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Comparative Performance Analysis of Variants of Particle Swarm Optimization of Optimal Reactive Power Dispatch

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Abstract

The Optimal Reactive Power Dispatch (ORPD) is non-linear problem and is a very effective tool in modern power system for designing a more secure and economic system. It has control variables, which are a combination of continuous and discrete and helps in obtaining the most optimized result satisfying all the equality and inequality constraints. The results obtained not only reduces the real power losses of the system but also helps in restricting the voltage deviation to a much greater extent and thus maintaining the stability of the entire system. In this paper, the ORPD problem is solved as a single objective problem with two different objectives like minimization of real power loss and minimization of voltage deviation. Here, four different variants of PSO are used to solve the problem and the results are compared. The algorithms considered in this paper are tested on IEEE 30 bus and IEEE 57 bus system.

Keywords: ORPD, Particle Swarm Optimization, PSO Variants, Real Power Loss, Single Objective, Voltage Deviation

1. Introduction

The ORPD problem is one of the major problems in power system which helps in determing the optimal location and values of control variables to minimize the real power loss in the transmission system and also improve the voltage profile. It is a sub-problem of OPF and contribute towards the enhancement of the system security. The control variables that are considered for this problem are the generator bus voltages, tap-setting position of the tap-changing transformers and the value of the reactive power to be injected into the load buses. The objective is to optimize the objective functions but simultaneously satisfying many system constraints[1,2].

The decrease in transmission line loss save power and thus results in lowering the cost of power generation. Moreover, lowering the voltage deviation increases the system stability as most of the instruments work within a specified voltage limit and deviation of voltage beyond that limit would effect those instruments and thus subsequently result in the commencement of system instability. Many nature-inspired algorithms are used to solve the optimization problem and Particle Swarm Optimization (PSO) being one of the widely used one. In this paper, different variants of the PSO algorithm is tested to determine the superior variant among them[3–5].

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2. Problem Formulation

Two different objective functions are considered in this paper independently. The following are the objective functions:

2.1 Minimization of Active Power Loss

One of the major objectives to the solution of the of ORPD problem is to minimize the real Power Losses in the transmission lines (Ploss) while satisfying all the constrains. The objective function is mathematically expressed as follows:

$$\text{Min}\,(P_{\text{loss}}) = \sum_{k=1}^{NL} G_k (V_i^2 + V_j^2 - 2V_iV_j \cos\delta_{ij}) \tag{1}$$

where, NL is the total number of transmission lines in the system, G_k is the conductance of the k^{th} branch, V_i and V_j represent the magnitudes of the bus voltage for buses i and j respectively, δ_{ij} is the phase difference between V_i and V_j.

2.2 Minimization of Voltage Deviation

Another objective function for the problem is the minimization of Total Voltage Deviation (TVD), which is also called as Voltage Deviation Index (VDI). It is basically restricting the voltages at the load buses within a specified limit, thus improving the voltage profile of the system. It is nothing but the summation of the voltage deviation of all the load bus voltages from the reference voltage, V_R.

The mathematical expression for TVD is as follows:

$$TVD = \sum_{i=1}^{N_{PQ}} |V_i - V_R| \tag{2}$$

Here, V_R is taken as 1.0. And N_{PQ} represent the total number of load buses.

2.3 System Constraints

The objective functions are subjected to the following equality and inequality constraints:

2.3.1 Equality Constraint

These constraints show the load flow equations and are depicted as follows:

$$P_{gi} - P_{di} - V_i \sum_{j=1}^{N} V_j (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) = 0 \tag{3}$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N} V_j (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) = 0 \tag{4}$$

where, N represent the total number of buses, P_{gi} and Q_{gi} the active and reactive power generation and P_{di} and Q_{di} are the active and reactive power load demands at the i^{th} bus respectively. G_{ij} and B_{ij} are the conductance and susceptance between two different buses (i.e., i^{th} and j^{th}) respectively.

