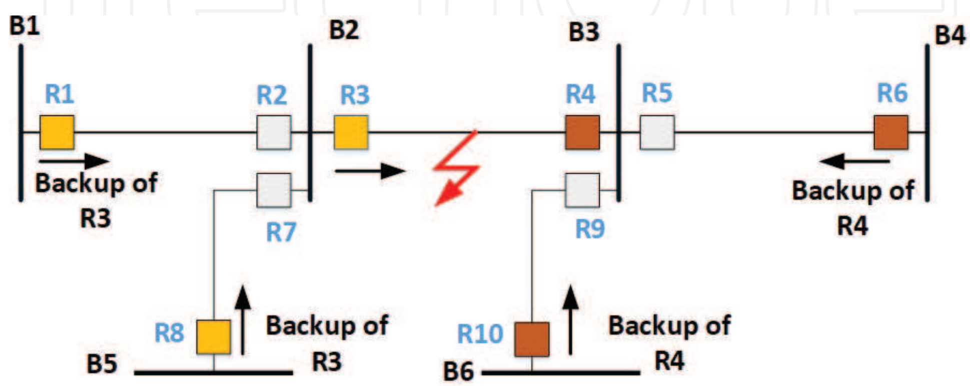

Figure 1. Primary-backup relation between relays in a distribution system.

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In a practical ED optimization, the generator constraints and network limits such as ramp rate limit, the prohibited zones of operation, generation capacity constraints and valve point effects are considered. Single quadratic equation is used to formulate the ED optimization problem:

$$\min F_t = \sum_{i=1}^{m} F(P_i) = \sum_{i=1}^{m} \alpha_i + \beta_i P_i + \gamma_i {P_i}^2 \tag{8}$$

where α_i, β_i and γ_i are the cost equation coefficients of unit i, P_i is the output power in MW and $F(P_i)$ is the cost function of that unit in \$/h. The index m denotes the number of generators in a system.

The fuel cost function in (8) as the objective function of ED problem here is associated with practical constraints. Considering the ramp rate limits, the momentary output power of a generator cannot exceed its previously generated power more than a certain amount of UR_i, the up-ramp rate limit and neither can it be less than that of the previously generated power by more than a certain amount of DR_i, the down-ramp rate limit of the generator. Therefore:

$$P_i - P_{i0} \le UR_i \tag{9}$$

$$P_{i0} - P_i \le DR_i \tag{10}$$

where P_i is the current power output and P_{i0} refers to the previous power output of generator i. UR_i and DR_i represent the up-ramp limit and down-ramp limit of the generator i, respectively, in which the current generated power has the following constraint in MW/t:

$$P_{i0} - DR_i \le P_i \le P_{i0} - UR_i \tag{11}$$

The input-output curves of the generation units have separate operation zones. The prohibited zones of operations are due to the operation of steam valve or the shaft bearing vibration of the generators. Therefore, the generated power is within the feasible zones of operation and outside the prohibited zones. For a generator i:

$$P_i \in \begin{cases} P_i^{min} \le P_i \le P_{i,1}^{l} \\ P_{i,j-1}^{u} \le P_i \le P_{i,j-1}^{l} \\ P_{i,n}^{u} \le P_i \le P_i^{max} \end{cases}, j = 2, 3, \dots, n; i = l, \dots, m \tag{12}$$

where j is the number of prohibited zones of operation for unit i, $P_{i,j}^{l}$ and $P_{i,j}^{u}$ are the lower and upper boundaries, respectively, of prohibited zone j of generator i, $P_i^{\min}$ and $P_i^{\max}$ are minimum and maximum power capacity, respectively, of a generator that produces. From (11) and (12), it can be deduced that the operational power of a generator must be within the constraint in (13) and also be out of the prohibited zones in (12):

$$\max\left(P_i^{\min}, P_{i0} - DR_i\right) \le P_i \le \min\left(P_i^{\max}, P_{i0} + UR_i\right) \tag{13}$$

