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Operation Mode Transition of a Low-Voltage Single Phase Microgrid based on Synchronization Controller

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Abstract: In case of system contingencies, improving the continuity of the electrical supply by islanding capabilities is of great interest. Besides, reconnecting the power network after an islanding event is also an important issue for maintaining the power system stability. This paper investigates the disconnection and reconnection of a microgrid consisting of two DG voltage source inverters in case of a grid disturbance. The main problem is to achieve a smooth transition between both modes of operation by implementing proper control strategies for the DGs and incorporating a robust synchronization controller. The synchronization controller is implemented to synchronize the microgrid with the main grid after an unintentional islanding condition. Flip flops are utilized to manage the set and reset operation of the static switch and the DG VSI operation mode depending on the network status. The system performance under the short circuit condition has been validated through simulations using SimPowerSystems toolbox in Matlab/Simulink software.

Keywords: Microgrid; Grid connected mode; Islanded mode; Synchronization controller; Grid disturbance.

1. Introduction

Due to the immense penetration of the renewable energy sources, the development of distributed generator power converters integrated to the low voltage network has rapidly increased [1, 2, 3, 4]. The microgrid in general, consists of three main elements which are: distributed generators, controllable loads, and storage elements. It has the ability to operate islandly or interconnected to the main network either a low or medium voltage network [5, 6, 7]. The transition between both modes of operation should be smooth in order to avoid deleterious overcurrent transients. Therefore, the voltage magnitude, frequency and phase angle of both networks should be matched to achieve this target. In other words, the difference between these quantities for the main grid and the microgrid should be as small as possible before the reconnection process. In the event of grid disturbances, unstable power conditions may emerge because of the microgrid disconnection from the main grid. However, these instabilities should be eliminated at the instant of reconnection if both networks are successfully synchronized [8, 9, 10].

The synchronization problem has been discussed by many researchers lately. Most of the papers focuses on two major objectives: the first one is fault ride-through capability to limit the fault current so that the microgrid can still work in grid connected mode or the implementation of fast grid voltage synchronization algorithms using sophisticated schemes. Many techniques have been investigated to achieve the requirements of the fault ride-through either for individual distributed generators or at the point of common coupling between the microgrid and main grid to alleviate the disconnection probability. Reference [11] presents a fault ride through scheme using a mutual inductance placed at PCC to suppress the fault current and to maintain the microgrid grid-connected. The inductance requires no control but may misoperate for some fault locations or reverse power flow conditions. Enhancing the performance of the microgrid system and achieving smooth transition between its operation modes are proposed in [12] by installing

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a superconducting fault current limiter (SFCL) at PCC between the main grid and the microgrid. Reference [13] investigates the microgrid fault ride through capability by installing a SFCL and implementing a relay protection coordination when a short circuit takes place inside the microgrid. Different fault cases have been proposed in [14] for a microgrid consisting of photovoltaic, wind generator and energy storage with the existence of a SFCL to relieve the short circuit current and recover the voltage sags. A control strategy for enhancing the microgrid ability to ride-through both balanced and unbalanced grid voltage sags is depicted in reference [15]. Fast fault detection techniques have been also intensively investigated to satisfy the microgrid synchronization with the main grid [16, 17]. Reference [18] presents two synchronization Phase-locked loops for synchronizing the microgrid with the main grid where one PLL is used to detect the microgrid phase voltage and the other for detecting the grid phase voltage. The quadrature grid voltage detection from a PLL for the sake of microgrid synchronization is presented in [19] and [20]. Detecting the phase and amplitude error in a dq based reference frame using a single PLL for network synchronization have been investigated in [21] and [22]. Reference [23] presents a synchronization system based on a frequency locked loop in a stationary reference frame for phase angle detection. An active synchronizing control scheme which adopts a central based coordinated control for multiple DGs is presented in [24]. Also, a dual second order generalized integrator based on a frequency locked loop is presented in [25]. A transfer strategy based on droop control of local microsources is presented in [26] where the algorithm satisfies frequency synchronization and then phase synchronization regardless of the voltage magnitude coincidence.

