Power Quality Improvement Utilizing Photovoltaic Generation Connected to a Weak Grid

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Submission date: 11-Dec-2020 04:23PM (UTC+0700)
Submission ID: 1471946931
File name: Binder1.pdf (1.69M)
Word count: 39116
Character count: 293171

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***Abstract*--Microgrid research and development in the past decades have been one of the most popular topics. Similarly, the photovoltaic generation has been surging among renewable generation in the past few years, thanks to the availability, affordability, technology maturity of the PV panels and the PV inverter in the general market. Unfortunately, quite often, the PV installations are connected to weak grids and may have been considered as the culprit of poor power quality affecting other loads in particular sensitive loads connected to the same point of common coupling (PCC). This paper is intended to demystify the renewable generation, and turns the negative perception into positive revelation of the superiority of PV generation to the power quality improvement in a microgrid system. The main objective of this work is to develop a control method for the PV inverter so that the power quality at the PCC will be improved under various disturbances. The method is to control the reactive current based on utilizing the grid current to counteract the negative impact of the disturbances. The proposed control method is verified in PSIM platform. Promising results have been obtained.**

***Keywords*—Photovoltaic, PV, solar power, power quality, reactive power, unbalance, symmetrical, weak grid.**

I. INTRODUCTION

Nowadays, most of the renewable energy sources such as Photovoltaic (PV) panels are connected to the grid using inverters. They can feed substantial power to the grid. However, high penetration levels of PV panels could bring significant impacts to the power system. A review of some reports and a survey to utility engineers regarding impacts of PV penetration is presented in [1]. Several concerns about high PV penetration include transient condition during cloud passing, voltage rise in steady state and the need to include voltage regulation in PV inverters.

Since the voltage regulation corresponds to reactive power flow in power system, a PV inverter should have an additional capability to control the reactive power flow. Thus, the PV plant would provide voltage support in steady state and transient (fault) condition in order to reduce network losses and improve transmission capacity.

Many studies about reactive power control in a grid-connected PV inverter have been done [2]-[7][9]. Generally, a PV inverter absorbs or injects reactive power or current depending upon its control strategies, such as constant voltage, constant reactive power, or constant power factor type. The control strategy is commonly supported by a PI controller or a V-Q slope characteristic. It is also possible to employ an intelligent controller [7]. Some controllers work in a *dq* reference frame to simplify the control process. Reactive power flow can also be determined by active power flow associated to system impedance (Rs/Xs). For unbalanced system, it is common for PV and other distributed generation inverters to apply a symmetrical component method in the control process [6][9]-[11]. In [6], the controller defines control parameters (k^+ and k^-) to balance the positive- and negative-sequence voltages (voltage equalizing strategy). Moreover, the injected reactive current to the grid is mostly based on the required voltage or power. To convert to the current, the process frequently needs extensive calculation. In this paper, a different approach to the control strategy is based on utilizing the available reactive current flowing in the power system, which corresponds to system voltage. Different from the previous approaches, the strategy is simple, comprehensive and robust, because the reactive current produced by the PV generator just emulates to the reactive current circulating in the grid. Since the main objective of this research is to improve the grid power (voltage) quality, this system is also effective for all conditions especially unsymmetrical faults.

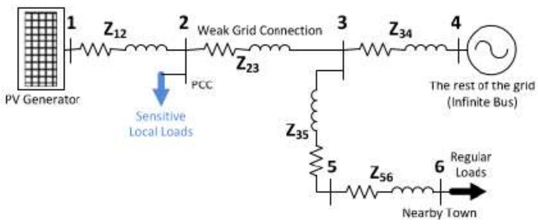

Figure 1. A single line diagram of a typical PV installation.

A typical system of interest is illustrated in the single line diagram in Fig. 1. As shown, a typical PV installation is connected to the main grid via weak lines (weak grid system). On the same site, regular loads and sensitive loads (e.g. medical equipment, computer center, and a radar installation) may be connected to the same bus. The major concern is mostly on the

This work was supported by the U.S. Department of Energy with the National Renewable Energy Laboratory (NREL) and the United States Department of State Bureau of Educational and Cultural Affairs under Fulbright Senior Research Program.

power quality of the grid at the installation of the PV inverter, that may affect the performance of the loads connected to the point of common coupling (PCC). This paper intends to reveal the benefit of PV generation and the significance of the proposed control strategy to the power (voltage) quality improvement in a microgrid system.

II. PV Inverter to Improve Power Quality

PV panels convert solar energy to electrical energy. They generate active power in a DC quantity. In order to deliver the active power from PV panels to the grid, an inverter along with a MPPT controller is commonly used to interface PV panels to the grid. In addition, the PV inverter will be equipped with a reactive power controller.