Total delivered power from the units needs to meet the power demand and transmission loss in the grid.

$$\sum_{i=1}^{m} P_i = P_D + P_L; i \in m \tag{14}$$

where P_D and P_L represent the demand power and the power loss in the gird, respectively. The overall power loss of the committed units is based on the output power, which is formulated by B matrix coefficients known as Kron's formula:

$$P_L = \sum_{i=1}^{m}\sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \tag{15}$$

The power loss itself cannot be more than some permissible values:

$$\left|P_{Lf,k}\right| \le P_{Lf,k}^{\max} \; ; k = j, \dots, L \tag{16}$$

where the real power flow of line j is represented with $P_{Lf,k}$ and k is the number of transmission lines in a system. The power loss cannot be more than a maximum value of $P_{Lf,k}^{\max}$.

3. Particle swarm optimization algorithm

PSO algorithm is a nature inspired method from social behavior of bird flocking and fish schooling, which is first introduced by Erberhart and Kennedy in 1995 [22]. As a population-based stochastic optimization technique using swarm intellects in the search space, this technique is based on interaction of swarm of particles. Every particle includes two values of position and velocity that are updated during the iteration runs by considering each particle's best experience (best position) and the best achieved experience (global position) of all particles.

The update of position and velocity of the particles must be processed, and it has to follow Eqs. (17)–(19) for satisfying the constraint of an optimization problem. Each particle movement is based on the changes in its position and its velocity:

$$p_i^{k+1} = p_i^k + v_i^{k+1} \tag{17}$$

where p_i^{k+1} and p_i^k are the position of particle i in the iteration $k+1$ and k, respectively, v_i^{k+1} is the velocity of the particle in $k+1$ iteration. A particle's velocity is defined as follows:

$$v_i^{k+1} = w \times v_i^k + c_1 \times rand_1 \times \left(pbest_i - p_i^k\right) + c_2 \times rand_2 \times \left(gbest - p_i^k\right) \tag{18}$$

where $pbest_i$ is the best so far position of the particle i as the best experience, while $gbest$ is the best position among the whole swarm with all the particles in movement as global experience. c_1 and c_2 are the weighting factors, while $rand_1$ and $rand_2$ are two random numbers between zero and one. The parameter w is the inertia factor varying between $[w_{\min}, w_{\max}]$, as shown in (19), which is a linear decreasing inertia weight in this chapter.

$$w = w_{\max} - \frac{w_{max} - w_{\min}}{iter_{\max}} \times k \tag{19}$$

where k and $iter_{\max}$ are the current iteration and the maximum number of iteration during simulations, respectively.

The general steps of PSO on solving an optimization problem are as follows:

1. Set initial parameters $w_{\min}$, $w_{\max}$, c_1 and c_2.
2. Generate initial populations having initial positions p and velocities v.
3. Set iteration $k = 1$.
4. Calculate fitness of particles $F_i^k = f\left(p_i^k\right), \forall i$ and find the index of the best particle b.
5. Select $pbest_i^k = p_i^k, \forall i$ and set $gbest^k = p_b^k$.
6. Update inertia factor: $w = w_{\max} - \frac{w_{max} - w_{\min}}{iter_{\max}} \times k$.
7. Update the velocity and position of particles.

$$v_i^{k+1} = w \times v_i^k + c_1 \times rand_1 \times \left(pbest_i - p_i^k\right) + c_2 \times rand_2 \times \left(gbest - p_i^k\right); \forall i$$
$$p_i^{k+1} = p_i^k + v_i^{k+1}; \forall i$$

8. Calculate fitness $F_i^{k+1} = f\left(p_i^{k+1}\right), \forall i$ and obtain the index of the best particle b_1.
9. Update $pbest$ for all particles.

$$\text{if } F_i^{k+1} < F_i^k \text{ then } pbest_i^{k+1} = p_i^{k+1} \text{ else } pbest_i^{k+1} = pbest_i^k$$

