ANALYSES OF STEADY-STATE VOLTAGE STABILITY CONSIDERING REACTIVE-VOLTAGE REGULATION COEFFICIENT

Yibo ZHOU[1], Yangyong CAOKANG[2], Shi ZHANG[3]

Based on the local voltage stability index, The sensitivity matrix of load node local voltage stability index to generator node excitation system reactive-voltage regulation coefficient is established. According to the sensitivity information, the reactive-voltage regulation coefficient of each generator is optimized to improve the static voltage stability of the power grid. The analysis results of 39 buses system verify the feasibility and accuracy of the proposed sensitivity matrix. When the reactive-voltage regulation coefficient of the key generator node which has a great impact on the static voltage stability of the load node is adjusted according to the sensitivity index, the static voltage stability of the power system could be improved. This study can contribute to realize the optimal setting of reactive-voltage regulation coefficient of generators in multi-machine system.

Keywords: static voltage stability, reactive-voltage coefficient, local voltage stability index, generator excitation system, sensitivity matrix

1. Background

Voltage stability represents the ability of all buses to continuously maintain reasonable voltage under rated operating conditions after disturbance [1]. At present, the power system has become one of the most important energy supply systems in society, the demand of power grid is increasing, the operation of power generation and transmission equipment is getting closer to its limit value. Under certain extreme operating conditions, the risk of voltage instability increases, which seriously threatens the safety of power system operation [2-5].

Synchronous generators are very important to maintain the reactive-voltage level of the grid, with the characteristics of large reactive power regulation range, rapid regulation and no additional investment, which has an

[1] Key Laboratory of Modern Power System Simulation and Control & Renewable Energy Technology, Ministry of Education, Northeast Electric Power University, Jilin 132012, China, Corresponding author, doctoral candidate, e-mail: zhouyiboaa@126.com.
[2] Changchun Power Supply Company, State Grid Jilin Electric Power Company Limited, Changchun 130000, China,
[3] Key Laboratory of Modern Power System Simulation and Control & Renewable Energy Technology, Ministry of Education, Northeast Electric Power University, Jilin 132012, China, Research Associate.

important impact on the static voltage stability of the system [6-8]. The regulation coefficient of excitation system describes the reactive-voltage characteristics of synchronous generator [9-11]. In reference [12], single-machine infinite bus system is taken as an example, the influence mechanism of load voltage droop compensation in generator excitation control on power system stability is discussed. Reference [13] proposed the optimization model of the reactive-voltage regulation coefficient of generation to improve the voltage level and decrease the active power loss. In reference [14], taking the single machine infinite bus system as an example, the influence of generator excitation control on the static voltage stability of the system is demonstrated. The above research lacks the analysis of the influence of the excitation system difference coefficient of each generator unit on the static voltage stability of the load node in the multi machine system, which can’t provide guidance for the setting of the excitation system reactive-voltage regulation coefficient in the multi machine system to improve the static voltage stability.

In fact, the local voltage index L could be used to evaluate the static voltage stability of the power system. The physical concept of the index is clear, and it does not need to consider whether the Jacobian matrix is singular. The calculation speed is fast, and the boundary is definite. The calculation results in different grid topologies can be directly compared [15-17]. Using this index can not only quantify the static voltage stability of the system, but also help to establish the sensitivity relationship between the static voltage stability of load node and the generator regulation coefficient of excitation system [18-21].

In this paper, the new type of generator node considering the reactive-voltage regulation coefficient of generation is redefined, and the power flow equation considering the reactive-voltage regulation coefficient of generation is established. This paper presents a sensitivity matrix which can be used to analyze the relationship between the difference adjustment coefficient of generator excitation system and the static voltage stability of load node in multi machine system. The accuracy and effectiveness of the sensitivity matrix to reflect the static voltage stability of each excitation system for any load node are demonstrated by simulation analysis. The sensitivity matrix can be used to optimal tuning the reactive-voltage regulation coefficient of generation in multi machine system.

