Research on Distribution Network Loss Allocation with Small Hydropower Groups

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Abstract: On the basis of Longnan power grid with small hydropower groups, this paper proposes a loss allocation method combining marginal loss coefficient method and branch dissipation power transfer component method, aiming at the fact that marginal loss coefficient method does not consider the influence of balancing nodes and different balancing nodes on allocation results. Firstly, starting from the circuit law, Norton's equivalent is used to equivalent all power supplies to node injection current. Based on the branch dissipation power transfer component method, the network losses that each power supply node including the balancing node should share are obtained. Then, the marginal network loss coefficient method is used to obtain the network losses shared by other nodes except the balancing node. Finally, the calculation and analysis of the Longnan power grid with small hydropower are carried out, which verifies the feasibility of the proposed method and has reference value for the distribution of network losses of other distributed power grids.

1. Introduction
Under the background that the country strongly advocates clean energy and strictly implements environmental protection policies, representative distributed small hydropower has been applied on a large scale. Especially, the large-scale application of small hydropower not only ensures a good power supply in the region but also serves as a clean, green and flexible power source, thus effectively supplementing regional power resources and generating huge economic and social benefits.[1] At the same time, with the rapid development of small hydropower groups and large-scale access to the power grid, there is a loss allocation problem [2-3]. This paper takes distribution network loss allocation with small hydropower groups as an example to carry out research.

2. Marginal loss coefficient method

2.1 Basic Principle of Marginal Network Loss Coefficient Method
The marginal network loss coefficient method is a sensitivity method to distribute the total net loss to generators and load nodes. By solving the active and reactive marginal network loss coefficients of each node, the allocation of network loss to each node is completed[4-5].

The formula for calculating the total net loss \( L(V_i, \theta_j) \) of the system is:

\[
L = \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} G_{ij} \left( V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij} \right)
\]

(1)

From the above formula, the marginal net loss coefficients of active and reactive power can be
obtained as follows:

\[
\begin{bmatrix}
K_P \\
K_Q
\end{bmatrix} = \begin{bmatrix}
\frac{\partial L}{\partial P} \\
\frac{\partial L}{\partial Q}
\end{bmatrix} = \left( J^T \right)^{-1} \begin{bmatrix}
\frac{\partial L}{\partial \theta} \\
\frac{\partial L}{\partial V}
\end{bmatrix}
\] (2)

In the formula above, \( J \) is the Jacobian matrix of the power flow equation.

The network loss allocation amount of each node is obtained as follows:

\[
L_{i, \text{pro}} = \alpha L_i = \alpha K_{pi} \cdot P_i + \alpha K_{qi} \cdot Q_i
\] (3)

In the formula (3), \( \alpha \) is the scale factor.

3. Dissipative Power Transfer Component Loss Allocation Method

3.1 Loss Allocation Based on Dissipative Power Transfer Theory

For a sinusoidal steady-state circuit with \( n \) nodes and \( b \) branches, under the action of current source \( k \) alone, the response current through branch \( l \) (with terminals \( i \) and \( j \)) can be obtained by circuit law, expressed as \( I^b_{ik} \)[8]:

\[
I^b_{ik} = \alpha_{ik} \overline{I^n_k}/
\]

\[
\overline{a}_{ik} = (Z_{ik} - \overline{Z}_{jk})/z_l
\] (5)

\( I^b_k \) is the injection current of the power supply at node \( k \), \( \alpha_{ik} \) is only determined by the structure and parameters of the circuit. \( Z_{ik} \) and \( Z_{jk} \) are elements of the impedance matrix of the circuit node, and \( z_l \) is the impedance of branch \( l \)[9].

The total loss of branch \( l \) is expressed as \( L_l \):

\[
L_l = r_l |I^b_k|^2 = r_l (I^b_k \cdot \overline{I^b_k}) = r_l \left( \sum_{k=1}^{n} \overline{a}_{ik} \overline{I^n_k} \right) \left( \sum_{k=1}^{n} \overline{a}_{ik} \overline{I^n_k} \right)
\] (6)

In the formula, \( r_l \) is the resistance of branch \( l \) and the system loss is the summation of \( L_l \) of all branches.