In this paper, a synchronization controller is implemented within the islanded control unit of the microgrid to achieve seamless reconnection of the DGs voltage source inverters. The proposed controller is flexible and reliable where it exchanges the needed information with the inverters of the DGs inside the microgrid instantaneously. The islanded control unit is used to ensure high quality voltage profile and to provide the needed power for the local loads. During a short circuit condition, the static switch will open and the control units of the DGs will switch to the islanded mode where a synchronization controller is triggered to synchronize the DGs inside the microgrid with the main grid before reclosing the static switch.

The remainder of the paper is organized into five sections. Following the introduction, single line diagram of the proposed system and the control structure of the DG inverter in grid-connected mode are presented in section 2. The structure of the synchronization controller is investigated in section 3. Section 4 presents the results of the simulations which are conducted via Simpowersystems toolbox in Simulink. Finally, section 5 presents the conclusion.

2. Description of the proposed model

A single-phase power system model which includes two VSIs, two resistive loads, both forming the microgrid structure is depicted in Figure1. No energy storage devices are involved. A static switch (STS) is placed to connect and disconnect the microgrid from the utility grid when needed. $\boldsymbol{R_{line}}, \boldsymbol{L_{ine}}$ are the resistance and inductance of the line which are resistive in nature as the microgrid is at the distribution level. $\boldsymbol{L_1}, \boldsymbol{L_2}$ indicate the output inductance of the DGs voltage source inverters. $\boldsymbol{P_1}, \boldsymbol{Q_1}$ and $\boldsymbol{P_2}, \boldsymbol{Q_2}$ are the real and reactive power generated by the two DGs voltage source inverters. Both distributed generators inject the required active power to their loads then the rest of power (denoted by $\boldsymbol{P_T}, \boldsymbol{Q_T}$) transfers to the utility grid.

Both DGs have identical control strategies in grid-connected mode. The voltage source inverters of the DGs were modelled as ideal controlled voltage sources. The control strategy for grid connected mode is shown in Figure 2 and investigated in [27, 28].