10. Update $gbest$ of the population

$$\text{if } F_{b1}^{k+1} < F_b^k \text{ then } gbest^{k+1} = pbest_{b1}^{k+1} \text{ and } b = b1 \text{ else } gbest^{k+1} = gbest^k$$

11. If $k < Iter_{\max}$ then $k = k + 1$ and go to step 6 else go to step 12.
12. Print $gbest^k$ as optimum solution.

4. Simulation results

Application of PSO on solving the defined problems in previous sections is validated here. In the first case study system, the overcurrent relay coordination problem in a distribution network is solved. The size of population and iteration numbers of PSO are 60 and 100, respectively. In the second case study system, the ED problem is addressed with population size of 100 and 500 iterations. c_1, c_2, $w_{\min}$ and $w_{\max}$ in both case study systems are the same and set to 2, 2, 0.4 and 0.9, respectively.

4.1. Case study 1: relay protection coordination

A 15-node radial network system including a total of 13 loads is considered, and PSO is employed to determine the optimal settings of all 28 digital over-current relays shown in **Figure 2**. Identical digital relays are used with same current transformer (CT) ratio 500:1. The constraint values of the relays are as follows: t_{imin} and t_{imax} for each relay is set to 0.1 and 4 s, respectively; TMS_{min} and TMS_{max} constraints are 0.1 and 1.1, respectively; PS_{min} and PS_{max} are 0.5 and 2.5, respectively [16].

The primary-backup relationships of the relays in the system are shown in **Table 1**. According to the objective function in (3), the maximum fault currents sensed by the relays are also required. Therefore, the case study system in **Figure 2** has been modeled in DigSILENT PowerFactory software with simulating three-phase faults occurring in front of each relay. The collected data have been shown in **Table 2**. The load parameters of the radial network are shown in **Table 3**.

After data collection in DigSILENT PowerFactory software, the optimal settings (TMS and PS) of all 28 overcurrent relays are obtained by solving (3) subject to the constraints in (4)–(7) using the PSO in MATLAB software. The algorithm was executed 100 times to achieve accurate results. **Table 4** shows the best TMS and PS settings of the relays to provide a reliable protection scheme

