Research and Application of Diversified Load Access Adapting to Distribution Network Planning

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Abstract The distribution network planning method mainly focuses on the division of power supply areas, without predicting the load of the distribution network, which affects the final planning effect. Therefore, this article studies the research and application of diversified load access in distribution network planning. Establish a diversified load access adaptive distribution network planning model, identify the main stakeholders in distribution network planning, and minimize the overall operating cost as the objective function to minimize the cost of distribution network planning, coordinated with its power flow distribution. Through numerical examples, it has been verified that the planning method can meet the needs of practical economic benefits and can be applied in practical life.

Keywords Diversified load access adaptation · distribution network planning method · tidal current distribution

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1 Introduction

Through flexible dispatching in different planning areas, the loss of distribution network is reduced and the economic benefits of distribution network operation are higher. At present, the distribution network often suffers from line faults, resulting in large-scale blackouts, which seriously affects the living electricity environment of residents [1, 2]. Therefore, this paper designs a diversified load access adaptive distribution network planning method. From the perspective of diversified load access, the planning environment will be more in line with the actual needs of the power grid and provide power security for the surrounding residents.

2 Design of Diversified Load Access Adaptive Distribution Network Planning Method

2.1 Extraction of Diversified Load Output Characteristics of Distribution Network

This paper analyzes the load data of renewable energy generation and reasonably plans the operation mode of distribution network according to the load output. This paper divides the diversified load of the distribution network into photovoltaic output and wind power output to ensure the effectiveness of distribution [3–6]. The output prediction of photovoltaic power generation includes global solar radiation theory and photovoltaic effect [7]. Under the condition of ignoring light scattering and occlusion, the light radiation intensity is as follows:

$$I_t = I_0 \sin \alpha \tag{1}$$

In formula (1), I_t is the light intensity ignoring other conditional factors; I_0 is the light radiation intensity vertically irradiated by the sun; α is the solar altitude angle. Combining I_t by applying photovoltaic effect, the characteristics of photovoltaic power generation output are obtained:

$$P_t = P_s \frac{(R, k, I_t)}{I_0}[1 + \alpha(T - T_t)] \tag{2}$$

In formula (2), R is the state coefficient; P_t is the output of photovoltaic at time t; T is the actual temperature; P_s is the PV rated output; T_t is the standard temperature; k is the clear sky coefficient. Wind power generation is determined according to the relative position of the fan shaft and wind direction, and the speed of air flow directly determines the output of wind power conversion [8–10]. In this paper, Weibull distribution is used to describe the wind speed characteristics, and its probability density function is as follows:

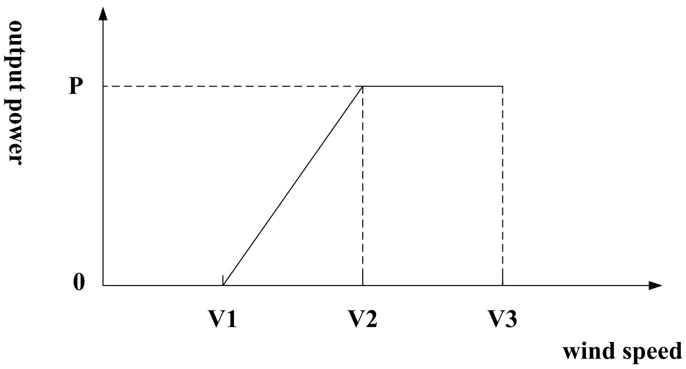

Fig. 1 Output power characteristic curve

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3}$$

In formula (3), $f(v)$ is the complementary function of cumulative distribution function; c is a scaling function; v is the air flow rate on site. According to $f(v)$, the wind power load output is determined as follows:

$$P_v = \begin{cases} 0 \\ (A + Bv + Cv^2)P_r \\ P_r \end{cases} \tag{4}$$

In Eq. (4), P_v is the wind power load output; A, B, and C are the parameters of rated power generation curve; P_r is the maximum power output of a wind turbine under standard operating conditions. According to A, B, and C, characteristic variation relationship between active power of wind turbines and air flow velocity under different air flow velocities is obtained as shown in Fig. 1.

As shown in Fig. 1, P is the maximum power output of a wind turbine under standard operating conditions; $V1$ is the minimum wind speed at which the wind turbine begins to rotate and generate electricity; $V2$ is the wind speed at which the output power of the wind turbine reaches the rated power; $V3$ is the maximum wind speed at which a wind turbine stops operating to protect its own safety. When $V < V1$ or $V \geq V3$, the output power of the distribution network $P = 0$, which cannot ensure the planning benefits. When $V1 \leq V < V2$, the output power increases with the increase of wind speed; When $V2 \leq V < V3$, the output power remains stable, which can ensure the benefits of distribution network planning.