2. Power flow equations considering the influence of reactive-voltage regulation coefficient

The basic concept of the reactive-voltage regulation coefficient should be introduced first. The reactive-voltage regulation coefficient is the linear slope describing the change of the generator terminal voltage with the change of the generator's reactive power, and its expression is

$$\beta_i = -\frac{V_{iref} - V_i}{Q_{iref} - Q_i} \tag{1}$$

Where *i* is the number of the generator node, and β_i is the reactive-voltage regulation coefficient of generation of the generator node, V_{iref} and Q_{iref} are voltage reference value and reactive power reference value, V_i and Q_i are voltage and reactive power of node *i*.

From equation (1), in a single-machine single-load system, if the β value of the generator is less than 0, the voltage control point of unit wiring generator equivalent to moves towards the high-voltage side of the transformer, which is equivalent to the generator compensating reactance of the transformer. The compensating reactance shortens the electrical distance between the generator and the load. The traditional PV control mode of generators is equivalent to a bus with the regulation characteristic set to 0. Therefore, setting the adjustment coefficient β to a negative value can improve the static voltage stability of the load node.

However, the value of β cannot be set too small. If the adjustment coefficient has been set too small, which will cause the synchronous generator to face a large reactive power fluctuation range when the grid voltage fluctuates slightly, which is not conducive to the stability of the power system.

Then a correction equation for power flow calculation taking into account the reactive-voltage regulation coefficient has been established. After the generator takes into account the reactive-voltage regulation coefficient, the voltage of the PV node and the Vθ node is no longer a fixed value, and the correction equation of the power flow calculation will also change. For a power system with n nodes, there is a balance node, (n-m) generator nodes with a certain P and (m-1) PQ nodes. The system has 2n-1 equations, including the active power expressions of all nodes except the balance node, a total of (n-1) equations; the reactive power expressions in the PQ node, a total of (m-1) Expression; the expression of generator node β, a total of (n-m+1). The established correction equation is as follows:

$$\begin{bmatrix} \Delta P \\ \Delta Q \\ \Delta \beta \end{bmatrix} = \begin{bmatrix} H_{(n-1)\times(n-1)} & N_{(n-1)\times n} \\ J_{(m-1)\times(n-1)} & L_{(m-1)\times n} \\ M_{(n-m+1)\times(n-1)} & K_{(n-m+1)\times n} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{2}$$

Where ΔP, ΔQ and $\Delta \beta$ are the unbalance of the injection power and the reactive-voltage regulation coefficient of the excitation system respectively. *H, N, J, L, M* and *K* are submatrices of the Jacobian matrix, respectively. $\Delta \delta$ and ΔV

are the voltage phase angle and voltage amplitude correction of each node. The elements of *H, N, J* and *L* are consistent with the traditional modified equation. The elements *M* and *K* in the Jacobian matrix represent the partial derivatives of the reactive-voltage regulation coefficient to the voltage phase angle and voltage amplitude respectively.

So far, the correction equation that takes into account the reactive-voltage regulation coefficient is established, and then the power flow calculation that takes into account the reactive-voltage regulation coefficient can be carried out.

3. Sensitivity analysis of local voltage stability index to reactive-voltage regulation coefficient

The literature [22-24] defines the local static voltage stability index L_j of the load buses as

$$L_j = \frac{\left| \sum_{i \in \alpha_L} \frac{Z_{ji}^* \tilde{S}_i}{\dot{V}_i} \right|}{V_j} \tag{3}$$

Where Z_{ji}^* is the mutual impedance conjugate between load node *j* and *i*, $\tilde{S}_i$ is the equivalent load of load node I, $\dot{V}_i$ is the voltage phasor of load node *i*, and V_j is the voltage amplitude of load node *j*.

The local voltage stability index of all load nodes in the system constitutes the system stability index vector $L = [L_1, L_2, ..., L_n]$, where 1~n is all load nodes in the system, then the voltage stability index of the system is

$$L = \|L\|_\infty \tag{4}$$

Using the L index to represent the local voltage stability of the load node of the power system has the advantage of clear physical concepts and monotonic changes in the index with the change of load level. The closer the L index is to 0, the higher the static voltage stability of the node, and its value is closer to 1. Then the static voltage stability of the node decreases. If the index is equal to 1, the node is in critical voltage stability, and if the index is greater than 1, the node has static voltage instability.