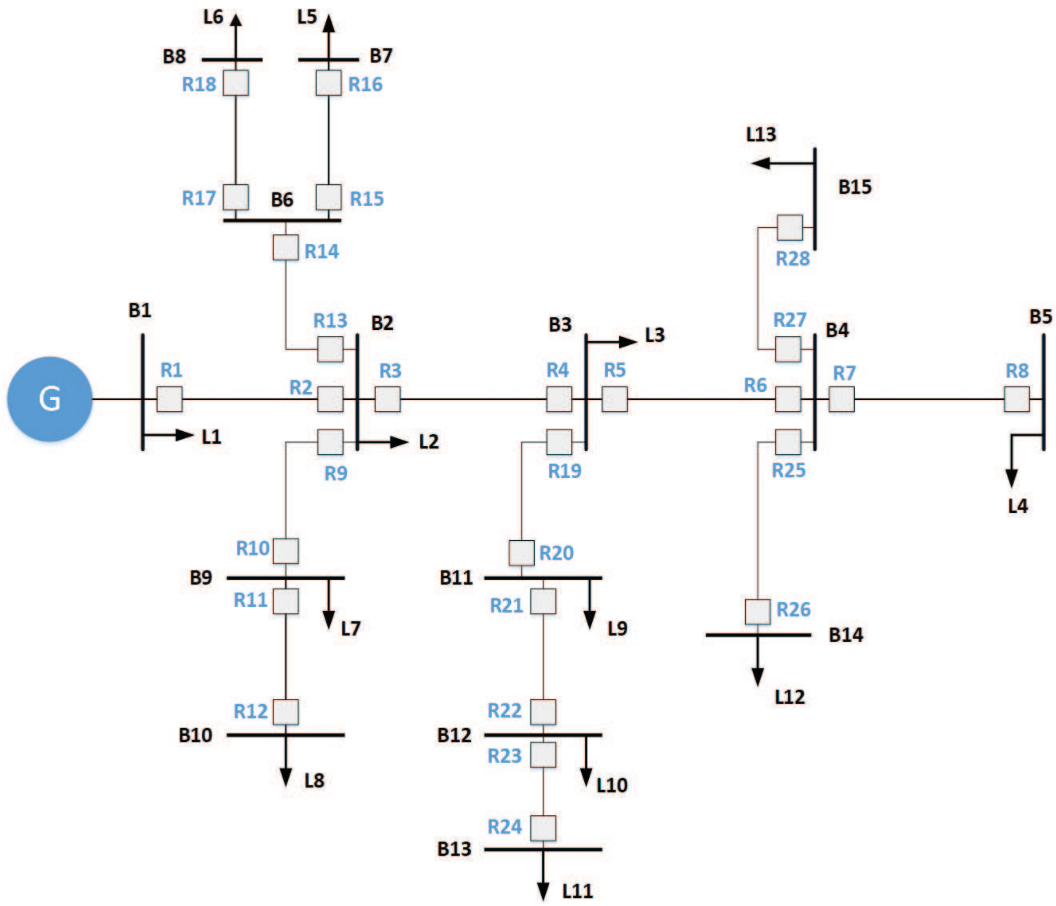

Figure 2. A 15-node distribution system as case study one.

Primary	Backup	Primary	Backup	Primary	Backup	Primary	Backup
1	—	8	—	15	13	22	—
2	—	9	1	16	—	23	21
3	1	10	—	17	13	24	—
4	—	11	9	18	—	25	5
5	3	12	—	19	3	26	—
6	—	13	1	20	—	27	5
7	5	14	—	21	19	28	—

Table 1. Primary-backup pair relationship of the relays.

Relay	Fault current (kA)	Relay	Fault current (kA)	Relay	Fault current (kA)	Relay	Fault current (kA)
1	22.778	8	4.636	15	7.7	22	4.636
2	11.532	9	11.509	16	5.79	23	4.632
3	11.509	10	7.71	17	7.7	24	3.866
4	7.71	11	7.7	18	5.79	25	5.785
5	7.7	12	5.79	19	7.7	26	4.636
6	5.79	13	11.509	20	5.79	27	5.785
7	5.785	14	7.71	21	5.785	28	4.636

Table 2. Maximum fault currents.

Load	Active power (MW)	Reactive power (Mvar)	Load	Active power (MW)	Reactive power (Mvar)
1	4	1.5	8	0.5	0.2
2	1	0.2	9	2	0.8
3	2.5	1	10	1	1
4	3	2	11	2.5	0.9
5	1	0.5	12	1	0.5
6	3	0.7	13	3	2
7	1	0.5			

Table 3. Load parameters in case study one.

in the distribution system. The total operation time of the relays in this system is 26.189 s. **Figure 3** illustrates the convergence curve of PSO in solving the objective function.

4.2. Case study 2: economic dispatch

A 15-unit test system is used to investigate the feasibility of PSO in solving the nonsmooth economic dispatch considering transmission losses, ramp rate limits and the prohibited

Relay	TMS	PS	Relay	TMS	PS
1	0.74394	0.54999	15	0.42632	0.79222
2	0.32216	1.2551	16	0.54396	0.67839
3	0.3416	1.5153	17	0.21794	0.61987
4	0.55245	2.4141	18	0.12037	1.1896
5	0.36342	0.60859	19	0.31997	0.66671
6	0.4309	1.0805	20	0.56566	1.1323
7	0.11188	1.2611	21	0.26376	0.60754
8	0.2726	1.822	22	0.14313	1.8741
9	0.45395	1.1148	23	0.12496	0.7978
10	0.15359	1.3933	24	0.55302	1.3848
11	0.32133	0.50089	25	0.22254	0.65529
12	0.26418	2.4727	26	0.2904	1.6316
13	0.32088	1.9075	27	0.13471	0.77885
14	0.73899	2.1497	28	0.10277	2.4925
OF (s)	26.189				

Table 4. Obtained TMS and PS values of relays by PSO.

