PSO Based Optimal Reactive Power Dispatch for the Enrichment of Power System Performance

K. Manasvi, B. Venkateswararao, Ramesh Devarapalli, and Upendra Prasad

1 Introduction

Electrical power system network is a modern-day issue with a lot of complexities. Therefore its operation and control have become a significant challenge to system operators. For proper and efficient working of a system voltage and the losses must be within limits. ORPD is a well familiar nonlinear optimization problem involving control variables that are both discrete as well as continuous. The formulation of ORPD problem differs depending on the assortment of variables, objectives and constraints [1]. ORPD shows a significant role in refining the economy and security in the process of the power system. Instead of dealing with the generation of additional power, minimizing the losses can be considered a reasonably good scheme.

Many methods are implemented for ORPD. There are several conventional techniques like differential evolutionary (DE), Dual linear programming and Quadratic programming [2]. Besides, these traditional methods modern optimization techniques are also developed for reactive power dispatch such as Genetic algorithm and self-adaptive Genetic algorithm, which are discussed in the sections below.

In early 1960, Carpentier [3] was the first to introduce optimal power flow. Thereafter OPF took the researchers by storm, and different methodologies were developed. ORPD is nonlinear in nature and is multi-objective, Varadarajan and Swarup [4] developed a DE based technique for diminution of active power transmission losses. The objective function of reducing the losses is amalgamated with penalty factors and is tested on IEEE systems. Manmundur and Chenoweth [5] used dual

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linear programming, which is very suitable for the reduction of losses under operating circumstances. In this ORPD control variables are optimally tuned, satisfying all the constraints.

Burchett et al. [6] proposed Quadratic programming for optimal power flow, it is suitable for divergent starting points or infeasible solutions. The optimal solution is attained by considering the second derivatives of the objective function. Zhang and Zhang [7] developed a genetic algorithm to supply reactive power effectively. The genetic algorithm comprises natural selection and genetics. Its rudimentary operators include selection, crossover and mutation. The outcomes of GA are proven to be better than conventional methods.

Subbaraj and Rajnarayanan [8] modified the GA with Self adaptive real coded GA for ORPD. This paper targets to enhance the enactment of GA with self-adaptation by considering continuous, discrete and binary variables. Abbasy and Hosseini [9] applied the Ant Colony Optimization procedure for resolving the ORPD problem. This methodology deals with the representing of elucidation space on an exploration graph, everyplace non-natural ants walk, and position approaches given to the elementary ant system boosts the algorithm's enactment in every position. Li et al. [10] developed the hybridization algorithm by using DE and ABC methods.ABC individually was found better than DE and the hybridization of two methods DE-ABC was found better than individual applied techniques. The ORPD is identified as an emerging research problem, and a variety of algorithms have been proposed by the various researchers to obtain the optimal parameters [11–17]. And it has been found that the application of metaheuristics [18, 19], its hybrid versions [20], and robust control techniques [21] became popular in getting optimal solution of a power system research problems.

This paper presents the well familiar algorithm, PSO. By using this method, the convergence characteristics of the system are improved, thereby leading to an increase in system performance by reducing losses.

2 ORPD Problem Construction

Reactive power flow can be categorized into different classes. In the economic point of view, network active power losses reduction is deliberated as the primary objective.

2.1 True Power Losses Minimization

The ORPD problem for reduction of active power losses is formulated as

$$F_L = \mathrm{Min}(P_L) = \sum_{k=1}^{N_l} G_K[V_m^2 + V_n^2 - 2V_m V_n \cos(\delta_m - \delta_n)] \quad (1)$$

G_K Represents the conductance of the line coupled between m and n. Buses are denoted with m, n. Voltage levels at the buses are represented as V_m, V_n. δ_m, δ_n are the angles at the buses m, n respectively. N_l, N_b, N_g represents number of transmission lines, buses and generators present in the system respectively.

