Optimal reactive power dispatch using particle swarm optimization algorithm for Yangon distribution network

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Abstract. Optimal Reactive Power Dispatch (ORPD) is very efficient to optimize the control variables like as generator voltages, transformer tap setting and values of reactive power injection for loss reduction in power system. ORPD is the one of the complexity of optimization problems including with equality and inequality constraints of power systems. Many research papers have developed in ORPD applied to the IEEE test systems with various intelligent methods for the loss reduction. In this paper, the test system is carried out on Yangon Distribution Network (YDN) composed of different voltage level such as 230 kV, 66 kV and 33 kV, and supplied by various types of generation sources. Thus, it is very high in losses and difficult to find out the control variables of ORPD in YDN. The main objective is to reduce the both active and reactive power losses in YDN. Particle Swarm Optimization (PSO) method implemented in ORPD problem of YDN is very applicable and effective to obtain the minimum losses while all the bus voltage profile is acceptable in voltage constraints. The obtained results from ORPD using PSO algorithm could enhance YDN efficiently.

Keywords: Optimal reactive power dispatch, Particle swarm optimization, Active power losses, Bus voltage profile, Yangon Distribution Network (YDN)

1. Introduction

Optimal reactive power dispatch (ORPD) is one of the optimization problems in power systems that optimized the setting control variables using generator voltages \(V_G\), transformation ratio (Tap) and reactive power sources (capacitor \(Q_C\) / reactor \(X_L\)). The Optimal Reactive Power Dispatch (ORPD) is a non-linear optimization problem with lot of uncertainties[1]. Optimal Power Flow (OPF) is a main concern in the power system. Currently, planner and operator often use Optimal Reactive Power Flow (ORPD) as a powerful assistant tool in both planning and operating stage [2]. The objective function of ORPD is to reduce the both active and reactive power losses, and to be acceptable all bus voltage magnitudes within specifying limits, while satisfying all the equality and inequality constraints in power system. The reactive power generation, although itself having no production cost, does however affect the overall generation cost by the way of the transmission loss. The power flow equations is
considered as equality constraints and voltage limitations within maximum and minimum range, and transformer taps, and capacity restrictions of various reactive power generating sources as like shunt capacitor banks are inequality constraints. The transformer tap ratios and outputs of shunt capacitors/reactors are discrete in nature. ORPD is sub-problem of Optimal Power Flow (OPF), which is one of the non-linear optimization problems with the complexity formulations and control variables. Reactive power optimization problem is a global optimization problem which inherently has multiple local minima solution and non-linear and discontinuous constraints.

Although, many researchers have been observed the ORPD problem of IEEE test systems with intelligent methods for loss minimization, there is no investigation the ORPD problems in the specific case study area. In this research, Particle Swarm Optimization (PSO) method is effectively used to solve the ORPD problem of 31-buses system of Yangon Distribution Network (YDN) to achieve the minimum active and reactive power losses, and maintain all bus voltage magnitudes within the acceptable limits. This research includes two cases which are power demand, 893.62 MW and 952.52 MW. The obtained results of optimal setting and control variables are changing upon demand variation case one and two, and global and local study capabilities of PSO are used to search for minimum active and reactive power losses. The results of PSO algorithm applied to the ORPD problem of YDN are better compared to other conventional method.

2. Yangon Distribution Network

Yangon Distribution Network is mainly supplied by grid connected power and thermal power in Yangon generation stations. There are various types of voltage level such as 230 kV, 66 kV and 33 kV interconnected network system in YDN which is constructed 31-bus system and fourteen generator buses among them three generator buses are hydro generating system such as Hlawga, Hlaingtharyar and Thanlyin from 230kV transmission line. The remaining generator buses are thermal generation stations such as Hlawga, Ywama, Ahlone, Therketa and recently new generation units, MCP are added in Hlawga, Egat-1, Egat-2 and MSP in Ywama, Toyothai in Ahlone and Maxpower in Tharketa[3]. Single line diagram for Yangon Distribution Network is shown in figure 1.

