Reactive Power Optimization using Particle Swarm Optimization

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Abstract— Reactive power plays an important role in supporting the real power transfer with voltage profile improvement and system reliability. It is a critical element for a transmission system operator to minimize the real power losses of system with minimizing the cost associated with it. Optimum scheduling of reactive power reduces the active power losses in the transmission system which is the main objective function of the work. In this paper work, a Particle Swarm Optimization method is used for Reactive Power Optimization problem. Particle Swarm Optimization swarm intelligence based search technique used to solve non-linear, complex power system problems. Reactive power optimization is made by reducing real power losses along with improving voltage profile. Proposed algorithm is implemented on IEEE 30-bus test system for PSO and Newton method using MATPOWER.

Key words: MATPOWER, Particle Swarm Optimization methodology (PSO)

I. INTRODUCTION

Reactive power optimization is an important function both in planning for the future and day-to-day operations of power systems. It uses all the reactive power sources judiciously, while planning suitable location and size of VAR compensation in a system. To control frequency, stability, security and voltage profile of the system and to ensure the generation and transmission, ancillary services like frequency control, network control and system restart are needed. Reactive power and voltage control is one of the ancillary services to maintain voltage profile through injecting or absorbing reactive power in electricity market. A number of optimization techniques have been proposed in the literature to solve the reactive power optimization problems. This paper reviews optimization techniques for solving the reactive power optimization problem.

Methods like dynamic programming, genetic algorithm, evolutionary programming, artificial intelligence, and particle swarm optimization solve non-convex optimization problems efficiently and often achieve a fast and near global optimal solution. Among them PSO was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems. The PSO technique can generate high-quality solutions within shorter calculation time and stable convergence characteristics.

As the electricity supply industry all over the world is moving towards deregulation, the philosophy of reactive power management and power system operation is expected to change greatly, so that the significance of competition, coordination between market participants, and security requirements can be identified.

In a vertically integrated utility, reactive power facilities are owned and operated by a single utility. The costs and contribution of a reactive power supply are not precisely evaluated. Under a deregulated environment, the obligations and rights of the owners of reactive power facilities become essential issues that affect not only the investments returns of the power industry but also the security of the power system.

The main objectives of the research project are - study on Particle Swarm Optimization methodology (PSO) for application in Reactive power optimization problem, Power loss reduction and voltage deviation reduction with Active and Reactive power constraints and Voltage magnitude, Generator bus reactive power, and transmission line flow constraints.

II. PROBLEM FORMULATION

The aim of reactive power optimization is minimize the power loss and improve the voltage profile in the transmission network. The control variables are generator bus voltage, transformer tap changing and shunt capacitor bank.

The equality constraints are active and reactive power, the inequality constraints are bus voltage constraints, reactive source reactive power capacity constraints, generator reactive power constraints, and the transformer tap position constraints and transmission line flow constraints. The equality constraints can be automatically satisfied by load flow calculation, while in the inequality constraints lower/upper limit of control variables corresponds to the coding on the Particle Swarm optimization so the inequality constraints of the control variables are satisfied which can be described as follows:

Objective Function[8]:

\[ F = F_1 + F_2 = P_{LOSS} + VD \]  

Where,

\[ P_{LOSS} = \text{Network real power loss} \]

\[ VD = \text{Voltage deviation} \]

For Power Loss\[8\]:

\[ F_1 = P_{LOSS} = \sum_{k=1}^{N} b_k [V_i^2 + V_j^2 - 2V_iV_j \cos \theta_{ij}] \]  

For Voltage Profile\[8\]:

\[ F_2 = V_{dev} = \frac{\sum_{N_{pq}} |V_i - V_{ref}|}{N_{pq}} \]  

Where,

\[ V_{dev} = \text{Voltage deviation} \]

\[ V_{ref} = \text{load bus reference voltage value} \]

\[ V = \text{load bus voltage} \]

\[ N_{pq} = \text{load bus number} \]

This includes following constraints:

A. Equality Constraints\[8\]:

1) Real Power Constraints:

\[ P_{Gi} - Q_{Bi} - \sum_{j=1}^{N_B} V_j (G_{ij} \cos (\theta_i - \theta_j) + B_{ij} \sin (\theta_i - \theta_j)) = 0 \]  

(4)
2) Reactive power constraints:
\[ Q_{ci} - Q_{di} - V_i \sum_{j=1}^{N_g} V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij} ) = 0 \]  
Where,
- \( V_i \) = Voltage magnitude at bus i
- \( V_j \) = Voltage magnitude at bus j
- \( P_{ii}, Q_{ii} \) = Real and reactive powers injected into network at bus i
- \( G_{ij}, B_{ij} \) = Mutual conductance and susceptance between bus i and j
- \( N_g \) = Total number of buses excluding slack bus
- \( \Theta_{ij} \) = Voltage angle differences between bus i and bus j

