Reactive Power Optimization of Genetic Algorithm Based on Sensitivity Analysis

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ABSTRACT

Aiming at the problems of traditional genetic algorithm, such as easy to fall into local optimal solution and low computational efficiency, the genetic algorithm is improved with sensitivity analysis. The proposed method combined with sensitivity analysis to cross and mutation operation, which can quickly find the solution to meet the requirements. The proposed method was applied to a regional power grid to verify the effectiveness.

Keywords: Reactive power optimization, genetic algorithm, sensitivity analysis

INTRODUCTION

Reactive power optimization is the basic problem of economical operation of power system. Reactive power balance is an important measurement to save active power loss. In the power system operation stage, the existing reactive power resources in the system can be optimally configured through reactive power optimization so as to achieve the objective of optimizing the reactive power flow distribution of the power grid, reducing the active power loss of the power grid and improving the system voltage level.

The problem of reactive power optimization is a nonlinear and multi-objective function problem. In recent years, intelligent optimization algorithms such as simulated annealing, tabu algorithm and genetic algorithm have been widely used for the optimization of reactive power. However, in the process of large-scale optimization, the algorithm above is prone to problems such as long solution time, unable to get the optimal solution when the solution falls into an infinite loop, and "dimensionality disaster".

Voltage/reactive sensitivity analysis is an important method of voltage stability analysis. The magnitude of the voltage/reactive sensitivity index of the system node reflects the voltage stability of the system. In order to improve the efficiency and reduce the dimensionality of the search, literature proposed the sensitivity analysis. By analyzing the sensitivity of the network loss to the reactive power injected into the node, the node with high sensitivity was selected as the reactive compensation switching point to realize the reactive power optimization of the system.

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In this paper, the reactive power optimization method combined with sensitivity is proposed. By analyzing the sensitivity of the nodes’ reactive power to the node voltage, the effect of each node’s voltage on the reactive power change is obtained. Based on the sensitivity analysis and the genetic algorithm, the reactive power optimization is used to solve the problem. Finally, through the example analysis and comparison, the improvement effect of the sensitivity analysis to the optimization algorithm is obtained, and the effectiveness of the proposed method is verified.

**REACTIVE OPTIMIZATION MODEL**

The purpose of reactive power optimization is to minimize the network loss, improve the voltage quality and save the operating cost of the system. Then the power system can operate safely and stably. The mathematical model includes the objective function, the power constraint equation and the variable constraint equation.

**The Objective Function**

The mathematic model of reactive power optimization can be described as:

\[
\begin{align*}
\max C(u,x) \quad \text{or} \quad \min C(u,x) \\
\begin{cases}
  f(u,x) = 0 \\
  g(u,x) \leq 0 \\
  u \in Y
\end{cases}
\end{align*}
\]  

(1)

In the formula, \( C(u,x) \) is the objective function of the mathematical model, \( u \) is the control variable, \( x \) is the state variable, \( f \) is the equality constraint, \( g \) is the inequality constraint, and \( Y \) is the solution set of the desired problem.

Different optimization goals corresponding to the mathematical model is not the same, and they can be described as:

- The network loss is the minimum, the objective function is
  \[
  \min S_{loss} = \sum_{k=1}^{n} I_k^2 R_k
  \]
  Among them, \( I_k \) is the electric current on the branch \( k \), \( R_k \) is the resistance on the branch \( k \), \( n \) is the number of branch of the distribution network.

- Transformer tap and reactive power compensator switching the minimum times. The objective function is:
  \[
  \min Num = \sum_{i=1}^{n} |x_i - x'|
  \]
  \( n \) is the total number of transformers and reactive power compensators in the grid, \( x_i \) is the state of transformer or reactive power compensator ‘i’ before optimizing, \( x' \) is the state after optimizing.

**Restrictions**

1) Current constraints
\[
P_i = V \sum_{j=1}^{N} V_j (G_{ij} \cos \delta_j + B_{ij} \sin \delta_j) = 0
\]
\[
Q_i = V \sum_{j=1}^{N} V_j (G_{ij} \sin \delta_j - B_{ij} \cos \delta_j) = 0
\]

(3)

2) Node voltage constraints
\[V_{i_{\text{min}}} \leq V_i \leq V_{i_{\text{max}}}
\]

3) Transformer, line capacity constraints
\[I_i \leq I_{pl} \quad \text{or} \quad S_i \leq S_{l_{\text{max}}}
\]

4) Transformer tap gear constraints
\[T_{i_{\text{min}}} \leq T_i \leq T_{i_{\text{max}}} \quad T_{i_{\text{min}}} \quad T_{i_{\text{max}}} \]
Indicates the upper and lower limits of number i transformer tap changer.