![Figure 1. Single line diagram of Yangon Distribution Network](image-url)
3. Methodology

The ORPD problem intends to obtain minimizing the active and reactive power losses while satisfying the equality and inequality constraints in a power system. The minimum losses are achieved by the parallel searching up to maximum number of iteration of reactive power variables as like voltage magnitude of generation bus \((V_{gi})\), the value of reactive power compensation \((Q_{ci})\), transformer tap settings \((t_{k})\).[1]

This is mathematically stated as:

\[
\min \sum_{k \in N_k} P_{kloss} = \sum_{k \in N_k} g_k (v_j^2 + v_j^2 - 2v_jv_j \cos \theta_j)
\]  

(1)

Equality constraints:

Active power flow balance equation at all buses excluding slack bus

\[
P_{gi} - P_{di} = \sum_{j \in N_i} v_i (g_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) = 0
\]

(2)

Reactive power flow balance equations at all PQ buses (load bus)

\[
Q_{gi} - Q_{di} = \sum_{j \in N_i} v_i (g_{ij} \sin \theta_{ij} + B_{ij} \cos \theta_{ij}) = 0
\]

(3)

Inequality constraints:

Reactive power generation limit for each generator bus

\[
Q_{gi}^{\text{min}} \leq Q_{gi} \leq Q_{gi}^{\text{max}}, i \in N_g
\]

(4)

Voltage magnitude limit for each bus

\[
V_{i}^{\text{min}} \leq V_i \leq V_{i}^{\text{max}}, i \in N_B
\]

(5)

Transformer tap-setting constraint

\[
T_{i}^{\text{min}} \leq T_i \leq T_{i}^{\text{max}}
\]

(6)

Power flow limit constraint of each transmission line

\[
S_{ij} \leq S_{ij}^{\text{max}}
\]

(7)

Static square penalty function is used to handle inequality constraints. So the augmented function (fitness function) would be as equation (2)

\[
F_p = \sum_{k \in N_k} P_{kloss} + \text{PenaltyFunction}
\]

(8)

3.1. Particle Swarm Optimization

PSO is a fast, simple and efficient population-based optimization method. It is an exciting new methodology in evolutionary computation and a population based optimization tool like Genetic algorithm. It has been motivated by the behavior of organisms such as fish schooling and bird flocking. It requires less computation time and less memory because of its inherent simplicity[6]. Each particles updates its position depending on its own best position; global best position, Gbest among the particles and its preceding velocity according to the velocity update equation and position update equation:

\[
v_i^{k+1} = w \times v_i^k + c_1 \times r_1 \times (P_{best_i} - x_i^k) + c_2 \times r_2 \times (g_{best} - x_i^k)
\]

(9)

\[
x_i^{k+1} = x_i^k + \chi \times v_i^{k+1}
\]

(10)

The inertia weight by using below equation provides good balance global and local explorations

\[
w = w_{\text{max}} - \frac{w_{\text{max}} - w_{\text{min}}}{\text{iter}_{\text{max}}} \times \text{iter}
\]

(11)
4. The Detail Procedure for ORPD Using PSO for 31 Bus YDN

1. Read system data, and initialize control variables such as voltage magnitude of generation buses (Vgi), the value of reactive power compensation (Qci), and transformer tap settings (tk) of YDN within their specific limitations, and then, assign population size, max-no of iteration, 200, and values of PSO parameters
2. Start with iteration =0
3. Produce the particles and their velocities based on uniform random distribution number
4. Run with Newton load flow for each particle to compute the losses
5. Calculate the fitness function by using Static square penalty function for each particle
6. Search to obtain Personal best of all particles and “Global best particles from their fitness
7. Update the iteration one after another
8. Compute the velocity of each particle with velocity update equation and control not to be violated of its limit
9. Compute the new position of each particle with position update equation
10. Run Newton load flow again for each particle to calculate losses
11. Compute again the fitness function for each particle using Static square penalty function
12. For each particle if the solution of current fitness, P is better than Personal best, Pbest then Pbest=P
13. Regard the best solution of Pbest as Gbest
14. Check the iteration is completed or not, if the number of iteration does not reach maximum number, go to step 7 repeatedly, until to reach maximum number of iteration, otherwise, go to step 15
15. Obtain optimal setting and control variables from the Gbest values and minimum active and reactive power losses from its fitness.

5. Simulation Result

This section presents the performance results by using PSO algorithm applied to YDN 31 bus System in detail. The per unit value of fourteen generator bus voltages, the value of transformer tap setting, and the value of reactive power compensations are obtained as the result of optimal setting and control variables. The PSO based ORPD algorithm is implemented on MATLAB platform and execute using two different case studies. In case 1, ORPD problem is solved using PSO with 893.62 MW load demand condition. In case 2, reactive power dispatch is done 952.52 MW load demand condition without considering the voltage stability level of the system.

5.1 Case 1

In this case, the optimal reactive power dispatch problem is solved under morning peak power demand 893.62 MW condition using the PSO. The PSO algorithm is performed with different control parameter settings for searching the optimal values of control variables until to achieve the minimum losses. The optimal control variables and both active and reactive power losses obtained using above settings are presented in Table 1. The result of ORPD method in YDN 31-bus system is active power losses 6.5989 MW and reactive power losses is 80.76 MVAr. The percentage of loss reduction is 13.092.

