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TWO-LEVEL VOLTAGE SHIFT OF ACTIVE ISLANDING DETECTION METHOD OF DISTRIBUTED GENERATION

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ABSTRACT

In this research, a new active method is proposed to solve the islanding condition by using a two-level voltage shift method developed from the standard voltage shift method. However, this new method is likely to disturb the stability of the system than the voltage shift method because it shifts less voltage level to detect islanding condition. In addition, the voltage shift method is to reduce or increase the voltage level to detect islanding condition for under-voltage relay (UVR) or over-voltage relay (OVR) work. Simulation results on Matlab/Simulink show that the two-level voltage shift of the active islanding detection method can determine anti-islanding condition very quickly within 0.04 seconds, it does not have a nondetection zone and also it is less likely to disturb the stability of the system than the voltage shift method.

Keywords: Islanding Detection, Distributed Generation, Grid-Connected

Introduction

Electricity is considered as one of major powers used in human's various activities. Electricity is mostly produced from fossil fuels which will at some time in the future be depleted, and this has become one of the serious problems which countries throughout the world have been discussing (REN21, 2018). One of the solutions to remedy this electrical power shortage is to connect the distributed electricity generation unit or distributed generation (DG) acquired from alternative or renewable energy sources into the power system network. Although DG will maintain more balance for the electrical system, it still has some drawbacks, especially the disadvantages from islanding condition.

Islanding condition refers to the condition in which the electricity utility system ceases the operation, but DG still generates power into the power system network in order to distribute the power loads. The source of this condition may be caused when DG cannot detect a fault, but the power system can detect it, and the release of the power system due to damaged equipment, caused by a mistake from the administrator of the utility system or caused by other natural phenomena. Once islanding condition occurs, it should be avoided because when this condition occurs, it causes changes in the voltage and frequency at the location of isolation. It is possible that the size of voltage and frequency will not fall under the accepted range of the equipment which causes the damage, and it may affect the operation of a lot of the equipment of the utility system. It may also be a hazard to operators who assume that there is no electricity in the connection line, whereas as the connection line is related to the islanding condition, so there is still electricity in this line from the DG. When there is a connection in the power system network again, it may cause a re-tripping event or cause damage to equipment due to different phases (IEEE Std. 929, 2000 ; IEEE Std. 1547, 2003 ; Mahat et al., 2008) (Yingram et al., 2015).

Solutions for islanding condition in small DGs tend to be local techniques because they are cheaper than remote techniques (Yingram, 2015). However, because the tendency to use small DGs has increased continuously, this has caused the quality of grid voltage and the stability of the grid system to become lower. Therefore, the technique against the anti-islanding condition is to minimize the perturbation of the power system.

This research proposes a two-level voltage shift method of distributed generation. The normal voltage shift method has been used to develop this new method model. On the one hand, the advantage of the voltage shift method is the high power quality produced without injecting a harmonic signal or phase signal. However, the new method is less likely to affect the stability of the system than the voltage shift method. This paper used values in IEC 62116 because it is consistent with the electric power system in Thailand AC 220 volts 50 Hz (Yu et al., 2010). This paper presents a new active islanding detection method which includes: the voltage shift of the active islanding detection method to show the advantages and disadvantages of the method, a proposed methodology that shows a two-level voltage shift islanding detection algorithm, a demonstration of the methodology using Matlab/Simulink, which validates the new methodology by simulation, and a conclusion.

Method

A. Voltage shift of active islanding detection method

This section presents the voltage shift method (Yingram, 2015 ; Yu et al., 2010) to show the advantages and disadvantages of the method. The detail of the voltage shift method (Velasco et al., 2010 ; Hu & Sun, 2009 ; Ye et al., 2004) is a method that uses positive feedback. Voltage and current waveforms of the inverter are shown in Figure 1.

Figure 2 displays the voltage shift method and the initiation of the voltage shift method. First, the voltage in every period at the point of common coupling (PCC) is measured (V_{PCC}), and then calculated by using dV/dt of V_{PCC}.

By inspecting dV/dt, if $|dV/dt| = 0$ the voltage remains the same which allows the control system to restart at the first step. However, if $|dV/dt| > 0$, the voltage changes which allows the control system to operate and perform the next step.

When $|dV/dt| > 0$, the control system releases a voltage shift (this article assigns "voltage < 85% of normal voltage", which is voltage < 187 V where the under voltage should be determined according to IEC62116 in the utility system). The method used in this article is to convert direct current (DC) voltage to be input into the inverter in order for the inverter to make alternating current (AC) voltage output < 85%, where the pattern of wave length released into the utility system as shown in Figure 3, is the pattern of constant voltage at < 187 V 3 cycles.

