New energy consumption analysis based on impedance type electrical distance

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Abstract. All along, electrical distance is used to characterize the electrical tightness between two nodes, widely used in reactive power partitioning and reactive power location. In fact, the electrical distance can also be used to select new energy access points. Most of the existing electrical distances are also calculated by the sensitivity method. The electrical distance obtained by the sensitivity method lacks the concept of space and the calculation is not accurate. The new electrical distance calculated by the equivalent transmission impedance not only reflects the close relationship between the two power quantities, but also has the concept of “distance”. It is persuasive and has a wider application range. This paper will use the new electrical distance, apply to the selection of new energy access points for the 6-node distribution network, and build a consumption analysis map to track and analyze the consumption of new energy.

1. Introduction

With the country's increasing emphasis on environmental pollution issues and the encouragement and support of clean energy, the development of projects using new energy power generation is unstoppable. With the advancement of science and technology, the government's support has increased, and new energy power generation projects including hydropower, wind power, photovoltaic power generation, biomass power generation and other power generation projects have gradually grown. In order to better absorb new energy, we must first choose the right new energy access point. The location of the access point can be selected based on the electrical distance.

The concept of electrical distance was first proposed by P. Lagonotte[1], which had two meanings: one is the concept of “electrical connection”, that is, the relationship between the electrical quantities generated by the power flow between two nodes. Most of the stage methods are directed to this concept[2-3], the second is the concept of “spatial positional relationship”. The traditional electrical distance has a sensitive electrical distance, although the degree of coupling between nodes can be expressed by the relationship between two nodes, but only the amount of voltage amplitude information is used. And the sensitivity electrical distance is multi-valued. Although the sensitivity electrical distance is improved[4-8], the fundamental idea of these improved methods has not changed, and only the reactive/voltage is considered as a parameter for sensitivity consideration, so it is difficult to be convinced.

The literature[9] attempts to propose a new electrical distance calculation method from the impedance point of view, namely the equivalent transmission impedance method. This new electrical distance takes into account both reactive and active. At the same time, the electrical distance calculated
by this method can reflect the close electrical connection between the two nodes, and also automatically meet the symmetry of the electrical distance.

This new type of electrical distance reflects the degree of electrical connection between the two nodes and refers to the energy transfer relationship between the two nodes. Therefore, the electrical distance between the power supply and the load reflects the ability of the power supply to control the load. Different electrical distances describe the relationship between the electrical parameters of the nodes. With the greater influence, the electrical distance becomes smaller, vice versa. According to the new electric energy, the maximum distance of the electrical distance between the power supply and the load node can be connected according to the new electric energy, and the new energy consumption analysis map can be formed by using the power flow tracking to analyze the new energy consumption.

2. Power flow tracing

The electrical distance can visually represent the electrical connections between the nodes and select the appropriate new energy access point based on the electrical distance. The derivation of the power component theory using the superposition theorem.

2.1 Traditional electrical distance

2.1.1 Sensitivity method electrical distance

The traditional sensitivity electrical distance considers the degree of coupling between nodes to be represented by the voltage offset between two nodes, that is, the unit reactive power is injected at node j, and the voltage offset ratio at node i and node j is:

\[
\alpha_{ij} = \frac{\Delta V_i}{\Delta V_j} = \frac{\Delta V_i/\Delta Q_j}{\Delta V_j/\Delta Q_j}
\]

Where \( \Delta V_i/\Delta Q_j \) is generally the corresponding element in the voltage-reactive sensitivity matrix. The voltage-reactive sensitivity matrix generally has two methods: one is to define the inverse of the Jacobian matrix \( VQ \) as a voltage-reactive sensitivity matrix; the other is to consider only the voltage and the linearized system flow equation. The reactive relationship ignores the change in the amount of active injection, \( \Delta P = 0 \), the order of \( \Delta V = S \Delta Q \) is reduced, and the definition \( S = [D_{ij} - J_{ij}J_{ij}]^{-1} \) is the voltage-reactive sensitivity matrix, where \( J_{ij} \) is the corresponding element in the Jacobian matrix. Compared with \( \partial Q/\partial V \), the sensitivity matrix considers more information and is more accurate. However, the multi-value solution of the sensitivity method for the description of the voltage offset ratio is determined by the inaccuracy of the sensitivity method itself. This cannot be solved.