System voltage instability usually starts from one or several nodes in the system and extends to the entire network. The magnitude of the L index value of each load node can reflect the magnitude of the voltage stability of the node. Therefore, the ability of each load node in the system to maintain voltage can be evaluated through the L index, and the critical load node can be found.

For a multi-machine system, the sensitivity matrix of the load node L index to the reactive-voltage regulation coefficient of the generator node can be established to accurately and intuitively obtain the generator nodes that have a greater impact on the static voltage stability of each load node for adjustment.

For a complex power network, since the voltage stability index reflects the voltage stability characteristics of the load node, and the regulation coefficient reflects the external reactive-voltage characteristics of the generator, it is difficult to directly obtain the relationship between local voltage stability index and the reactive-voltage regulation coefficient. It is necessary to first obtain the derivative of the L index with respect to the load node voltage, then obtain the derivative of the load node voltage with respect to the voltage of the generating node, and finally obtain the derivative of the voltage of the generating node to the reactive-voltage regulation coefficient. The calculation expression is as follows

$$\frac{\partial L_j}{\partial \beta_i} = \sum_{x \in \alpha_L} \sum_{m \in \alpha_G} \frac{\partial L_j}{\partial V_x} \frac{\partial V_x}{\partial V_m} \frac{\partial V_m}{\partial \beta_i} \tag{5}$$

Where $\partial L_j / \partial V_X$ is the sensitivity of the local voltage stability index of the load node to the voltage of the load node, $\partial V_X / \partial V_m$ is the sensitivity of the voltage of the load node to the voltage of the generator node, and $\partial V_m / \partial \beta_i$ is the sensitivity of the voltage of the generator node to the reactive-voltage regulation coefficient of the excitation system.

Because the line reactance in the actual transmission network is much larger than the resistance, and the relative balance point of the voltage phase of each node is small. So the simplification of equation (3) is

$$L_j = \frac{\sqrt{\left(\sum_{i \in \alpha_L} \frac{Q_i X_{ij}}{V_i} \right)^2 + \left(\sum_{i \in \alpha_L} \frac{-P_i X_{ij}}{V_i} \right)^2}}{V_j} \tag{6}$$

According to Equation (6), the sensitivity of L_j of load node *j* to voltage amplitude V_j of this node can be obtained as

$$\frac{\partial L_j}{\partial V_j} = -\frac{Q_j X_{jj} \sum_{i \in \alpha_L} \frac{Q_i X_{ij}}{V_i} + P_j X_{jj} \sum_{i \in \alpha_L} \frac{P_i X_{ij}}{V_i} + V_j^3 L_j^2}{V_j^4 L_j} \tag{7}$$

The sensitivity of L_j of load node *j* to voltage amplitude V_i of other load node *i* except this point is

$$\frac{\partial L_j}{\partial V_i} = -\frac{Q_i X_{ij} \sum_{i \in \alpha_L} \frac{Q_i X_{ij}}{V_i} + P_i X_{ij} \sum_{i \in \alpha_L} \frac{P_i X_{ij}}{V_i}}{V_i^2 V_j^2 L_j} \tag{8}$$

The derivation process of the L index shows that the sensitivity of the load node voltage V_j to the generator node voltage V_i is

$$\frac{\partial V_j}{\partial V_i} = -\sum_{y \in \alpha_L} Z_{jy} Y_{yi} \tag{9}$$

It is known that the correction equation of power flow calculation taking into account the reactive-voltage regulation coefficient of the generator is expressed as

$$\begin{bmatrix} \Delta P \\ \Delta Q \\ \Delta \beta \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \\ M & N \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{10}$$

The inverse of the matrix is obtained

$$\begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \\ \Delta \beta \end{bmatrix} \tag{11}$$

The voltage of generator node and voltage of other nodes are respectively represented, and the matrix is deformed as

$$\begin{bmatrix} \Delta \delta \\ \Delta V_1 \\ \Delta V_2 \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \\ \Delta \beta \end{bmatrix} \tag{12}$$

Where, ΔV_1 is the voltage unbalance of generator nodes taking into account the reactive-voltage regulation coefficient of generation, and ΔV_2 is the voltage unbalance of PQ nodes. Then the sensitivity of voltage V_i of generator node to the reactive-voltage regulation coefficient β_i of the excitation system of this node $\partial V_i / \partial \beta_i$, is the corresponding diagonal element of B_{23}, while the sensitivity of voltage V_i of generator node to the reactive-voltage regulation coefficient β_j of excitation system of other generator nodes $\partial V_i / \partial \beta_j$, is the corresponding non-diagonal element of B_{23}.