2.3.2 Inequality Constraint

The inequality constraints of the independent variables are:

- Generator constraints:

$$V_{gi}^{min} \le V_{gi} \le V_{gi}^{\max},\ i = 1,\ldots,N_g \tag{5}$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{\max},\ i = 1,\ldots,N_g \tag{6}$$

where, N_g represent the total number of generator buses, $V_{gi}^{\min}$ and $V_{gi}^{\max}$ are the minimum and maximum limits of the generator bus voltages respectively and $Q_{gi}^{\min}$ and $Q_{gi}^{\max}$ are the limits of reactive power output of the alternators. V_{gi} and Q_{gi} are the amount of voltage and reactive power output at the i^{th} bus.

- Transformer constraints:

$$T_i^{min} \le T_i \le T_i^{max}, i = 1,\ldots,N_T \tag{7}$$

where, NT represent the total number of tap changing transformers and $T_i^{\min}$ and $T_i^{\max}$ are the minimum and maximum limits of tap-changing positions of the transformer respectively. T_i is the tap-setting of the transformer at the i^{th} bus.

- VAR compensator constraints:

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}, i = 1,\ldots,N_C \tag{8}$$

where, N_C represent the total number of shunt compensators and $Q_{ci}^{\min}$ and $Q_{ci}^{\max}$ shows the minimum and maximum limits of the reactive power injection respectively at the i^{th} bus.

- Operating constraints:

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max}, i = 1, \ldots, N_{LB} \tag{9}$$

$$S_{Li} \le S_{Li}^{max}, i = 1, \ldots, NL \tag{10}$$

where, N_{LR} represent the total number of load buses, $V_{Li}^{\min}$ and $V_{Li}^{\max}$ are the minimum and maximum limits of the voltages at the load buses and $S_{Li}^{\max}$ is the maximum limit of apparent power flow at the i^{th} bus.

From the above constraints, the reactive power generation and the load bus voltages are the dependent variables. These variables are constrained using penalty coefficients to the objective function in eq. (1). The objective function is thus modified as,

$$f = p_{\text{loss}} + \lambda_V \sum_{i=1}^{N_V^{\lim}} (V_i - V_i^{\lim})^2 + \lambda_Q \sum_{i=1}^{N_Q^{\lim}} (Q_{gi} - Q_{gi}^{\lim})^2 \tag{11}$$

Here, λ_V and λ_Q are penalty coefficients, $N_V^{\lim}$ is the number of buses on which the voltages are outside limits and $N_Q^{\lim}$ is the number of buses on which the reactive power generations are outside limits. The limits of $V_i^{\lim}$ and $Q_{gi}^{\lim}$ are defined as follows:

$$V_i^{\lim} = \begin{cases} V_i^{\min}, if\ V_i < V_i^{\min} \\ V_i^{\max}, if\ V_i > V_i^{\max} \end{cases} \tag{12}$$

$$Q_i^{\lim} = \begin{cases} Q_i^{\min}, if\ Q_{gi} < Q_i^{\min} \\ Q_i^{\max}, if\ Q_{gi} > Q_i^{\max} \end{cases} \tag{13}$$

3. Overview of some PSO Strategies

Particle Swarm Optimization (PSO) is an optimization technique that was developed by Dr. Eberhart and Dr. Kennedy in the year 1995[6]. It is stochastic in nature and is widely used for optimization problems in almost every field of engineering. It is a population-based algorithm inspired by the collective behavior of some intelligent animals like the flocks of birds or the schools of fishes. In this algorithm, a group of particles is randomly generated within a specified limit and the particle with the best fitness value leads to the optimal result. There is a velocity function associated with every particle which helps the particle to move in the search space and update its position optimally.

