Research on Key Technologies of Connecting Various Distributed Power Sources to Smart Grid

Xuejian Guo\textsuperscript{1}, Yong Liu\textsuperscript{1}, Ronghua Yu\textsuperscript{1}, Yintie Zhang\textsuperscript{2, *}, Wei Zhang\textsuperscript{2}

\textsuperscript{1}State Grid International Development Co., Ltd, China
\textsuperscript{2}Information Systems Integration Branch, NARI Technology Co., Ltd, China

*Corresponding author e-mail: zhangyintie@sgepri.sgcc.com.cn

Abstract. In order to solve the impact of distributed power supply (DG) access on the fault location and voltage quality of distribution network, the paper combines the characteristics of random fluctuating DG grid connection, and studies a way to use SVG dynamic reactive power compensation to maintain randomness The control strategy of the voltage stability of the fluctuating distributed power supply node, based on the detailed analysis of the determination method of the SVG capacity, a new optimization strategy for the distribution system containing different types of DG is proposed, that is, using the static reactive power generator VG and output-adjustable DG's own reactive power capacity for fine-tuning control, the use of traditional static compensation device comprehensive adjustment optimization strategy. At the same time, the economic optimization operation model of the distributed energy system is analysed to verify the feasibility of the optimization strategy.

1. Introduction

With the gradual practical application of smart grids in China, distributed power sources (DG) with good compatibility with them are gradually applied to distribution networks. The integration of DG into the power distribution system has a series of advantages such as adjusting the peak-to-valley difference of the power grid, energy storage, saving investment, and providing uninterrupted power supply for important loads. However, the incorporation of DG changes the power flow direction, line current and node voltage in the original power grid. For random fluctuating DGs whose output is greatly affected by environmental factors, the node voltage of the power grid tends to fluctuate frequently. Therefore, it is very necessary to study key technologies such as relay protection and reactive power optimization of distribution networks containing DG and propose new countermeasures [1].

2. Technical analysis of distributed power supply

Distributed generation (DG) refers to a small-scale power generation system directly connected to the distribution network or distributed near the user site. DG is mainly used to meet specific needs and can generate electricity economically, efficiently, and reliably. Its energy form It mainly includes solar energy, wind energy, internal combustion engine, combined heat and power, micro gas turbine and fuel cell [2].

With the further opening of the electricity market and the year-on-year decrease in the cost of distributed generation, DG will occupy an increasing share of the power supply of the power system.
Most of the urban and rural power distribution systems in China are still dominated by radial chain structures. With many DGs connected to the distribution network, the distribution network has changed from a radial network to an interconnected network with power and users, such as Figure 1. This will have a great impact on the structure and operation of the distribution system. The access of DG makes the flow of each branch in the distribution network no longer flow in one direction, thus changing the operation mode of the traditional power system.

3. A variety of key technologies for distributed power grid connection

3.1. Basic technical requirements of distributed power grid connection
In order to ensure that the distributed power supply maintains its due quality and efficiency in the distribution network, we need to make the distributed power supply meet certain technical requirements during the access process, so that the distributed power supply has good economic benefits and application prospects. For example: First, ensure that the voltage of the distribution network is qualified, so that the voltage offset caused by the distributed power supply access to the distribution network is within the allowable range, and the safety and order of the distributed power supply access work is fully guaranteed. Secondly, the current of the power distribution equipment in the power distribution network during normal operation is kept at the rated value, and the current with dynamic and thermal stability is within the appropriate value. Finally, keep the power quality of the distributed power source connected to the distribution network qualified, so that it causes various changes in the voltage within the specified value. For example: voltage flicker, harmonics, swells and dips are within the allowable range [2].

3.2. Line flow
Under the influence of frequent start and stop and weather conditions, there may be a large-scale clustering phenomenon in the output power. The load flow of the distribution line will continue to undergo large changes due to these effects, resulting in large-scale changes in the flow. The three-phase asymmetry makes the changes appear random, as shown in Figure 2. Ordinary power flow algorithms will no longer be applicable. Two solutions are currently proposed for this.
Use load tracking control to ensure that the power flow on the feeder remains unchanged, so that the traditional power flow algorithm can be continued. It is a multi-agent control system based on coordinated control of the output of diesel generator systems and energy storage capacitor banks to compensate for the output changes and load changes of PV power generation and wind power generation systems, to keep the load on the line unchanged. Tracking method. However, due to the use of computer network communication between the diesel generator and the energy storage capacitor system, there is a problem of communication delay, which will reduce the control performance, so this method has the problem of how to compensate for the communication delay [3].