A. PV Model

The PV generator consists of PV panels and a PV inverter along with its controller. The DC side of the PV inverter is attached to PV panels, and the AC side of the PV inverter is connected to the grid. PV panels generally operate as a current source. While a grid-connected PV inverter works in a current-controlled mode [6][9][10][12]. The PV inverter and its controller determine the PV output currents sent to the grid, which is usually based on sliding mode control [12]. This paper chooses a three-phase dependent current source as an average model for representing the PV generator. The Norton equivalent circuit of the dependent current source is shown in Fig. 2, where $I_{a\text{-}pv}$, $I_{b\text{-}pv}$ and $I_{c\text{-}pv}$ are connected to a three-phase reference current of the controller ($I_{ref(a,b,c)}$).

B. PV Controller

The PV output currents comprise of the active and reactive current. To produce the PV output currents, the controller has to drive the PV inverter using the three-phase reference current ($I_{ref(a,b,c)}$). The main block diagram of the PV inverter control strategy is shown in Fig. 3.

The quantity of active power sent to the grid is determined by the intensity of sunlight striking on PV panels as well as the environment surrounding the panels. To get maximum active power, the PV inverter is supported by the maximum power point tracking (MPPT) controller, which regulates the DC-bus voltage [12]. Hence, the active power delivered to the grid is relatively independent on the electric power system condition. On the other hand, the active power from PV panels may influence the performance of the power system.

Different from active power flow, the PV generator will contribute reactive currents flowing to the grid. The reference current for reactive currents as well as unbalanced currents will be constructed by utilizing grid currents. According to Watanabe [13], instantaneously, reactive power is being exchanged between phases of the power system. The reactive as well as unbalanced current is flowing in the power system without transferring energy.

Therefore, the controller has to sense the currents flowing in the grid. A current sensor is placed on each phase of the grid to detect three-phase grid currents ($I_{grid} = I_{43}$). Based on the three-phase grid current, the control strategy focuses on developing a three-phase active positive-sequence current ($I_{+active(a,b,c)}$).

From the output signals of grid current sensors, the controller separates the grid currents into positive-sequence, negative-sequence and zero-sequence current components. If the system is balanced, then the grid currents only have positive-sequence currents. To obtain the three-phase positive-sequence current ($I_{+(a,b,c)}$), the three-phase grid/line currents ($I_{grid(a,b,c)}$) are processed with symmetrical component extraction according to equation (1) and (2).

$$\begin{bmatrix} I_+ \\ I_- \\ I_o \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_{+a} \\ I_{+b} \\ I_{+c} \end{bmatrix} = \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}[I_+] \quad (2)$$

Where:

I_a, I_b, I_c = line currents

I_+, I_-, I_0 = positive-, negative-, and zero-sequence currents

$a = e^{j120^o}$ and, $a^2 = e^{-j120^o}$

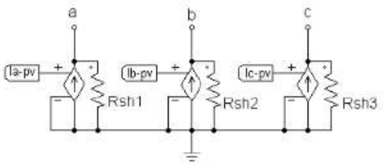

Figure 2. A three-phase PV average model

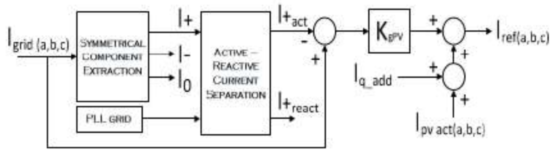

Figure 3. A block diagram of a PV inverter control strategy.

The positive-sequence currents, which are three-phase balanced currents, consist of active and reactive currents. As a consequence, the three-phase positive-sequence currents have to be split into three-phase active and reactive positive-sequence currents. To obtain the active currents, the positive-sequence currents are synchronized to the grid voltages using a phase lock loop (PLL) controller. The active currents are in-phase with the grid voltages, while the reactive currents are perpendicular to the grid voltages. Both the active and reactive positive-sequence currents are three-phase balanced currents.

$$I_{+(a,b,c)} = I_{+\,active(a,b,c)} + I_{+\,reactive(a,b,c)} \quad (3)$$

Finally, the three-phase active positive-sequence current is subtracted from the grid currents. As a result, the controller will automatically produce a three-phase reactive unbalanced current ($I_{r(a,b,c)}$), which consists of reactive currents as well as negative- and zero-sequence currents for unbalanced system.

$$I_{r(a,b,c)} = I_{grid\,(a,b,c)} - I_{+\,active(a,b,c)} \quad (4)$$

$$I_{r(a,b,c)} = I_{+\,reactive(a,b,c)} + I_{-(a,b,c)} + I_{0\,(a,b,c)} \quad (5)$$

However, the PV inverter will not employ the entire reactive unbalanced current ($I_{r(a,b,c)}$) component as for supporting the whole power system. The inverter supplies only a fraction of this current (multiplied by a gain, K_{gPV}) for improving the voltage regulation at the PCC bus. The gain K_{gPV} is a constant between 0 and 1, and is associated with the system impedance.