3.1 General PSO

For a general PSO, let $x_{j,ni}$ be the j^{th} particle of the population at the i^{th} iteration, $v_{j,n,i}$ be the initial velocity of $x_{j,n,i}$ then the updation of each particle takes place according to the following equation:

$$\begin{aligned} v_{j,n,i+1} &= v_{j,n,i} + (c_1 \times r \times (pbest_{j,i} - x_{j,i})) \\ &+ (c_2 \times r \times (gbest_i - x_{j,i})) \end{aligned} \tag{14}$$

$$x_{j,n,i+1} = x_{j,n,i} + v_{j,i+1} \tag{15}$$

where, $p^{best}{}_{j,i}$ is the best value of the j^{th} particle among all its population for the j^{th} iteration and $g^{best}{}_i$ is the global best particle corresponding over the entire population (or swarm) for the iteration. The variables c_1 and c_2 are the acceleration coefficient, which helps the particles to move towards the finest position and r stand for any random number within the range [0,1]. The PSO algorithm in many cases is unable to determine the optimal solution as it has the tendency to get stuck in the local optima. Thus, to overcome this problem many changes have been made in the algorithm in the recent past to improve the search quality of the algorithm. There are many variants of PSO discussed in 7 and are stated below:

3.2 RPSO

In many PSO variants, an inertia weight function w is multiplied to the initial velocity $v_{j,n,i}$, which is a random number within a specified limit. In RPSO as proposed in 7, the value of w is varied from 0.5 to 1 by the flowing equation:

$$w = 0.5 + \frac{r}{2} \tag{16}$$

Thus, the equations (1) can be modified for RPSO as follows:

$$v_{j,n,i+1} = (w \times v_{j,i}) + (c_1 \times r \times (p^{best}{}_{j,i} - x_{j,i})) + (c_2 \times r \times (g^{best}{}_i - x_{j,i})) \tag{17}$$

3.3 LPSO

In LPSO, as mentioned in 7, the inertia weight function is made dependent on the number of iterations of the program. The weight function decreases with the increase in the number of iterations and it ranges from 1 when the iteration count is 0, upto 0.1 when iteration count reaches maximum. The equation of the weight function is given as:

$$w_i = w_1 - \left(\frac{w_1 - w_0}{i_{\max}} \times i \right) \tag{18}$$

where, w_i is the weight function for the iteration, w_1 and w_0 are the upper and lower limits of the weight respectively. The variable i represent the number of iteration and i_{max} represent the maximum number of iterations. Here the values of w_1 and w_0 are set as 1 and 0.1 respectively.

3.4 Improved PSO based on Success Rate

A new variant of PSO is proposed in 7 where it is improved based on the success rate. Here the acceleration coefficient c_1 is divided into two different parts, c_{1b} which signifies the coefficient towards best that helps the particles to accelerate towards the best value, and c_{1w} which signifies the coefficient away from the worst, i.e. it accelerates the particles away from the worst value or position. Here, the values of every particle is updated depending upon its previous best and worst values or positions. In this method, the weight function is calculated depending on the rate at which the particle successfully attain the optimal value. Let $OF_{j,n.i}$ be the value of the objective function for the j^{th} particle of the n^{th} population at the i^{th} iteration. Then the value of the total number of success of the particle j is determined as:

$$S_j = \begin{cases} 1, if\ OF_{j,n,i} < OF_{j,n,i-1} \\ 0, otherwise \end{cases} \tag{19}$$

$$SR = \frac{1}{N}\sum_{j=1}^{N} S_j \tag{20}$$

where, N stand for the total number of particles and $OFbest_{j,\,i-1}$ is the best value of the objective function of the previous iteration. Thus, for a minimizing function as for the cases stated in this paper, if $OF_{best\ j,n,i} < OF_{best\ j,n,i-1}$, then the success rate SR is set to 1.0, or else 0. The weight function is written as:

$$w_i = ((w_1 - w_0) \times \mathrm{SR}) + w_0 \tag{21}$$

The velocity is modified as follows:

$$v_{j,n,i+1} = (w_1 \times v_{j,i}) + (c_{1b} \times r \times (p_{best\ j,i} - x_{j,i})) - (c_{1w} \times r \times (pworst_{j,i} - x_{j,i})) + (c_2 \times r \times (gbest_i - x_{j,i})) \tag{22}$$