3.3. Key technologies affected by voltage

3.3.1. PI node with constant P and constant current amplitude I. The distributed power source connected to the grid through the voltage control inverter is processed as a PV node, and the distributed power source connected to the grid through the current control inverter is processed as a PI node; the corresponding reactive power can be obtained from the voltage obtained in the previous iteration. The constant current amplitude and active power are calculated as follows:

\[ Q_{k+1} = \sqrt{I^2 (e_k^2 + f_k^2)} - P^2 \]  

Where \( Q_{k+1} \) is the reactive power value of the distributed power supply at the k + 1 iteration, and \( e_k \), \( f_k \) is the real and imaginary parts of the voltage obtained at the k iteration; I is the magnitude of the constant current amplitude of the distributed power supply value; P is the constant active power value.

3.3.2. P is constant, U is indefinite, and Q is limited by P and U. Through automatic grouping and switching of capacitor banks, the power factor of the wind farm can be guaranteed to meet the requirements. The output reactive power of the capacitor bank is also related to the amplitude of the node voltage. Therefore, P-Q (v) model should be used to represent such nodes. The output active power \( p_e \) given by the P-Q (v) node is the output active power of the asynchronous motor, and the node voltage U is obtained after each iteration.
\[ s = r(U^2 - \sqrt{U^4 - 4x^2 P^2}) \]

\[ Q' = \frac{r^2 + x^2 (x_m + x_o) s^2}{r x_m s} P e \]

4. Economic optimization operation model of distributed energy system

The distributed energy system economic optimization operation model is established under the condition that the system satisfies the normal operation and load consumption of each distributed energy, through reasonable planning to arrange the output plan of each unit and timely load adjustment, so that the total power of the distributed energy system the operating cost is minimal. The model is a complex, non-linear, multi-objective optimization problem. Its economic operation mainly considers economic costs, environmental costs, and backup costs of distributed energy. The consideration of demand-side controllable resources is mainly reflected in demand. Side load constraints. To sum up, the cost function of economic optimization of distributed energy system is:

\[ \min C = C_F + C_H + C_B \]

Power generation cost \( C_F \) is:

\[ C_F = \sum_{t=1}^{N_t} \sum_{i=1}^{M} \left[ c_f F_i(P_i) + O_i(P_i) + C_{dep}(P_i) \right] + \]

\[ \sum_{t=1}^{N_t} \left[ C_{buy}(t) - C_{sell}(t) \right] P_{grid}(t) \]

Among them, \( C_F \) is the cost of power generation; \( N_t \) is the total number of calculations; \( c_f \) is the fuel price; \( F_i(P_i) \) is the fuel consumption of the unit; \( O_i(P_i) \) is the operation and maintenance cost of the unit; \( C_{dep}(P_i) \) is the depreciation cost of the unit; \( C_{buy} \) and \( C_{sell} \) are respectively at time The electricity purchase price and the on-grid electricity price in the period; \( P_{grid} \) represents the power value exchanged with the grid during the \( t \) period. The environmental cost \( C_H \) is:

\[ C_H = \sum_{i=1}^{N_t} \sum_{k=1}^{M} 10^3 \beta_i \sum_{i=1}^{M} \alpha_{ik} P_i(t) + \alpha_{grid,k} P_{grid}(t) \]

In the formula: \( C_H \) is the environmental pollution emission treatment cost; \( k \) is the pollutant type number; \( \alpha_{ik} \) is the pollutant emission factor of different unit types; \( \alpha_{grid,k} \) is the pollutant emission factor of the system power generation; \( \beta_i \) is the cost of pollutant treatment. The compensation fee \( C_B \) is:
\[ C_B = \sum_{t=1}^{N_t} \left( \lambda_{w,t}^o p_{w,t}^o + \lambda_{w,t}^u p_{w,t}^u + \lambda_{s,t}^o p_{s,t}^o + \lambda_{s,t}^u p_{s,t}^u \right) \]  

(7)

In the formula: \( C_B \) is the reserve capacity fee; \( p_{w,t}^o \) is the load deficit caused by the excessively large wind power dispatch value; \( p_{w,t}^u \) is the nest power caused by the too small wind power dispatch value; \( p_{s,t}^o \) is the load deficit caused by the excessive photovoltaic power dispatch value; \( p_{s,t}^u \) is the amount of electricity caused by too small photovoltaic power generation dispatch value; \( \lambda_{w,t}^o \) is the wind power over-dispatch compensation coefficient; \( \lambda_{w,t}^u \) is the wind power under-dispatch compensation coefficient; \( \lambda_{s,t}^o \) is the photovoltaic power over-dispatch compensation coefficient, \( \lambda_{s,t}^u \) is the photovoltaic power under-dispatch compensation coefficient.