This current combined with the active current ($I_{PV\,active(a,b,c)}$) from PV panels will become the three-phase reference current.

$$I_{ref\,(a,b,c)} = I_{PV\ active(a,b,c)} + K_{gPV}\ I_{r(a,b,c)} \quad (6)$$

If the PV inverter possesses satisfying conversion effect, then the reference current becomes the output currents of the PV inverter (I_{PV})

$$I_{PV(a,b,c)} = I_{PV\ active(a,b,c)} + K_{gPV}\ (I_{+\,reactive(a,b,c)} + I_{-(a,b,c)} + I_{0(a,b,c)}) \quad (7)$$

Thus, the generated current by the PV generator contains the current components that will counteract the load- and disturbance-impact on the PCC voltage. As a result, the voltage at the PCC will be corrected to normal per unit value.

The main control system mentioned above is an open loop. As a result, the PCC voltages may not equal to the reference voltage, and a small voltage gap (ΔV_{PCC}) may occur. To create a close loop system, a simple PI controller will be integrated to the main controller. The PI controller adjusts the reactive current generated by the PV inverter. However, the PI controller cannot operate without the main controller since it is not capable to handle unbalance condition. The block diagram of the PI controller with anti-windup is shown in Fig. 4.

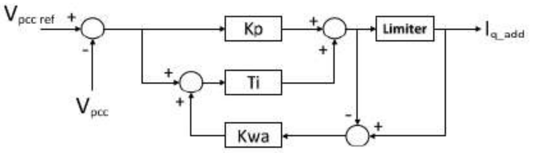

Figure 4. PI controller.

III. Microgrid System Investigated

A. System under Study

The system under study is depicted in Fig. 1. From the figure, it can be seen that the three-phase dependent current source representing a high power PV plant is connected to the point of common coupling (PCC – bus 2) through a star-star winding connection power transformer (represented by impedance Z_{12}). The PV plant, which is a type of distributed generation (DG), is usually located some distance away from the transmission line. Therefore, the PCC (bus 2) is connected to bus 3 via a weak line. It is considered to be a weak grid connection, which is normally characterized by high impedance ($Z_{23} = Z_{weak}$). The short circuit ratio (SCR) at this point is smaller than 10 [8]. SCR is the ratio of PCC short circuit power to maximum apparent power of generator. Bus 3 is the terminal of a three-phase infinite voltage source/grid with small equivalent impedance (Z_{34}).

To prove the concept proposed above, the system in Fig. 1 is simulated under dynamic conditions and transient faults. In case of the fault occurrence, the PV generator is still connected to the grid (fault ride-through) and supports the voltage level at PCC. The system parameters under study are listed in Table I.

Table I
System Parameter under Study

MVA base	10MVA
KV base (L-L)	20kV
Z_{12}	7%
Z_{weak} (Z_{23})	50% (SCR ≈ 2)
Z_{34}	5%
Z_{35}	7%
Load (bus 5)	0.4pu, PF = 0.9 lag
K_{gPV}	0.1
Z_f	1%

B. Dynamic Simulations of a Quasi-Steady-State System

Under normal condition, the voltage and current of the system change dynamically due to predominantly the fluctuation of solar irradiation. In reference to Fig. 1, the voltage equation under normal condition can be presented as follow:

$$V_2 = V_3 + I_{PV} Z_{23} \quad (8)$$

Or in reference to the voltage at bus 4 (V_4), we can also write the equation as follow:

$$V_2 = V_4 - I_{43} Z_{34} + I_{PV} Z_{23} \quad (9)$$

Where

$$I_{43} = I_{35} - I_{PV} \quad (10)$$

1) Night Operation of the PV generation

At night, the PV panels do not generate active power ($P_{PV} = 0$). The PV inverter still works as a reactive power controller and generates small reactive currents. Fig. 5 shows that the load current is supplied mostly by the grid since there is no contribution of active current from PV generator. The system is stable. In this case, the system is open loop. The value of the PCC voltage (phase-neutral) is 0.992p.u.