For a system of n generator sets and m load nodes, all $\partial L_j / \partial V_x$ are combined into an $m \times m$ order matrix, all $\partial V_x / \partial V_m$ are combined into an $m \times n$ order matrix, and all $\partial V_m / \partial \beta_i$ are combined into an $n \times n$ order matrix. The influence of the variation of the reactive-voltage regulation coefficient of the excitation system of each generator set on the L index of each load node can be expressed as

$$\begin{bmatrix} \Delta L_1 \\ \Delta L_2 \\ \cdots \\ \Delta L_m \end{bmatrix} = \begin{bmatrix} \frac{\partial L_1}{\partial \beta_1} & \frac{\partial L_1}{\partial \beta_2} & \cdots & \frac{\partial L_1}{\partial \beta_n} \\ \frac{\partial L_2}{\partial \beta_1} & \frac{\partial L_2}{\partial \beta_2} & \cdots & \frac{\partial L_2}{\partial \beta_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial L_m}{\partial \beta_1} & \frac{\partial L_m}{\partial \beta_2} & \cdots & \frac{\partial L_m}{\partial \beta_n} \end{bmatrix} \begin{bmatrix} \Delta \beta_1 \\ \Delta \beta_2 \\ \vdots \\ \Delta \beta_n \end{bmatrix} \tag{13}$$

In formula (13), the left side of the equation is the perturbation of the voltage stability index of the load node, and the right side of the equation is the perturbation of the regulation coefficient of each power generation node. The $m \times n$ order partial derivative matrix is the sensitivity matrix of the load node L index in the network corresponding to the system to the adjustment coefficient of each generator excitation system.

4. Tuning strategy of reactive-voltage regulation coefficient of generation

The steps for adjusting the reactive-voltage regulation coefficient of the excitation system through *L*-*β* sensitivity are as follows:

(1) Calculate the local voltage stability index of each load node under the initial power flow.

(2) The load nodes are sorted according to the degree of voltage stability. Then extract the regions and nodes whose index is close to 1. One or more key load nodes are found.

(3) Establish the sensitivity matrix of the local voltage stability index to the reactive-voltage regulation coefficient of the excitation system according to the formula (13).

(4) Analyze the sensitivity matrix and adjust the reactive-voltage regulation coefficient of the excitation system of the generator node that has a greater impact on the static voltage stability of the critical load node.

In step (4), the optimization tuning model of the adjustment coefficient aimed at improving the static voltage stability of the power system can be described as follows

$$\mathrm{F} = \min\{\mathrm{L}\} \tag{14}$$

In the formula, L is the static voltage stability index of the system.

In the above optimization process, the feasible region of the adjustment coefficient must comply with the voltage safety constraints of each node and the search domain constraints of the adjustment coefficient.

$$U_{\min} \le U \le U_{\max} \tag{15}$$

$$\beta_{\min} \le \beta \le \beta_{\max} \tag{16}$$

The adjustment result of the adjustment coefficient also needs to meet the constraints of the reactive power output of each generator

$$Q_{s.\min} \le Q_G \le Q_{s.\max} \tag{17}$$

In the formula, U is the node voltage, $\beta_{\min}$ is the minimum value of the adjustment coefficient search domain, $\beta_{\max}$ is the maximum value of the adjustment coefficient search domain, and $Q_{s.\min}$ and $Q_{s.\max}$ are the minimum and minimum reactive power output of the synchronous generator, respectively. Maximum value.

For the above models, the quasi-Monte Carlo algorithm can be used to solve the problem. The quasi-Monte Carlo algorithm can traverse all possible combinations of solutions to ensure that the global optimal value is searched. However, the computational time cost will increase exponentially when solving high-dimensional optimization problems. It is more suitable for solving optimization problems with a small feasible region of solution.