The values of w_1 and w_0 are taken as 1 and 0.1 respectively and coefficient c_2 is taken as 2.0 which is kept fixed for all the cases. The values of c_{1b} and were initially taken as 1.0. Then the value of c_{1b} was gradually increased to 1.9 in steps of 0.05 but the value of c_{1w} was reduced to 0.1 in the same interval of 0.05. Thus, for every combination of the coefficients of c_{1b} and c_{1w}, the ORPD problem is solved for the dieffernt objective functions individually. Therefore, a total of 19 combination for the pair of c_{1b} and c_{1w} are taken for the IPSO-SR variant. The combination for which the objective function gives the best value is chosen and the control variables are recorded. All the 19 combinations are shown in Table 1.

Table 1. Combination Pairs

Combi nation pair number	Value of c_{1b}	Value of c_{1w}	Combi nation pair number	Value of c_{1b}	Value of c_{1w}
1	1	1	11	1.5	0.5
2	1.05	0.95	12	1.55	0.45
3	1.1	0.9	13	1.6	0.4
4	1.15	0.85	14	1.65	0.35
5	1.2	0.8	15	1.7	0.3
6	1.25	0.75	16	1.75	0.25
7	1.3	0.7	17	1.8	0.2
8	1.35	0.65	18	1.85	0.15
9	1.4	0.6	19	1.9	0.1
10	1.45	0.55			

4. Simulation Results and Discussion

The different variants of PSO as discussed in the literature have been tested on IEEE 30 bus and IEEE 57 bus systems to solve the 'ORPD problem'. The problem is considered as a single objective and the analysis for the two different objective functions are done individually. The software used in this paper is MATLAB R2014b. The total number of population taken for every case is 100.

4.1 IEEE-30 Bus System

The standard IEEE-30 bus system has total 6 generators situated at the buses 1, 2, 5, 8, 11 and 13. There are 41 branches with 4 branches having adjustable transformers at 6–9, 6–10, 4–12 and 28–27. The system data of this test system are obtained from[8].

There are total 13 control variables and are listed below:

- 6 generator voltages at buses 1, 2, 5, 8, 11, 13. Bus 1 is the slack bus. The voltages are in the in the range [0.95, 1.1] p.u.
- 4 tap-changing transformer taps in the lines between 6-9, 6-10, 4-12 and 28-27. The range is [0.9, 1.1] p.u.
- 3 shunt compensators placed at buses 3, 10 and 24 within the range of [0, 0.36] p.u.

The case studies for the two different objective functions are as follows:

4.1.1 Minimization of Real Power Loss

The objective is to minimize the active power loss in the system by finding the optimal solution of the control variables for the ORPD problem. Here, the objective function in eq. (1) is solved and the simulation results are shown in Table 2 along with the convergence characteristic in Figure 1 for the IEEE 30 bus system.

The results of the IPSO-SR for all the 19 combination pairs are elaborated in Table 3.

The results from Tables 2, 3 and Figure 1 show the optimal values of the control variables for all the algorithms. It concludes that the IPSO-SR give the best solution for the optimization of the real power loss among all the other variants of PSO as compared in this paper. The best combination pair, which gives the minimum active power loss, is the 19th combination as depicted in Table 3.