2.2 Build a Diversified Load Access Adaptive Distribution Network Planning Model

Based on the characteristics of diversified load access processing, this paper finds out the main stakeholders of design of power supply system: design and plan the power supply system in an economical and efficient manner by minimizing the cost of power dispatch as the objective function. In the planning process, this paper takes the minimization of comprehensive costs as the objective function of the planning model in terms of coordinating the minimization of comprehensive costs, the maximization of benefits for each entity, operational safety, and reliability assurance, and the expression is as follows:

$$\min\ C_n = C_{n,s} + C_{nJ} + C_{n,o} + C_{n,e} - F_c \tag{5}$$

In formula (5), $\min\ C_n$ is the digital representation of minimized power dispatch costs; $C_{n,s}$ is a long-term construction investment in the power supply system; C_{nJ} is the energy loss expenditure in the process of power transmission and distribution; $C_{n,o}$ ensures the stable operation of the power system and the various costs required for electricity supply; $C_{n,e}$ is the system failure expenses for distribution networks; F_c is the benefit of carbon dioxide emission reduction. The network loss cost is expressed as:

$$C_{nJ} = \sum_{s=1}^{S} T_s \sum_{t=1}^{24} C_{n,s} \Delta t \tag{6}$$

In formula (6), S is a typical planning scenario; T_s is the duration of scenario s; Δt is the unit time interval. Combined with the support conditions of ESS for partial loss of power load in the distribution network, this paper divides the distribution shortage into three cases: First, the power grid is disconnected after fault; second, the fault is power grid disconnection; third, island nodes access ESS. The electrical constraints of the distribution network planning model are added, and the distribution network planning model is built. The model expression is as follows:

$$P_{s,j} = U_{s,j} \sum_{j=1} \min C_n (G_{ij} \cos\theta_{ij} + C_{nJ} \sin\theta_{ij}) \tag{7}$$

In Eq. (7), $P_{s,j}$ is the distribution network planning model expression; $U_{s,j}$ is the voltage of node j in the scene; G_{ij} is the power transmission constraint from node i to node j; θ_{ij} is the line transmission power limit. Staying $P_{s,j}$ under the maximum conditions, the distribution network needs to meet the power flow constraints to ensure the economic benefits of distribution network planning.

2.3 Coordinate Power Flow Distribution of Distribution Network Planning

Under the constraints regarding the overall architecture of the power supply system, this article maximizes its design benefits while ensuring its operational economy because of profits. Thus, the power flow constraint conditions are as follows:

$$S_{s,t,j} = S_{s,t-1,j} - \mu_c \Delta t P_{s,j} \quad (8)$$

In Eq. (8), $S_{s,t,j}$ is the power flow constraint condition of the planning model; $S_{s,t-1,j}$ is the power flow distribution of node j at time $t-1$ in scenario s; μ_c is the charging efficiency. In this paper, diversified load access nodes and capacities that meet various constraints will be transferred to distribution enterprises under different scenarios to optimize the economic benefits of distribution to the greatest extent.

3 Example Analysis

3.1 Experiment Preparation

This experiment simulates the distribution network as a test example. The power node is node 1, the original load node is 2–33, and the new load node is 34–38. The solid line represents the original line and does not need to be upgraded or replaced; dotted lines represent replaceable lines, and dotted lines represent lines to be built. The distribution network structure is shown in Fig. 2.

As shown in Fig. 2, this paper selects the typical operation scenario of distribution network and sets the rated capacity of each DG as 100 kW. Considering the original load size of the distribution network, set the replacement circuit as 5, 6, 7, 16, 18, 19, 25, 26, 27, 31. The new node numbers are 34, 35, 36, 37, 38. Among them, the reactive power is 120 kvar, and the accessible node locations are 25, 26, 27, 28. The accessible node locations are 29, 30, 31, 32, the reactive power is 75 kvar, and the accessible node locations are 6, 7, 8, 22. The active power of node 37 is 100 kW, the reactive power is 60 kvar, and the accessible node locations are 9, 10, 11, 12. The active power of node 38 is 90 kW, and the reactive power is 30 kvar. The accessible node locations are 13, 14, 15, 16. Under this condition, the parameters of the lines to be planned and the replacement lines are set as shown in Table 1.