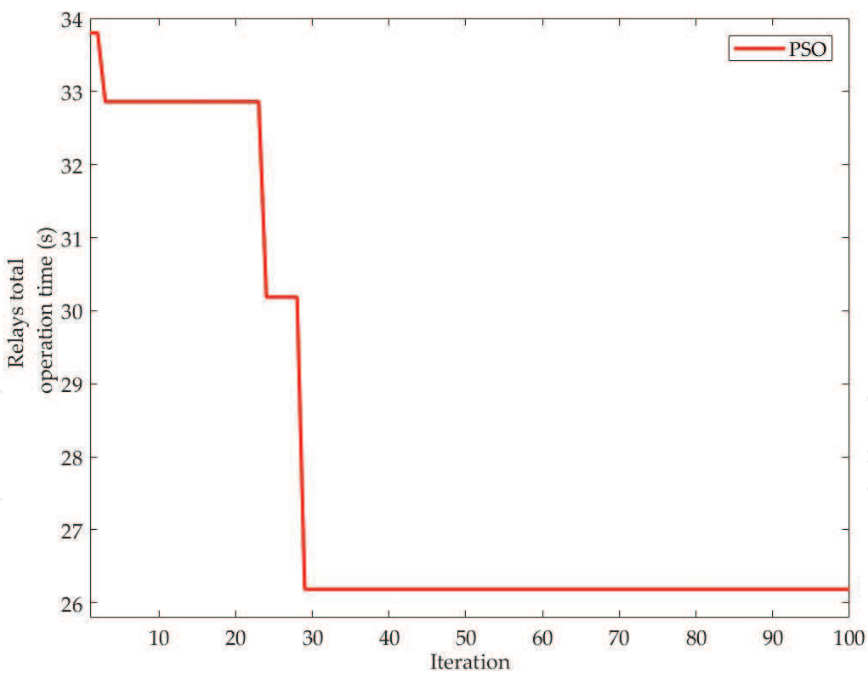

Figure 3. Convergence of PSO solution in case study one.

operation zones of the thermal generators. The cost curves data and operation limits of the 15-unit system are shown in **Table 5**. The B loss coefficients to calculate the power loss can be found in [4].

Unit	P_i^{min}	P_i^{max}	P_{i0}	α_i	β_i	γ_i	UR_i	DR_i	Prohibited zones (MW)
1	150	455	400	671	10.1	0.000299	80	120	
2	150	455	300	574	10.2	0.000183	80	120	[185 225] [305 335] [420 450]
3	20	130	105	374	8.80	0.001126	130	130	
4	20	130	100	374	8.80	0.001126	130	130	
5	150	470	90	461	10.40	0.000205	80	120	[180 200] [305 335] [390 420]
6	135	460	400	630	10.10	0.000301	80	120	[230 255] [365 395] [430 455]
7	135	465	350	548	9.8	0.000364	80	120	
8	60	300	95	227	11.2	0.000338	65	100	
9	25	162	105	173	11.2	0.000807	60	100	
10	25	160	110	175	10.7	0.001203	60	100	
11	20	80	60	186	10.2	0.003586	80	80	
12	20	80	40	230	9.90	0.005513	80	80	[30 40] [55 65]
13	25	85	30	225	13.1	0.000371	80	80	
14	15	55	20	309	12.1	0.001929	55	55	
15	15	55	20	323	12.4	0.004447	55	55	

Table 5. Generation unit characteristics of a 15-unit system in case study two.