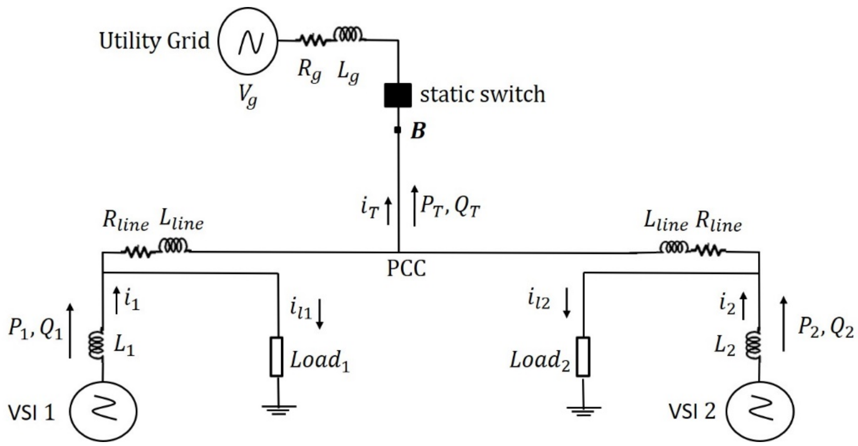

Figure 1. Single line diagram of the proposed model

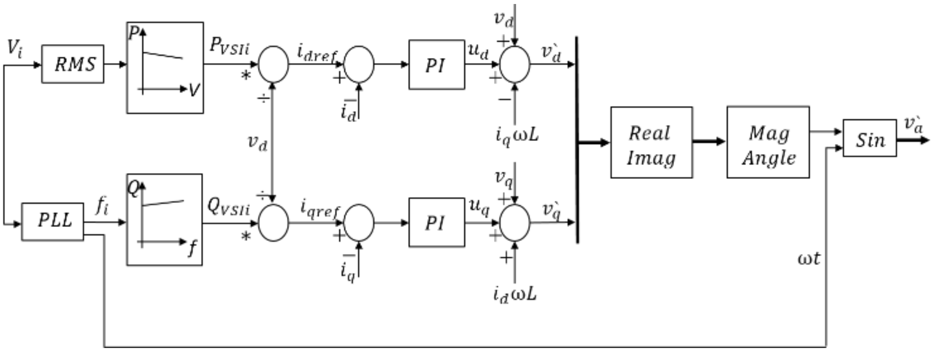

Figure 2. Control strategy of the single phase VSI in grid connected mode

3. Structure of the synchronization controller

When the DG is operating in the islanded mode, the reference voltage of the DG voltage source inverter is generated using an advanced control strategy. The control strategy employs a sinewave generator as an external dc source to generate the reference frequency and voltage magnitude for the DG operation when islanded. The operation mode of the voltage source inverter is changed from grid connected mode to islanded mode once a short circuit condition is revealed. However, the voltage source inverter of the DG should be coincided with the main grid before reconnection to avoid undesirable overcurrent transients [29, 30]. Therefore, during the islanded operation of the DG, the synchronization controller is triggered to minimize the voltage magnitude, frequency, and phase angle of the voltage source inverters to be matched with the main grid. As long as the microgrid is synchronized with the main grid, it is again reconnected and the control strategy of the voltage source inverters are changed from islanded mode to grid connected mode.

The structure of the synchronization controller which includes the control strategy of the voltage source inverter during islanded mode of the DG is presented in Figure 3. The voltage magnitude and frequency are generated from an external sinewave generator when the DG voltage source inverter works in islanded mode. The phase angle of the voltage source inverter extracted based on the sinewave generator θ_{ext} is chosen first. Then the new phase angle is chosen by the switch to synchronize the voltage source inverters of the DGs with the main grid. This new phase angle is nominated by θ_{new} which is derived once the synchronization controller is activated during the islanded mode. This is to make sure that the voltage source inverters of the DGs are synchronized with the utility grid. The synchronization criterion is accomplished by taking the phase difference between the utility grid voltage and the voltage source inverter voltage. Then, the sine of this angle difference went over a PI controller and compared with the old phase angle to extract the new phase angle of the DG. The sinewave of the new phase angle of each voltage source inverter is multiplied with the voltage magnitude to generate the reference sinewave voltage. This voltage is now passed through a voltage controller which is operated in island mode.

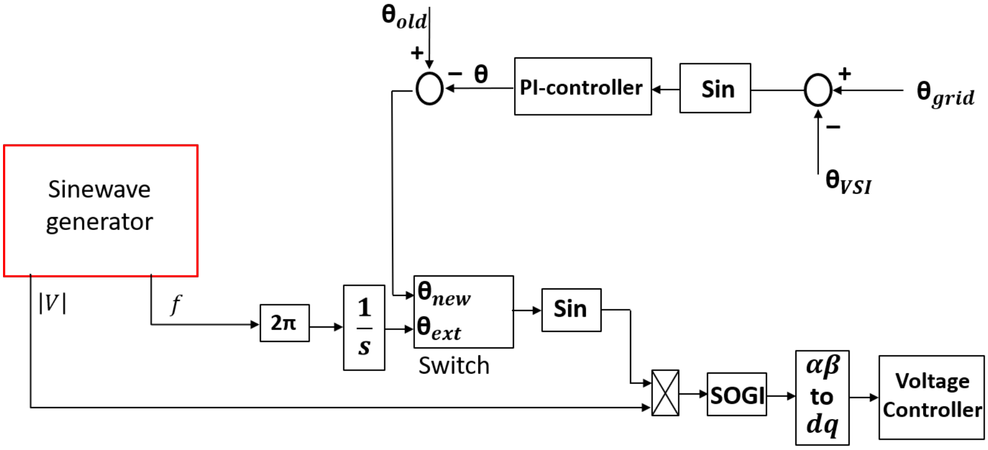

Figure 3. Synchronization controller structure

Figure 4 shows the proper coordination of flip flop 1 which represents the static switch, and flip flop 2 which represents the operation mode of the DG voltage source inverter. The protection scheme monitors the instantaneous grid current value. Then, the protection scheme output becomes high and subsequently the flip flops of the static switch, and the DG VSI operation mode are adjusted to the set command once the current overrides a specified or threshold value due to a short circuit occurrence in the main grid. Once the fault is cleared, the fault clear signal is set high manually to reset the flip flops. Therefore, the static switch is again reclosed and the operation mode of the VSI is changed to grid connected mode. The fault clear is triggered once the synchronization criterion derives the new phase angle during the islanded operation mode.