For large grids with many components, the power grid has many variables to be optimized. Although the power grid can be divided into layers and sub-regions can be solved separately to reduce the difficulty of solving the model, the time cost of solving the model is still very large and it is often difficult to accept. Therefore, this paper adopts the model solving method based on the particle swarm optimization (PSO) algorithm, which can effectively reduce the cost of solving time and greatly improve the efficiency of model solving.

The position of the particle is represented by a vector of reactive-voltage regulation coefficients [$\beta_1, \beta_2, \cdots, \beta_n$], The particle velocity and position update formulas can be described as follows

$$v_{id}^{k+1} = \omega_1 v_{id}^k + c_1 r_1 \left(p_{id} - x_{id}^k \right) + c_2 r_2 \left(p_{gd} - x_{id}^k \right) - \omega_2 r_3 \left(p_{id} + p_{gd} \right) \tag{18}$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \tag{19}$$

In the formula, $X_i^k = \left(x_{i1}{}^k, x_{i2}{}^k, \ldots, x_{iD}{}^k \right)$ is the D-dimensional position vector of the ith particle in generation k; $V_i^k = \left(v_{i1}^k, v_{i2}^k, \ldots, v_{iD}^k\right)$ is the D-dimensional velocity vector of the ith particle in generation k; c_1, c_2 are acceleration factors; r_1, r_2 are random numbers in (0,1); $P_i^k = \left(p_{i1}^k, p_{i2}^k, \cdots p_{iD}^k\right)$ is the optimal position of the ith particle as of generation K; $P_g^k = \left(p_{g1}^k, p_{g2}^k, \cdots, p_{gD}^k\right)$ is the optimal position searched by the whole particle swarm optimization up to the k generation; ω is inertia weight coefficient.

5. Case study

This paper takes the IEEE Bus39 system as an example for simulation. The system structure diagram is shown in Fig.1. The system includes 10 generator sets and 17 load nodes. First, set the reactive-voltage regulation coefficient of the excitation system of all generator nodes in the system to -0.001, and calculate the local voltage stability index value of each load node in the system at this time. The simulation results are shown in Table 1.

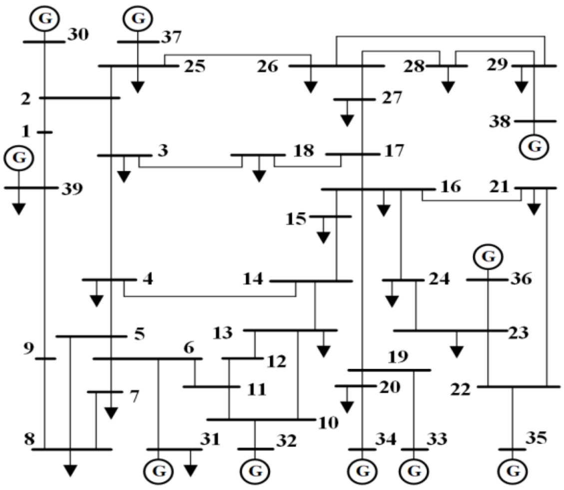

Fig. 1. IEEE39 node example system

Table 1

L index of load node

Node number	L index	Node number	L index
3	0.64	21	0.81
4	0.72	23	0.52
7	0.63	24	0.69
8	0.62	25	0.28
12	0.43	26	0.93
15	0.73	27	0.98
16	0.70	28	0.45
18	0.82	29	0.28
20	0.18	—	—

Sort the load nodes in the system according to the local voltage stability index L from large to small, and the sorting results are: 27, 26, 18, 21, 15, 4, 16, 24, 3, 7, 8, 23, 28, 12, 29, 25, 20. The greater the value of the local voltage stability index, the lower the static voltage stability of the load node, so the three key load nodes with the largest L value are selected: 27, 26, and 18. Then, the sensitivity matrix of the local voltage stability index of the load node to the reactive-voltage regulation coefficient of the generator node excitation system is formed. Analyze the sensitivity coefficients of key load nodes in the sensitivity matrix, that is, select key generator nodes. Fig. 2. is the sensitivity information of the local voltage stability index of the critical load node 27 to the reactive-voltage regulation coefficient of the excitation system of each generator node. It is known from Fig. 1 that the maximum sensitivity of the local voltage stability index of the load node 27 to the reactive-voltage regulation coefficient of the excitation system of each generator node is 35 and 38. Therefore, the key generator nodes of load node 27 are 35 and 38.