5.2 Case 2

Again in this case, by considering night peak demand 952.52 MW condition using the PSO. The optimal control variables are obtained listed in Table 1. The result of ORPD for this cases is active power losses 7.354 MW and reactive power losses is 109.97 MVAr. The percentage of loss reduction is 18.38.
5.3 Comparison of Simulation Bus Voltage Profile Existing and PSO
In the operation of power system network, the voltage acceptable limit is very important. Comparison of simulation bus voltage Newton’s Raphson Method and Particle Swarm Optimization (PSO) are shown in figure 1. and figure 2. Moreover, Table 2 gives the comparison between the results obtained using Newton’s load flow and Particle Swarm Optimization approach.

| Bus location | Optimal Setting and Control Variable | Optimized values from PSO result |
|--------------|--------------------------------------|----------------------------------|
| 1            | Vg_1                                 | 0.9838 pu                        |
|              |                                      | 1.0035 pu                        |
| 2            | Vg_2                                 | 1.0548 pu                        |
|              |                                      | 1.0376 pu                        |
| 5            | Vg_5                                 | 1.0186 pu                        |
|              |                                      | 1.0443 pu                        |
| 7            | Vg_7                                 | 1.0084 pu                        |
|              |                                      | 1.0508 pu                        |
| 9            | Vg_9                                 | 0.9947 pu                        |
|              |                                      | 0.9704 pu                        |
| 17           | Vg_17                                | 0.9764 pu                        |
|              |                                      | 1.0033 pu                        |
| 19           | Vg_19                                | 0.9957 pu                        |
|              |                                      | 0.9710 pu                        |
| 20           | Vg_20                                | 0.9639 pu                        |
|              |                                      | 1.1049 pu                        |
| 21           | Vg_21                                | 0.9803 pu                        |
|              |                                      | 0.9886 pu                        |
| 22           | Vg_22                                | 1.0321 pu                        |
|              |                                      | 0.9731 pu                        |
| 23           | Vg_23                                | 0.9950 pu                        |
|              |                                      | 0.9712 pu                        |
| 24           | Vg_24                                | 1.0039 pu                        |
|              |                                      | 1.0334 pu                        |
| 25           | Vg_25                                | 1.0559 pu                        |
|              |                                      | 1.0385 pu                        |
| 26           | Vg_26                                | 1.0551 pu                        |
|              |                                      | 1.0379 pu                        |
| 1-19         | T_1                                  | 1.0169                           |
|              |                                      | 1.0275                           |
| 1-20         | T_2                                  | 1.0386                           |
|              |                                      | 0.9891                           |
| 2-28         | T_3                                  | 0.9878                           |
|              |                                      | 1.0087                           |
| 17-31        | T_4                                  | 0.9844                           |
|              |                                      | 1.0012                           |
| 7-27         | T_5                                  | 1.0085                           |
|              |                                      | 1.0457                           |
| 3-29         | T_6                                  | 1.0101                           |
|              |                                      | 1.0140                           |
| 5-30         | T_7                                  | 1.0089                           |
|              |                                      | 0.9893                           |
| 3            | QC_3                                 | 6.5883 MVar                      |
|              |                                      | 13.8897 MVar                     |
| 5            | QC_5                                 | 8.8169 MVar                      |
|              |                                      | 18.1140 MVar                     |
| 17           | QC_17                                | 6.5989 MVar                      |
|              |                                      | 3.7548 MVar                      |

Table 2. Result comparison of Newton’s Load Flow method and PSO method.

| Loss          | Newton’s Load Flow method | Particle Swarm Optimization |
|---------------|---------------------------|------------------------------|
|               | Case 1 | Case 2 | Case 1 | Case 2 |
| Real Power loss | 7.593 MW | 9.01 MW | 6.5989 MW | 7.354 MW |
| Reactive Power loss | 132.37 MVar | 146.63 MVar | 80.76 MVar | 109.97 MVar |
Figure 2. Comparison of bus voltage existing system and PSO method for case 1

Figure 3. Comparison of bus voltage existing system and PSO method for case 2

6. Conclusion
In this paper, ORPD using Particle Swarm Optimization are employed to obtain voltage acceptable limit and minimum transmission losses for 31-bus YDN. The control variables for this study include the voltages of the generators, the transformer tap ratios, and reactive power generation of var sources (switched shunts). From the tabulated results and convergence characteristics of 31 bus YDN, it is observed that the proposed PSO algorithm is having reduced active power loss for case 1 is 6.5989 MW and case 2 is 7.354 MW. The loss reduction for both two cases is 13.092% and 18.38 % receptively. Therefore, PSO is better than other conventional method.

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