Based on MATLAB Simulation to Analyze the Online Source Interaction of the Photovoltaic Power Grid

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Abstract. Firstly, the influence of voltage fluctuation and power loss on power flow distribution is analyzed by theoretical formula. Then, under the simulation experiment of MATLAB, the related problems arising from the power quality of the distribution network when the distributed photovoltaic power generation is connected to the power grid are studied, and the influence of voltage fluctuations and harmonics on it is analyzed. Through simulation test, the corresponding voltage, current and power waveforms are obtained. To study the effects of the waveform, and incorporate FFT analysis tools to observe harmonic content. The simulation results show that the node voltage will increase with the reverse current phenomenon of pv and netease. In the process of grid-connection, a large number of higher harmonics are difficult to filter completely.

1. Introduction

With the development of economy, energy sources are becoming increasingly scarce. As a clean and renewable energy, photovoltaic power generation has gradually entered people's life\cite{1}. Distributed photovoltaic power generation is one of the main utilization methods, so to study the effect of distributed grid-connected photovoltaic is imminent\cite{2}. Distributed generation through the inverter connected to the electricity grid which affect the power quality\cite{3}. In literature \cite{4}, the windowed interpolation basis 2FFT algorithm is used to detect and analyze various parameters of harmonics more clearly, and the harmonics of the grid-connected photovoltaic model are analyzed in the same way. Similarly, voltage distribution and fluctuation are also a manifestation of the influence of distributed photovoltaic grid connection on power quality\cite{5}. In literature \cite{6}, the forward and backward generation algorithm was used to calculate the power flow of the distributed photovoltaic integrated into the 10kV distribution network, and the dynamic voltage change of the distributed photovoltaic connected to the grid was simulated by MATLAB. Therefore, it is necessary to study the influence of distributed photovoltaic power grid connection. The relevant influence studied in this paper will provide data reference and relevant Suggestions for future distributed photovoltaic power grid connection technology.

Based on MATLAB simulation experiment, this paper studies the power flow related to distributed photovoltaic grid-connection, and adopts kirchhoff's first law calculation method to reflect the impact of distributed photovoltaic grid-connection on the voltage drop and power loss of the system. The output voltage and power of photovoltaic power generation are observed by simulating the grid-
connected model of photovoltaic power generation, and the voltage fluctuation and harmonic influence of photovoltaic power generation connected to the power grid are analyzed through waveforms.

2. A brief analysis of distributed photovoltaic power generation

2.1. Photovoltaic power generation

Composition of photovoltaic power generation system: photovoltaic array, battery, inverter, controller and other parts. The core of the photovoltaic power generation system is the photovoltaic module, which receives sunlight and generates a photocurrent (direct current), which is converted into usable alternating current (ac) by an inverter. On the other hand, energy can also be stored in batteries and other energy storage devices, such as when the need to release[7].

2.2. Grid-connection principle and characteristics of distributed photovoltaic power generation

![Figure 1 Structure diagram of photovoltaic power generation system](image1)

Figure 1 is the structure diagram of a typical photovoltaic power generation system. The photovoltaic panel directly converts light radiation into electric energy. The stronger the radiation, the greater the current. Figure 2 shows the equivalent simplified circuit of the photovoltaic power generation system[8],

![Figure 2 The equivalent circuit of a photovoltaic power system](image2)

$I_p$ is the photocurrent generated by the solar panel, $I_{PV}$ is the output current of the photovoltaic array, $C_{PV}$ is the filter capacitance at the outlet side of photovoltaic array, $U_{PV}$ is the dc voltage on both sides of the capacitor, $L_{PV}$ is the filter inductance on the ac side of the inverter, $R_{AC}$ is the equivalent resistance of the filter inductance, $C_{AC}$ is the filter capacitance of the ac side, $U_{AC}$ is the voltage of the filter after passing through the transformer (transformer ratio N), $L_S$ and $R_S$ are the equivalent inductance and equivalent resistance from the transformer to the grid node, respectively. $I_S$ is the current integrated into the grid by the photovoltaic power station, $U_S$ is the bus voltage of the union point.

The current relationship of photovoltaic panels:

$$I_p - I_{PV} = I_0 (\exp \frac{qu}{AkT} - 1)$$

(1)
Where: \( I_0 \) is the reverse saturation current of the PN junction, \( k \) is the boltzmann constant 0.86×10⁻³eV/K, \( q \) is the electron charge 1.6×10⁻¹⁹C, \( A \) is the curve constant of the PN junction, and \( T \) is the absolute temperature.