The control system will measure V_{PCC} after releasing a voltage shift one more time. If $V_{PCC} < 187$ V, that means the existing condition is islanding condition which causes the control system to force DG to cease distributing electricity to the load. If $V_{PCC} \geq 187$ V, the control system will be forced to reset back to the first step.

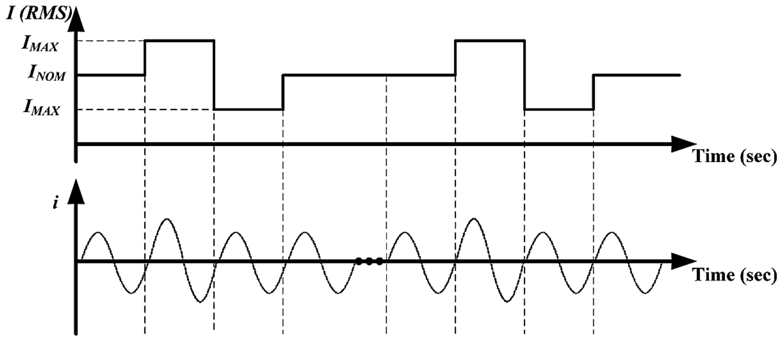

Figure 1 Changing of periodic current magnitude.

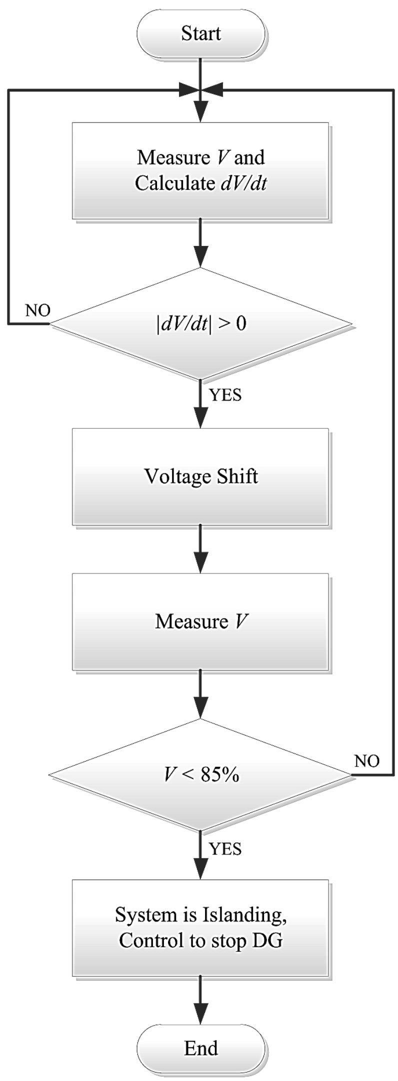

Figure 2 Voltage shift islanding detection algorithm.

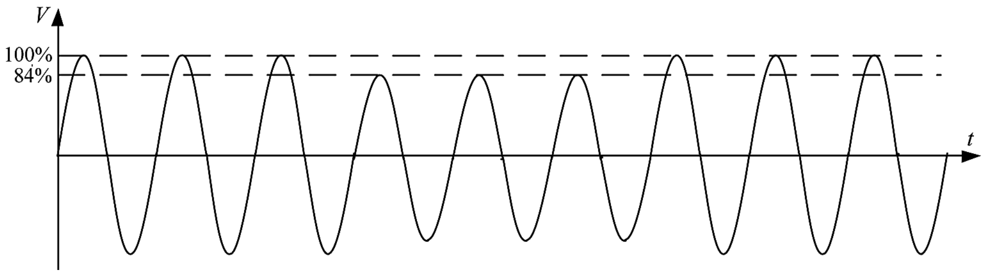

Figure 3 Attribute of the voltage 3 cycles.

After the control system releases voltage, if the existing condition is the islanding condition and, V_{PCC} is the same constant voltage < 187 V 3 cycles, this allows the control system to operate using the DG to cease the electricity distribution to the load. If such condition is not islanding condition, this causes V_{PCC} measured at < 187 V, but P ($P = P_{DG}$) will be lower which is different from Δ P which is higher. It can be proven as follows. In normal conditions, P_{load} affects P_{DG} and P_{Grid} in the PCC (Velasco et al., 2010; Ye et al., 2004).