2.2 Constraints

The equality constraint for solving the problem of ORPD is given as

$$P_{Gm} - P_{Dm} - V_m(G_{mn}\cos(\delta_m - \delta_n) + B_{mn}\sin(\delta_m - \delta_n)) = 0 \quad (2)$$

$$Q_{Gm} - Q_{Dm} - V_m(G_{mn}\sin(\delta_m - \delta_n) + B_{mn}\cos(\delta_m - \delta_n)) = 0 \quad (3)$$

Inequality restrictions given below,

Generator limitations:

True power, wattless power and voltage at the generator buses must be within limits.

$$P_{Gm,}\text{min} \leq P_{Gm} \leq P_{Gm,}\text{max} \quad m = 1 \ldots N_G \quad (4)$$

$$Q_{Gm,}\text{min} \leq Q_{Gm} \leq Q_{Gm,}\text{max} \quad m = 1 \ldots N_G \quad (5)$$

$$V_{Gm,}\text{min} \leq V_{Gm} \leq V_{Gm,}\text{max} \quad m = 1 \ldots N_G \quad (6)$$

N_G is the no.of generators.

Transformers tap setting limitations:

Tap locations of the transformer must be within the permissible limits

$$T_{m,}\text{min} \leq T_m \leq T_{m,}\text{max} \quad m = 1 \ldots N_i \quad (7)$$

N_t is the number of transformers.

Upper and lower limits restrict the reactive power offered by switchable VAR sources are given as,

$$Q_{cm,}\text{min} \leq Q_{cm} \leq Q_{cm,}\text{max} \quad m = 1 \ldots N_c \quad (8)$$

N_c is the no.of capacitors

3 Particle Swarm Optimization

PSO algorithm is replicated from the natural behaviour of animals like birds flocking and schooling generally practised by fish. Eberhart and Kennedy [22] were the proposals of this algorithm during the year 1995. Because of its intrinsic properties, it is very fast, easy to access and requires less storage. This algorithm effectively optimizes the problem by iteratively enhancing the quality of the solution. Each particle is assumed having velocity and position which are given by

$$V_{ij}^{k+1} = w \times V_{ij}^{k} + c_1 \times r_1 \times \left(P\text{best}_{ij}^{k} - Z_{ij}^{k}\right) + c_2 \times r_2 \times \left(G\text{best}_{j}^{k} - Z_{ij}^{k}\right) \quad (9)$$

$$Z_{ij}(k+1) = Z_{ij}(k) + V_{ij}(k+1) \quad (10)$$

Eberhart and Shi prefaced the weight factor w used in this method in 1999. This enables quick convergence by damping the calculated velocities through iterations stated. The acceleration constant c_1 is called as cognitive rate and c_2 as social rate. The random numbers r_1 and r_2 have range from 0 to 1. Flow chart of PSO provided in Fig. 1.

3.1 Implementation of ORPD Using PSO

In general, PSO converges quickly and nearer to the global solution. The steps for the implementation of ORPD using PSO are as follows:

- Random control variables (stated in Table 1) are generated in between the given limits.
- Fitness function is calculated, and the present particles are assigned as the Pbest (Present best)
- Gbest is determined by substituting all Pbest values in the given objective function.
- By using Pbest and Gbest values velocity is calculated, and the corresponding position of the particle gets updated.
- The objective function of each particle is compared with its Pbest. Previous values are compared with the present values, and values are replaced with the best values.
- Find the Gbest value and repeat the steps (2) to (6) till the iterations are satisfied.