Element \( S \) in Sensitivity Matrix \( S \) represents the voltage offset at node i when the unit is reactive at node j in the system. At this time, the voltage offset ratio at node i and node j is \( \alpha_{ij} = S_{ij}/S_{ji} \), measured by element \( \alpha_{ij} \). The electrical distance between any node i and j of the system. To ensure the symmetry of the electrical distance, the electrical distance between the two nodes i and j is generally defined as:

\[
D_{ij} = D_{ji} = -\log(\alpha_{ij}/\alpha_{ji})
\]

2.1.2 Sensitivity method electrical distance

The spatial electrical distance is proposed based on the sensitivity matrix \( S \). Let \( d_j = |g(S_j/S_j)| \) be the ratio of the voltage offset of node j itself to the voltage offset of node i when node unit is injected at node j. The larger the value, the smaller the influence of j on the i node, 2 nodes The farther the electrical distance is between. The matrix \( D \) composed of \( d_j \) is an n-th order square matrix (n is the number of nodes other than the balance node in the system), and the nodes of the system are mapped to an n-dimensional space with the row vector of \( D \) as the coordinate, \( d_j \) can be understood as The coordinates
of the node $i$ in the $j$-th plane direction in the $n$-dimensional space, then the Euclidean distance between
the node $i$ and the node $j$ is expressed as:

$$L_{ij} = \left( (d_{i1} - d_{j1})^2 + (d_{i2} - d_{j2})^2 + \cdots + (d_{in} - d_{jn})^2 \right)^{1/2}$$

In the formula, $L_{ij} = L_{ji}$.

The spatial electrical distance defined by Equation (1) takes into account the interaction between the
various nodes of the system, and can express the electrical distance more intuitively.

2.2 Traditional electrical distance
Since all operating parameters are distributed by impedance when the power supply and network
topology are constant, the electrical distance should also be measured by impedance. Referring to the
decoupling idea of the sensitivity method, the power is tracked according to the power supply [12-14],
and a single power supply to a single-load power supply network is obtained, and then the transmission
impedance is separately calculated according to the transmission relationship and finally synthesized
into an actual impedance. It should be pointed out that the trend tracking in this paper takes the complex
power as the research object rather than the reactive power. On the one hand, the reactive power has no
direction to form the power flow; on the other hand, the line itself transmits the complex power, which
is more comprehensive than the reactive power. It contains the electrical information.

If there is a power transmission relationship between node $i$ and node $j$, it can be considered that a branch
is formed between the two nodes, which is independent of whether the two nodes are directly connected,
and is called a generalized branch. As shown in Figure 1.

![Generalized branch equivalent diagram](image)

**Fig 1** Generalized branch equivalent diagram

The impedance $z_{ij}$ of the generalized branch can characterize the power loss caused by the
transmission of power from node $i$ to node $j$, called the equivalent transmission impedance. It can be
seen that the equivalent transmission impedance can describe both the transmission loss and the spatial
positional relationship between the two nodes. This is because the transmission impedance is used as
the line parameter and is related to the length of the line.

If there is a power transmission relationship between the two nodes, a generalized transmission impedance
can be formed between the two nodes. In the same way, the power supply can build a single-supply-
single-load network with power-to-load.

Assume that the figure is the equivalent generalized branch of any node, and the node voltage and
power information are included in the figure. $z_{ij}$ is the equivalent transmission impedance of the branch
$i-j$, which can be used to characterize the electrical distance of this transmission process.