Table 2. Comparative results of IEEE 30 bus system for Ploss

Control Variables (p.u.)	PSO	L-PSO	RPSO	IPSO-SR
V_{G1}	1.1	1.1	1.1	1.1
V_{G2}	1.1	1.1	1.1	1.1
V_{G5}	1.1	1.1	1.1	1.1
V_{G8}	1.1	1.1	1.1	1.0882
V_{G11}	1.1	1.1	1.1	1.1
V_{G13}	1.1	1.1	1.1	1.1
T_{6-9}	0.9981	1.1	1.1	0.9758
T_{6-10}	1.1	1.1	0.9	1.1
T_{4-12}	0.9726	1.0063	0.9729	0.9553
T_{28-27}	0.9896	0.998	0.9746	0.9644
Q_{sc3}	0	0	0	9.4958
Q_{sc10}	36	36	23.6235	36
Q_{sc24}	9.4856	10.3176	10.056	9.9367
P_{loss} (MW)	4.7915	4.8655	4.7392	4.719
TVD (p.u.)	2.0175	1.6571	2.0632	2.1737

Table 3. PLOSS for the combination pairs for IEEE 30 bus system

Combination pair number	Ploss (MW)	Combination pair number	Ploss (MW)
1	4.9988	11	5.0172
2	5.0846	12	4.9312
3	4.938	13	4.938
4	4.938	14	4.8655
5	5.0846	15	5.0023
6	4.938	16	4.938
7	5.0029	17	4.8655
8	4.8712	18	4.8711
9	4.938	19	4.719
10	5.0414		

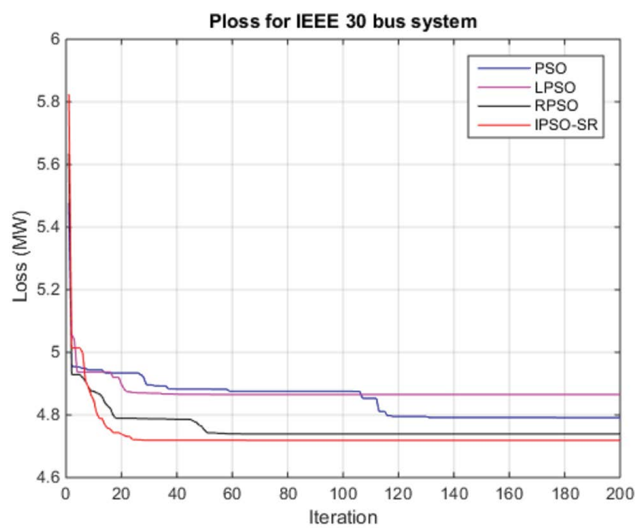

Figure 1. Convergence characteristics for minimizing ploss for the ieee 30-bus test system.

4.1.2 Minimization of Voltage Deviation

The objective is to minimize the Total Voltage Deviation (TVD) and thus improving the voltage profile of the system. Here, the objective function in eq. (2) is solved and the simulation results is shown in Table 4. The convergence characteristic is shown in Figure 2 for the TVD for all the listed algorithms for the IEEE 30 bus system.

The results of the IPSO-SR for all the 19 combination pairs are elaborated in Table 5.

The results obtained from Tables 4, 5 and Figure 2 state that the minimum voltage deviation for the system is obtained by the IPSO-SR algorithm over the other variants of PSO. Once again, the best result is observed for the combination pair number 19 of the ISPO-SR as seen from Table 5.

Table 4. Comparative results of IEEE 30 bus system for TVD

Control Variables (p.u.)	PSO	L-PSO	RPSO	IPSO-SR
V_{G1}	1.0149	0.9977	0.95	0.95
V_{G2}	0.95	0.95	1.1	0.95
V_{G5}	1.0551	1.0196	1.0194	1.0171
V_{G8}	1.0262	1.0201	0.9958	1.015
V_{G11}	0.9502	1.1	0.9632	1.0492
V_{G13}	1.1	0.9871	0.9785	1.0747
$T_{6\text{-}9}$	0.9062	1.1	0.9778	1.0706
$T_{6\text{-}10}$	0.9516	0.9	0.9	0.9513
$T_{4\text{-}12}$	1.1	0.9	0.9	1.0614
$T_{28\text{-}27}$	0.9537	0.9561	0.9468	0.9536
Q_{sc3}	0	36	24.4983	29.8764
Q_{sc10}	0	0	11.4438	19.3082
Q_{sc24}	13.7761	17.3418	11.6722	13.4728
TVD (p.u.)	0.1583	0.1383	0.1257	0.1242
P_{loss} (MW)	12.5611	9.9641	24.6529	9.6383