2.3. Analysis of influence of photovoltaic grid-connection on power flow distribution

The user side of the traditional distribution network is not connected to any power supply. After the access of the distributed photovoltaic power generation system, the power grid becomes a multi-source network, so there may be counter-current and complex voltage distribution[9].

![Figure 3](image)

**Figure 3** Schematic diagram of access node of distributed photovoltaic power generation system to distribution network

As shown in figure 3 N nodes distribution feeders L, the NTH node voltage is \( V_N \), the initial voltage is \( V_0 \), the impedance between nodes is set to \( Z_i = R_i + jX_i \) (i=1,2,3...N), the voltage drop uniformly release feeder point end, the PV system capacity at node \( i \) is \( P_{pv} + jQ_{pv} \). The rated voltage is \( U_N \), calculation of power loss and voltage loss at node:

\[
\Delta S_i = \frac{S_i}{U_N} (R_i + jX_i) \quad (i=1,2,3...N)
\]

\[
\Delta S_i \text{ is the power loss between } i-1 \text{ and } i, S_i \text{ is the power of } i \text{ node, } R_i \text{ is the resistance between } i-1 \text{ and } i \text{ circuit, } X_i \text{ is the impedance between } i-1 \text{ and } i.
\]

\[
\Delta U_i = \frac{P_i R_i + Q_i X_i}{U_N} \quad (i=1,2,3...N)
\]

\( \Delta U_i \) is the voltage loss between \( i-1 \) and \( i \), \( P_i \) is the node active power, \( Q_i \) is the node reactive power.

For \( \Delta U_i \) and \( S_i \), we have:

\[
\begin{align*}
S_1 &= (P_1 + Q_1) + (P_2 + Q_2) + (P_3 + Q_3) + ....... + (P_k + Q_k) + ....... + (P_N + Q_N) \\
S_2 &= (P_2 + Q_2) + (P_3 + Q_3) + ....... + (P_K + Q_K) + ....... + (P_N + Q_N) \\
S_3 &= (P_3 + Q_3) + ....... + (P_K + Q_K) + ....... + (P_N + Q_N) \\
&...... \\
S_K &= (P_K + Q_K) + ....... + (P_N + Q_N) \\
S_N &= (P_N + Q_N)
\end{align*}
\]

\[
\begin{align*}
\Delta U_1 &= U_{0-1} = \frac{P_R + Q_X X_1}{U_N} \\
\Delta U_2 &= U_{1-2} = \frac{P_R + Q_X X_2}{U_N} \\
\Delta U_3 &= U_{2-3} = \frac{P_R + Q_X X_3}{U_N} \\
&...... \\
\Delta U_K &= U_{K-1,K} = \frac{P_R + Q_X X_K}{U_N} \\
\Delta U_N &= U_{N-1,N} = \frac{P_R + Q_X X_N}{U_N}
\end{align*}
\]

\[
\begin{align*}
U_1 &= U_0 - \Delta U_1 \\
U_2 &= U_1 - \Delta U_2 \\
&...... \\
U_N &= U_{N-1} - \Delta U_N
\end{align*}
\]

When a distributed photovoltaic system is connected to the power grid, reactive power output is usually not adjusted. When distributed PV is connected, the voltage drop at node \( i \):

\[
\Delta U_i = \frac{(P_i - P_{pv}) R_i + (Q_i - Q_{pv}) X_i}{U_N}
\]

As can be seen from formula (7), the apparent power of the origin of \( S_i = P_i + Q_i \) is partially offset by the power of photovoltaic power generation, so that the power flow of the line decreases, and then the line voltage decreases and the node voltage increases, playing the role of node "support". However, if the photovoltaic power is too large and exceeds the load power, the "over-offset" will be formed,
and the node voltage will be too high. If the terminal voltage is exceeded, the voltage drop will become negative. Then the current will appear countercurrent phenomenon.

3. Influence analysis of distributed photovoltaic power generation grid connection based on MATLAB simulation

3.1. MATLAB simulation analysis of grid connection of photovoltaic power generation system

In figure 4, the model of solar panel adopts SPR-45E-WHT-D, and the PV curve model: $S=1000\,W/m^2$, sunshine intensity and battery temperature 45 °C, temperature fluctuation limit between $55^\circ C - 5^\circ C$. The change of radiation intensity is $1000\,W/m^2 - 200\,W/m^2$. Effective working time accounts for 40% of the cycle. The three-level inverter is used in the inverter. The switching frequency of IGBT is controlled by PWM modulation technology, and the discharge signal is generated to IGBT according to the required reference voltage. In the simulation in this paper, the carrier frequency is set to 1650 Hz ($33*50$). The MPPT algorithm adopts the perturbation observation method. The MPPT system automatically changes the VDC reference signal of the voltage stabilizer in the inverter to obtain the dc voltage with the maximum power extracted from the PV array. PLL and measurement: synchronous and voltage/current measurements are required. The direct current of the inverter is converted into alternating current, which is then absorbed into the large power grid after LC filtering and transformer boosting. It includes two 35-kv feeders, load, grounding transformer and an equivalent 110-kv transmission system.