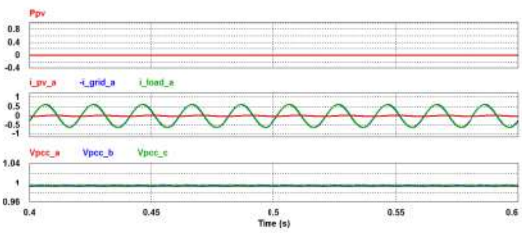

Figure 5. At night ($P_{PV} = 0$), system currents in phase A (middle), PCC voltages (bottom) for an open loop system.

Actually, the PCC voltage gap (ΔV_{PCC}) is small (< 1%). However, if to fill the voltage gap is needed, the PI controller can adjust the reactive power generated by PV inverter. The PI controller output signal (I_{q_add}) will be added to the main controller output as shown in Fig. 3. Fig. 6 (bottom) shows the additional reactive power. The system is close loop and the PCC voltages equal to 1p.u.

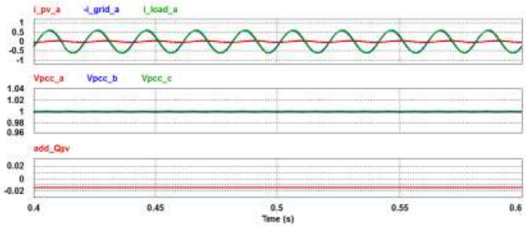

Figure 6. At night ($P_{PV} = 0$), system currents in phase A (top), and PCC voltages (1p.u) (middle), an additional reactive power (bottom) for a close loop system.

2) Power Changes of PV Generation

The fluctuation of solar irradiation due to earth rotation and weather condition as well as temporary cloud passing will vary the active power generated by PV panels. The PV active current will also change following the solar irradiation variation. The PV active current will create a voltage across Z_{23}. As a result, the PCC voltage will fluctuate according to equation (8). However, the reactive power controller will keep the PCC voltage constant at 1p.u by adjusting the reactive current component of I_{PV}.

Figure 7 shows that the active current generated by PV generator is larger than the load current. Part of the PV active current flows to the grid. From Fig. 7, when solar irradiation (PV active power (P_{PV})) fluctuates, the grid current fluctuates following the PV output current because the load current is constant. The fluctuation of solar irradiance has no effect on the system performance and stability. Fig. 8 also shows the same system performance when cloud passing occurs in a short time so that P_{PV} slightly decreases. Active power reduction depends on the cloud condition that obstructs the PV panels from sunlight.

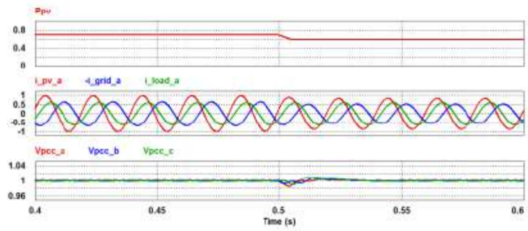

Figure 7. Solar power drops (top), system currents in phase A (middle) and PCC voltages (bottom) when solar irradiation changes

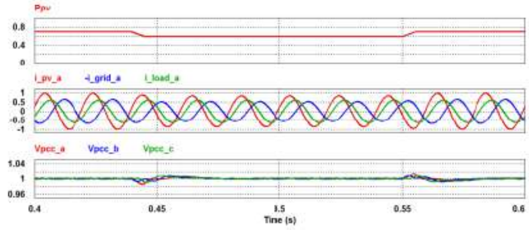

Figure 8. Solar power fluctuation (top), system currents in phase A (middle) and PCC voltages (bottom) when cloud passing

C. Dynamic Simulations under Transient Faults

The system under study experiencing different kinds of fault is depicted in Fig. 9. From this figure, only the main circuit is affected by large fault current. The branch connected to the PV plant is not drawn, because the current source nature of the PV inverter does not contribute to the fault current. The dependent current source basically generates currents according to the reference currents which consists of the active current ($I_{PV\,active}$) from PV panels and the reactive unbalanced current derived from the grid currents. Moreover, as a current source, currents from the grid are prevented flowing into the PV generator.

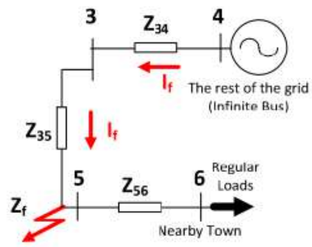

Figure 9. System under fault condition.

During the fault, $I_{35} = I_f$, and, as the amount of the fault current $I_f >> I_{PV}$, the current contributed from the PV plant will not affect significantly the voltage at bus 3.

$$I_{43} = I_f - I_{PV} \approx I_f \tag{11}$$

The voltage at the bus 3 can be expressed as

$$V_3 = \frac{Z_f + Z_{35}}{Z_f + Z_{35} + Z_{34}} V_4 \tag{12}$$

And the voltage at the bus 5 can be expressed as

$$V_5 = \frac{Z_f}{Z_f + Z_{35} + Z_{34}} V_4 \tag{13}$$

Thus, for a solid ground fault, the voltage at bus 5 is theoretically zero. Meanwhile at bus 3 as well as bus 2, there are significant voltage drops depending on the ratio Z_{35} to Z_{34}.