Table 5. TVD for the combination pairs for IEEE 30 bus system

Combination pair number	TVD (p.u.)	Combination pair number	TVD (p.u.)
1	0.1912	11	0.1775
2	0.1401	12	0.1323
3	0.1414	13	0.141
4	0.1486	14	0.1296
5	0.1628	15	0.1375
6	0.1933	16	0.184
7	0.1404	17	0.1315
8	0.2082	18	0.127
9	0.1661	19	0.1242
10	0.1313		

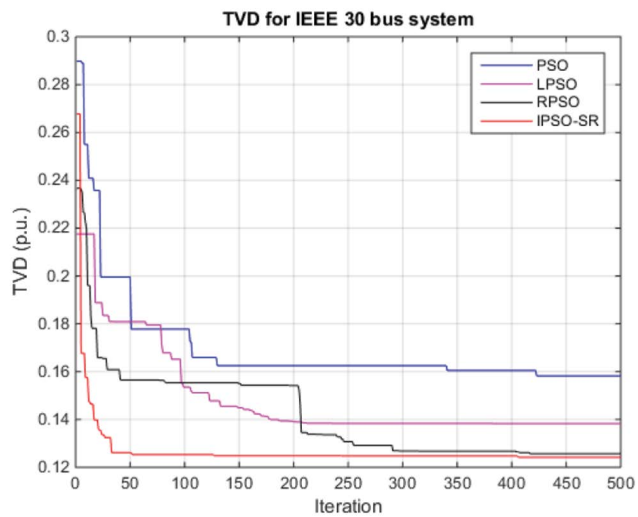

Figure 2. Convergence characteristics for minimizing tvd for the ieee 30-bus test system.

4.2 IEEE-57 Bus System

The standard IEEE-57 bus system has 7 generators, 80 transmission lines with 15 lines having tap-changing transformers connected to them. The system data of this test system are obtained from[8].

There are total 25 control variables for the ORPD problem, which are listed below:

- 7 generator voltages at buses 1, 2, 3, 6, 8, 9 and 12 where bus number 1 is the slack bus. The voltages are in the range [0.94, 1.06] p.u.
- 15 tap-changing transformer taps in the lines between 4–18, which has two tap-changing transformers, 21–20, 24–26, 7–29, 34–32, 11–41, 15–45, 14–46, 10–51, 13–49, 11–43, 40–56, 39–57 and 9–55. The range is [0.9, 1.1] p.u.
- 3 shunt compensators placed at buses 18, 25 and 53 within the range of [0, 0.1] p.u., [0, 0.059] p.u. and [0, 0.063] p.u. respectively.

The case studies for the two different objective functions are as follows:

4.2.1 Minimization of Real Power Loss

The algorithms are used to solve ORPD problem with the objective to determine the optimal solution of the control variables for the least amount of real power loss in the system. The results of the simulation are elaborated in Table 6. The convergence characteristic for the minimum power loss for the IEEE 57 bus system is shown in Figure 3.

The results for all the 19 combination pairs of the IPSO-SR algorithm are shown in Table 7.

Thus, the results form from Tables 6, 7 and Figure 3 implies that the ISPO-SR gives the best result among the other variants of PSO for determining the minimum power loss of the IEEE 57 bus system, and that for the 19th combination pair among all the combinations of the algorithm as observed from Table 7.