This system has many local minima with high dimensionality that draws realistic analysis for practical applications. PSO is applied on the 15-unit test system, and the results are compared with best results in literature on the same system: ACHS [8], SQPSO [11], ABC [6], IPSO [12], PSO-MSAF [13], DSPSO-TSA [14], ICA [5], GAAPI [9], MPSO [10], SOH-PSO [15], GCPSO [10], PC-PSO [15], BF [7], SPSO [15], PSO [4] and GA [4].

The simulation is tested for 100 times to ensure reliable analysis. **Table 6** shows the optimum results of each method for the 15-unit system. **Figure 4** illustrates the convergence of PSO method in 100 different trials, while the final fuel costs in 100 trials are shown in **Figure 5**. **Table 7** shows the best economic dispatch of power using PSO for ED optimization in the 15-unit system.

The optimum cost of 15-unit system with the proposed PSO solution is 32701.282 ($), which has better result than other methods. GA has the most deviating results compared with other hybrid and improved methods in this test system. Also, the mean value of final fuel cost of generators using PSO over 100 trials is less than minimum values obtained by other method, which indicates higher quality of solution and better performance of PSO compared with other algorithms on the same test system. The power loss in the grid obtained from PSO is less than other algorithms, which shows better dispatching scheme using PSO. The best convergence of PSO to the minimum fuel cost of generators in the grid while satisfying the constraints is shown in **Figure 6**.

In case study two, PSO achieves better results when compared with other hybrid or improved methods. It is worth mentioning that the maximum iteration number is 500 and the population

Method	Best cost ($/h)	Mean ($/h)
PSO	32701.282	32704.10578
ACHS [8]	32706.6500	32706.65
SQPSO [11]	32706.6740	32708.4457
ABC [6]	32707.85	32707.95
IPSO [12]	32709.00	32784.5
PSO-MSAF [13]	32713.09	32759.64
DSPSO-TSA [14]	32715.06	32724.63
ICA [5]	32715.4305	NA
GAAPI [9]	32732.95	NA
MPSO [10]	32738.4177	NA
SOH-PSO [15]	32751.39	32,878
GCPSO [10]	32764.4616	NA
PC-PSO [15]	32775.36	NA
BF [7]	32784.5024	32796.81
SPSO [15]	32798.69	NA
PSO [4]	32,858	33,039
GA [4]	33,113	33,228

Table 6. Comparison of PSO results with other methods in case study two.