$$P_{load} = P_{DG} + P_{Grid} = \frac{V^2}{R} \tag{1}$$

$$V = \sqrt{R \cdot (P_{DG} + P_{Grid})} \tag{2}$$

Deriving $P_{DG} + P_{grid}$ and from (1)

$$\frac{\partial(P_{DG} + P_{Grid})}{\partial V} = 2 \cdot \frac{V}{R} \tag{3}$$

$$\frac{\partial(P_{DG} + P_{Grid})}{\partial V} = 2 \cdot \frac{\sqrt{R \cdot (P_{DG} + P_{Grid})}}{R} \tag{4}$$

$$\frac{\partial(P_{DG} + P_{Grid})}{\partial V} = 2 \cdot \sqrt{\frac{(P_{DG} + P_{Grid})}{R}} \tag{5}$$

The active power variation is expressed by

$$\Delta P_{DG} + \Delta P_{Grid} = 2 \cdot \Delta V \cdot \sqrt{\frac{P_{load}}{R}} \tag{6}$$

From the Equation (6) R and P_{load} are constant. When releasing constant voltage at < 187 V (< 85%) 3 cycles into the power system network in which the existing condition is not islanding condition, V_{PCC} (ΔV) is the same, but ΔP_{DG} and ΔP_{Grid} have changed. This research shows the variation of active power in Figure 7.

This presented model is shown in Figure 4 with the voltage shift block in Figure 5, and the shift block is included within the model in Figure 4.

The voltage shift method is a method utilized to inspect the existing conditions by releasing the signal of voltage shift in every case. This presented model will create islanding condition in a 0.2 sec. period, and the operation simulation is shown in Figure 6. When the islanding condition occurs, the inverter releases voltage < 85% of normal voltage 3 cycles, or < 187 V 3 cycles into the load. Next, measure the voltage at the PCC, which is V_{PCC} in order to be inspected. If V_{PCC} < 187 V, this means the existing condition is the islanding condition which allows the control system of the inverter to control and cease the electricity distribution to the load. According to the simulation, it was found that DG ceases distributing electricity to the power system network at 0.24 sec. Therefore, this method will take the time, equivalent to 0.04 sec., for anti-islanding condition, but it will perturb the power system network whenever it releases the voltage shift to inspect the existing condition.

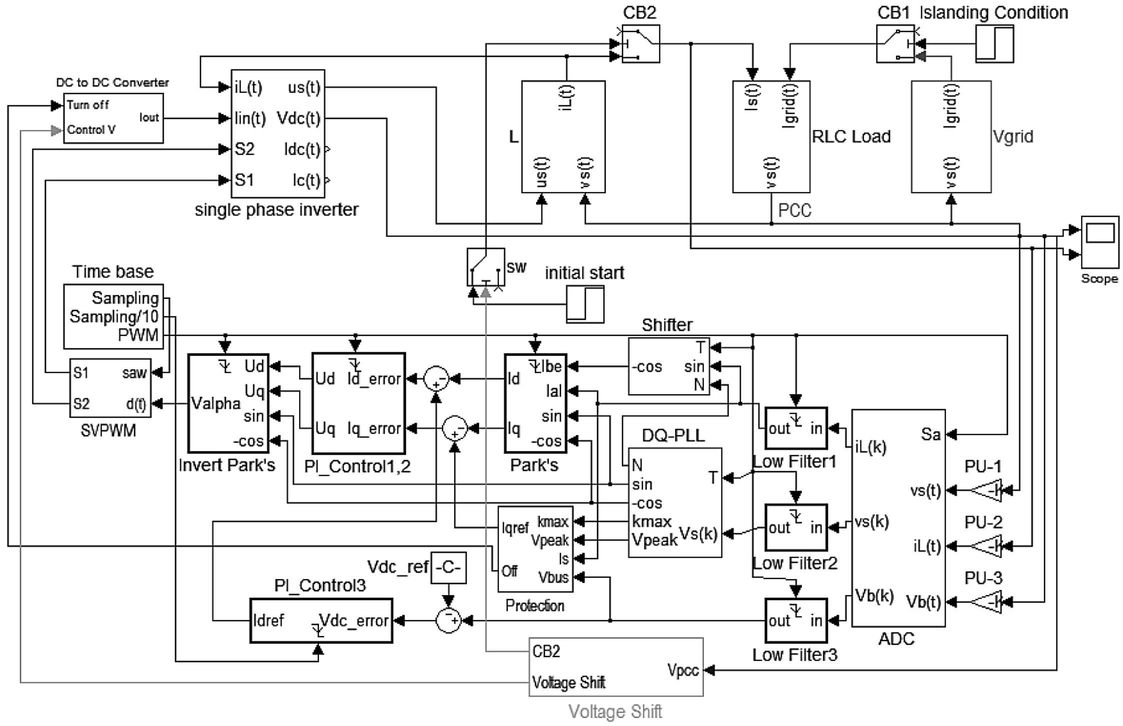

Figure 4 Model of a single phase grid-connected inverter with voltage shift block.