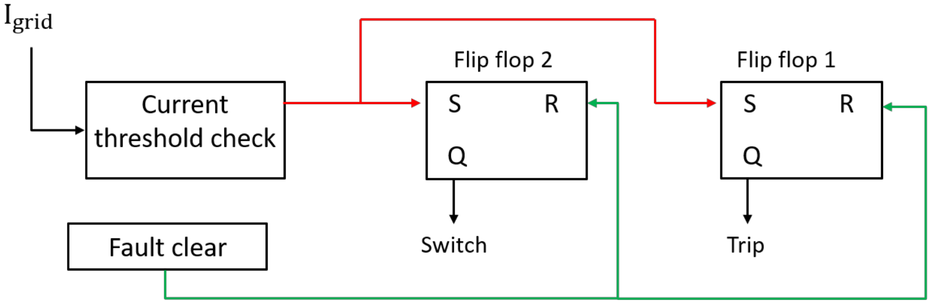

Figure 4. Coordination of the static switch, and operation mode of the DG VSI

4. Simulation results

The single-line diagram presented in Figure 1 is implemented as a simulation model by using Sim Power Systems toolbox in Simulink. The parameters of the utility grid and the microgrid are all presented in Table 1. A short circuit is proposed to occur at point B shown in Figure 1 where the short circuit begins at t = 2 s and lasts for 300 ms. The disconnection and reconnection of the DGs voltage source inverters are verified considering that the fault location is at point B.

Table 1. System Parameters

System parameters	Values
Grid	
Grid voltage (V_g)	230 V rms
Grid Frequency (f)	50 Hz
Grid Resistance ($\mathrm{R_g}$)	0.0025 Ω
Grid Inductance ($\mathrm{L_g}$)	0.1 mH
Microgrid VSIs	
VSI Inductance ($\mathrm{L_{1,2}}$)	0.1 mH
Line Resistance ($\mathrm{R_{line}}$)	0.5 Ω
Line Inductance ($\mathrm{L_{line}}$)	1 mH
VSI 1 rated power (S)	9.4 kVA
VSI 2 rated power (S)	12.3 kVA

Figure 5 (a)-(c) depict the system behavior under short circuit condition without opening the static switch. It can be seen that the fault current has a transient peak of about 5kA. The peak value of the PCC voltage is dropped to lower value and the rms voltage of both voltage source inverters (VSIs) is oscillating out of the acceptable limits. Thus, the microgrid VSIs should isolate themselves and switch to island control mode.

In this case, the fault is proposed to occur at the grid side and the total load demand is also considered as zero. The static switch will open and the microgrid VSIs will operate in island control mode. In island control mode, the microgrid VSIs frequency and phase angle will oscillate with a different value than the main grid. Before the fault clearance and reclosing of the static switch, the synchronization controller is triggered by the system operator to synchronize the microgrid VSIs with the main grid before the static switch is reconnected. Both VSIs are current controlled when they are operating in grid connected mode and voltage controlled when the microgrid is disconnected from the main grid. The system was initially operating in grid connected mode then the microgrid is disconnected at t=2 s. Therefore, the control mode of both VSIs changed from current control (Grid-Connected) to voltage control (Island-Mode) operation. Figure 6 depict the voltage and current of both VSIs before and after the disconnection of the microgrid from the main grid. The voltage and current transient appeared at the moment of disconnection is due to the unintentional short circuit effect and the switching of the control mode from grid connected to islanded operation.

