Voltage Variation of Smart Grid with Distributed Power

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Abstract. In order to solve the voltage regulation problem of the smart grid with distributed power. A convergence power flow program suitable for DG-containing systems based on Newton algorithm was written. The result was that Type-A DG will reduce the voltage level, while Type-B and Type-C DG will support the system voltage level. In the simplified modeling and analysis method of distribution network, triangular load distribution model is better than uniform load distribution model. The effect of DG on the voltage distribution on the feeder is closely related to the total capacity and access position of DG.

Keywords: Smart Grid, Distributed Generation, Power Flow Calculation, Voltage Analysis

1. Introduction
One of the fundamental characteristics that distinguishes smart grid from traditional grid is the support for large-scale access to distributed power. DG (Distributed Generation) technology has the advantages of small investment, clean environmental protection, power supply reliability, and flexible power generation methods. The emergence of DG has changed the one-way mode of power distribution system flow, made the flow unpredictable, and also caused a series of power quality problems, which affected the reliability of system operation. This paper analyzes and studies the law of voltage changes after the distributed power is connected to the grid.

2. Development Status
Distributed power and energy storage devices have been very common in the United States. Some old power plants will be shut down and the demand for new energy will increase [1]. DG has the characteristics of high reliability, high quality, high efficiency, and flexibility, which can meet a series of requirements of industry and commerce, housing, etc. It is expected that a few years later, it will provide new opportunities for peak shaving and small company waste heat generation. Europe first applied DG in the world. At present, the capacity of Denmark, Finland, Norway and other countries have approached or exceeded 50% of their total installed power generation capacity. In Germany, the largest DG application in Europe, wind power installed capacity reached 23 million kW at the end of 2008, and solar power generation installed capacity reached 5.4 million kW. The research on DG in China is relatively small, and most of them focus on the power supply itself. The research on distributed power to power system planning and operation focuses on qualitative analysis [2].
3. Methodology

3.1. Interface Model of DG and Grid Connection Requirements

The power generation part is directly connected to the high-voltage network for unified dispatching, which belongs to centralized power generation, rather than distributed power generation. The International Large-scale Electric Power System Committee defines distributed power generation as: unplanned or centrally dispatched power production methods, which are usually connected to the distribution network, and the general generation scale is between 50-100MW.

In different research fields, DG has different classification methods. Table 1 is a partial classification of distributed power generation technology [3], where “*” indicates that there is a distributed power source of this scale.

| Technical support         | Non-renewable energy | Output | Small | Medium | Large |
|---------------------------|----------------------|--------|-------|--------|-------|
| Hydropower                | Renewable Energy     | AC     |       | *      | *     |
| Wind Power                | Renewable Energy     | DC     |       | *      | *     |
| Fuel Power                | Fossil fuels         | DC     | *     | *      | *     |
| Biomass Power Generation  | Renewable or Waste Energy | AC |       | *     | *     |

The interface between DG and the distribution network generally has three forms [4]: synchronous generator, asynchronous generator, DC/AC or AC/AC converter, which is shown in Fig. 1. During power flow calculation, the voltage-controlled DG is processed as the PV node, and the power factor-controlled DG is processed as the PQ node [5]. The DG connected to the grid through a rectifier or inverter is treated as a power electronic converter.

![Figure 1. Converter interconnects with the grid](image)

\[
\begin{align*}
P_A &= \frac{1}{s} \left( V^2 + i^2 X_a \right) \\
Q_A &= \frac{V^2}{X_m} + i^2 X_a \\
P_B &= \frac{EV}{X_d} \sin \delta \\
Q_B &= \frac{EV}{X_d} \cos \delta - \frac{V^2}{X_d} \\
P_C &= \frac{V_{ac} V_s \sin(\delta - \theta)}{X_T} = \frac{m U_{fe} V_s}{X_T} \sin \psi \\
Q_C &= \frac{V_{ac} V_s \cos(\delta - \theta)}{X_T} = \frac{m U_{fe} V_s \cos(\delta - \theta)}{X_T} - \frac{V_s^2}{X_T} 
\end{align*}
\]
The above formulas are the equations of the asynchronous generator (A), the synchronous generator (B), and the power electronics interface model (C) in that order.

3.2. Node Types and Processing Methods of DG in Power Flow Calculation

For power distribution systems, it is usually assumed that the voltage difference between adjacent nodes is small and there is no grounding branch to enable Newton-Raphson algorithm.

\[
\begin{align*}
\Delta P_i &= P_i - V_i \sum_{j=1}^{n} V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \\
\Delta Q_i &= Q_i - V_i \sum_{j=1}^{n} V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) \\
H_{ij} &= \frac{\partial \Delta P_i}{\partial \theta_j} = V_i V_j B_{ij} \cos \theta_{ij} \\
N_{ij} &= V_j \frac{\partial \Delta P_i}{\partial V_j} = -V_i V_j G_{ij} \cos \theta_{ij} \\
J_{ij} &= \frac{\partial \Delta Q_i}{\partial \theta_j} = V_i V_j G_{ij} \theta_{ij} \\
L_{ij} &= V_j \frac{\partial \Delta Q_i}{\partial V_j} = V_i V_j B_{ij} \cos \theta_{ij}
\end{align*}
\] (2)

3.3. Analysis of Voltage Changes in Distribution Networks by Distributed Power Sources

Because the load distribution on the line is rarely uniform, a triangular load model is used, which is shown in Fig. 2. Voltage loss \( \Delta U \) consists of two parts: \( \Delta U_{sd} \) and \( \Delta U_{DG} \), where \( \Delta U_{sd} \) is caused by the system power alone, including two parts: \( \Delta U_{sd1} \) is caused by the equivalent comprehensive load after point d, \( \Delta U_{sd2} \) is caused by the load distributed in a triangular form before point d. \( \Delta U_{DG} \) is caused by DG alone.

\[ \Delta U_{sd} = \Delta U_{sd1} + \Delta U_{sd2} \]

4. Analysis and Results

4.1. Comparison of Whether DG Is Connected

Model check diagram without DG is shown in Fig. 3, and with DG at node 6 is shown in Fig. 4. From the following comparison, it can be seen that the result of the voltage distribution based on the
triangular load model is consistent with the result of strict power flow, and it is far superior to the result of uniform load distribution model.

![Figure 3. Model check diagram without DG](image1.png)

![Figure 4. Model check diagram with DG at node 6](image2.png)

In the graph, Curve 1: strict power flow calculation, Curve 2: triangle load, Curve 3: uniform load

4.2. Effect of DG on Voltage
DG is connected to node 6, the input data is shown in Table 2 and the results are shown in Fig. 5.

| Program | DG’s contribution | DG’s capacity |
|---------|-------------------|---------------|
| 1       | 0                 | 0             |
| 2       | 30%               | 0.9+j0.4359   |
| 3       | 65%               | 1.95+j0.9444  |
| 4       | 100%              | 3+j1.4530     |

![Figure 5. Test results](image3.png)
When the position of DG is unchanged, the voltage level will increase as the access capacity increases. Similarly, using the control variable method, we can get a negative correlation between the voltage level and the distance of DG.

5. Conclusion
Type-A DG will reduce the voltage level, while Type-B and Type-C DG will support the system voltage level. In the method of simplified modeling and analysis of distribution network, the triangular load distribution model is better than the uniform load distribution model. The voltage distribution on the feeder has a positive correlation with the total capacity of the DG and a negative correlation with the distance. It is necessary to reasonably arrange the DG and determine a specific voltage regulation scheme.

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