Table 6. Comparative results of IEEE 57 bus system for Ploss

Control Variables (p.u.)	PSO	L-PSO	RPSO	IPSO-SR
V_{G1}	1.06	1.06	1.06	1.06
V_{G2}	1.06	1.06	1.06	1.06
V_{G3}	1.06	1.06	1.06	1.06
V_{G6}	1.06	1.0497	1.06	1.06
V_{G8}	1.06	1.06	1.06	1.06
V_{G9}	1.06	1.06	1.06	1.06
V_{G12}	1.06	1.06	1.06	1.06
T_{4-18}	1.1	1.1	1.1	1.1
T_{4-18}	1.1	1.1	1.1	1.1
T_{21-20}	1.1	1.1	1.1	1.1
T_{24-26}	1.1	1.0308	1.0822	1.1
T_{7-29}	1.1	1.1	1.1	1.1
T_{34-32}	0.9692	1.1	0.9693	1.1
T_{11-41}	1.1	1.1	1.1	1.1
T_{15-45}	0.995	1.1	1.0023	0.9
T_{14-46}	1.0091	1.0518	1.0078	0.9164
T_{10-51}	1.1	1.1	1.1	0.9345
T_{13-49}	0.9745	1.0122	0.9778	0.9
T_{11-43}	1.1	1.1	1.1	0.9
T_{40-56}	1.1	1.1	1.1	1.0733
T_{39-57}	1.1	1.1	1.1	1.0412
T_{9-55}	1.1	1.1	1.1	1.1
Q_{sc18}	10	1.3769	10	10
Q_{sc25}	5.9	5.9	5.9	5.9
Q_{sc53}	6.3	6.3	6.3	6.3
P_{loss} (MW)	26.1507	26.7281	26.1354	25.3875
TVD (p.u.)	2.8947	4.5918	2.9813	3.1028

Table 7. PLOSS for the combination pairs for IEEE 57 bus system

Combination pair number	Ploss (MW)	Combination pair number	Ploss (MW)
1	26.8998	11	26.8083
2	26.3514	12	26.7878
3	26.8896	13	27.0204
4	26.6503	14	27.1197
5	26.6144	15	26.7272
6	27.1778	16	26.8094
7	26.9463	17	26.7566
8	27.0204	18	26.3514
9	27.0445	19	25.3875
10	26.8055		

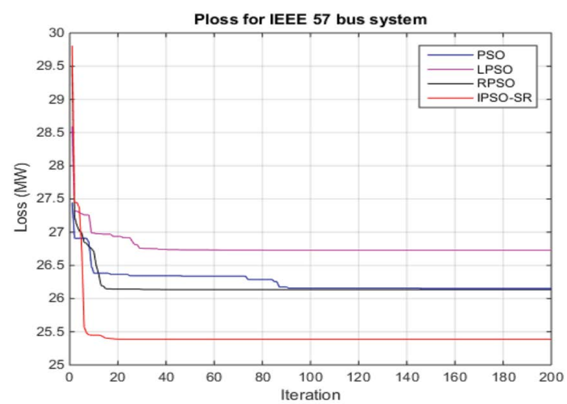

Figure 3. Convergence characteristics for minimizing ploss for the IEEE 57-bus test system.

4.2.2 Minimization of Voltage Deviation

In this section, the different variants of PSO are applied to solve the ORPD problem for minimizing the Total Voltage Deviation (TVD) of the system. The objective function in eq. (2) is solved and the results obtained are shown in Table 8. The convergence characteristic of TVD for IEEE 57 bus system is shown in Figure 4.

The detailed results for all the 19 combination pairs of the IPSO-SR are shown in Table 9.

The results from Table 8, 9 and Figure 4 proves that the optimal result for the minimum TVD for IEEE 57 bus system is also obtained from IPSO-SR. The combination pair number 19 is the most preferred one as it gives the best solution compared to all other combinations for the problem of ORPD as seen from Table 9.