However, I_{PV} can be controlled such that the currents from the PV plant have the ability to improve the voltage at the PCC (bus 2). Thus, it will protect the sensitive local loads connected to bus 2 from experiencing a severe voltage dip.

$$V_2 = V_4 - I_f Z_{34} + I_{PV} Z_{23} \quad (14)$$

Assuming that X/R of the system impedance is high, and the reactive unbalanced currents generated by PV inverter controller significantly support the voltage regulation. If K_{gPV} can be chosen such that

$$K_{gPV} = \frac{Z_{34}}{Z_{23}} \quad (15)$$

Then

$$I_f Z_{34} \approx I_{PV} Z_{23} \quad (16)$$

As a result, the value of bus 2 voltage is close to bus 4 voltage ($V_2 \approx V_4$). Thus, the disturbance effect of the fault is neutralized by the additional reactive power generated by the PV plant and the ratio of the line impedance. The value of K_{gPV} can also be applied to the normal condition.

1) Fault and breaker logic

The following figures illustrate the process of the proposed control strategy drawn in Fig. 3. When t < 0.6s, the system is normal and balanced. During 0.6s < t < 0.9s, a disturbance happens. And when t > 0.9s, protection system detects the fault so that breaker is active. So the disturbance is cut off, and the system returns to normal and balance. The system breaker is closed at t = 1.05s assuming that fault has been removed at this point. The system is stable. Detailed fault and breaker logic are presented in Fig. 10.

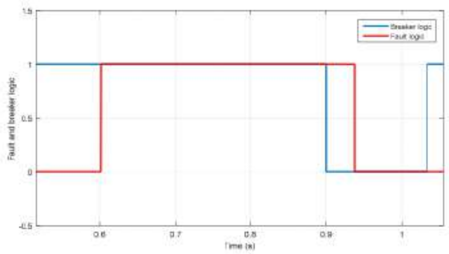

Figure 10. Fault and breaker logic under transient faults

To explain the main-control process, a double-line to ground fault is selected as the demonstration case. When the fault happens at bus 5 (phase A and B), the voltage sag also takes place at the PCC. The large grid currents flow into the faulty bus (Fig. 11 top). The current sensors detect the fault currents. From the current sensor output, the symmetrical component extractor creates a three-phase positive-sequence current as shown in Fig. 11 (bottom). Then, the three-phase positive-sequence current is decomposed into three-phase active and reactive positive-sequence currents. Only the active positive-sequence current (Fig. 12 top) that is in-phase with the grid voltage is needed in the next process. Fig. 12 (bottom) shows the distinction between the positive-sequence current and the active positive-sequence current. Then, the three-phase active positive-sequence current is subtracted from the three-phase grid current in order to generate three-phase reactive unbalanced current ($I_{r(a,b,c)}$) (Fig. 13 top). This current is multiplied by a gain (K_{gPV}) because the inverter supplies only a small quantity (Fig. 13 bottom) to enhance the PCC voltage.

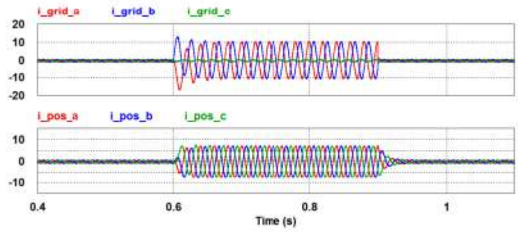

Figure 11. Grid (fault) currents (top), and positive-sequence currents (bottom).

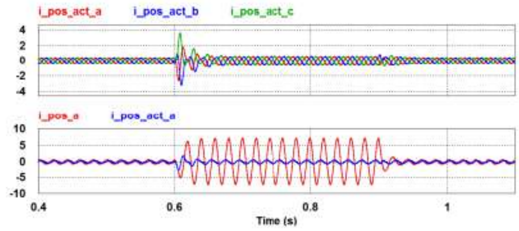

Figure 12. Three-phase active positive-sequence currents (top), and distinction between positive-sequence current and active positive-sequence current – phase A (bottom)