GENETIC ALGORITHM WITH SENSITIVITY

Sensitivity Analysis

Sensitivity method uses the differential relationship between some physical quantities in the system to obtain the sensitivity between variables. In the actual system, when the control variable changes slightly, the system state variables and output variables will change slightly. The relationship of variation expressed by this differential relationship between them is called sensitivity index. Sensitivity relates to the sensitivity of the changes in the control variables and disturbance variables to changes in the state of the system. For the problem of reactive power optimization, from the viewpoint of power flow distribution, the variation of reactive power injected into any bus will affect all the node voltages, which will affect the active injection of nodes. Therefore, the optional voltage node is used as an intermediate variable to determine the sensitivity of network loss to number ‘i’ node active and reactive injection. Application of sensitivity analysis can reduce the search space of genetic algorithm and its calculation time.

The system active loss is expressed as follows:
\[
P_{\text{loss}} = \sum_{i=1}^{N} V_i \sum_{j=1}^{N} V_j (G_{ij} \cos \delta_j + B_{ij} \sin \delta_j)
\]

(4)

Then the sensitivity of correlation between the active network loss and node active and reactive injection can be expressed as:
\[
S_{P_{i}}^{P_{\text{loss}}} = \frac{\partial P_{\text{loss}}}{\partial P_i} = \frac{\partial P_{\text{loss}}}{\partial \delta} \cdot \frac{\partial \delta}{\partial P_i} + \frac{\partial P_{\text{loss}}}{\partial V} \cdot \frac{\partial V}{\partial P_i}
\]
\[
S_{Q_{i}}^{P_{\text{loss}}} = \frac{\partial P_{\text{loss}}}{\partial Q_i} = \frac{\partial P_{\text{loss}}}{\partial \delta} \cdot \frac{\partial \delta}{\partial Q_i} + \frac{\partial P_{\text{loss}}}{\partial V} \cdot \frac{\partial V}{\partial Q_i}
\]

(5)

(6)

Then
\[
\begin{bmatrix}
S_{Q_{i}}^{P_{\text{loss}}} \\
S_{P_{i}}^{P_{\text{loss}}}
\end{bmatrix}
= \begin{bmatrix}
\frac{\partial \delta}{\partial P_i} \cdot \frac{\partial V}{\partial P_i} \cdot \frac{1}{V} \\
\frac{\partial \delta}{\partial Q_i} \cdot \frac{\partial V}{\partial P_i} \cdot \frac{1}{V}
\end{bmatrix}
\begin{bmatrix}
\frac{\partial P_{\text{loss}}}{\partial \delta} \\
\frac{\partial P_{\text{loss}}}{\partial V}
\end{bmatrix}
= [J^T]^{-1}
\begin{bmatrix}
\frac{\partial P_{\text{loss}}}{\partial \delta} \\
\frac{\partial P_{\text{loss}}}{\partial V}
\end{bmatrix}
\begin{bmatrix}
\frac{\partial P_{\text{loss}}}{\partial V} \\
\frac{\partial P_{\text{loss}}}{\partial \delta}
\end{bmatrix}
\]

(7)
\[ \frac{\partial P_{loss}}{\partial V} \] is active power loss for the node voltage of the first derivative; \( J \) is the flow calculation of Jacobian matrix.

\[
\begin{align*}
\frac{\partial P_{loss}}{\partial V} V_i &= 2V_i \sum_{j=1}^{N} V_j G_{ij} \cos \delta_{ij} \\
\frac{\partial P_{loss}}{\partial \delta_i} &= -2V_i \sum_{j=1}^{N} V_j G_{ij} \cos \delta_{ij}
\end{align*}
\]

The reactive power loss of the system is expressed as follows:

\[ Q_{loss} = \sum_{i=1}^{N} V_i \sum_{j=1}^{N} V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) \]  

(8)

The sensitivity of the reaction system reactive power to the degree of node voltage can be expressed as:

\[
\begin{align*}
\frac{\partial Q_{loss}}{\partial V} V_i &= -2V_i \sum_{j=1}^{N} V_j G_{ij} \cos \delta_{ij} \\
\frac{\partial Q_{loss}}{\partial \delta_i} &= 2V_i \sum_{j=1}^{N} V_j G_{ij} \cos \delta_{ij}
\end{align*}
\]

(9)

When the sensitivity is determined, those with high sensitivity will be selected as compensation bus.