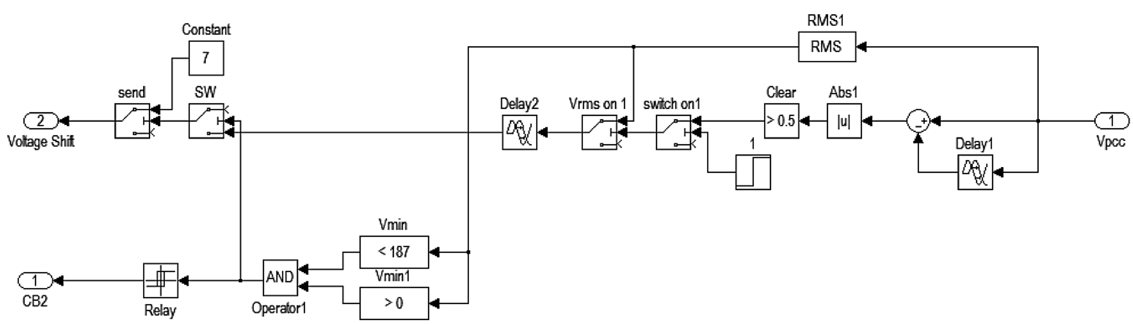

Figure 5 Voltage shift block.

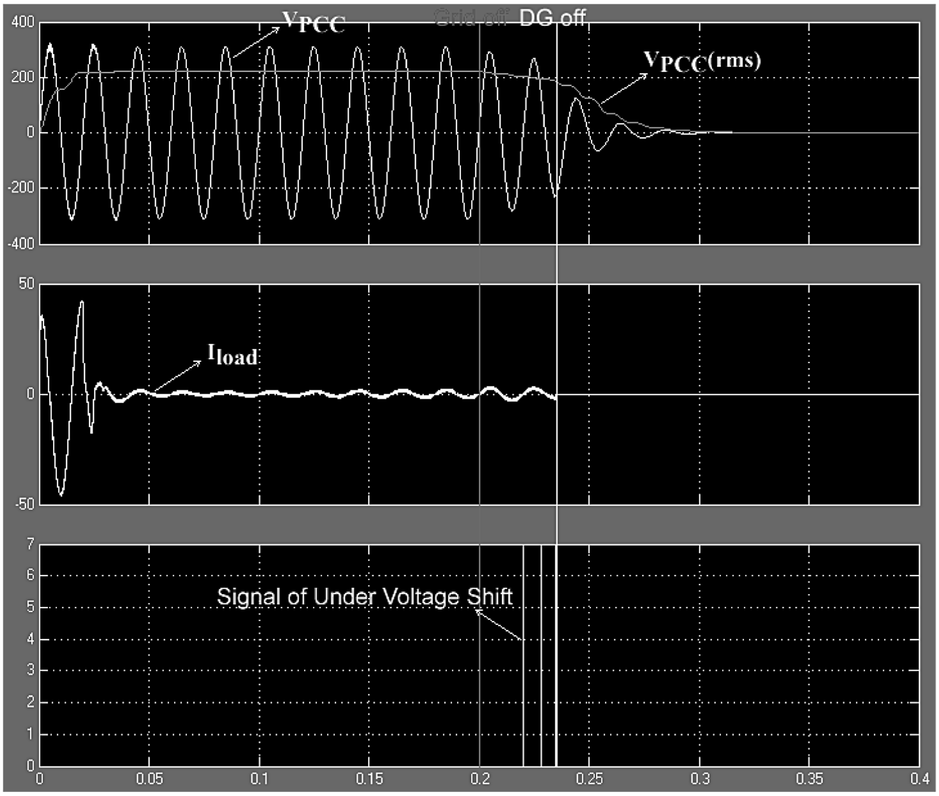

Figure 6 Simulation result of voltage shift method.

Figure 7 shows the simulation results when it is not islanding condition, but the inverter releases a constant voltage (< 187 V 3 cycles) into the load. As the period of releasing voltage is 0.4-0.46 sec. According to the simulation results, it appears that V_{PCC} remains unchanged, but P_{DG} and P_{Grid} change which can be seen from the results in the Equation (6).