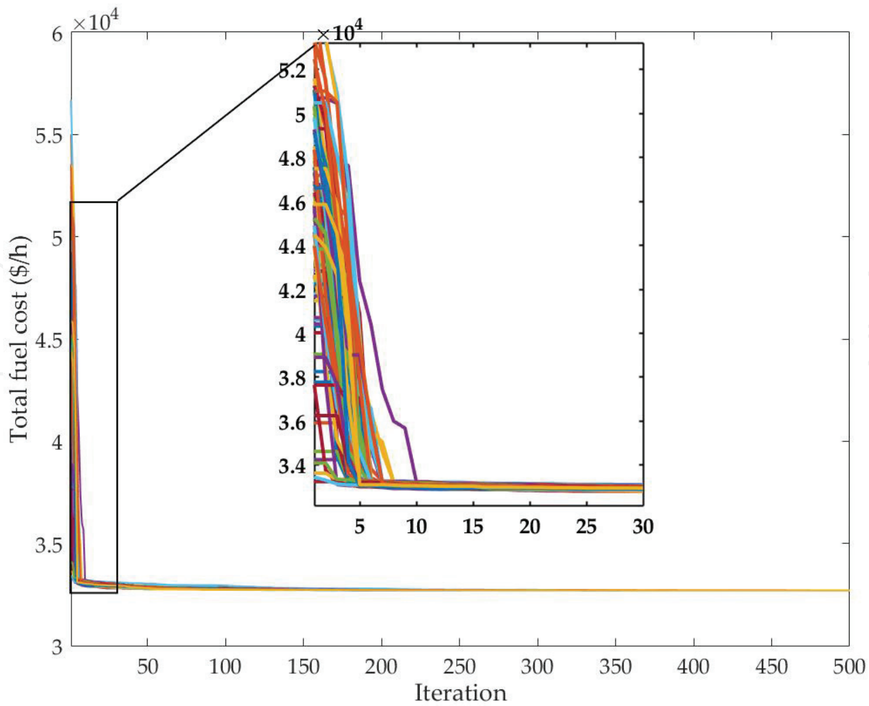

Figure 4. Convergence curve of PSO over 100 different trials.

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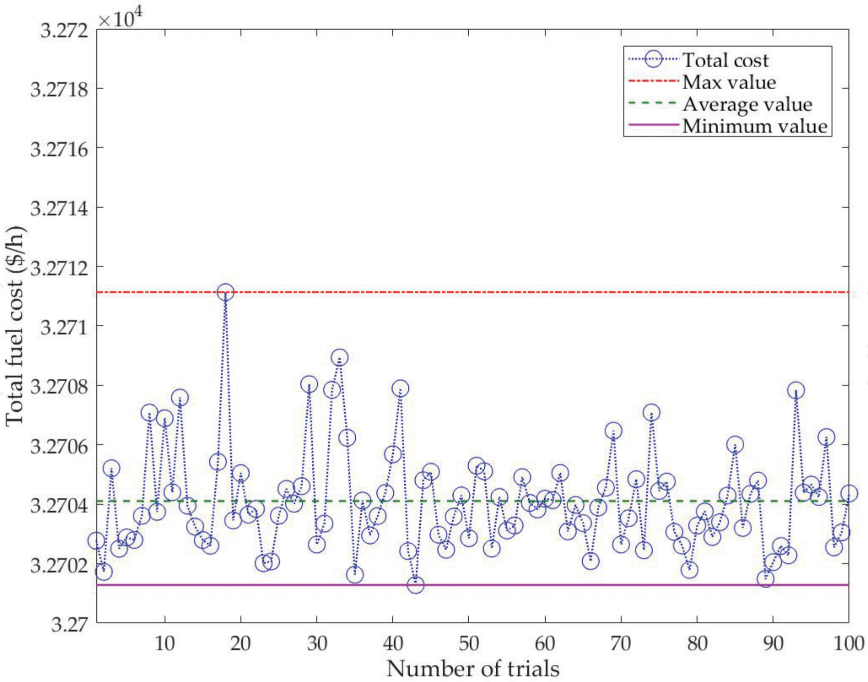

Figure 5. Cost distribution with PSO over 100 different trials.

Unit (MW)	PSO	ICA [5]	GCPSO [10]	MPSO [10]	GA [4]	PSO [4]	ABC [6]	SOH-PSO [15]
P1	454.9963	455	449.89252	455	415.3108	439.1162	455	455
P2	379.9998	380	366.99066	380	359.7206	407.9727	380	380
P3	130	130	130	130	104.4250	119.6324	130	130
P4	129.9954	130	130	130	74.9853	129.9925	130	130
P5	169.9999	167.4174	170	170	380.2844	151.0681	169.9997	170
P6	459.9999	460	460	460	426.7902	459.9978	460	459.96
P7	430	430	430	430	341.3164	425.5601	430	430.00
P8	66.1794	113.4737	75.88460	92.7278	124.7867	98.5699	71.9698	117.53
P9	64.9485	25.1555	50.22689	43.0282	133.1445	113.4936	59.1798	77.90
P10	159.2255	155.3478	160	140.1938	89.2567	101.1142	159.8004	119.54
P11	79.9996	80	80	80	60.0572	33.9116	80	54.50
P12	79.9901	80	77.87063	80	49.9998	79.9583	80	80.00
P13	25.0001	25	25	27.6403	38.7713	25.0042	25.0024	25.00
P14	15.0005	15	15.8312	20.7610	41.9425	41.4140	15.0056	17.86
P15	15.0029	15	39.66146	22.2724	22.6445	35.6140	15.0014	15
Total power	2660.338	2661.394	2661.35806	2661.6235	2668.4	2262.4	2735.959	2662.29
Power loss	30.338	31.291	30.86593	29.978	38.2782	32.4306	30.9591	32.28
Cost ($)	32701.282	32715.4305	32764.4616	32738.41778	33113	32858	32707.85	32751.39