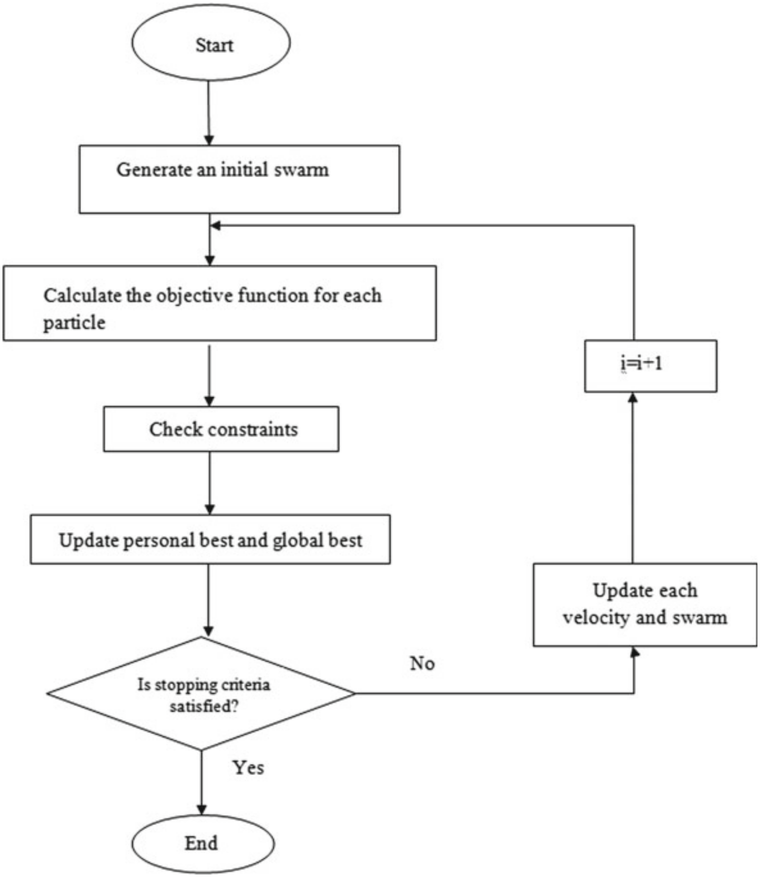

Fig. 1 Implementation of PSO

Table 1 Limits of control variables

Variables	Min in p.u	Max in p.u
Voltages of generator buses	0.90	1.10
Transformers tap locations	0.95	1.05
Size of shunt capacitors	0.0	0.2

4 Simulation Results

4.1 Minimizing True Power Loss

Table 1, minimum and maximum limits of the control variables of IEEE 14 and IEEE 30 bus system are shown. These limits are represented in p.u.

Table 2 Optimal values with PSO

Control variables	Control variable value with PSO
VG1	1.1098
VG2	1.0824
VG3	1.0225
VG6	1.0293
VG8	1.0140
T4-7	0.9971
T4-9	0.9906
T5-6	1.0123
QC9 in MVAR	14.7614
QC14 in MVAR	5.4675
Power loss in MW	**12.6107**
Voltage deviation in p.u	0.722

[a]Voltages and Transformers values are represented in p.u

4.1.1 IEEE 14 Bus System

This system comprises of 14 buses with 5 generator and 9 load buses. Transformers with tap changers are connected between 4–7,4–9, 5–6 and 9, 14 are the buses where the capacitors are connected. This addition of capacitors helps in increasing the bus voltage, which ultimately leads to efficient achievement of the considered objective function. So, totally there are ten control variables in this system.

The main objective here is the diminution of active power loss. The output of control variables are tuned using PSO such that the total losses in the system are low, and the results for the IEEE system 14 is shown in Table 2. The curve representing the convergence characteristics is shown in Fig. 2. The mean value and its SD are revealed in Table 3.

The evaluation made with altered optimization procedures is displayed in Table 4, where the losses are minimized to a greater extent which concludes the effectiveness of PSO over other conventional methods and Genetic algorithm.

4.1.2 IEEE 30 Bus System

This system comprises of 30 buses with 6 generators and 24 load buses. Tap changing transformers are connected between lines 4-12, 6-9, 6-10, 27-28. Reactive power compensators (capacitors) are placed at 3, 10 and 24 bus such that the total voltages are boosted. So, totally there are 13 control variables in this system.

The result of the control variables that are tuned in order to achieve the best of the objective function are given in Table 5, and its convergence characteristics are shown in Fig. 3.The mean and the standard deviation achieved for this system are shown in Table 6. The voltages are represented in p.u, and the angles are given in degrees.