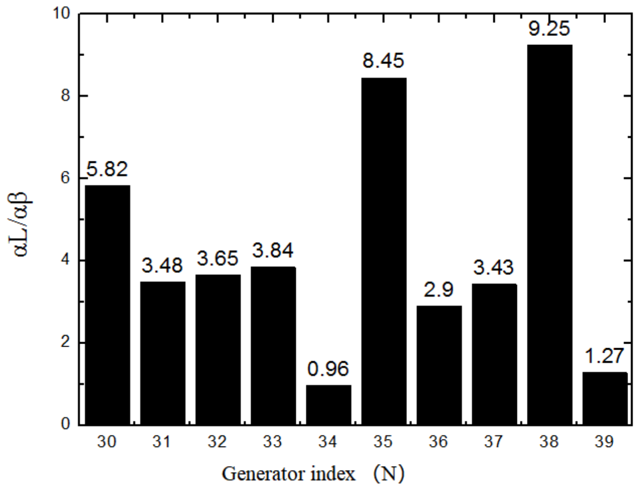

Fig. 2. Sensitivity of load node 27 to the reactive-voltage regulation coefficient of each generator

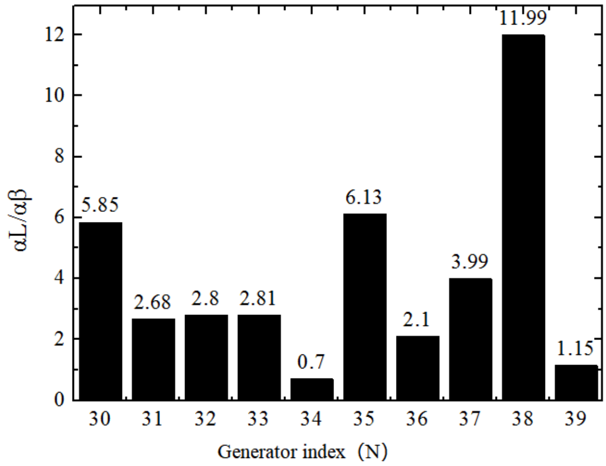

Fig. 3. Sensitivity of load node 26 to the reactive-voltage regulation coefficient of each generator

Fig. 3. is the sensitivity information of the local voltage stability index of the critical load node 26 to the reactive-voltage regulation coefficient of the excitation system of each generator node. It is known from Fig. 2 that the maximum sensitivity of the local voltage stability index of the load node 26 to the reactive-voltage regulation coefficient of the excitation system of each generator node is 35 and 38. Therefore, the key generator nodes of load node 27 are 35 and 38.

Fig. 4. relates to the sensitivity information of the local voltage stability index of the critical load node 18 to the reactive-voltage regulation coefficient of the excitation system of each generator node. As known from Fig. 3, the generator nodes with the highest sensitivity of the local voltage stability index of the load node 18 to the reactive-voltage regulation coefficient of the excitation system of each generator node are 30 and 35. Therefore, the key generator nodes of load node 18 are 30 and 35.

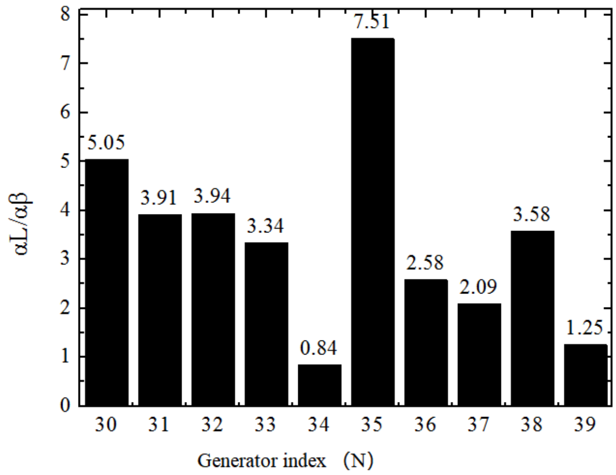

Fig. 4. Sensitivity of load node 18 to the reactive-voltage regulation coefficient of each generator

