Optimization of Control Strategy for Photovoltaic Power Generation System in Weak Grid

Pengfei Chen¹*, Youning Zhao² and Yitong Wang³

¹School of Automation, Wuhan University of Technology, Wuhan, Hubei, 430070, China
²School of Automation, Wuhan University of Technology, Wuhan, Hubei, 430070, China
³School of Automation, Wuhan University of Technology, Wuhan, Hubei, 430070, China

*Corresponding author’s e-mail: victorcpf@whut.edu.cn

Abstract. With the continuous use of traditional fossil energy, the energy crisis and environmental pollution problems become increasingly obvious. As a recyclable, renewable and pollution-free clean energy, solar energy has received more and more social attention. Photovoltaic power generation has become one of the main forms of solar energy utilization for its convenience, safety and other advantages. This paper presents a control method to achieve maximum output efficiency tracking, guaranteeing the output current quality of photovoltaic cells. The design of photovoltaic power generation system and the setting of control parameters are often based on ideal conditions. However, in the real process such as long distance transmission, a large number of line impedances will inevitably be introduced into the power grid, which will lead to the increase of harmonic content of grid connected current and the generation of spike resonance among parameters. Under the combined action of non-linear load and line impedance, how to improve the system stability and reduce the negative impact on the inverted grid connected system has become a problem to be solved. This paper presents an impedance reconfiguration method to increase the stability of photovoltaic power generation system in weak grid.

1. Introduction
The progress and development of modern society cannot be separated from the use and development of energy. At present, the main energy supply in most countries is primary energy such as oil and coal, which is non-renewable and easy to cause environmental pollution. The exhaustion of traditional energy and the destruction of the ecological environment make all walks of life pay more attention to the development and utilization of clean and renewable energy. As a new type of environmental energy, solar energy has the advantages of renewability, safety, environmental protection and large storage capacity. Through the photovoltaic power generation system, solar energy can be effectively used to achieve the purpose of energy saving, emission reduction, safety and environmental protection, which can greatly reduce the consumption of traditional energy, and effectively alleviate the pollution caused by the use of fossil energy to the environment[1]. Existing current control strategies can achieve most of the appropriate results in a strong grid environment where the network impedance is negligible.
the grid presents the characteristics of weak grid, the impedance of the power network cannot be ignored. Through the appropriate power tracking algorithm, the photovoltaic cells can be kept at the highest output efficiency. However, because the performance of the inverter will be greatly affected, the gain of the control loop will change, the quality of the grid connected current will deteriorate, and the harmonic content will increase, resulting in the reduction of control performance of the photovoltaic power generation system. When the serious situation occurs, the system will break down. In this paper, the output impedance of the inverter is reconfigured by adding a feed-forward loop to the control loop, so that the amplitude of inverter output impedance in the low and medium frequency band is improved, and the phase angle difference between grid impedance and inverter output impedance at the intersection is reduced. The stability and adaptability of photovoltaic power generation system in weak grid environment is realized[2].

2. Maximum Power Point Tracking (MPPT)

Figure 1 shows the port characteristic curve of a photovoltaic cell. Photovoltaic power generation system is greatly affected by the environment, and environmental factors such as light, temperature and so on will have a greater impact on the output efficiency of photovoltaic cells. The output efficiency of the photovoltaic array corresponds to different working points on the port characteristic curve of the photovoltaic cells. MPPT technology can make full use of the solar energy to track the maximum power point in real time to maximize the efficiency of photovoltaic cells.

![Port characteristic curve of photovoltaic cell](image)

Figure 1. Port characteristic curve of photovoltaic cell

2.1. incremental conductance method

Figure 2 is the flow chart of conductance increment control. It can be seen from the photovoltaic cell port characteristic curve that there is a pole to make the output efficiency of photovoltaic cell reach the maximum value, and the slope of the curve is zero. In the left region of the maximum value, the slope always keeps positive and gradually decreases. Similarly, the polarity of the slope on the right side of the maximum power point is also constant negative, which does not change with the change of the port voltage. By using the characteristics of photovoltaic cells for maximum power tracking, the purpose of maintaining the maximum output efficiency can be achieved.

The algorithm formula is as follows:

\[ P = UI \]  \hspace{1cm} (1)

Simultaneous differential transformation on both sides of an equation.

\[ \frac{dP}{dU} = I + dI \frac{U}{dU} \]  \hspace{1cm} (3)

\[ dP = IdU + UdI \]  \hspace{1cm} (2)
According to the above analysis, when \( \frac{\partial P}{\partial U} = 0 \), the efficiency output reaches the maximum value.

\[
\frac{I}{dt} + \frac{U}{dU} = 0
\]  

(4)

Through the incremental conductance method, the maximum output efficiency point of photovoltaic cells in different environmental scenarios can be tracked easily and quickly[3].

