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Particle Swarm Optimization based Reactive Power Optimization of Utility Grid with Wind Generation

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Abstract-*Reactive power is important function of regulating voltage. In developing countries like Ethiopia, the electric utility company should optimize the reactive power for the transmission/distribution system to improve the active power loss of the distribution/transmission system. This paper presents a method to minimize the active power loss in a practical power system and determines the best location placement of a new installed wind generation with aim of loss reduction and voltage profile improvement. Reactive power optimization problem is nonlinear and has both equality and inequality constraints. A southern region 21-bus power network system is used for testing the developed algorithm. A mathematical model of reactive power optimization was established based on the constraint conditions. The results have been validated using MATLAB programming. After completing the reactive power optimization based on the particle swarm algorithm with wind generation, the active power network loss value of the system was reduced by 18.43%. Particle swarm optimization algorithm and Mat-power 3.2 toolbox are used to solve the reactive power optimization problem*

Keywords: Particle Swarm, Optimization, Reactive Power, Utility, Mat-power 3.2 and MATLAB

1. Introduction

Particle swarm optimization, PSO is a fast, simple and efficient population-based optimization method. Each particle updates its position based upon its own best position, global best position among particles and its previous velocity vector according to the following equations [1]:

$$V_i^{k+1} = WV_i^k + C_1 r_1 (p_{besti} - X_i^k) + C_2 r_2 (g_{best} - X_i^k)$$
(1)

$$X_i^{k+1} = X_i^k + \chi \times V_i^{k+1} \qquad (2)$$

Where,

v_i^{k+1} : The velocity of i^{th} particle at $(k+1)^{th}$ iteration

w : Inertia weight of the particle [0.2, 1]

v_i^k : The velocity of i^{th} particle at k^{th} iteration [-0.003, 0.003]

$c_{1,} c_2$: Positive acceleration constants having values between [2.1, 2]

r_1, r_2 : Randomly generated numbers between [0, 1]

p_{best_i} : The best position of the i^{th} particle obtained based upon its own experience

g_{best} : Global best position of the particle in the population

x_i^{k+1} : The position of i^{th} particle at $(k+1)^{th}$ iteration

x_i^k : The position of i^{th} particle at k^{th} iteration

χ : Constriction factor [0.729]. It may help insure convergence.

Suitable selection of inertia weight w provides good balance between global and local explorations.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} x iter \qquad (3)$$

Where, $w_{\max}$ is the value of inertia weight at the beginning of iterations, $w_{\min}$ is the value of inertia weight at the end of iterations, $iter$ is the current iteration number and $iter_{\max}$ is the maximum number of iterations.

1.1. PSO Parameters Selection

The selection of the PSO parameters for general problem is listed in table-1. Programmers may change some of these parameters based on different problems.

Table 1: PSO Parameters Selection

Particle size	20-50 works well for most of the optimization problems. However, as the dimension increase, the number of the particle should also increase according. Particle size = 50
Dimension of the particles	Equals the number of control variables = 8
Domains of the particles	Depends on the upper bound and lower bound constraints
Acceleration factor	[C1=2.1, C2=2]
Stopping criteria	• Iteration number = 200 • Difference between the current best solution and the previous best solution • No improvement after a certain number of iterations
Inertial Weight	[Final Inertia weight = 0.2,Initial Inertia weight = 1]
Constriction Factor	[0.729].

1.2. Procedure for RPO using PSO for SNNPR 21-bus Power Network

The main optimization steps of the PSO based reactive power optimization are as follows:

(1) Define control variables (vg1, vg2, vg3, T1, T2, T3, QC4 and QC13) within their permissible range, define population size (=50), no of iteration (=200), assume suitable values of PSO parameters, input the data of 21 bus power network system.

(2) Take iter=0

(3) Randomly generate the population of particles and their velocities

(4) For each particle run NR load flow to find out losses.

(5) Calculate the fitness function of each particle using eq. (11)

(6) Find out "personal best (P_{best})" of all particles and "global best(G_{best})" particle from their fitnesses

(7) Iter=iter+1

(8) Calculate the velocity of each particle using eq. (1) and adjust it if its limit gets violated

(9) Calculate the new position of each particle using eq. (2)

(10) For each particle run NR load flow to find out losses.

(11) Calculate the fitness function of each particle using eq. (11)

(12) For each particle if current fitness(P) is better than P_{best} then P_{best}=P

(13) Set best of P_{best} as G_{best}

(14) Go to step no. 7, until max. No of iterations is completed.

