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The Research Review of the Stability of Grid-Connected Photovoltaic Generation System

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Abstract: The rapid development of large-scale photovoltaic power generation is an effective means to alleviate the energy crisis and saving haze. With the continuous expansion of photovoltaic grid-scale, grid access conditions are increasingly demanding. Given the inverter under different grid conditions, its parts are subject to a certain extent, and thus cause stability problems. This paper describes the influence of output filter, phase-locked loop (PLL), digital delay and weak grid on the stability of the grid-connected photovoltaic generation system, both from the inverter itself and connected grid.

1. Introduction

In recent years, excessive consumption of fossil fuels has not only led to energy crisis, but also caused environmental pollution and climate change. Photovoltaic power generation has the advantages of no noise, no pollution, less restriction, low failure rate and easy maintenance, which makes it the focus of research in the field of new energy development and utilization. Data display that in 2014, the non-fossil fuels consumption accounted for 11.2% of the primary energy consumption in China, and PV installed capacity reached 28 million 50 thousand kilowatts. In 2015, the cumulative installation of photovoltaic power is 223.2GW on a global scale [1]. And the 13th Five-year Plan has determined that the scale of photovoltaic power generation raises 50% to 150 million KW from the previous 100 million KW in 2020 [2]. Photovoltaic power generation will continue to play an critical role in promoting energy saving and emission reduction.

Photovoltaic grid-connected power generation system mainly includes photovoltaic array, inverter and access grid, and the inverter is composed of main circuit, filter and controller [3]. The performance of inverter depends on the dynamic response accuracy and response speed of the control link, the distortion rate of grid current, and the stability of grid connection.

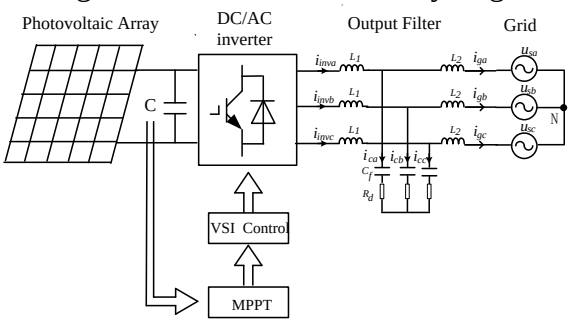

Fig. 1. The structure diagram of single stage three-phase photovoltaic inverter system

With the expansion of the scale of photovoltaic grid connected power generation system, the problem of harmonic pollution caused by the use of a large number of electric power devices is aggravated, which leads to a large number of background harmonics in the access grid. Moreover, large scale photovoltaic power stations are usually located in the northwest region, and the power generated needs to be connected to the regional power grid through long transmission lines and

multi-level boosting. As the permeability of the photovoltaic power generation increases continuously, the equivalent impedance of the PV connected-grid power generation system decreases to the equivalent of the grid impedance, and the access grid will be characterized by the weak network. The existence of grid impedance causes the harmonic content of grid connected current to increase, and the distortion of current waveform is serious. This paper mainly describes the influence of output filter, PLL, digital delay and weak grid on the stability of the grid-connected photovoltaic generation system, both from the inverter itself and connected grid.

2. The influence of filter on stability of photovoltaic connected-grid generation system

In order to suppress a large number of harmonics in the output current of photovoltaic power generation system and optimize the quality of grid connected power, it is usually necessary to add an additional filter device to reduce the harmonic content to meet the requirements of the power quality in the grid standard (IEEE519 Std.) standard of photovoltaic power generation. The most commonly used inverter output filter is the single inductor L filter. But the carrier cycle of the large capacity PV system cannot be too high, and the required filter will cause the inductance of L will be very large, which will increase the volume and cost of the grid-connected inverter. In contrast, the LCL filter has obvious advantages in high-power applications. First of all, the effect of LCL on high frequency suppression is better. Secondly, the LCL filter can effectively reduce the total inductance value of the required filter and reduce its volume and weight under the same satisfied filtering requirements.

The research shows that the LCL filter is particularly sensitive to the impedance of the grid when the filter connects flexibly to the weak grid, and the equivalent input impedance of the grid will affect the filter characteristics of the filter and the stability of the network system. The reference [2] analyses the design of LCL filter for PV grid-connected inverter needs a compromise to consider the harmonic performance and the stability of the resonance from the angle of improving the adaptability of photovoltaic inverter to the access conditions. Reference [3] proposes a LCL passive network model and describes the problem of multi inverter resonance in distributed generation system. According to the above analysis, the filter parameters has a certain effect on the stability of the system.

