Research on ADN “source-grid-load” coordinated operation index system

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Abstract. With the large-scale access of distributed generation (DG), problems such as harmonic pollution and increased access point voltage have been brought to the operation of the distribution network. The active distribution network (ADN) integrates a wealth of controllable resources to promote network optimization and green energy consumption. At present, the research on the "source-network-load" coordinated operation index system focuses on a certain direction, and does not consider the multi-dimensional influencing factors. Based on this, this paper starts the research, from the perspective of safety, economy, environment and coordination. In four aspects, the PCA algorithm is used to determine the evaluation index, and the AHP model is used to establish the evaluation system, and the calculation method of each index is explained and calculated to deepen the understanding of the evaluation system established in this article.

1. Introduction
The development of smart grid and the access of various types of distributed generation (DG) make the traditional distribution network develop to active distribution network. Compared with traditional distribution network, ADN has obvious changes in planning, protection and control. ADN is a new type of distribution network which can control different types of distributed energy, and takes active control measures to meet the two-way demand between power supply and customers. ADN improves the utilization ratio of distribution network assets and power supply reliability by active management.

Coordination and interaction between DG and load demand of distribution network must be considered in ADN planning. The existing grid interaction research does not take the power supply and users as a whole to conduct comprehensive research. And, it only aims at one partial aspect, for instance, source-grid interaction or user interaction. In addition, previous researchers have not established a comprehensive index system to evaluate the interaction between power supply and users.

In this paper, a new ADN planning system considering the interaction and coordination among source, network and load is established. Then, considering the specific characteristics of ADN, the evaluation index system is established from four aspects of safety, economy, environmental friendly and coordination, and the calculation method of each index is introduced in detail. The index system can objectively evaluate the planning and construction effect of ADN.

2. The theoretical system of “source-grid-load” coordination
The "source" in the ADN ternary structure refers to various types of distributed power sources and energy storage devices in the distribution network. Among them, distributed power can be divided into
controllable DG and intermittent DG. "Network" refers to the distribution network that includes power facilities such as transformers, cables and overhead lines, tie switches and section switches, high and low voltage distribution cabinets, and "load" refers to various load resources on the demand side, including conventional loads, Load reduction, Shiftable Load (SL), etc. The main purpose of "source grid load" coordination is to maximize the effect of resource utilization. The coordinated development of the three components is the key factor to promote ADN.

Fig.1 The “source-grid-load” coordination system

2.1. The source-grid coordination
The source-grid coordination mainly includes two aspects:
(1) In ADN, it is necessary to ensure the reasonable access of various types of DG, and to ensure the balance of power demand and supply.
(2) Give full play to the advantages of traditional energy and new energy to ensure the best coordination effects.

The source-grid coordination will greatly promote the predictability, controllability and schedulability of renewable energy. The purpose of "source grid" coordinated planning is to connect as many DGS as possible into the grid.

2.2. The grid-load interaction
There are many kinds of loads, and different types of loads have different requirements for power supply reliability. The security and economy of power grid operation depend on load characteristics. With the development of demand side management technology, encouraging users to take the initiative to cut peaks and fill valleys through electricity price policies, becomes an important measure to improve the safe and stable operation of power system. Interruptible loads are emergency backup power generation resources that can be control by the power grid and they are another forms of backup. In addition, the state also strongly encourages the coordinated development of multiple energy sources. Nowadays, the rapid development of flexible load can realize the two-way flow of power with the grid, which plays an important role in power grid regulation.

2.3. The source-load interaction
With the development of power grid diversification, the power supply and load will appear in the future power grid. The resources that the power grid can be used to dispatch are not only power supply, but also load. All kinds of controllable power grid equipment and different types of demand side resources can be used by active regulation of power grid. The grid fluctuation caused by new energy can be balanced by flexible load, but it needs effective load management and control.
3. The “source-grid-load” coordination operation index system

The goal of “source-grid-load” coordination operation is to make the ADN run in a safer, more economical and more environmentally friendly state. In addition, the index system can not only reflect the operation effect of the three, but also reflect the degree of coordination among the three parts.