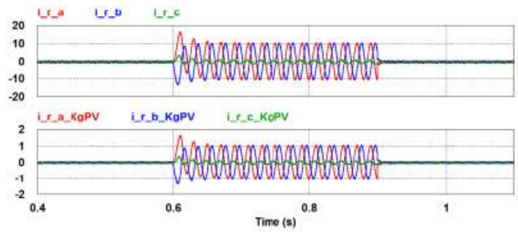

Figure 13. Reactive unbalanced currents: from the grid (top), and after multiplied by K_{gPV} (bottom)

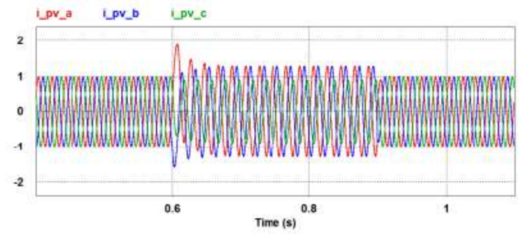

Figure 14. Three-phase reference currents (= PV inverter output currents)

Finally, the large active current ($I_{PV\ active}$ = 0.7p.u) from PV panels is added to create the three-phase reference current as

(Fig. 14). The amount of active power generated from PV panels is not affected by the disturbances. For dependent current source's gain equals one, the PV output currents equal to the reference currents.

2) Symmetrical faults

Symmetrical faults happen when there is a three-phase short circuit. In this case, a three-phase to ground fault through Z_f occurs at bus 5. During the fault, the grid fault-current (I_f) rises considerably (Fig. 15 bottom). The fault disturbs the voltage of the adjacent buses including PCC voltage. The three-phase voltage at PCC declines significantly (Fig. 15 top).

The PV inverter senses the three-phase grid fault-current (I_f) and the controller responses quickly by generating reactive currents to counteract the voltage dip at the PCC. For a symmetrical-fault case, there is no unbalanced current. Fig. 16 (top) describes that the PV output current is a summation of the active current (from solar power, $P_{PV} = 0.7$p.u) and the reactive current proportional to the grid fault-current. It can be seen that the system is stable and the PCC voltage is corrected very well to 1p.u, as shown in Fig. 16 (bottom), according to equation (16) and due to the PI controller. The PCC voltage is balanced as well. Hence, the voltage quality is enhanced.

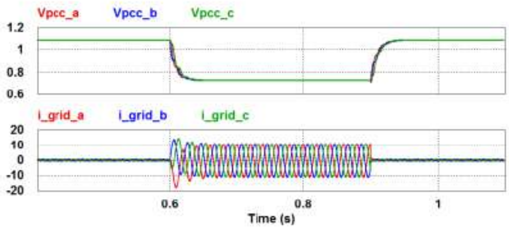

Figure 15. Voltages at PCC (top), and grid currents (bottom) without reactive power control for a three-phase to ground fault (symmetrical fault)

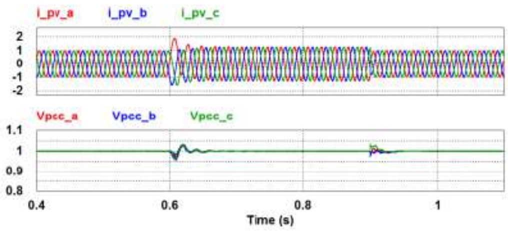

Figure 16. PV output currents (top) and voltages at PCC (bottom) with reactive power control for a three-phase to ground fault (symmetrical fault)

3) Unsymmetrical faults

The unsymmetrical faults introduced in this paper includes a single-line to ground fault, a line-to-line fault and a double-line to ground fault. The faults through Z_f create unbalanced voltage and current. Thus, the PV inverter has to produce reactive unbalanced currents to compensate unbalanced disturbances.

a) Single-Line to Ground Fault

Fig. 17 illustrates the voltage at the PCC when bus 5 experiences a single-line to ground fault at phase A. The phase-A voltage decreases about 30%, while the other phases stay a slightly higher than the normal voltage. Obviously, the phase-A grid current will rise very high and flow to the faulty bus. The phase-A grid current peak is about 10p.u (Fig. 17 bottom). The grid currents are unbalanced due to the unsymmetrical fault.

Consequently, during the fault the output current of the PV inverter will also be unbalanced, which is similar to the grid currents with a proportional gain K_{gPV}. Since K_{gPV} is selected to be 0.1, the PV reactive unbalanced current peak (phase A) is about 1p.u. From Fig. 18, it can be seen that the PV generator produces reactive unbalanced currents during the fault in addition to the active currents ($P_{PV} = 0.7$p.u) as shown in Fig. 18 (top). The unbalanced voltage drop is compensated very well so that voltage at PCC is three-phase balanced voltage waveform and its magnitude is 1p.u (rms) (Fig. 18 bottom). The system is stable and the voltage quality is enhanced.