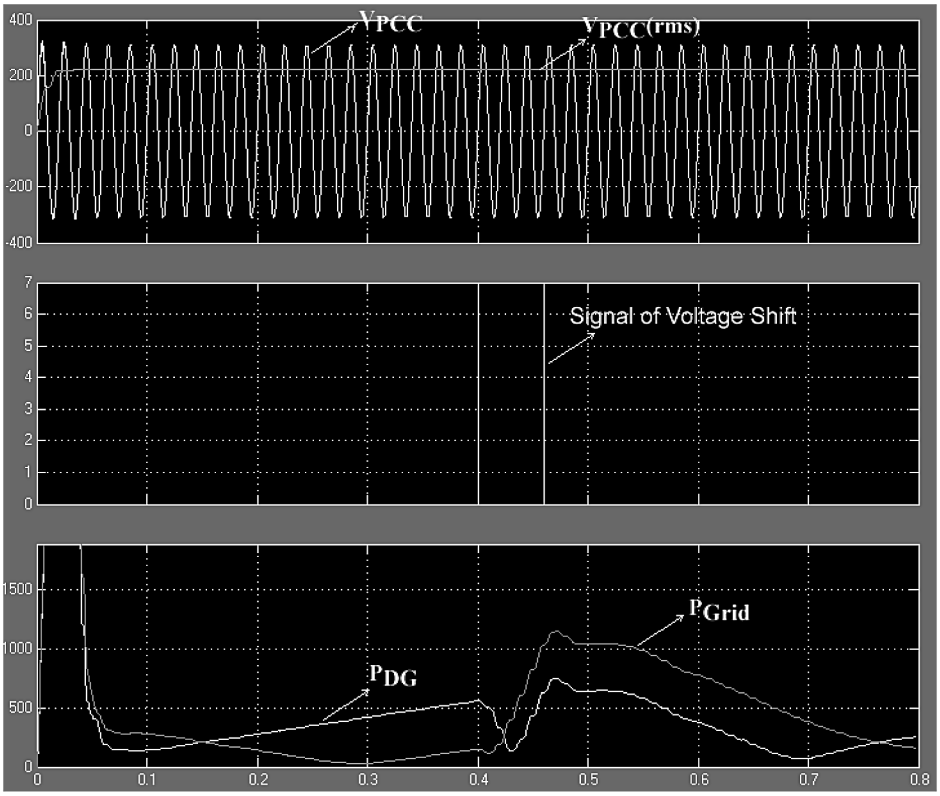

Figure 7 Inject a signal to vary the under voltage in normal condition.

B. Proposed Methodology

This section proposed a two-level voltage shift method. The concept of the two-level voltage shift of the active islanding detection method is the, "Injection of two-level voltage waveform, less than normal voltage 1 waveform and more than normal voltage 1 waveform. This is to compare whether or not the reduction or increment of the voltage has changed in the same direction as the voltage injections. If the voltage is in the same direction, this shows that the islanding condition has already occurred, but if the voltage remains in the regular condition, this shows that islanding condition did not happen."

Therefore, the algorithm can be illustrated in a flowchart as shown in Figure 8. This is the initiating process of the two-level voltage shift islanding detection method. First of all, the voltage will be measured at the PCC, in order to measure the V_{PCC}. After that, the dV/dt of V_{PCC} is calculated and the dV/dt inspected. If $|dV/dt| = 0$, it means the voltage has not changed, and the procedure must be restarted once again at the first step. However, if |*dV/dt*| > 0, it means the voltage has changed, and the next procedure can be started.

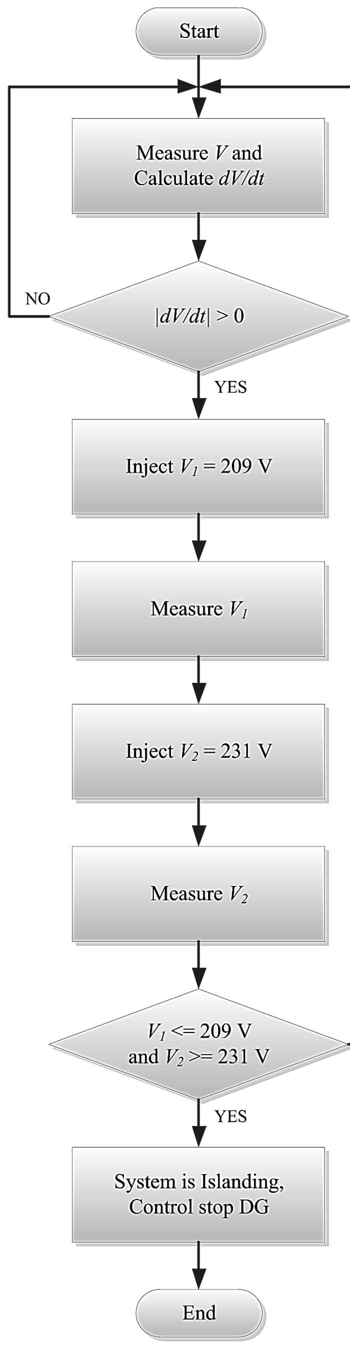

Figure 8 Two-level voltage shift islanding detection algorithm.