Table 7. Optimum solution of PSO compared with other methods in case study two.

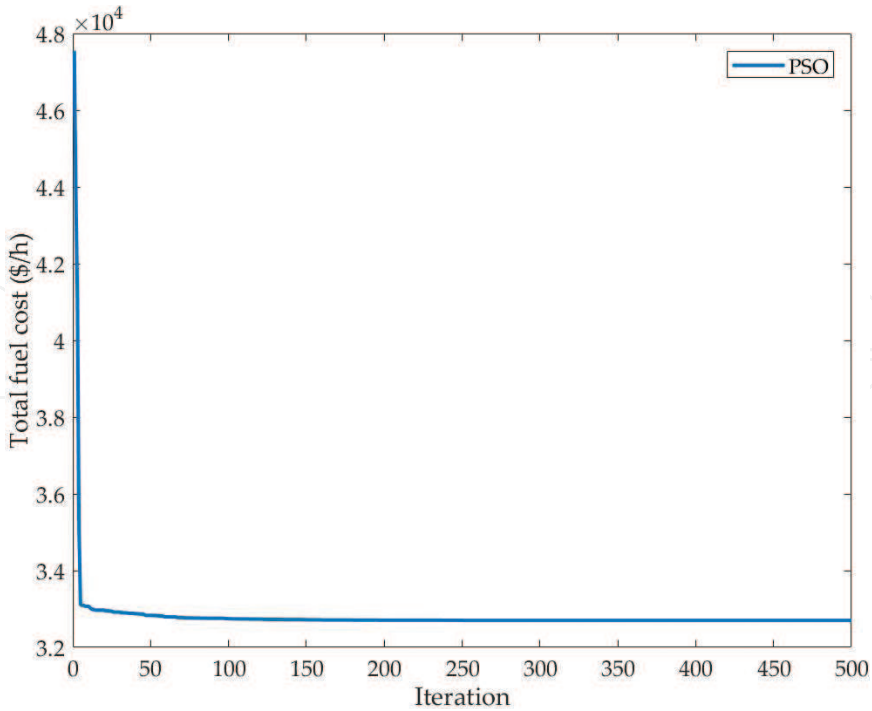

Figure 6. Convergence of PSO with best fuel cost result for ED problem in case study two.

size is 100. In most of the quoted methods, the iteration and population sizes vary that can affect the final results. For example, the PSO in [4] has population size and iteration number of 100 and 500, respectively. The population size, iteration, crossover rate, mute rate and crossover parameter of GA [4] are 100, 200, 0.8, 0.01 and 0.5, respectively.

Different system configuration and programming language frameworks can also influence the results in which MATLAB 2015Ra was used for programming.

5. Conclusions

Distribution network relay coordination and the economic dispatch of generators in the electric power system were modeled as optimization problems. Particle swarm optimization (PSO) was successfully employed to solve the defined problems where two case study systems were conducted to validate the results. In the first case study system, PSO provided proper relay settings that allow all the relays in a system to perform with high reliability and accuracy. In the second case, the optimal power outputs of thermal generators in the grid were scheduled to satisfy the load demands and other practical constraints on the generators and the grid with minimum fuel costs. The compared results with other methods demonstrated higher quality of solution, and less fuel costs obtained by PSO. The general performance of PSO in this chapter indicates applicability of this method on practical power system-related problems that are difficult to be handled by conventional methods.

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