Figure 2. Control flow chart of incremental conductance method
3. Inverter part of photovoltaic power generation system

3.1. Equivalent model of grid connected single inverter

The control system obtains the reference input of grid connected current by using phase locked loop technology, and compares it with the actual public grid connected current input to calculate the error. The error value of the current feedback from the acquisition controller and filter capacitor will be input into the PWM modulator. By changing the duty cycle of the power device, the inverter from DC side to AC side is realized, and the grid connection requirements are met. In order to facilitate the reconfiguration of the output impedance of the inverter, the model of the photovoltaic grid connected system under the weak grid is transformed equivalently, and the block diagram of the model is shown in Figure 4[4].

\[
G_a = K_{pwm} \cdot G_m \cdot G_i \\
S^2 \cdot L_1 \cdot (C + Z_1) + S \cdot K_i \cdot K_{pwm} \cdot (C + Z_1) \cdot G_m + 1
\]  

(5)

\[
G = G_a \cdot G_b
\]  

(6)

Gm is a delay link in numerical control, Kpwm is the amplification factor of the inverter, Gi is the current controller, \( G = G_a \cdot G_b \), and G is the total loop gain of the whole inverter.
According to the equivalent model block diagram, the equivalent circuit model under weak grid can be drawn, as shown in Figure 5.

![Inverter equivalent circuit mode](image)

Figure 5. Inverter equivalent circuit mode

\[ Z' = \frac{1 + G}{Gb} \]  \( (7) \)

\( Z' \) is the output impedance of the inverter from the Uabc side of the photovoltaic power generation system.

3.2. Reconfiguration of inverter output impedance

To change the output impedance of the inverter control system by impedance reconfiguration, adding a specific feedback loop in the inverter grid connected circuit can realize the output impedance approaching infinity, so as to control and change the output current of the inverter, ensure that the inverter grid connected system has strong adaptability under the condition of weak grid, and improve the stability of the grid connected system.

According to 3.1, \( Z' = \frac{1+G}{Gb} \) can be known. The output admittance of the inverter \( Y = \frac{1}{Z'} = \frac{Gb}{1+G} \) can be obtained by calculating the reciprocal of the equation left and right. The feedback branch can be equivalent to a negative impedance \( Z' \), which is infinitely close to \( Z'' \) in parallel to the output impedance of the inverter system. \( Z' \approx -Z'' \), When this effect is actually realized, it is equivalent to adding a special branch at the common grid connected voltage terminal to transfer the current \( I'' \) into Iabc to achieve the effect of negative feedback. Because \( I'' = \frac{U_{abc}}{Z'} \), a voltage gain of approximately -1 is introduced in the control block diagram before the admittance is output to the inverter. It can be seen that when the output impedance of the inverter realizes the effect of impedance reconfiguration, the interference of common grid connected voltage harmonics on the control circuit of the photovoltaic power generation system can be greatly reduced, thus the stability of the inverter grid connected system can be improved[5]. The control block diagram is shown in Figure 6.
Equivalent control block diagram for $\frac{1}{Z'}$ at dashed frame 1. The analysis of the formula of Ga and control block diagram shows that Gm is a delay link in the control system, and the gain introduced by dashed frame 1 to point A is negative feedback of Ga, so the gain introduced to point A by dashed frame 2 is only different from that of point A by Gm. Therefore, in the actual grid connected system control, the input side of the control is set to zero, only the parallel impedance $Z_2$ ($Z_2 = -Z' \cdot G_m$) are needed to achieve the impedance reconfiguration effect of the above inverters. Since the input impedance and the output impedance of the original inverter are approximately parallel, the reconfigured output impedance $Z_{eq}$ is analysed as follows:

$$Z_{eq} = \frac{Z' \cdot Z_2}{Z' + Z_2} = Z' \frac{-Gm}{1 - Gm}$$

(8)

From the above formula, it is known that the output impedance of the reconfigured inverters is $\frac{Gm}{1 - Dm}$ times larger than that of the original inverters.

3.3. Stability Analysis of Inverter System after Impedance Reconfiguration

3.3.1. Nyquist Curve Analysis.

After reconfiguring the grid impedance when the grid impedance of the photovoltaic power generation system no longer changes, the inverter loop gain before and after reconfiguring follows respectively: Before reconfiguration:

$$G' = \frac{Z_0}{Z'}$$

(9)

After reconfiguration:

$$G'' = \frac{Z_0}{Z_{eq}}$$

(10)

From this, the Nyquist curve of the loop gain of the grid connected control system of the inverter can be drawn as shown in Figure 7.
From the analysis of Figure 7, it can be seen that under the condition that the internal environment of the inverter is relatively stable and the corresponding weak grid limit is not exceeded, assuming that the grid impedance is no longer changed, the output impedance of the inverter does not meet the requirements of Nyquist curve for stability proof before reconfiguration, which shows that the system is in an unstable state. After reconfiguring the output impedance of the inverter, it can meet the stability requirements and keep the system stable.

3.3.2. Current Waveform and Harmonic Analysis.

In order to get more intuitive changes before and after the output impedance reconfiguration of the inverters in photovoltaic power systems in weak grid, the model simulation by SIMULINK can obtain the current waveforms before and after the reconfiguration and the comparison diagram of harmonic analysis.
By comparing the above results, it can be seen that the output current waveform can be maintained stable after reconfiguring the output impedance of the inverters in weak grid, while the content of grid connected harmonics can be significantly reduced, and the harmonics can be better suppressed in high frequency components[6].

4. Concluding remarks
The maximum output efficiency the photovoltaic cells can be tracked by incremental conductance method, which ensures the quality of the output current of the photovoltaic cells. In view of the instability of photovoltaic grid connected power generation system caused by over-reactance in weak grid, the method of reconfiguring the output impedance of the inverter proposed in this paper can effectively reduce the high frequency component of grid connected harmonics, effectively improve the stability of photovoltaic power generation system, ensure the quality of output current, and may provide effective security and reliability for grid connected power generation system.

References
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