In this paper, the principal component analysis method is used to select a reasonable evaluation index, and the analytic hierarchy process is used to establish a reasonable index system. The “source-grid-load” coordination operation index system of ADN is shown in Fig.2.

![Fig.2 The Index System](image)

3.1. Safety indexes A

(1) Voltage limit rate $A_1$

The over-limit rate of this part of the voltage node is the ratio of all voltage nodes in the area.

$$A_1 = \frac{m_{nq}}{m_{ns}} \times 100\%$$  \hspace{1cm} (1)

In the formula, $m_{nq}$ refers to the number of nodes with qualified voltage in the network, and $m_{ns}$ refers to the total number of nodes in the network.

(2) Current limit rate $A_2$

This part represents the ratio of the number of line current exceeding the set value to the total line.

$$A_2 = \frac{m_{lo}}{m_{ls}} \times 100\%$$  \hspace{1cm} (2)

In the formula, $m_{lo}$ is the number of overloaded lines in the network (the line current reaches more than 80% of the rated value).

(3) N-1 verification pass rate $A_3$

It includes three parts: the N-1 verification qualification rate of the substation, the N-1 verification qualification rate of the transformer and the N-1 verification qualification rate of the line.

(a) N-1 verification pass rate of substation $A_{31}$

The index is that the number of substations meeting N-1 accounts for the total number of substations in a certain area.

$$A_{31} = \frac{m_{Tt}}{m_{Ts}} \times 100\%$$  \hspace{1cm} (3)

In the formula, $m_{Tt}$ is the number of substations in the network that meet N-1 verification, and $m_{Ts}$ is the total number of substations in a certain area.

(b) N-1 verification pass rate of transformer $A_{32}$

This index is the ratio of the number of transformers that meet N-1 verification to the total number of transformers in a certain area.

$$A_{32} = \frac{m_{Tq}}{m_{Ts}} \times 100\%$$  \hspace{1cm} (4)

In the formula, $m_{Tq}$ is the number of transformers that meet the N-1 verification in the network, and $m_{Ts}$ is the total number of transformers in a certain area.
(c) line transmission line N-1 verification pass rate $A_{33}$

This indicator is the ratio of the number of transmission lines that meet the N-1 verification to the total transmission lines in a certain area.

$$A_{33} = \frac{mlq}{mls} \times 100\%$$  \hspace{1cm} (5)

In the formula, $mlq$ is the number of transmission lines that meet the N-1 verification pass, and $mls$ is the total number in the network.

(4) Power supply reliability rate $A_4$

Power supply reliability rate, this index refers to the ratio of the normal power supply reliable time period of the power supply to the total power supply time.

$$A_4 = \frac{mt}{mts} \times 100\%$$  \hspace{1cm} (6)

In the formula, $mt$ is the normal power supply time length of the power supply, and $mts$ is the total power supply time length of the power supply.

3.2. Economic indexes $B$

(1) Peak and valley difference rate $B_1$

The difference between the peak and valley values of the power system load curve is the primary factor that affects economic indicators. The larger the value, the power system needs to perform a larger range of peak shaving, and the peak and valley values meet the economic efficiency of power system operation. The specific calculation method is as follows.

$$B_1 = \left| mpb - mpc \right| / mml \times 100\%$$  \hspace{1cm} (7)

Among them, $mpb$ is the peak, $mpc$ is the trough, and $mml$ is the maximum system load.

(2) Power system cost $B_2$

(a) Power supply cost of the system $B_{21}$

Including the cost of purchasing electricity from the higher-level grid and the income from selling electricity (negative cost), and the cost of purchasing electricity from DG. The calculation formula is as follows.

$$B_{21} = \sum_{t=1}^{T} \left( \alpha_1 c_1 p_1 + \alpha_2 c_1 p_1 + \sum_{i=1}^{N_{DG}} C_{dg} P_{dg} \right) L$$  \hspace{1cm} (8)

In the above formula, $T$ represents the total number of time periods in the scheduling cycle, $i$ represents the i-th time period, and $L$ represents each time interval. $\alpha_1$ and $\alpha_2$ are respectively the amount of electricity purchased by ADN corresponding to the higher-level power purchase and the electricity sales mark, $c_1$ is the transaction price of the ADN and the upper-level power grid during the t period, $p_1$ is the active power of AND interacting with the upper-level power grid during the t period, and $N_{DG}$ is the distributed power source $C_{dg}$ is the on-grid electricity price of the i-th DG, and $P_{dg}$ is the active power of the i-th DG. The above formula shows the calculation formula of ADN's power supply cost.