3.2. Analysis of influence on power quality

The generation of power quality problem lies in the asymmetry and nonlinearity of power transmission equipment, which leads to the distortion of waveform. The influence of power quality is mainly manifested in two aspects: voltage fluctuation and harmonic wave.

3.2.1. Voltage fluctuations and deviations. Generally, the power curve of photovoltaic power generation is normally distributed according to the change of day and night. Meanwhile, the power curve will fluctuate with the change of cloud cover and temperature, leading to the fluctuation of power grid voltage.
The waveform curve in figure 5 is the irradiation intensity, which starts to change at 0.3 sampling cycles. The irradiation intensity decreases from 1000W/m² to 200W/m², and rises to the original value at the end of a sampling cycle. The red waveform curve in figure 6 shows the PV dc side voltage, the reference value of the voltage \( V_B \) is 100V, and the set dc voltage is 4.8. The actual curve is stable around 4.6, with a certain voltage drop. The waveform curve in figure 7 shows the actual output power of PV18kV, and the reference power is \( S_B = 10kV \). Because the irradiation intensity causes changes in the current of photovoltaic power generation, the minimum power affected is 4kV. From the figure, we can clearly see the power change of the solar panel caused by irradiation. At the same time, you will find that the small fluctuation of voltage at the beginning is also obviously reflected in the power.

3.2.2. Harmonic. Nowadays, with the continuous development of photovoltaic power generation systems, more photovoltaic power generation systems will be connected to the power grid, and the problem of harmonic pollution is inevitable. The main reason of harmonic generation in photovoltaic power generation comes from inverter. Inverter has a large number of electronic components, which will produce high harmonic when making dc to ac. Although there are corresponding filtering devices
before being connected to the power grid, with the continuous development of photovoltaic gridconnection, the number of harmonic sources connected to the power grid will continue to increase. The superposition of multiple harmonics will cause certain security risks[10]. I observed the influence of harmonics in this simulation and compared it with the waveform after filtering to observe its changes.

Figure 10 shows the voltage waveform of the output of the inverter with the reference value of V2=220V. It can be seen from the waveform that there are many clutter signals. These high-frequency harmonics seriously pollute the voltage output signal and it is difficult to distinguish the three-phase ac voltage signal of the sinusoidal waveform. In figure 11, the reference voltage is V3=10kV, and when compared with it, it can be more obvious that the ac voltage connected to the grid after filtering is smoother, so the filtering effect of three-phase voltage is still very good. The FFT Analysis toolbox is used to analyze the voltage harmonic content below.

From figures 12 and 13, we can see more intuitively that the harmonic content of the ac voltage converted by the dc power through the inverter is THD=100.81%, and the main high harmonic frequency is around 250Hz. After filtering, the harmonic content THD=0.12%, the high-frequency harmonics of 250Hz and above are significantly reduced, and the waveform becomes smooth and can be directly connected to the distribution network.

However, it is found that the waveform of grid-connected output three-phase current is not smooth, as shown in figure 14 FFT analysis. This indicates that there are harmonics in the three-phase current. This is because a large number of high-order harmonics are generated when the inverter switch device IGBT is on and off. These harmonics are still difficult to be filtered out and always exist in the power grid. Although the voltage and current are of the same frequency and phase, the filtering effect of the current is much worse than that of the voltage. Therefore, if a large number of distributed photovoltaic
power generation should be connected to the power grid in the future, the filtering system of the current should be further improved.

4. Conclusion
Distributed photovoltaic power generation has a broad prospect of development. However, when distributed photovoltaic is connected to the grid, it will bring changes in power quality, power flow direction and other aspects, which will affect the safe operation of large power grid. This paper elaborates on this problem from two aspects, namely, theoretical formula derivation and numerical simulation experiment. The analysis shows that the distributed photovoltaic power should not be too large, otherwise it is easy to generate counter-current phenomenon, and the node voltage will increase due to the access of photovoltaic power generation. During the grid-connected process, a large number of high-order harmonics are difficult to be completely filtered, especially those carried by the current, and the voltage fluctuation is more obvious when the radiation intensity changes.

In the future, the author will further analyze other influencing factors of distributed photovoltaic, and based on the analysis results, propose control strategies and solutions conducive to photovoltaic grid-connection, so as to promote the safer and more stable development of distributed photovoltaic.

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