**Genetic Algorithm Based on Sensitivity Calculation**

**BUILD FITNESS FUNCTION**

Fitness is the basis of genetic algorithm search, guiding the search direction of genetic algorithm, using the objective function listed above as the fitness value.

\[ f = w_i \sum_{k=1}^{n} I_k^2 R_k + w_2 \sum_{i=1}^{n} |x_i - x| \]

(11)

An integer coding method is used in this paper. The coding objects are transformer taps (coded as 1-17) and reactive power compensation devices (input as 1, no input as 0). The encoding length is the number of transformers in the power grid and the total number of compensation equipment.

**GENERATION OF INITIAL SOLUTION**

According to the current grid operating conditions, the transformer gear position and reactive power compensator switching method to generate the initial sequence. Individuals generated by the above formula will not exceed the limit can also guarantee the type of individual.

**CROSS**

Combined with the sensitivity analysis of the cross-operation. Calculate the sensitivity of each node and select the node with higher sensitivity corresponding to the transformer tap or reactive power compensator for cross-operation.
VARIATION

Variation operation is an auxiliary method of generating new individuals, but they determine the local search capabilities of genetic algorithms and maintain community diversity and prevent premature occurrence. The sensitivity coefficient of the objective function to the active and reactive injection of a node provides an evaluation of the effect of adjusting the active injection amount of the node. Reference sensitivity coefficient, as follows:

\[ X_i = [x_{i1}, x_{i2}, \cdots, x_{in}], \quad i = 1, 2, \cdots, N \]

\[ X_i \] is the parent individual, \( N \) is the number of individuals in the population inventory, \( n \) is the length of the chromosome, which is the number of control variables.

Calculate the fitness of \( x \), and solve the sensitivity of each node in the network. Choose a value of the large sensitivity and mutate the related individual based on the sensitivity value. When an individual exceeds the minimum or maximum limit after mutation, it is set to the limit value. After improved mutation operation, offspring individuals will converge to the optimal result faster.

TERMINATION CONDITIONS AND THEIR IMPROVEMENT

The termination condition is that the number of iterations reaches the maximum number of iterations and the optimal individual obtained is a feasible solution to the problem.

Sensitivity analysis is introduced into genetic algorithm to achieve crossover and mutation operation, which can improve the performance of genetic algorithm and meet the needs of grid reactive power optimization (see Figure 1).

![Flow Chart Of Combined With Sensitivity Analysis of The Genetic Algorithm](image)

Figure 1. Flow Chart Of Combined With Sensitivity Analysis of The Genetic Algorithm.
CASE STUDY

In order to verify the effectiveness of the proposed method, a case study is carried out by taking the regional power grid as an example. In this paper, the performance of the computer is Intel Core i5 2.0 GHz, 4G memory computer, Visual Studio2010. Using C++ programming language to achieve the proposed method.

The system based on sensitivity analysis genetic algorithm to optimize reactive power. The specific results are in the table 1 below.

<table>
<thead>
<tr>
<th>TABLE I. SENSITIVITY ANALYSIS BEFORE AND AFTER THE COMPARISON TABLE.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of over-voltage-limited nodes</td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Not combined with sensitivity analysis</td>
</tr>
<tr>
<td>Combined with sensitivity analysis</td>
</tr>
</tbody>
</table>

From the Table I, combining sensitivity analysis to optimize reactive power system, the number of over-voltage-limited nodes in the power grid changed from 3 to 0, while active power loss, the number of transformer tap adjustments and reactive power compensator switching times are reduced in different degree.

CONCLUSION

In this paper, according to the defects of genetic algorithm in solving reactive power optimization problems, the traditional genetic algorithm is improved with the sensitivity analysis. And compared the algorithm before and after the improvement. The conclusion shows that the optimal solution can be obtained by combining the sensitivity analysis with reactive power optimization. The network loss of the power network is smaller and the switching times of the transformer tap and the switching times of the reactive power compensator are also smaller. In addition, we will further study how to better integrate with the actual project to meet on-site requirements.

REFERENCES