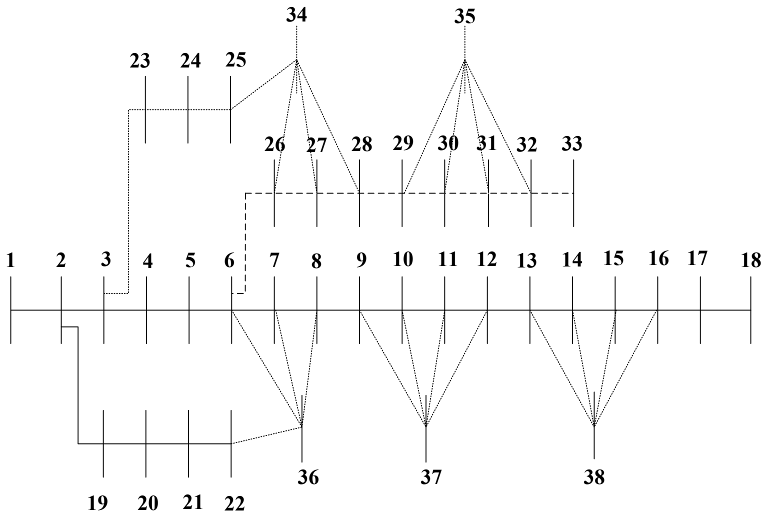

Fig. 2 Schematic diagram of distribution network structure calculation example

As shown in Table 1, 34 nodes replace 26, 27, and 28 nodes; 35 nodes replace 29 and 30; nodes 5, 6, and 7 take over the work of nodes 6, 7, and 8; node 17 takes over the work of node 16. DG configuration is 12 (0,5), 17 (4,2), 29 (0,3), 32 (1,2). The replacement lines are numbered 5, 6, 7, 18, 25, 31, and the new load access positions are 6, 11, 13, 22, 29. In order to ensure the effectiveness of distribution network planning, this experiment carried out distribution network planning under the condition that DG grid connection was considered to ensure the effectiveness of this grid connection collaborative planning.

3.2 Experimental Results

Under the above experimental conditions, this paper randomly selects the locations of multiple load access nodes and analyzes the network loss of distribution network planning in four seasons of a year: the conventional distribution network planning method based on distributed energy access and the conventional distribution network planning method based on source network storage collaboration.

As shown in Table 2, the diversified load access nodes are set as 1–24, 18–33, 23–27, and 9–13 in this paper, the planned capacity of the distribution network after the distribution network planning is different, and the network loss changes accordingly.

Table 1 Parameters of lines to be planned and alternative lines

Line number	Node numbers at both ends		Branch impedance (Ω)		Investment cost (10,000 yuan/km)	Line status
	Extreme point 1	Extreme point 2	*R*	*X*		
34	34	26	0.3450	0.1874	10	New line
35	34	27	0.3881	0.2108	10	New line
36	34	28	0.1254	0.0681	10	New line
37	35	29	0.4142	0.2249	10	New line
38	35	30	0.3131	0.1701	10	New line
5	5	6	0.8190	0.7070	5.5	Replaceable circuit
6	6	7	0.1872	0.6188	5.5	Replaceable circuit
7	7	8	0.7114	0.2351	5.5	Replaceable circuit
16	16	17	1.2890	1.7210	5.5	Replaceable circuit
18	2	19	0.1640	0.1565	5.5	Replaceable circuit
19	19	20	1.5042	1.3554	5.5	Replaceable circuit
25	6	26	0.2030	0.1034	5.5	Replaceable circuit
26	26	27	0.2842	0.1447	5.5	Replaceable circuit
27	27	28	1.0590	0.9337	5.5	Replaceable circuit
31	31	32	0.3105	0.3619	5.5	Replaceable circuit

Table 2 Experimental results

Diversified load access node location	Season	Conventional distribution network planning method based on distributed energy access		Conventional distribution network planning method based on source network storage collaboration		The diversified load access adaptive distribution network planning method designed in this article	
		Network losses in distribution network planning (kW)	Distribution network planning capacity (kVA)	Network losses in distribution network planning (kW)	Distribution network planning capacity (kVA)	Network losses in distribution network planning (kW)	Distribution network planning capacity (kVA)
1–24	Spring	808.621	1459.237	632.615	1647.645	321.432	2056.762
	Summer	716.824	1454.492	654.784	1678.155	326.465	2083.311
	Autumn	1074.176	1460.684	732.754	1636.467	345.746	2040.734
	Winter	950.452	1459.816	693.124	1652.682	362.612	2081.908
18–33	Spring	580.826	1712.855	562.154	1979.371	354.154	2146.543
	Summer	1034.351	1719.962	613.546	1980.774	343.746	2154.682
	Autumn	1013.544	1703.111	754.356	1981.862	328.461	2136.688
	Winter	1195.293	1704.005	741.614	1977.862	345.656	2121.966
23–27	Spring	1192.452	1690.381	714.536	1879.947	328.461	2032.697
	Summer	1177.996	1689.214	715.463	1847.700	333.546	2045.669
	Autumn	1196.063	1687.423	815.462	1906.724	312.466	2031.478
	Winter	1198.562	1686.838	854.513	1864.512	325.135	2044.875
9–13	Spring	861.912	1759.702	715.414	1906.666	362.748	2253.457
	Summer	541.011	1758.833	642.545	1903.025	377.546	2245.682
	Autumn	549.093	1757.131	536.754	1907.586	358.346	2216.748
	Winter	971.605	1757.243	647.132	1879.191	372.135	2232.564

4 Conclusion

This article designs a diversified load access adaptive distribution network planning method. From the aspects of load output, planning models, and power flow balance, planning the distribution network is more in line with practical needs.

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