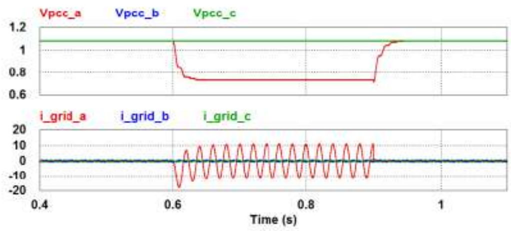

Figure 17. Voltages at PCC (top), and grid currents (bottom) without reactive power control for a single-phase to ground fault (unsymmetrical fault)

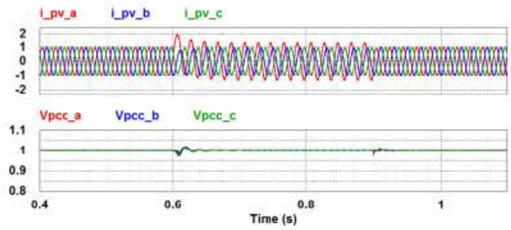

Figure 18. PV output currents (top) and voltages at PCC (bottom) with reactive power control for a single-phase to ground fault

b) Line-to-Line (double-line) to Ground Fault

Fig. 19 describes the voltage at the PCC when bus 5 experiences a line-to-line to ground fault at phase A and B. The phase-A and phase-B voltages drop about 30%, while the phase C voltage is still around the normal value. The three-phase unbalanced grid currents flow to the fault. Due to the control strategy proposed in this paper, the PV inverter will generate the active current and the reactive unbalanced current that is similar to the grid currents but with proportional gain K_{gPV}. Fig. 20 shows the PV output currents (top picture), and the PCC balanced voltages which are corrected to 1p.u (rms) during disturbance (bottom picture). The voltage quality is enhanced.

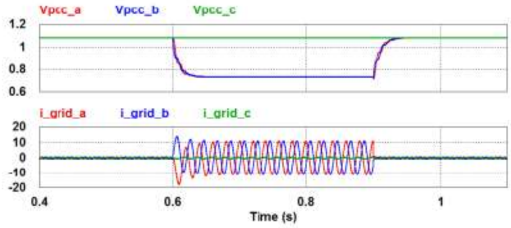

Figure 19. Voltages at PCC (top), and grid currents (bottom) without reactive power control for a line-to-line to ground fault

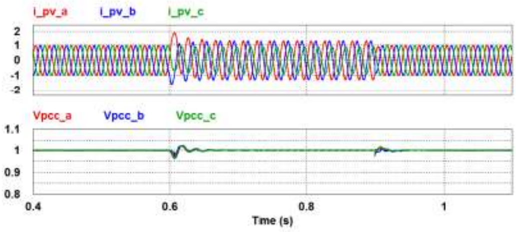

Figure 20. PV output currents (top) and voltages at PCC (bottom) with reactive power control for a line-to-line to ground fault

c) Line-to-Line Fault

Fig. 21 illustrates voltages at the PCC when bus 5 experiences a line-to-line fault between phase A and B. The short circuit between phase-A and phase-B causes voltage drops about 25% at the phase A and about 15% at phase B, while the phase C remains at a normal value. The fault also makes the phase angle of the three-phase PCC voltage unbalanced (Fig. 22). Obviously, phase-A and phase-B grid currents will rise very high and flow to the fault bus.

Similar to the previous unsymmetrical faults, based on the control strategy proposed, the PV inverter output currents will be a summation of the active current (P_{PV} = 0.7p.u), the reactive unbalanced current that is similar to the grid current with a proportional gain, and an additional reactive current from the PI controller as demonstrated in Fig. 23 (top picture). The figure also shows that the system is stable, and the voltage drop is recovered significantly. Fig. 24 shows the magnitude and the phase angle of the PCC balanced voltages during disturbance. The voltage quality is enhanced.

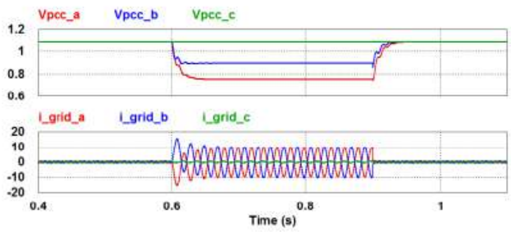

Figure 21. Voltages at PCC magnitude (top), and grid currents (bottom) without reactive power control for a line-to-line fault