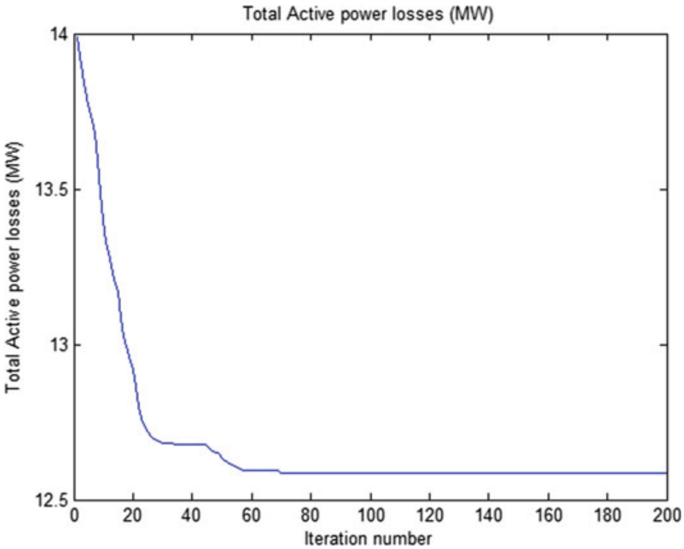

Fig. 2 Graph of convergence for minimization of losses for IEEE14 bus system

Table 3 Mean and standard deviation of IEEE 14 bus system

Technique	Mean value in MW	Standard deviation
PSO	12.6107	0.03459

Table 4 Comparison with different optimization techniques

Technique	EP[08]	SGA[08]	PSO
Power loss(MW)	13.34620	13.21643	12.6107

Penalty factor is imposed when control variables exceed their limits, and the value for the penalty is chosen based on the violated factor. The losses obtained in PSO is compared with different methods in Table 7 and found that the reactive power is dispatched optimally with a minimum amount of losses with the implementation of PSO.

5 Conclusion

In this paper, ORPD, which is a non-linear and non-convex optimization technique, is optimized for the objective functions of reduction of true power loss. The nature-inspired algorithm, which is PSO is used for this optimization and found effective when compared to the other conventional techniques like EP, DE, ABC and SGA, due to its random probability and quick convergence. Through these losses are reduced

Table 5 Optimal values with PSO

Control variables	PSO
Vg_1	1.1154
Vg_2	1.0841
Vg_5	1.0428
Vg_8	1.0429
Vg_{11}	1.0681
Vg_{13}	1.0085
$T_{4\text{–}12}$	1.0066
$T_{6\text{–}9}$	1.0167
$T_{6\text{–}10}$	0.9878
$T_{27\text{–}28}$	0.9876
QC3in MVAR	19.3599
QC10in MVAR	15.1235
QC24in MVAR	15.3625
Power loss in MW	**16.0494**
Voltage deviation in p.u	1.1023

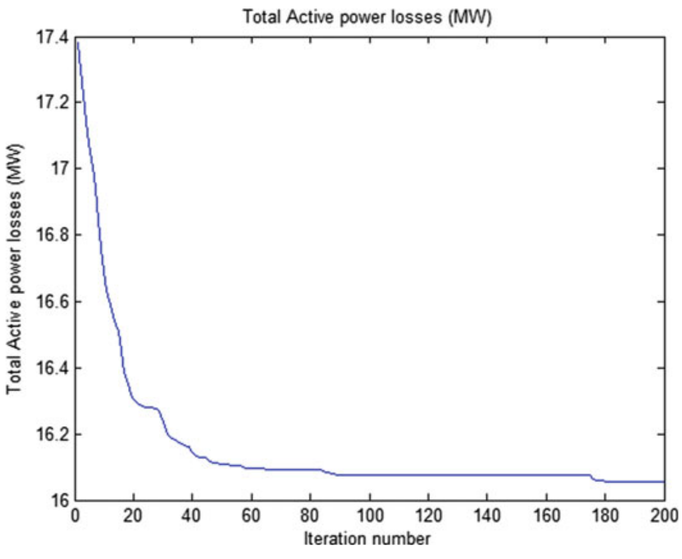

Fig. 3 Graph of convergence for minimization of losses for IEEE30 bus system

Table 6 Mean and standard deviation of IEEE30 bus system

Technique	Mean value in MW	Standard deviation
PSO	16.0494	0.0360042

Table 7 Relationship of true power loss with altered optimization methods

Method	True Power loss(MW)	Standard deviation
EP[08]	16.38962	0.09895
DE[10]	16.2187	0.4052
ABC[10]	16.2691	0.51401
DE-ABC[10]	16.2163	0.01098
SGA[08]	16.0929	0.01625
PSO	**16.0494**	0.0360042

and is executed for the IEEE14 and 30 bus systems. Authors implement the PSO for ORPD as a preliminary study, in future authors plan to use hybrid algorithm's like PSO along with BAT algorithm for ORPD problem, which my provide better results.

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