When |*dV/dt*| > 0, the inverter will release voltage V_1 (set V_1 = 95%, or V_1 = 0.95 × 220 = 209 V) into the power system, and V_1 at the PCC will be measured in order to record the readings. Then, the inverter will release voltage V_2 (set V_2 = 105%, or V_2 = 1.05 × 220 = 231 V) into the power system, and V_2 will be measured at the PCC point for recording as well. The characteristics of V_1 and V_2 are shown in Figure 9.

After the injection of V_1 and V_2, the voltage at the PCC is calculated and estimated. If $V_1 \leq 209$ V and $V_2 \geq 231$ V, shows that islanding condition has already occurred within the control system and this forces the DG to cease distributing electricity to the load. If it was not the condition shown and islanding condition did not happen, the algorithm would return to the start of the process.

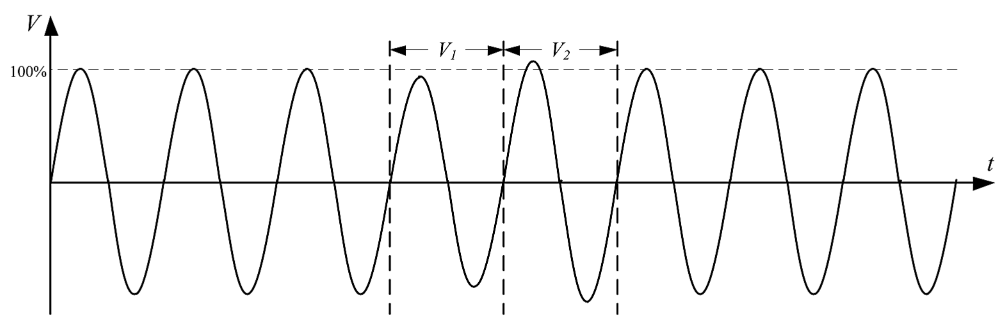

Figure 9 Characteristic of V_1 and V_2 injected into the system.

It can be seen that the new method is similar to the voltage shift method because it has been developed from the voltage shift method. However, the new method is likely to disturb the stability of the system as it shift less voltage level to detect islanding condition than the voltage shift method. Whereas, the voltage shift method reduces or increases the voltage level in order to detect islanding condition for UVR or OVR to work. Generally, UVR or OVR is set up according to IEEE Std. 929, IEEE Std. 1547, the international standard IEC 62116, UL 1741, Japanese Standard (JET Std. 2002), and Korean Standard (Korean PV 501, 2008). For example if the standard IEC 62116 is set up for OVR and UVR, OVR must be set on 115% of normal voltage, or OVR set = 1.15 × 220 = 253 V and UVR must be set on 85% of normal voltage, or UVR set = 0.85 × 220 = 187 V.

With the injection of the two-level voltage shift method analysis variation of active power as well as the Equation (6) is

$$\Delta P_{DG} + \Delta P_{Grid} = 2 \cdot \Delta V \cdot \sqrt{\frac{P_{load}}{R}}$$

According to the Equation (6), R and P_{load} are constant when the inverter injected two-level voltage shift waveforms into the power system where the DG and Grid are still connected. According to this equation, it can be analyzed that V_{PCC} (ΔV) remains unchanged, but ΔP_{DG} and ΔP_{Grid} will change.

Results and Discussion

This section provides proof of the two-level voltage shift islanding detection algorithm for the anti-islanding condition on Matlab/Simulink. The presented model, in Figure 10 shows $v_{grid} = 220^{2/1}(2)sin(\omega t)$, $f_0 = 50$ Hz, $Q_f = 2.5$, $R = 31.1$, $L = 39.6$ mH, $C = 255.86$ μF, $I_d = 10$ A, $I_{q0\_max} = 1$ and $K = 9$. In Figure 11 is the two-level voltage shift block shown within the model of Figure 10. The model creates the islanding condition at 0.2 sec.