Demand side load constraints: Demand side load is mainly divided into fixed load, random load, and transferable load. The fixed load is the user's minimum load demand, which can be predicted based on historical values; the random load is the user's temporary demand load, which is unpredictable; the transferable load is the user's load that is transferred from a certain time period to another time period, with Controllability, so rationally arranging transferable loads is the key to demand-side management in distributed energy systems.

\[
\begin{align*}
O_i^T (t,t+\Delta t) &= \Gamma_i^T (t,t+\Delta t) \Delta O_i^T \\
\sum_{i=1}^{N_i} O_i^T (t,t+\Delta t) &\leq O_{i,max}^I(\Delta t) \\
\sum_{i=1}^{N_i} O_i^O (t,t+\Delta t) &\leq O_{i,max}^O (\Delta t) = P_i^T (\Delta t)
\end{align*}
\]  

(8)

Where: \( O_i^T (t,t+\Delta t) \) is the amount of load transferred during time period \( \Delta t \); \( \Delta O_i^T \) is the unit transfer amount of type \( i \) load during time period \( \Delta t \); \( \Gamma_i^T \) is the number of units that can transfer load during time period \( \Delta t \); \( O_{i,max}^I \) and \( O_{i,max}^O \) are the maximum input and output of the load in the \( i \) period of the time period \( \Delta t \); \( P_i^T \) is the load of the first load before the \( i \) transfer [4].

5. Simulation analysis of voltage fluctuation in distribution network

In order to further analyse the impact of distributed power access on the voltage fluctuation of the distribution network, an IEEE13 node distribution network model with typical representatives is built in the simulation software PSCAD / EMTDC, as shown in Figure 3. Table 1 shows the distribution of the output forecast error at various periods when the distributed photovoltaic capacity is 600kW.
In order to analyse the impact of distributed power access on the voltage fluctuation of the distribution network under different capacities, node 8 is selected as the access point, which is connected to distributed photovoltaic with capacity of 300kW, 600kW, 900kW and distributed with capacity of 400kW, 800kW, 1200kW Wind power is connected to the grid when \( t = 2s \). The voltage fluctuations of nodes 3, 4, 8, and 9 are shown in Table 2, and the simulation diagram of the voltage fluctuations of node 8 is shown in Figure 4 [5].

### Table 2. Voltage fluctuations under different capacities

| Access capacity (kW)     | Voltage fluctuation node3 | Voltage fluctuation node4 | Voltage fluctuation node8 | Voltage fluctuation node9 |
|--------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| Distributed photovoltaic | 300 0.762% 0.753% 1.125% 1.106% | 600 1.432% 1.415% 2.016% 2.001% | 900 2.098% 2.001% 3.175% 3.029% | 400 0.932% 0.916% 1.369% 1.345% |
| Distributed wind power   | 800 1.739% 1.717% 2.583% 2.559% | 1200 2.671% 2.510% 3.688% 3.653% |
Figure 4. Simulation diagram of voltage fluctuation

From the results of Table 2 and Figure 4, the voltage fluctuation of the distribution network has a great relationship with the access capacity of the distributed power supply. The larger the access capacity, the greater the voltage fluctuation of the distribution network, and the voltage at the access point fluctuations are the most severe, and the further away from the access point, the less affected.

6. Conclusion
The voltage fluctuation of the distribution network has a great relationship with the size of the access capacity of the distributed power supply. The larger the access capacity, the greater the voltage fluctuation of the distribution network. The farther the access point is, the smaller the impact will be; the greater the short-circuit capacity of the node connected to the distributed power supply, the smaller the voltage fluctuation caused by the distribution network. The research results of this paper can provide effective theoretical reference and technical guidance for the access of distributed power in the distribution network.

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