The voltage of node \( k \) is expressed as \( V_k = e_k - jf_k \), the active power of node \( k \) is \( P_{gk} \), and the equivalent node injection current of node \( k \) can be expressed as follows:

\[
I_k = \frac{P_{gk}}{V_k} = \frac{e_k}{e_k^2 + f_k^2} P_{gk} + j \frac{f_k}{e_k^2 + f_k^2} P_{gk}
\] (7)

\[
\frac{\partial L_l}{\partial P_{gk}} = 2r_l \frac{g_k + jf_k}{e_k^2 + f_k^2} \overline{a}_{ik} \left( I^b_k \right) = 2r_l \left( \overline{a}_{ik}/|V_k|^2 \right) (I^b_k)
\] (8)

This is the marginal loss of the branch \( l \) with respect to the active power \( P_{gk} \) of the node \( k \).

The actual system network loss is expressed by \( L \). Then \( L \) is the summation of all branches of formula (6), so the marginal loss \( \frac{\partial L}{\partial P_{gk}} \) of the system is the summation of formula (8) of all branches:

\[
\frac{\partial L_l}{\partial P_{gk}} = 2 \sum_{l=1}^{m} 2r_l \left( \alpha_{ik}/|V_k|^2 \right) (I^b_k)
\] (9)

In the formula, \( m \) is the total number of branches in the power grid[10].

4. Example analysis

4.1 Distribution of Network Losses of Each Node

The 110kV Longnan power grid with small hydropower groups is equivalent to the topology structure shown in Figure 4-1 below, in which nodes 1, 2, 3, 8 and 14 are small hydropower nodes. Node 1 (Shijiba Hydropower Station and Liuyuan Hydropower Station) is regarded as a balancing node, and other hydropower stations and load nodes are regarded as PQ nodes. The voltage reference value and
power reference are taken as \( U_B = 110kV, S_B = 100MVA \), and the network loss allocation program is compiled using The Matlab simulation platform.

4.2.1 Balance Node Network Loss Allocation In this system, node 1 (Shijiba Hydropower Station and Liuyuan Hydropower Station) is selected as the balancing node. This node is the power supply node. According to the branch dissipation power transfer component theory, the net loss to be shared by each power supply node including the balancing node is shown in Table 4-1. The total net loss to be shared by the balancing node is \(-75.87MW\), and the proportional coefficient \( \alpha = 0.5 \). The net loss to be shared by the balancing node is \( 37.935MW \).

| Node number | Loss allocation (MW) |
|-------------|----------------------|
| 1           | -75.87               |
| 2           | 135.97               |
| 3           | 121.29               |
| 8           | 181.89               |
| 14          | 41.87                |

4.2.2 Distribution of Network Losses of Other Nodes The marginal loss coefficient method is used to simulate and obtain the loss allocation amount of each node as shown in Figure 4-2.

![Fig. 4-1 equivalent node diagram of Longnan power grid](image)

![Figure 4-2 Amount of Network Loss Allocated by Each Node](image)

From Figure 4-2, it can be seen that nodes 8, 10, 22, and 27 have a large amount of network loss allocation, of which node 8 is a power supply node (Bikou Power Station and Qilinsi Power Station), with a large output of 300MW and a negative amount of network loss allocation. The analysis shows that small hydropower stations connected to the distribution network can reduce the total net loss of the system. Node 10 (Zaoyang substation) has a large loss allocation because of its heavy load, with a load rate of 59.72% and a load size of 215MW; . Node 22 (Chengxian substation) has a large amount...
of network loss allocation due to its long distance from the power supply point and heavy load, with a load rate of 134% and a load size of 268MW. For node 27 (Huixian substation), although its load is relatively light, its network loss allocation is relatively large due to its farthest distance from the power supply point and relatively large transmission power loss. The network loss shared by each small hydropower station is shown in Figure 4-3.

![Network loss shared by small hydropower stations](image_url)

**Figure 4-3 Network loss shared by small hydropower stations**

From fig. 4-3, it can be seen that the amount of network loss shared by each small hydropower station in the small hydropower station group is proportional to its output. The larger the output of small hydropower station, the greater the benefit, the greater the amount of network loss shared conforms to the direction of market economy and embodies the principle of fairness in network loss sharing.

5. **Conclusion**

Through the simulation analysis of the Longnan power grid containing small hydropower, the superiority of the combination of the above two methods is verified. This method can reflect the incremental cost information of the system network loss caused by the power change of each node, thus providing a good economic signal for the development of the power grid, promoting the flow of power flow towards the direction of network loss reduction, achieving the purpose of optimizing power flow and guiding household investment.

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