B. Inequality Constraints[8]:
1) Bus voltage magnitude constraints:
\[ V_{i_{\min}} \leq V_i \leq V_{i_{\max}} ; i \in N_B \]  
2) Generator bus reactive power constraints:
\[ Q_{gi_{\min}} \leq Q_i \leq Q_{gi_{\max}} ; i \in N_g \]  
3) Transformer tap-setting constraints:
\[ T_{k_{\min}} \leq T_k \leq T_{k_{\max}} ; i \in N_T \]  
4) Reactive Power source capacity constraints:
\[ Q_{gi_{\min}} \leq Q_i \leq Q_{gi_{\max}} ; i \in N_c \]  
5) Transmission line flow constraints
\[ S_{ij} \leq S_{ij_{\max}} ; i \in N_i \]  

Where,
- \( Q_i \) = Reactive power generation at bus i
- \( N_g \) = Total number of buses
- \( G_k \) = Conductance of buses
- \( N_i \) = Number of generator buses
- \( S_{ij} \) = Apparent power flow through the \( i \)-th branch.
- \( T_k \) = Tap setting of transformer at branch \( k \).
- \( Q_{ci} \) = Reactive power generated by \( i \)-th capacitor bank.

Static square penalty function is used to handle inequality constraints. So the Augmented objective function (fitness function) would be as equation (9)
\[ F_p = \sum_{k \in N_E} P_{k_{\text{loss}}} + \text{Penalty Function} \]  
Where, Penalty Function
\[ = K_v \times \sum_{i=1}^{N} f(V_i) + K_q \times \sum_{i=1}^{N_g} f(Q_{gi}) + K_f \times \sum_{m=1}^{N_{\text{lim}}} f(S_{im}) \]

III. PARTICLE SWARM OPTIMIZATION
Particle Swarm Optimization (PSO) is a technique used to explore the search space of a given problem to find the settings or parameters required to maximize a particular objective. This technique, first described by James Kennedy and Russell C. Eberhart in 1995, originates from two separate concepts: the idea of swarm intelligence based off the observation of swarming habits by certain kinds of animals (such as birds and fish); and the field of evolutionary computation.

A. Particle(X):
It is a candidate solution represented by an \( m \)-dimensional vector, where \( m \) is the number of optimized parameters. At time \( t \), the \( i \)-th particle \( \text{X}(t) \) can be described as
\[ \text{X}(t) = [X_{i1}(t), X_{i2}(t),...,X_{in}(t)] \]
where \( X_i \)’s are the optimized parameters and \( X_k(t) \) is the position of the \( i \)-th particle with respect to the \( k \)-th dimension; i.e. the value of the \( k \)-th optimized parameter in the \( i \)-th candidate solution.

Population, \( \text{Pop}(t) \) : It is a set of \( n \) particle at time \( t \), i.e.
\[ \text{Pop}(t) = [X(1)(t), X(2)(t),..,X(n)(t)] \]

B. Swarm:
It is an apparently disorganized population of moving particles that tend to cluster together towards a common optimum while each particle seems to be moving in a random direction.

C. Personal best (Pbest):
The personal best position associated with \( i \)-th particle is the best position that the particle has visited yielding the highest fitness value for that particle.

D. Global best (Gbest):
The best position associated with \( i \)-th particle that any particle in the swarm has visited yielding the highest fitness value for that particle. This represents the best fitness of all the particles of a swarm at any point of time.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. This value is called pbest. Another "best" value that is tracked by the particle is called gbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called g-best. After finding the two best values, the particle updates its velocity and positions according to the following equations.
\[ v_{i_k+1} = w v_{i_k} + c_1 r_1 (p_{best} - x_{i_k}) + c_2 r_2 (g_{best} - x_{i_k}) \]
\[ x_{i_k+1} = x_{i_k} + v_{i_k+1} \]

And
\[ W = W_{\text{max}} \left[ \frac{W_{\text{max}} - W_{\text{min}}}{\text{ITER}_{\text{max}}} \right] \times \text{ITER} \]
Where
- \( W \) : is the inertial weighing factor
- \( W_{\text{max}} \) : Max. value of weighting factor
- \( W_{\text{min}} \) : Minimum value of weighting factor
- \( \text{ITER} \) : Current iteration number
- \( \text{ITER}_{\text{max}} \) : Maximum iteration number.
IV. DEVELOPMENT OF ALGORITHM

A. A step of RPO approaches for PSO:

1) STEP. 1: Define control variables (\(v_{g1}, v_{g2}, v_{g5}, v_{g8}, v_{g11}, v_{g13}, T_{11}, T_{12}, T_{36}, QC_{10} \) and \(QC_{24}\)).