The equivalent transmission impedance of the branch can be used to characterize the electrical
distance of the transmission process. Since the distance is generally a scalar, the transmission impedance
mode $|z_{ij}|$ is taken here as the electrical distance between the nodes. The electrical distance can reflect
the tightness of the power quantity and conform to the concept of "electricity," it also satisfies the
symmetry, that is, the forward electrical distance is equal to the reverse calculated electrical distance,
which conforms to the concept of "distance". The derivation analysis of the electrical distance calculated
by the sensitivity method shows that the concept of calculating the electrical distance by the transmission
impedance method is more clear, and the symmetry can be satisfied without mathematical processing
and the calculation is simple, there is no linearization problem, and the calculation result is more accurate.
3. Case Analysis

Using the 6-node example of the distribution network to analyze the access point of new energy and the new energy consumption process, the power flow distribution is shown in Figure 2:

![Fig. 2 Single-power 6-node system structure](image)

The power distribution of the load node and the voltage of the node are shown in Table 2 and Table 1:

| Load node | 2 | 3 | 4 | 5 | 6 |
|-----------|---|---|---|---|---|
| Power     | 0.17+j0.05 | 0.225+j0.06 | 0.165+j0.02 | 0.193+j0.05 | 0.1+j0.03 |
| Voltage   | 0.9885-j0.0242 | 0.9798-j0.0419 | 0.9757-j0.0507 | 0.9946-j0.0089 | 0.9923-j0.0128 |

The 6-node single power supply is used to analyze the power flow and calculate the transmission impedance between the nodes. Since the power supply's control force is considered when selecting the access point, it is only necessary to select the electrical distance of the power supply to the load, as shown in Table 3:

| Branch | 1-2 | 1-3 | 1-4 | 1-5 | 1-6 |
|--------|-----|-----|-----|-----|-----|
| Electric distance | 0.1493 | 0.1960 | 0.3306 | 0.0521 | 0.1425 |

It can be clearly seen from Table 3 that the power source and the node 4 have the largest electrical distance, that is, the power source has the weakest control force on the node 4 load, so that accessing the new energy source at the node 4 is the best access point.

The access point has been selected, first of all to analyze the consumption process of new energy by the maximum amount of consumption. Then use the enumeration method to analyze the difference in the effect of other nodes when accessing.

| Node | 2 | 3 | 4 | 5 | 6 |
|------|---|---|---|---|---|
| Active network loss | 0.0085 | 0.0045 | 0.0025 | 0.0072 | 0.005 |

Taking the size of the network loss as a measure of the effect of adding new energy, it can be clearly seen from Table 4 that the total active network loss of the system is the least when the 4-node is connected. Therefore, 4-node access works best.

The following is an analysis of the new energy consumption path. The 4-node distribution network is connected to the PV for consumption analysis. The power flow tracing is used to form a consumption path.
map, and the power transmission paths and transmission powers of different energy sources in the consumption map are indicated in FIG. 3.

As shown in FIG. 3, the red marked transmission path is a distribution path of a conventional energy source, and the blue marked transmission path is a consumption path of a new energy consumption. The PV consumption map formed by the trend tracking can clearly and clearly see the new energy consumption path, which is simple and clear.

The amount of access to PV at 4 nodes is about 23%, and the amount of consumption is actually very large, and the flow of consumption is analyzed. It can be seen from the PV consumption path that after the PV is added, it will affect the nodes. For example, when the transmission branch is \(1 \rightarrow 5 \rightarrow 6\), when the PV is not added, the power is all supplied by the conventional unit; after the PV is added, the photovoltaic power also exists. Transmission branch \(1 \rightarrow 5 \rightarrow 6\). This also fully demonstrates that when multiple power supplies are used, the power supply is not only consumed locally, but also consumed by the entire network.

4. Conclusion

Traditional electrical distance has always been an effective method for reactive power partitioning, but it is only inaccurate considering the connection between reactive power and voltage. The new electrical distance contains the relationship between complex powers, satisfies the symmetry, and the concept is more clear and the calculation is more accurate. Therefore, the new electrical distance can be applied in a wider range and can be applied to the choice of new energy access points. The specific conclusions are as follows:

1) The new electrical distance has a wider range of applications, not only applied to reactive partitioning, reactive site selection, but also to the selection of new energy consumption points. The access point selected by the new electrical distance is compared with the enumeration method, and the point selected by the new electrical distance is the best point for access;

2) The new energy consumption map obtained by the trend tracking can clearly and clearly indicate the consumption path and consumption of new energy, and can express the meaning of new energy consumption. It can be seen from the consumption chart that when multiple power sources are used, the power distribution of the power supply is not only absorbed locally, but also consumed by the whole network.
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