Table 8. Comparative results of IEEE 57 bus system for TVD

Control Variables (p.u.)	PSO	L-PSO	RPSO	IPSO-SR
V_{G1}	1.06	1.06	1.06	1.0341
V_{G2}	0.9926	1.06	1.06	1.06
V_{G3}	0.94	1.06	1.06	1.06
V_{G6}	1.06	1.06	0.94	0.9457
V_{G8}	0.94	1.06	0.9856	1.06
V_{G9}	1.06	1.06	1.06	1.0481
V_{G12}	1.012	0.9657	0.94	0.9805
T_{4-18}	0.9674	1.1	0.9	0.9
T_{4-18}	0.9	1.1	1.1	1.1
T_{21-20}	0.9979	0.9	0.988	0.9812
T_{24-26}	1.0422	1.1	1.0102	1.0448
T_{7-29}	0.9236	0.9837	0.9	0.9552
T_{34-32}	0.9	0.9	0.9	0.9
T_{11-41}	1.1	0.9562	0.9	1.1
T_{15-45}	0.9	0.9565	0.9	0.9276
T_{14-46}	0.9	1.0051	1.0071	1
T_{10-51}	0.9	0.998	0.9826	1.0005
T_{13-49}	1.1	0.9	0.9	0.9
T_{11-43}	0.9	0.9	1.0232	0.9
T_{40-56}	1.1	1.1	0.9812	0.9564
T_{39-57}	0.9	0.9	0.9	0.9
T_{9-55}	1.0283	1.0442	1.0224	1.0178
Q_{sc18}	0	0	10	2.9738
Q_{sc25}	5.9	4.7618	5.9	5.9
Q_{sc53}	6.3	6.3	0	6.3
TVD (p.u.)	1.1361	1.0527	0.8451	0.8345
P_{loss} (MW)	55.9151	31.6905	41.7314	35.5061

Table 9. TVD for the combination pairs for IEEE 57 bus system

Combination pair number	TVD (p.u.)	Combination pair number	TVD (p.u.)
1	1.1325	11	0.9643
2	1.0981	12	1.0657
3	0.9781	13	1.0021
4	1.1466	14	0.9175
5	1.1647	15	1.0023
6	1.1247	16	1.0393
7	1.07	17	0.8434
8	1.1551	18	0.9194
9	0.932	19	0.8345
10	0.9865		

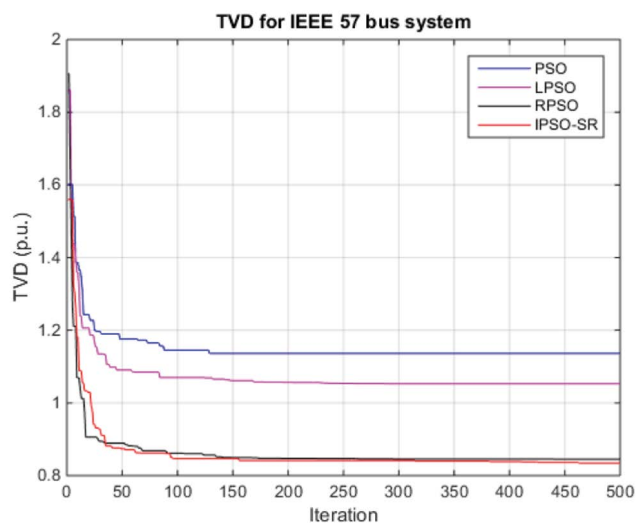

Figure 4. Convergence characteristics for minimizing TVD for the IEEE 57-bus test system.

5. Conclusions

The Particle Swarm Optimization (PSO) technique is one the mostly used techniques for solving the optimization problems. In order to accelerate the particles or control variables to reach the optimal values, some weight function is introduced into the velocity equation and the PSO is modified as L-PSO and RPSO as discussed earlier. However, among them the Improved PSO with the success rate strategy has proved to be superior in determining the optimal values of the control variables and thus finding the best solution of the objective functions of the ORPD problem. From the results, it is concluded that the combination pair number 19 of the IPSO-SR is the preferred pair for obtaining the optimal solution for the single-objective ORPD problem as considered in this paper.

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