2) STEP. 2: Define size of population, \(N=50\)

3) STEP. 3: Randomly generate the population of particles and their velocities

4) STEP. 4: Initialize suitable values of PSO parameters

5) STEP. 5: Input the data of 30 bus test system

6) STEP. 6: For each particle run NR load flow to find out losses.

7) STEP. 7: Calculate the fitness function of each particle using equation,

\[ F_p = \sum_{k=1}^{N} P_{loss} + \text{Penalty Function} \]

8) STEP. 8: Find out “personal best (Pbest)” of all particles and “global best(Gbest)” particle from their fitnesses

9) STEP. 9: No of iteration = 100

10) STEP. 10: Take iteration=0

11) STEP. 11: Calculate the velocity of each particle using equation,

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

and adjust it if its limit gets violated.

12) STEP. 12: Calculate the new position of each particle using equation,

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

13) STEP. 13: Calculate the fitness function of each particle using equation (9)

14) STEP. 14: For each particle if current fitness(P) is better than Pbest then Pbest=P

15) STEP. 15: Set best of Pbest as Gbest

16) STEP. 16: Iteration=iter+1

17) STEP. 17: Go to step no. 11, until max. no of iterations is completed.

18) STEP. 18: Coordinate of Gbest particle gives optimized values of control variables and its fitness gives minimized value of losses.

V. RESULTS

The proposed PSO-based approach for solving the reactive power optimization was applied to IEEE 30-bus test system. Implementation of this method is done using MATLAB 2011 and MATPOWER 3.2 programs. The generator active power generation was kept fixed except for the slack bus. The bus, line and generator data for these systems are taken from reference [15] The results are presented below:

<table>
<thead>
<tr>
<th>S.N</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Population size</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>Number of iterations</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Acceleration constant</td>
<td>2.0 and 2.1</td>
</tr>
<tr>
<td>4</td>
<td>Constriction factor</td>
<td>0.729</td>
</tr>
<tr>
<td>5</td>
<td>Max. and Min. velocity of particles</td>
<td>0.003 &amp; 0.003</td>
</tr>
</tbody>
</table>

Table : parameters used in pso

<table>
<thead>
<tr>
<th>Control Variables</th>
<th>Initial Case</th>
<th>Proposed PSO algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>0.9805</td>
<td>1.0736</td>
</tr>
<tr>
<td>V2</td>
<td>0.9315</td>
<td>0.9643</td>
</tr>
<tr>
<td>V5</td>
<td>0.9276</td>
<td>0.9418</td>
</tr>
<tr>
<td>V8</td>
<td>0.9806</td>
<td>1.0548</td>
</tr>
<tr>
<td>V11</td>
<td>1.069</td>
<td>1.0127</td>
</tr>
<tr>
<td>V13</td>
<td>0.977</td>
<td>1.1031</td>
</tr>
<tr>
<td>T11</td>
<td>0.9974</td>
<td>1.0193</td>
</tr>
<tr>
<td>T12</td>
<td>1.0205</td>
<td>1.0256</td>
</tr>
<tr>
<td>T15</td>
<td>1.0294</td>
<td>1.0106</td>
</tr>
<tr>
<td>T36</td>
<td>1.0492</td>
<td>1.035</td>
</tr>
<tr>
<td>QC10</td>
<td>16.0613</td>
<td>15.6332</td>
</tr>
<tr>
<td>QC24</td>
<td>11.5119</td>
<td>13.5829</td>
</tr>
</tbody>
</table>

Table 5.10: Control Variables

<table>
<thead>
<tr>
<th>Without PSO (NR)</th>
<th>With PSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (MW)</td>
<td>17.60</td>
</tr>
<tr>
<td>V (volt)</td>
<td>0.031</td>
</tr>
</tbody>
</table>

Table 5.11: Power loss

VI. CONCLUSION

The MATLAB program is developed and the results IEEE 30-bus test system for Particle Swarm Optimization From the results it is seen that real power loss on comparing with the base case results. Voltage deviation is also reduced as seen in plot. It is clear that as the real power loss is reduced and voltage deviation is controlled, usage of reactive power is optimized using PSO.

Fig. 1: shows the characteristics of real power loss after using the optimized values of control variables.
Fig. 2: graph plotted for voltage deviation and iteration shows that there is a reduction in voltage deviation is reduced to 0.02

REFERENCES


[10] Vivek Kumar Jain, Himmat Singh, HYBRID PARTICLE SWARM OPTIMIZATION BASED REACTIVE POWER OPTIMIZATION.