(15) Coordinate of G_{best} particle gives optimized values of control variables and its fitness gives minimized value of losses.

1.3 Active power loss minimization

The active power loss of the system equals the sum of the real power loss on each branch, and it can be described as:

Min F= Min(P_{loss})

$$f: P_{loss} = \sum_{K=1}^{N} G_{ij} (V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}) \quad (4)$$

Where,

N = number of branches,

G_{ij} = the conductance of the branch between bus i and bus j,

V_i = the voltage magnitude of bus i,

V_j = the voltage magnitude of bus j,

θ_{ij} = the difference of phase angle between bus i and bus j

1.4 Constraint

To process Reactive power optimization problem has both equality and inequality constraints.

I. Equality Constraint

The equality constraints are the power balance equations, which can be defined by the equations below:

a. Real Power Constraint:

$$H1=P_{gi}-P_{di}V_i \sum V_j(G_{ij}\cos\theta_{ij}+B_{ij}\sin\theta_{ij}) =0 \quad (5)$$

$i \in n$, *where set of numbers of buses except the swing bus*

b. Reactive Power Constraint:

$$H2=Q_{gi}-Q_{di}-V_i \sum V_j(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) =0 \quad (6)$$

$i \in n$, *where set of numbers of buses except the swing bus*

II. Inequality Constraint

The inequality constraints are the ranges of the voltage magnitudes, tap positions of the transformers, and reactive power injection.

a. Bus Voltage magnitude constraints:

$V_{i\text{-}min} \le V_i \le V_{i\text{-}max}$ (7)

b. Generator bus reactive power constraints:

$Q_{Gi\text{-}min} \le Q_{Gi} \le Q_{Gi\text{-}max}$ (8)

c. Transformer Tap position constraints:

$T_{i\text{-}min} \le T_i \le T_{i\text{-}max}$ (9)

d. Reactive power source capacity constraints:

$Q_{ci\text{-}min} \le Q_{ci} \le Q_{ci\text{-}max}$ (10)

Where,

N = number of branches,

G_{ij} = branch conductance between bus i and bus j,

V_i = voltage magnitude of bus i,

V_j = voltage magnitude of bus j,

θ_{ij} = phase angle difference between bus i and bus j

P_{Gi} = active power generation at bus i

P_{Di} = active power demand at bus i

Q_{Gi} = reactive power generation at bus i

Q_{Di} = reactive power demand at bus i

Q_{ci} = reactive power source i installation

III. Exterior Penalty Function (EPF) Method

Reactive power optimization problem is a constrained problem. In optimization, the constrained problems are usually converted into unconstrained problems for convenience. One of the commonly used methods to convert the constrained problem is adding exterior penalty function terms to the objective function. Penalty function is used to handle inequality constrains. So, the amplified objective function (fitness function) would be as eq. (11).

$$\text{Minimize F: } f + P(X, r_h, r_g) \quad (11)$$

$$X_i^l \le X_i \le X_i^u, i = 1, 2, 3 \dots, n$$

Where,

$P(r_h, r_g)$ is the penalty Function

r_h is the penalty multiplier for the equality constraint.

r_g is the penalty multiplier for the inequality constraint.

F is called the augmented function.

The equality constraint in this thesis will be automatically fulfilled by using MATPOWER 3.2 toolbox, so only inequality constraints need to be concerned. Therefore, the final objective function could be described as [2]:

$$F = P_{loss} + \sum r_{gi} (V_i - V_i^{lim})^2 + \sum r_{Ti} (T_i - T_i^{lim}) + \sum r_{Qi} (Q_i - Q_i^{lim})^2 \quad (12)$$

Where,

$$V_i^{lim} = \begin{cases} V_i^{max}, & V_i > V_i^{max} \\ V_i^{min}, & V_i < V_i^{min} \end{cases} \quad (13)$$

$$T_i^{lim} = \begin{cases} T_i^{max}, & T_i > T_i^{max} \\ T_i^{min}, & T_i < T_i^{min} \end{cases} \quad (14)$$

$$Q_{Gi}^{lim} = \begin{cases} Q_i^{max}, & Q_i > Q_i^{max} \\ Q_i^{min}, & Q_i < Q_i^{min} \end{cases} \quad (15)$$

In Exterior Penalty Function, if all the control variables are within the limits, the penalty function would be zero. On the opposing, if the control variables go outside the limits, then the penalty function would be added to the objective function to penalize the violation. In reactive power optimization, if the control variables go above the voltage limit, major damages to the power systems would occur. So, the voltage magnitudes, tap positions, and reactive power injection have to be sensibly examined.