The microgrid is reconnected at 2.3 s to the main grid where a fault clear signal is triggered manually and sent to both flip flops to reset their states. Both DGs inside the microgrid were operating in island mode until their VSIs are synchronized with the main grid. The synchronization controller of both VSIs is triggered at t=2.2 s by the system operator.

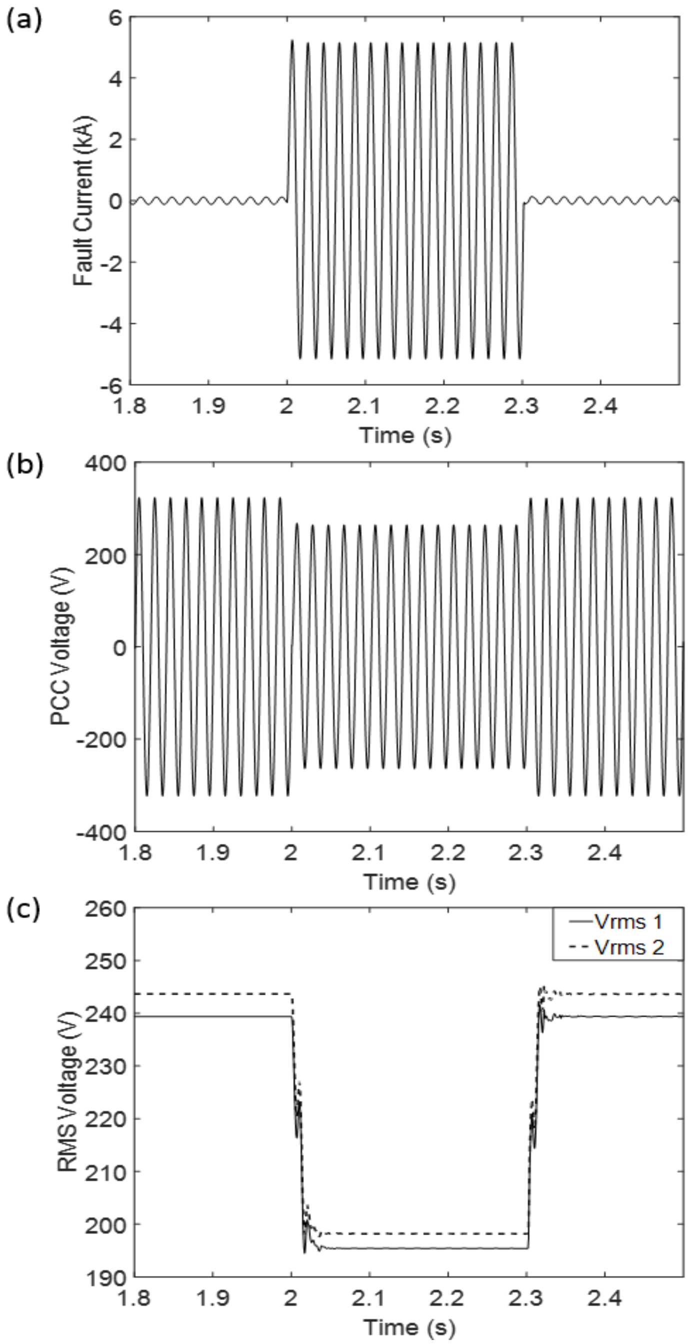

Figure 5. The system performance during a fault condition. (a) Fault current (b) PCC voltage (c) RMS voltage