Based on the above analysis of the sensitivity matrix, four sets of samples are designed to adjust the reactive-voltage regulation coefficient of the excitation system, and the change of the L index is observed to judge the accuracy of the established sensitivity matrix. The first group sets the reactive-voltage regulation coefficient of the excitation system of 35 and 38 nodes to -0.001, and the other nodes are still -0.01. The second group sets the reactive-voltage regulation coefficient of the excitation system at 30 and 35 nodes to -0.001, and the other nodes are still -0.01. The third group sets the excitation system reactive-voltage regulation coefficient of the 34 and 37 nodes to -0.001, and the other nodes are still -0.01. In the fourth group, the reactive-voltage regulation coefficient of the excitation system at the 34 and 36 nodes is set to -0.01, and the other nodes are still at -0.001. The simulation results are shown in Table 2.

Table 2

The L index after adjusting reactive-voltage regulation coefficient

Load node number	27	26	18
All generator nodes β is -0.001	0.98	0.93	0.82
35 and 38 nodes are set to -0.01	0.60	0.56	0.54
30 and 35 nodes are set to -0.01	0.71	0.67	0.48
34 and 37 nodes are set to -0.01	0.82	0.77	0.71
34 and 36 nodes are set to -0.01	0.81	0.78	0.68

Comparing the first set of samples with the other three sets of samples, reduce the reactive-voltage regulation coefficient of the excitation system of generator node 35 and generator node 38, the local voltage stability index of load node 27 and load node 26 is the smallest, and the static state of node 27 and node 26 Voltage stability has been maximized. The generator node 35 and the generator node 38 are just the key generator nodes selected through the established sensitivity matrix. The same principle, comparing the second set of samples with the other three sets of samples, reducing the reactive-voltage regulation coefficient of the excitation system of the generator node 30 and the generator node 35, the local voltage stability index of the load node 18 is the smallest, and the static voltage stability of this node Has been improved to the greatest extent. The generator node 30 and the generator node 35 are just the key generator nodes selected through the established sensitivity matrix.

Therefore, it can be concluded that the sensitivity matrix established in this paper can correctly reflect the relationship between the reactive-voltage regulation coefficient of the excitation system of each generator node and the local voltage stability index of each load node. When the reactive-voltage regulation coefficient of the excitation system of the key generator node with a large influence on stability is adjusted, the static voltage stability of the load node can be maximized.

Set the adjustment range of the adjustment coefficient of each generator to [0, -0.05], to improve the static voltage stability of the power grid as the goal, optimize the adjustment coefficient of the excitation system of the bus30 to bus39, The optimized setting results of the reactive-voltage regulation coefficient are shown in Table 3.

Table 3

The optimal setting of reactive-voltage regulation coefficient

Generator index	β	Generator index	β
30	-0.032	35	-0.04
31	-0.001	36	-0.033
32	-0.01	37	-0.038
33	-0.024	38	-0.035
34	-0.035	39	-0.01

Set the adjustment range of the adjustment coefficient of each generator to [0, -0.05], and the voltage constraint range of the load node to [0.95p.u,1.05p.u]. With the goal of improving the static voltage stability of the power grid, the tuning coefficient of the excitation system of the 30-39 node generators in the power grid is optimized.

It can be seen from Table 3 that generators which are more sensitive to the static voltage stability of the load node often need to be set a more negative regulation coefficient. It is beneficial to improve the overall static voltage stability of the power system.

6. Conclusions

(1) The sensitivity matrix of the local voltage stability index of the load node to the generator reactive-voltage regulation coefficient after taking into account the reactive-voltage regulation characteristic is established. According to this matrix, it is possible to accurately evaluate the influence of the reactive-

voltage regulation coefficient of the excitation system of each generator node on the static voltage stability of each load node and provide a basis for the optimization of the reactive-voltage regulation coefficient of the excitation system of the multi-machine system.

(2) An optimization model of reactive-voltage regulation coefficients with the goal of improving grid static voltage stability, reactive-voltage regulation coefficients of generator as optimization variables, and power and voltage as constraints is constructed. Based on the particle swarm method, an optimization model is given. The optimized setting value of the generator reactive-voltage regulation coefficient reveals the basic law that the generator node closer to the load needs to be set with a more negative adjustment coefficient.

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