2. SNNPR 21-Bus Power Network

To prove the effectiveness of the developed PSO based algorithm for reactive power optimization, a practical 21-bus distribution test system is used as shown in figure-1.

The voltage levels of the test system are 400KV, 230 kV, 132 kV and 66 kV. The Southern Region 21-Bus network system has three generators at bus numbers 1, 2 and 3. The first PV one is at bus 1; the second PV is at bus 2; the 3rd generator is at Bus 3(slack bus).This system includes of 21 transmission lines, three tap-ratio transformers in lines between bus numbers 1-6, 17-18 and 18-20. In addition, bus numbers 4 and 13 has been selected as shunt VAR compensation buses. The lower limits voltage magnitude of all buses is considered as 0.9 pu, while the upper limit is considered as 1.1 pu for the generator buses and 1.05 pu for the load buses.

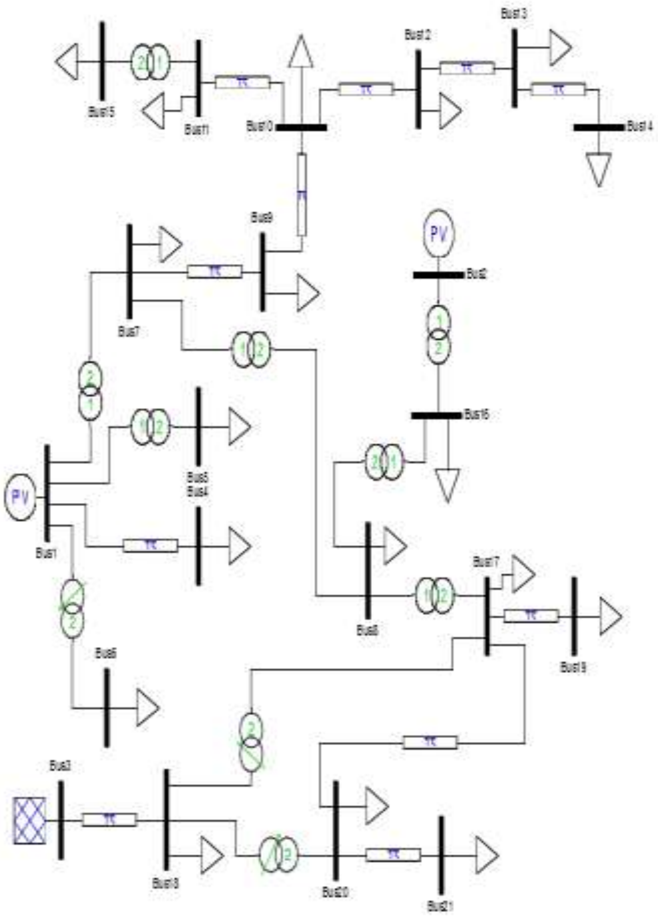

Figure 1: SNNPR 21-Bus Power Network System

The initial operating conditions for the developed method are given as follows for 100 MVA base. The total load of the system is 360.20MW and 29MVAr. MATPOWER toolbox is used to calculate the power flow of practical 21-bus distribution system. Before optimization, the total real and reactive power loss of the entire system is 18.543MW and 23.14MVAr, respectively.

3. SNNPR 21-Bus Power Network RPO with WGs

A comparison of the real power loss of base case, optimization without new WG and optimization when WG is installed on various buses of southern region 21-bus distribution network is illustrated in figure-2.

