Voltage Stability Analysis of Photovoltaic Plant with STATCOM Connected to Weak Buses of Distribution Network

Qing-he OU, Bin WU, Chuan-ke DUAN, Jian ZHANG, Xiao-feng YIN and Xing-de YAN
State Grid Bengbu Electric Power Supply Company, Bengbu, China

Keywords: PV plant, STATCOM, Weak bus.

Abstract. This paper investigates effect of static synchronous compensator (STATCOM) application on voltage stability of photovoltaic (PV) plant connected to weak buses. With integrated to weak grid, PV plant always confront security and stability problems, as the point of common coupling (PCC) voltage is sensitive to PV plant power output, which leads to large variation of PV plant PCC voltage. Meanwhile, PV plant voltage static stability limit and power transmit limit decrease with increase of grid impedance. STATCOM application in PV plant is able to stabilize PCC voltage magnitude by providing reactive power, which contributes to improving PV plant voltage stability. To research effect of STATCOM on PV plant performance, a simplified system of PV plant connected to weak grid with STATCOM application is modeled in Matlab/Simulink. The system is studied in the case of different grid strengths and PV plant power output with small disturbance in grid. Simulation results show that STATCOM application in PV plant connected to weak grid can reduce the variation of PCC voltage and increase PV plant voltage stability limit as well as power transmit limit under low SCR condition.

Introduction

With continuous development of distributed power technology, the power distribution network has gradually developed from passively to actively. Photovoltaic (PV) generation system is an important distributive generation form of active power distribution network [1]. However, voltage stability problems of weak bus in power distribution network can be influenced by large scale of distributed PV power [2]. Bus voltage variety can be easily caused when PV generation system access in power distribution network.

Dynamic performance of PV plant becomes more complicated when integrated to weak buses of power distribution network, which is often associated with stability issues. For one thing, in weak distribution network, the magnitude of point of common coupling (PCC) voltage turns highly sensitive to active and reactive power output from PV plant, which leads to large fluctuation of PV plant PCC voltage [3]. For another, the transmission line will consume large amounts of reactive power, which decreases PV plant voltage stability limit as well as active power transfer capacity [4]. However, Reactive power output by PV plant is usually confined considering the capacity of power converter.

Reactive power compensation is one of the major issues concerning a PV plant connected to weak bus of distribution network. Flexible AC Transmission System (FACTS) facility is needed to apply in PV plant to provide reactive power. Static Synchronous Compensator (STATCOM) application is able to satisfy reactive power requirements and improve voltage dynamic performance of PV plant. Some papers have investigated effect of STATCOM on PV plant dynamic performance. In [5], simulation results showed that the STATCOM helps to improve dynamic characteristics of PV plant during severe faults. In [6]-[7], the author discussed the effectiveness of STATCOM in terms of fast damping the power system oscillations and restoring stability. In [8], STATCOM application for improving stability of PV plant fed to a multi-machine system is investigated. However, these papers
do not consider the effect of STATCOM application on voltage stability of PV plant integrated to weak bus of distribution network that complicates the situation.

This paper mainly investigates voltage stability of PV plant with STATCOM connected to weak buses in distribution network. The rest of the paper is arranged as follows. Section II analyzes the problems of voltage stability in weak bus of distribution network and reveals effects of STATCOM on voltage stability of PV plant. Section III built a simulation model for PV plant connected to IEEE 33 buses system and further study effects of STATCOM on voltage stability of PV plant integrated to weak bus. In Section IV, conclusions are drawn.

**PV Plant Operation in Weak Bus of Distribution Network with Statcom Application**

Some grid codes have required that PV plant should have reactive power capacity to give certain support to PCC voltage. With connected to weak bus of distribution network, dynamics performance of PV plant is affected and voltage support capacity is limited.

**Characteristics of Weak Bus in Distribution Network**

Characteristics of weak bus in distribution network have been investigated. The weak bus covers following two aspects: 1. grid impedance is large to some degree. 2. grid inertia is low to some degree. Either of the two situations can become a problem for PV plant integration.

![Diagram](image1.png)

Figure 1. Diagram for illustrating characteristics of weak bus in distribution network.

Figure 1(a) shows a single bus system in distribution network. The active power at the end of line is obtained as Equation. (1).

\[
P = \frac{EV \cos(\theta + \delta)}{Z} - \frac{V^2 \cos \theta}{Z}
\]  

Figure 1(b) illustrates PV curve of single bus system. It can be found that as dV/dP is smaller than 0 the voltage keeps stable while the voltage loses stability with dV/dP being positive. As the PV plant is connected to weak point of distribution network, the PCC voltage will turn to be sensitive to PV plant power output variations. We always use the term dV/dP to represent voltage sensitivity as shown in Equation (2). As the voltage sensitivity is close to positive, the bus of distribution network turns weaker. Furthermore, the voltage sensitivity is closely related with grid impedance and active power output of distribution generation.

\[
\frac{dV}{dP} = \frac{Z}{E \cos(\theta + \delta) - 2V \cos \theta}
\]

**Voltage Stability of PV Plant in Weak Bus of Distribution Network**

The equivalent grid impedance that is defined as \(X_{eq}\) consists of the load impedance and the line impedance. Figure 2(a) depicts the phasor diagram for analyzing PCC voltage variation. It can obtain that PCC voltage phasor variation is

\[
\Delta U_{pcc} = X_{eq0} \Delta I_{wf} + I_{wf0} \Delta X_{eq}
\]

PCC voltage magnitude variation is
\[ \Delta U_{\text{pcc}} = \sqrt{U_{\text{pcc0}}^2 + 2U_{\text{pcc0}} \Delta (X_{\text{eq}} I_{\text{eq}}) \cos \theta + \Delta (X_{\text{eq}} I_{\text{eq}})^2} - U_{\text{pcc0}} \]  

(4)

PV plant current \( I_{\text{pv}} \) is related with power output. Equivalent grid impedance \( X_{\text{eq}} \) is related with grid strength. Therefore, PCC voltage variation is determined by PV plant power output and grid impedance. Larger grid impedance or higher power output will result in larger variation of PCC voltage.