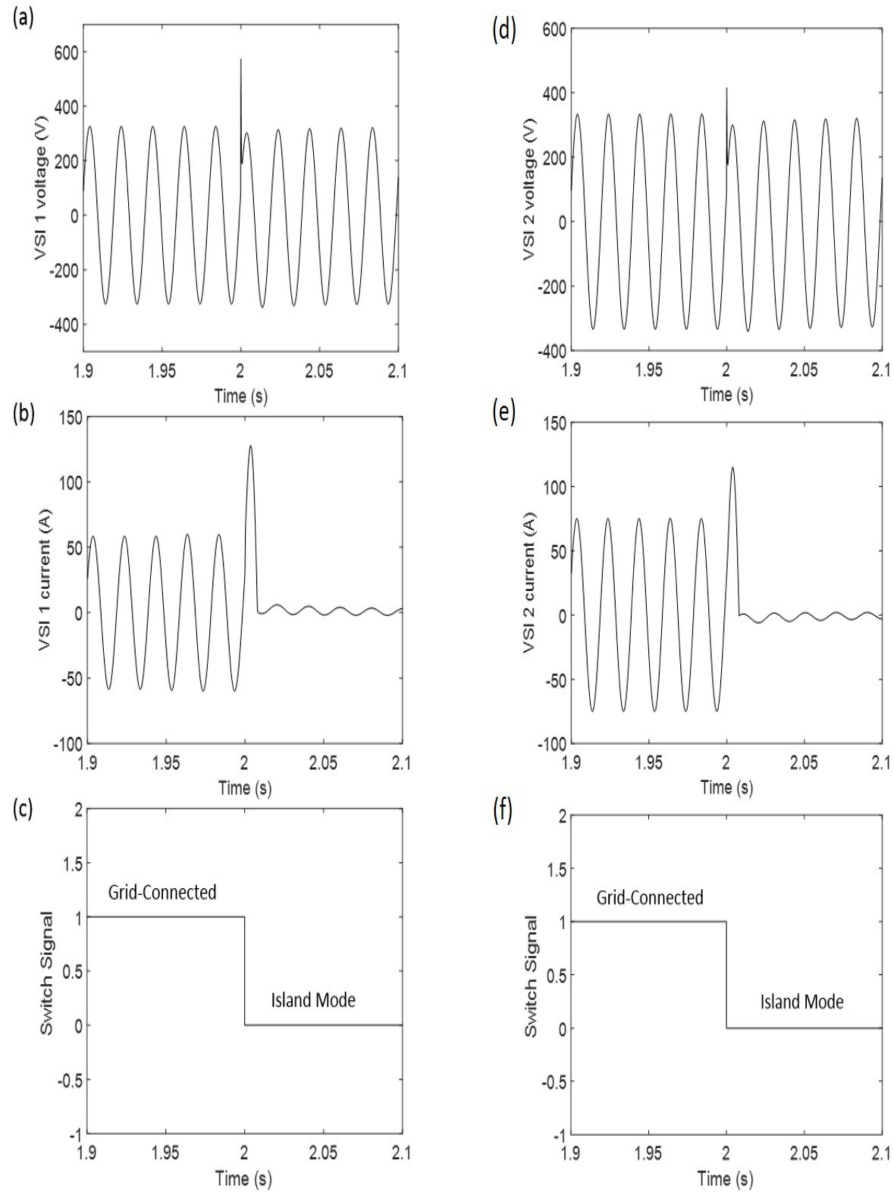

Figure 6. The performance of both DG voltage source inverters during the fault condition. (a) voltage of VSI 1 (b) current of VSI 1 (c) switch signal of VSI 1 (d) voltage of VSI 2 (e) current of VSI 2 (f) switch signal of VSI 2

Figure 7 demonstrates the detailed view of the reconnection of both VSIs voltage and phase angle with the main grid directly after the synchronization controller is triggered in the island mode. It is clearly shown that the proposed synchronization controller forces both VSIs voltage and phase angle to track the voltage and phase angle of the main grid. Once the reconnection process is completed, the DGs voltage source inverters are reconnected to the main grid and the control mode of both VSIs is changed from island mode to grid connected mode. It can be noted that the reconnection process of both VSIs is accomplished with free voltage transient and seamless transition from island mode to grid connected mode.