3. The influence of PLL on stability of photovoltaic grid-connected generation system

In a grid-connected inverter system, the PLL checks the phase information of the node voltage and passes it to the control link to keep the synchronization of the inverter and the grid. At present, there are many ways to implement the phase-locked method, such as zero crossing comparison method, low-pass filter phase-locked method and d-q transform synchronous phase-locked loop method. Among them, the d-q transform synchronous phase-locked loop has the advantages of simple and suppress the harmonic interference of the grid, and has been widely applied in distributed generation system. However, when the grid contains kinds of background harmonics and unbalanced three-phase voltage, the precision of phase lock will become worse, which causes the stability of grid-connected photovoltaic power generation system. In reference [3], the influence of three-phase voltage imbalance on phase locked algorithm is analyzed, and the effect of phase difference of phase locked loop on PV grid connected power generation system is studied by time domain response analysis. Reference [5] proposes a phase locked loop with variable sampling period. The implementation of this method requires variable sampling frequency, but it is not applicable to systems with fixed sampling frequencies. Therefore, the analysis of the performance of PLL and its impact on the stability of the system is critical to the expansion of the grid scale under different grid conditions.

4. The influence of digital delay on stability of photovoltaic grid connected generation system

Analog control has many shortcomings such as complicated control links and easily influenced

by external conditions of device parameters. So many power sources start to adopt digital control technology. However, digital control brings a new problem: there are delays in analog/digital sampling and control links. The delay of the inverter system can lead to the PWM control signal of the current cycle input only in the continuous period of action. The equation (1) gives the transfer function of the delay link.

$$G_{del}(s) = e^{-\tau s} \tag{1}$$

τ is Delay time, as a switch period. The switching frequency is 18kHz, and the substitution type equation (1) is obtained as follow:

$$G_{del}(s) = e^{-5.56\times10^{-5}s} \tag{2}$$

Figure 2 is the corresponding Bode diagram of the equation (2).

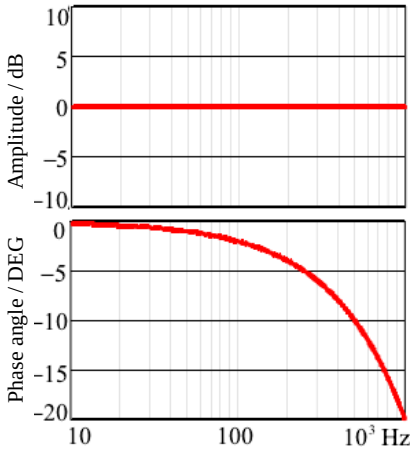

Fig. 2. G_{del} (s) Bode

As can be detected from Figure 2, the gain of Gdel(s) range is 0dB at a lower frequency, so when the system increases the delay link, the gain of the delay link does not change basically in a lower frequency range. However, from Figure 2, we can see that the phase angle of Gdel(s) decreases gradually, thus reducing the phase margin of the system. Assuming that the original system traversing frequency is ω, the phase margin of PV grid connected generation system is reduced after adding the delay link.

$$\Delta\theta = \frac{r\omega}{2\pi}\times 360° \tag{3}$$

Therefore, when the inverter uses digital control, the delay link will reduce the phase margin of the system, thus reducing the stability of the system. In this paper, an example of the single current loop control of the inverter side inductor, the stability of the system is analyzed in the simulation domain and the digital domain respectively. The comparison of the analysis results, in reference [5], shows that the delay has a great influence on the stability of the system on the simulated and digital domains. On this basis, the delay time range of keeping the system stable is analyzed.

5. The influence of weak grid access conditions on stability of photovoltaic grid-connected generation system

The PV inverter system based on ideal grid condition has good restraining effect on these harmonics. However, for large scale photovoltaic power stations, the existence of the grid impedance will reduce the harmonic suppression performance of the photovoltaic grid-connected generation system, leading to the increase of the harmonic content of the grid-connected current. At the same time, the grid impedance and the grid-connected system are easy to form resonance, thus forming a certain frequency of high order harmonics, which may eventually lead to the total

harmonic distortion of the grid current, which does not meet the requirements of the grid. And, the harmonic voltages of grid impedance caused by harmonic currents, will result in the deterioration of the grid voltage quality, which will affect the control precision of the grid connected inverter. When serious, it may cause grid-connected inverter to break off network, which restricts the scale of photovoltaic power generation system. According to [4], the impedance of grid mainly roots in 3 aspects: internal impedance, transmission line impedance and transformer impedance. The interaction between grid impedance and inverter output impedance and its influence on output filter will lead to system stability. In document [5], a small signal modeling of the grid-connected PV inverter system is carried out in the case of network impedance. Considering the impedance of power grid, the stability of system is analyzed by eigenvalues. The sensitivity of system state variables is analyzed by using the participation factor, and the controller parameters are designed by analyzing the eigenvalue locus. To sum up, how to analyze the impact of access impedance on the operating stability of grid-connected photovoltaic power generation system, and how to change the control strategy of grid-connected photovoltaic inverter to improve the stability margin of the grid-connected inverter system, which are problems worthy of study.

6. Conclusions

This paper studies the stability of photovoltaic grid connected generation system and the technical status of its solution. The conclusions are as follows:

For the inverter itself, the output filter, PLL and digital delay of the inverter have a significant impact on the stability of the system. For the angle of improving the stability of the system, Studying the optimal design methods of filter parameters, improving the PLL phase-locked precision and optimizing the digital control delay adjustment can effectively solve the stability problem of grid-connected PV system. For the conditions of the access to the grid, considering the impact of grid impedance on all links of the inverter, a targeted solution is crucial.

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