![Diagram for analyzing grid impedance and active power output effect on PV plant voltage stability.](image)

With connected to weak bus of distribution network, PV plant voltage static stability limit is varied with different grid impedance. From Figure 1, it can obtain that

\[ U_{\text{pcc}} = \sqrt{\frac{E^2}{2} + QX \pm \frac{E^4}{4} - X^2 P^2 + XEQ} \]  

(5)

The relationship in equation (5) is plotted with varying grid impedance and constant reactive power output by PV plant as shown in Figure 2(b). Voltage stability is estimated by analyzing the PV curves. The plots show that PV plant voltage static stability limit and active power transfer limit decrease with increase of grid impedance. PV plant cannot transmit more than 0.9pu active power as grid impedance is larger than 0.5p.u. without reactive power compensation device. It declares that PV plant need large amount of reactive power support to maintain the voltage for outputing active power in weak bus of distribution network.

**Effect of STATCOM Performance on Voltage Stability of PV Plant Connected to Weak Bus of Distribution Network**

![Equivalent circuit of PV plant with STATCOM connected to weak bus of distribution network.](image)

With PV plant integrated to weak bus of distribution network, the voltage stability problem becomes serious as analyzed above. In this case, the reactive power support should be large enough to keep the voltage within the acceptable range. Figure 2 shows the equivalent circuit of PV plant with STATCOM applied. STATCOM integrated to PCC bus is aimed to satisfy reactive power requirements of PV plant and improve voltage stability of PV plant. Effects of STATCOM on PV plant performance include two points. The first is reducing the variation of PCC voltage and maintaining the PCC voltage magnitude as a constant. The second is increasing PV plant voltage static stability limit as well as power transmit limit under large grid impedance condition.
Simulation Analysis

To test effect of STATCOM application on voltage stability of PV plant in weak bus of distribution network. A test system is built, as illustrated in Figure 3. PV plant is integrated to terminal of IEEE 33 buses system through a long transmission line. To research the effect of STATCOM on distribution network voltage stability, we built detailed time-domain model in Matlab/Simulink.

![PV plant](image)

Figure 3. Diagram of test system with PV plant integrated to weak bus of distribution network.

Firstly, effect of grid impedance on PCC voltage stability following small disturbance is studied. PCC voltage responses that follows grid disturbance are displayed with different grid impedance in Figure 5. A load increase occurs at 5s in PCC of PV plant connected to IEEE 33 system to simulate small disturbance of grid. Figure 5(a) shows responses of PCC voltage in the condition of \( Z_l = 0.625 \)pu, 0.5pu and 0.4pu respectively, without STATCOM injected. It reveals that stability of PCC voltage gets worse and steady value of PCC voltage becomes smaller with increase of grid impedance. Where, PCC voltage generates low frequency oscillation with low damping in \( Z_l = 0.625 \)pu. Figure 5(b) shows responses of PCC voltage in the condition of \( Z_l = 0.625 \)pu, 0.5pu and 0.4pu respectively, with STATCOM applied. It declares that PCC voltage’s setting time and overshoot turns smaller with STATCOM applied and perform better dynamics characteristics.

Also, investigate effect of STATCOM on stability of PCC voltage with large disturbance in weak buses. Figure 6 illustrates transient responses of PCC voltage and active power output with \( Z_l = 2 \). It is found that the PCC voltage gets shorter restoring time and PV plant’s active power has better dynamics with STATCOM applied. Furthermore, PCC voltage static stability limit and PV plant active power transfer limit are investigated by changing illumination intensity as shown in Figure 7. It reveals that increase of illumination intensity weakens PCC voltage stability and decreases voltage static stability limit as well as active power transfer limit. Furthermore, effect of STATCOM performance on voltage stability is researched. PCC voltage responses are observed with STATCOM integrated to PCC bus when illumination intensity changes.

![Figure 4](image)

Figure 4. Stability analysis of PCC voltage with varied grid impedances following small disturbance.
Conclusion

The system is studied with voltage stability analysis of PV plant connected to distribution network. Firstly, effect of grid impedance on PV plant voltage stability is studied. PCC voltage responses that follow grid disturbance are displayed with different grid impedances. Also, PCC voltage static stability limit and PV plant active power transfer limit are investigated by changing illumination intensity. It reveals that increase of grid impedance weakens PCC voltage stability and decreases PV plant voltage static stability limit as well as active power transfer limit. Furthermore, effect of STATCOM performance on voltage stability of PV plant is researched. PV plant voltage responses are observed with STATCOM integrated to PCC bus when SCR of system changes. It validates that STATCOM application is beneficial for reducing the PCC voltage variation and increasing PV plant voltage static stability limit as well as power transmit limit under low SCR condition. Meanwhile, the results show that weak bus of distribution network affects performance of STATCOM and the reactive power compensation effectiveness. It is better to increase the capacity of STATCOM with increase of grid impedance.

Acknowledgement

This research was financially Supported by State Grid Anhui electric power company science and technology project in 2018.

References