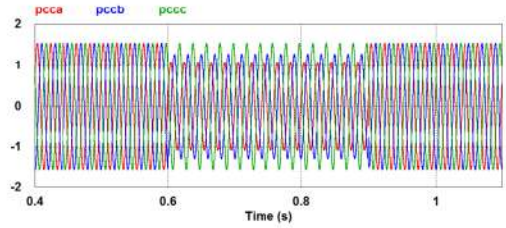

Figure 22. Unbalanced magnitude and phase angle of the PCC voltages without reactive power control for a line-to-line fault

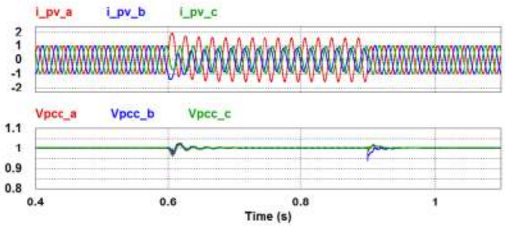

Figure 23. PV output currents (top) and voltages at PCC (bottom) with reactive power control for a line-to-line fault

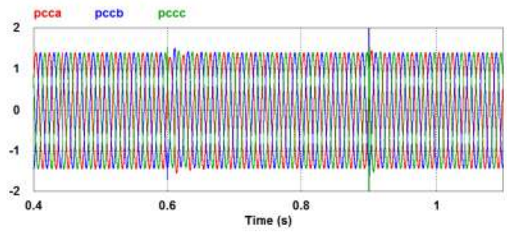

Figure 24. The balanced magnitude and phase angle of the PCC voltages with reactive power control for a line-to-line fault

D. The Effect of K_{gPV} Variation

The effect of K_{gPV} variation on the PCC voltage is described in Figure 25 and Figure 26. K_{gPV} is the impedance ratio that controls the voltage drop across Z_{23}. Without the assistance of K_{gPV}, equation (16) will not be justified. K_{gPV} can be varied corresponding to the variation of grid impedance (Z_{34}).

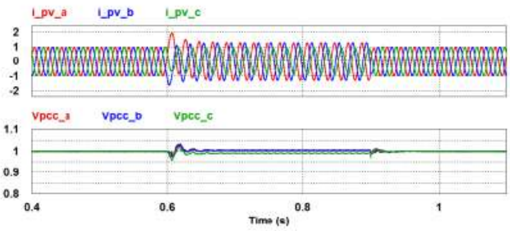

Figure 25. PV output current and PCC voltage when K_{gPV} = 0.104

Figure 25 shows the voltage of PCC during a fault (selected case: a double line to ground fault, phase A and B) when K_{gPV} is 0.104. Clearly, the PCC voltage is unbalanced and not equal to 1p.u. The phase-C voltage (< 1p.u) is lower than other two phases (> 1p.u). On the other hand, when K_{gPV} is 0.096 (Fig. 26), the phase-C voltage (> 1p.u) is higher than other two phases (< 1p.u).

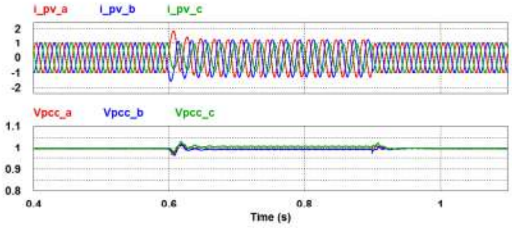

Figure 26. PV output current and PCC voltage when K_{gPV} = 0.096

IV. Conclusion

This paper presents the performance of the grid-connected PV source to support voltage regulation of microgrid system especially under transient faults. The high-power PV source is connected to the grid through a weak line with high impedance. Since PV panels only generate active power, the PV inverter is equipped with a reactive power controller to improve the power (voltage) quality.

The control strategy is based on utilizing the grid currents so that the PV generator creates a three-phase reactive unbalanced current. However, the inverter supplies only a small amount (multiplied by a gain, K_{gPV}) for improving the voltage at the PCC. The gain K_{gPV} is associated with the system impedance. This open loop strategy succeds to maintain the PCC voltage close to 1p.u. If it is necessary to make the PCC voltage equals to 1p.u value, a simple PI controller is integrated to the main controller. The PI controller adjusts the reactive current generated by the PV inverter. The advantages of this control strategy are simple because of less computation, comprehensive and robust due to emulating the reactive current circulating in the grid

The control method proposed in this paper is simulated in PSIM. Simulation results demonstrate that satisfactory results are obtained and the proposed control strategy is feasible to manage the voltage regulation. Power quality in terms of voltage level is improved under both normal conditions and transient disturbances. The system is stable and voltage dips at the PCC due to both symmetrical and unsymmetrical faults are corrected significantly.

Acknowledgment

The authors wish to acknowledge the support provided by Weihang Yan of the University of Denver, USA during the preparation of this paper.

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