(b) System network loss cost $B_{22}$

The loss of the distribution network refers to the cost required for the loss of the distribution network. The calculation formula is as follows.

$$B_{22} = \sum_{t=1}^{T} (Clos \cdot Plos) L$$  \hspace{1cm} (9)

In the above formula, $Clos$ represents the network loss cost of the distribution network, and $Plos$ represents the total active network loss of AND in the t period. It shows that the network loss calculation formula of AND.

(3) Reduce the cost of compensation for DG’s active contributions $B_3$.

The calculation formula is as follows:
\[ B_i = \sum_{i=1}^{T} \sum_{i=1}^{N_{dg}} (k_c C_{dg}) (P_{dg\text{lim}} - P_{dg}) L \]  

(10)

In the above formula, \( T \) represents the total number of time periods in the scheduling cycle, \( i \) represents the \( i \)-th time period, \( L \) represents each time interval, and \( N_{dg} \) is the total number of distributed power sources. \( k_c \) is expressed as the compensation coefficient, which represents the compensation of the grid company when the active power output of DG is limited and the user's economic income is reduced. A coefficient value greater than 1 can encourage users to accept the reduction of DG active power, and the value is 1.2 in this paper. \( P_{dg\text{lim}} \) represents the initial active power (value before reduction) of the DG signed by the \( i \)-th station during the period \( t \), and \( P_{dg} \) is the active output during the period \( t \).

3.3. Environmental Index C

To analyze the environmental benefits of various distributed power sources, three environmental indicators of energy utilization can be used for quantitative analysis: static efficiency, energy utilization reliability indicators, and environmental pollution indicators.

(1) Static efficiency \( C_1 \)

Refers to the ratio between the effective output \( W \) of the distributed power generation energy conversion technology and the input primary energy \( H \), usually expressed by \( \eta \), namely:

\[ C_1 = \frac{W}{H} \]  

(11)

(2) Energy utilization reliability index \( C_2 \)

\[ C_2 = \frac{E_t}{E} \]  

(12)

Where \( E \) is the amount of energy used; \( E_t \) is the amount of energy reserves. For non-renewable energy, it will decrease with the increase of mining and utilization time, while \( E \) increases with time, \( C_2 \) will become smaller and smaller. For renewable energy, \( E_t \) can be considered to be a fixed value, much larger than the utilization amount \( E \), and the value of \( C_2 \) is very large.

(3) Environmental pollution index \( C_3 \)

\[ w = T_0 \Delta S \]  

(13)

Among them, \( T_0 \) is the environmental standard temperature, \( \Delta S \) is the entropy production caused by the energy utilization process to the environment, including non-isothermal heat transfer entropy production, emission diffusion mixed entropy production, etc.

3.4. Coordination indexes D

Transformer load coordination D

Transformer load coordination can be expressed as:

\[ D_1 = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{m_i} (\eta_{ij} - \eta_{T_{avg}})^2} \]  

(14)

In the formula, \( n \) is the number of transformer substations, \( m_i \) is the \( i \)-th transformer of the \( m \)-th substation, \( \eta_{ij} \) is the load rate of the \( ij \)-th transformer, \( \eta_{T_{avg}} \) is the average load rate of all transformers.

4. Appendices

This paper expounds the specific meaning of "source network load" coordination from the perspectives of source grid coordination, grid load interaction, source load interaction and "source grid load" index system of active distribution network. The PCA method is used to determine the evaluation index, and the AHP is used to establish the evaluation index system from four aspects of safety, economy, environment and coordination, and each index is explained and calculated in detail. The index system can evaluate ADN objectively and comprehensively, and has higher practical value in the new distribution network with coordinated development of multiple energy sources.
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