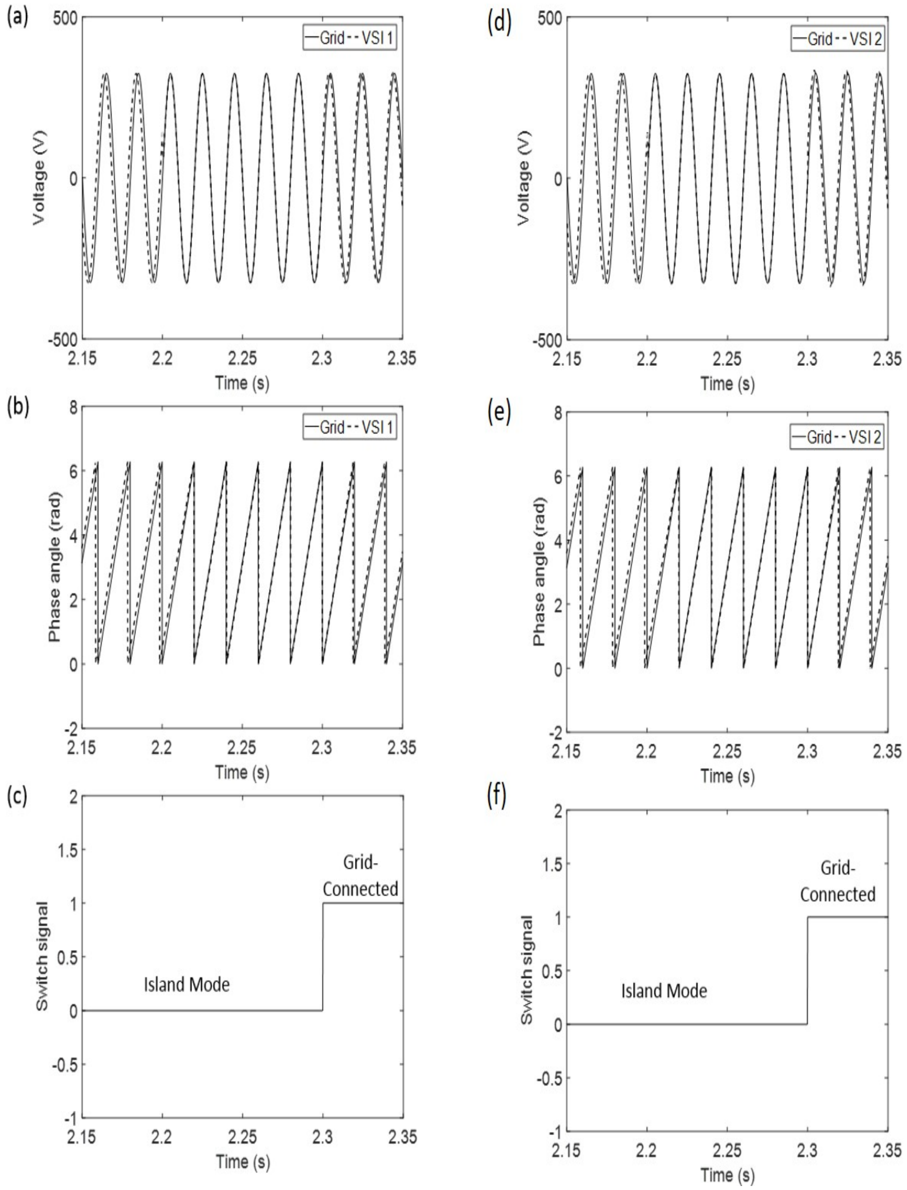

Figure 7. The performance of both DG voltage source inverters during reconnection process. (a) voltage of the grid and VSI 1 (b) phase angle of the grid and VSI 1 (c) switch signal of VSI 1 (d) voltage of the grid and VSI 2 (e) phase angle of the grid and VSI 2 (f) switch signal of VSI 2

Figure 8 shows a detailed view of the disconnection and reconnection process of the microgrid from the main grid in terms of the PCC voltage, current, real and reactive power. It is clearly shown that the voltage exhibits some transient at the moment of disconnection due to the unintentional short circuit effect. At the moment of reconnection, the transition between both modes exhibits free voltage transient. The PCC current shows some transient at the moment of disconnection and reconnection process. The current transient at the moment of disconnection is appeared due to the unintentional short circuit effect and it is worth noting that the current will cease to oscillate only at the next current zero crossing. At the moment of reconnection, the current transient is established due to the conflict of the transition from the voltage control mode to current control mode. The variation of active and reactive power at PCC when transferring from island mode to grid connected mode is reflected on the PCC current during reconnection. The active and reactive power at PCC, VSI 1, VSI 2 are also presented in the same figure. The system was operating initially in grid connected mode and both VSIs were injecting real and reactive power into the main grid. At t=2 s, the microgrid is disconnected and operates in island mode. Since the load demand is zero, the active and reactive power exhibits zero value during the island mode. At t=2.3 s, the microgrid is reconnected to the main grid. It is obvious that the active and reactive power exhibit fewer transient at the moment of disconnection and reconnection process. This transient is due to the conflict of the voltage controller and current controller of both operation modes when the transition occurred between both.