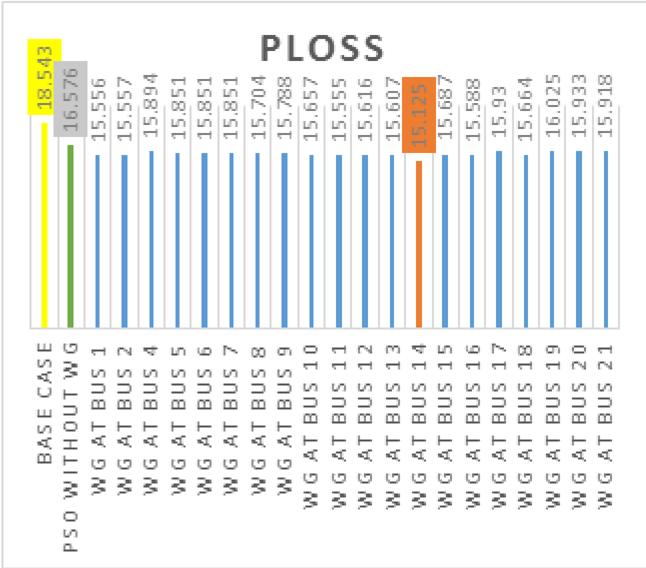

Figure 2: Comparison of loss reduction

It can be seen that optimization with a new WG can further reduce the active power loss than optimization using PSO without WG. After integrating a new WG on bus 14, the total active power loss can be reduced to minimum 15.125 MW. The optimal placement of a new WG is on bus 14.

Figure-3 shows the optimal loss reduction process of the proposed method when a small wind turbine is installed on bus 14. The particles start to converge after conducting 90 iterations. Finally, the total power loss of the system is 15.125 MW. The total CPU time is 210sec.

In the figure-3 below shows the graphical representation of total active power loss with respect to total number of iterations. After 90 iterations, no improvement is displayed.

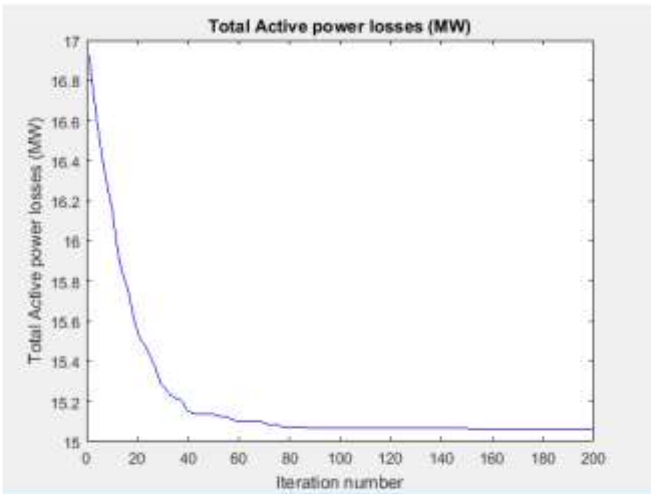

Figure 3: SNNPR 21-Bus Loss Reduction with WG

The results from table-2 show the optimal settings of control variables to get minimum active power loss when anew WG is installed on bus 14. The total active power loss after optimization with a new WG is 15.125 MW.

Table 2-Optimal Results of Control Variables with WG

Bus	Control Variables	Min	Max	With New WG on Bus 14
1	V_{G1}(p.u)	0.9	1.1	0.9399
2	V_{G2}	0.9	1.1	1.0827
3	V_{G3}	0.9	1.1	1.1206
14	V_{WG}	0.9	1.1	0.98
1-6	T_1	0.95	1.05	0.974
17-18	T_2	0.95	1.05	1.0062
18-20	T_3	0.95	1.05	1.0019
4	Q_{C4}(MVAr)	0	20	19.5529
13	Q_{C13}	0	10	6.4804
Active Power Loss (MW)				**15.125**

CONCLUSION

The combined technique of particle swarm optimization algorithm with MATPOWER toolbox is applied to solve reactive power optimization problem and to determine the optimal placement of new installed WG in existing system. The performance of the developed technique was tested on the SNNPR 21-Bus power network and the simulation results were compared without and with integrating wind generation to the system. It can be observed that reactive power optimization approach for distribution system with a wind generation can further reduce the active power loss than without wind generation. The benefit of lower active power loss obtained will provide better economic dispatch and secure operation in power system. Before the reactive power optimization, the reactive power in 21-Bus power network is arbitrary distributed. When 2 MW wind generations is installed into the system, the active power loss was reduced from 18.543MW to 15.125MW which is 18.43 %. The optimization meaningfully decreased the active power loss of the system. Results were attained after conducting 90 iterations, which replicates the excellent searching ability of particle swarm optimization algorithm for solving nonlinear problems. As the output of the wind generation increases, the active power loss of the system could be decreased. The Mat-power 3.2 toolbox is used to calculate the power flow and manage the equality constraints in Particle Swarm Optimization based reactive power optimization.

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