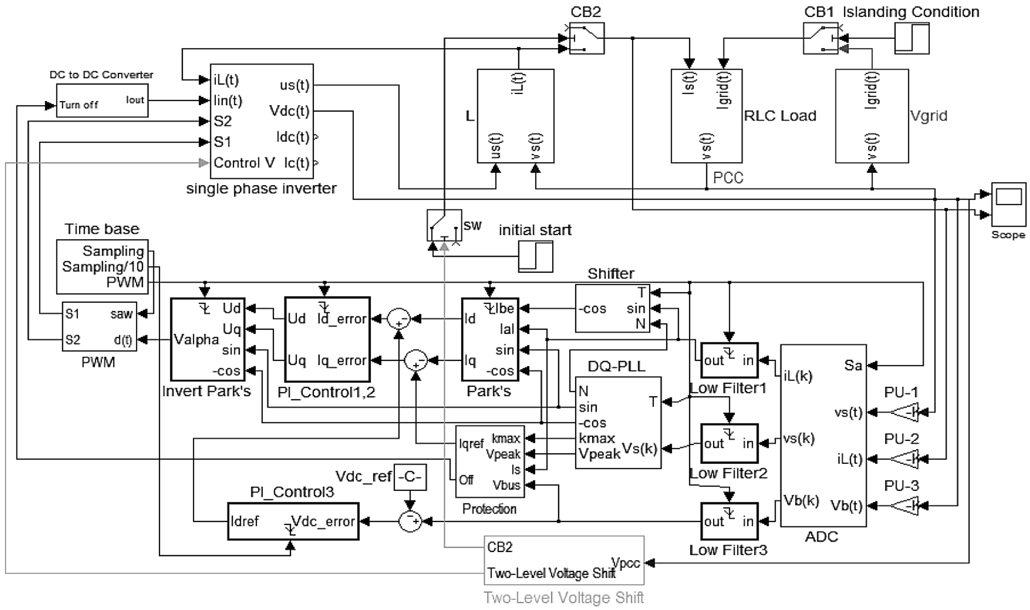

Figure 10 Model of a single phase grid-connected inverter with two-level voltage shift block.

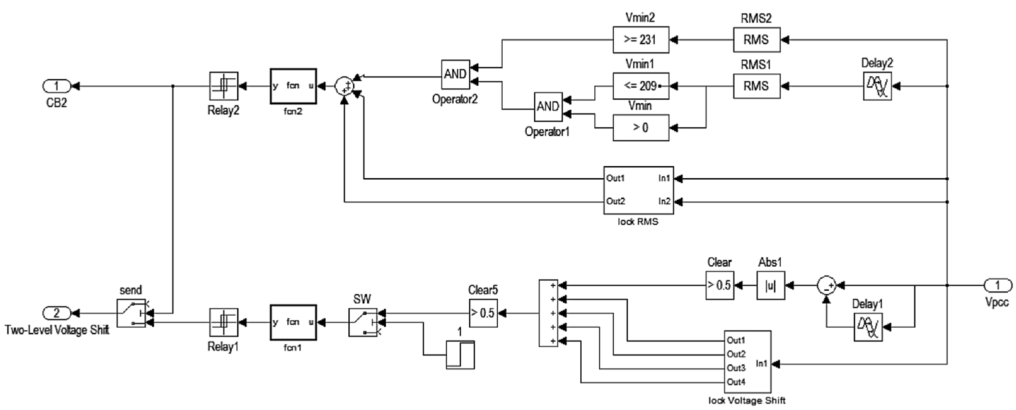

Figure 11 Two-level voltage shift block.

From the algorithm of the two-level voltage shift method exhibited in Section 3, it can be seen that in every case, the method checks the islanding condition by injecting a two-level voltage shift. The paper set constant voltage at V_1 = 209 V and set constant voltage at V_2 = 231 V. Simulation results in Figure 12 can be replaced in every case of the two-level voltage shift method.

From Figure 12, when the Grid was off, the islanding condition was at 0.2 sec. This will cause a variation in voltage which the two-level voltage shift block can detect. Next, the control system releases V_1 = 209 V and V_2 = 231 V into the load and, then measures V_1 and V_2 at the PCC respectively, and analyses, whether V_1 <= 209 V and V_2 >= 231 V is real or not. The inverter will command the DG to cease the operation as seen from Figure 12 where the condition is true, and the control system will command the DG to stop distributing electricity into the power system at the period of 0.24 sec. This means that this new method can perform anti-islanding condition within 0.04 sec.

Regarding Figure 13, it shows the simulation results of releasing V_1 = 209 V and V_2 = 231 V into the load where the existing condition is not islanding condition. By releasing a two-level voltage shift, it fixes the period at 0.4-0.44 sec. According to the simulation results, it was found that V_{PCC} remains unchanged, but at the period of releasing, the signal will cause P_{DG} and P_{Grid} to change which corresponds with the Equation (6). The variation of P_{DG} and P_{Grid} in Figure 13 is likely to be smaller than P_{DG} and P_{Grid} shown in Figure 7. Therefore, the two-level voltage shift method is less likely to disturb the stability of the system than the voltage shift method.