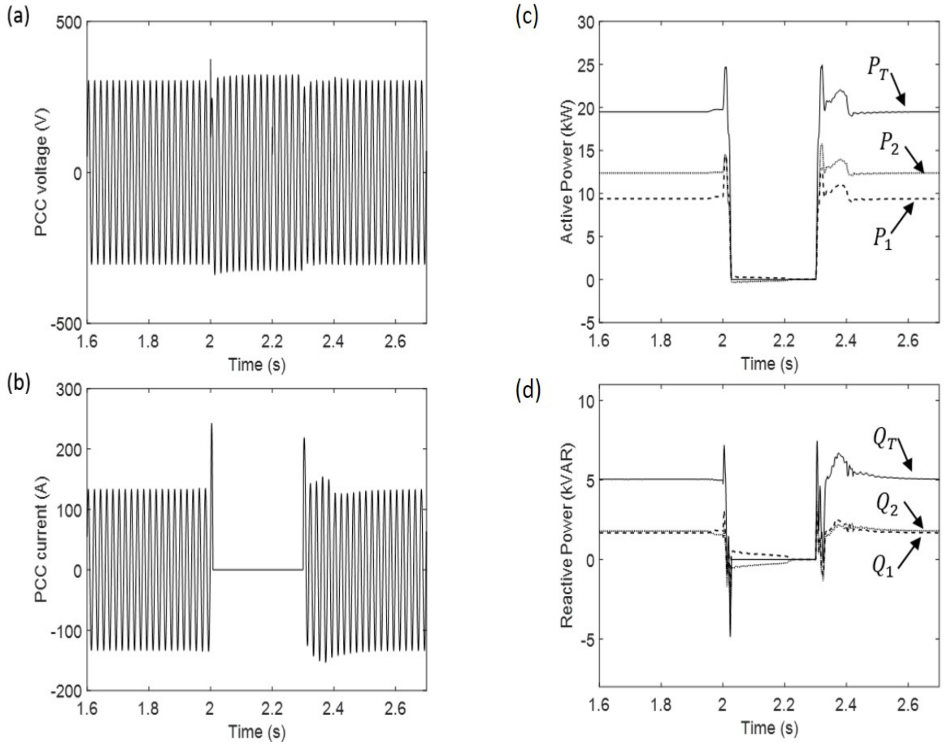

Figure 8. Complete view of the system parameters before and after the islanding event. (a) PCC voltage (b) PCC current (c) Active power of DG VSI 1, DG VSI 2, and PCC (d) Reactive power of DG VSI 1, DG VSI 2, and PCC

5. Conclusion

This paper investigates the performance of a synchronization controller installed within the control unit of each DG VSI inside the microgrid under a short circuit event. Disconnection and reconnection of the microgrid or the DG voltage source inverters have been validated through proper coordination of flip flops which manage the static switch and the operation mode of the DG VSI. The fault location is proposed to occur at the grid side. It was observed from the simulation results that the synchronization controller forces the DG voltage source inverters to track the voltage magnitude and phase angle of the main grid. Furthermore, it was noticed that the real and reactive power of the DG voltage source inverters have fewer transients at the disconnection and reconnection instants. These transients are due to the conflict between the current control in grid connected mode and voltage control in the islanded mode. This problem can be considered as a future work.

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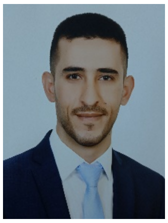

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