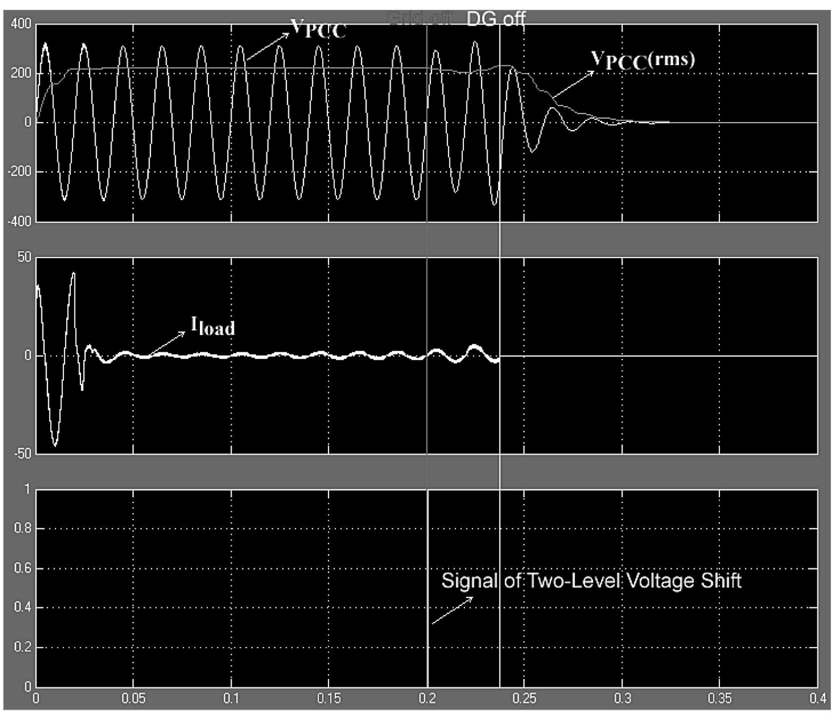

Figure 12 Simulation result of two-level voltage shift method.

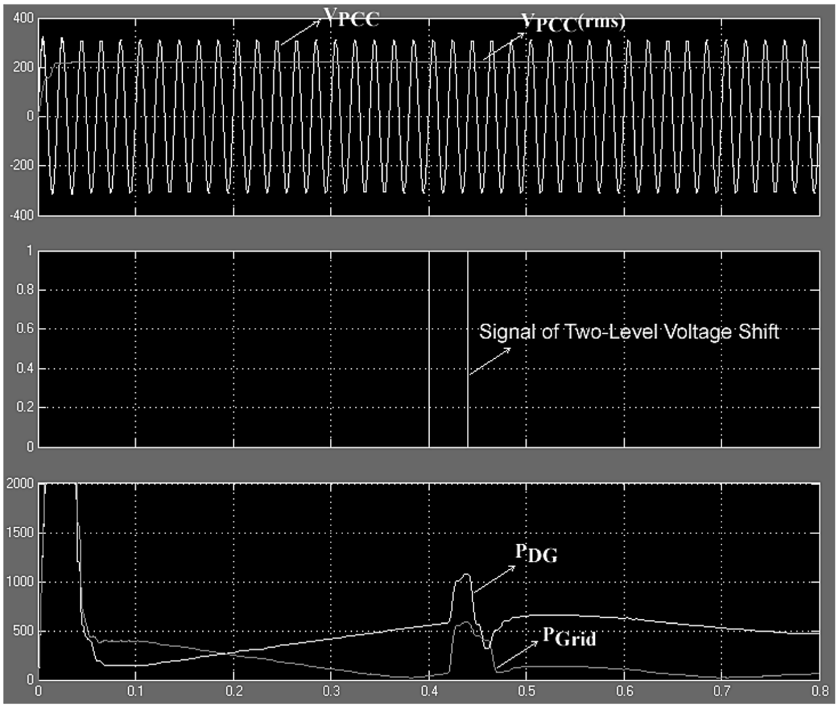

Figure 13 Inject a signal of two-level voltage shift in normal condition.

Conclusion

Simulation results show that the two-level voltage shift of the active islanding detection method can determine the anti-islanding condition very quickly, and it can determine anti-islanding condition within 0.04 sec. It does not have a nondetection zone, and also it is less likely to disturb the stability of the system than the voltage shift method.

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