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Single Phase PV Grid-Connected in Smart Household Energy System with Anticipation on Fault Conditions

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ABSTRACT

This paper proposes an algorithm of Smart household energy systems to anticipate fault conditions in power system grid. Single phase PV grid-connected in smart household energy system is a smart system that determines electrical supply conditions to the load in residential electrical system. The smart system is consisted of two voltage source, conventional electricity system from national electricity provider as preferred source and photovoltaic as the alternative source. In smart system, fault conditions can be anticipated by selecting the appropriate voltage sources to supply the load. The condition of smart system can be described in power flow regulation to the load by detection and identification of amplitude, phase angle, and frequency of the voltage source compared to the system reference. The system mechanism is based on detection of voltage source using static transfer switch (STS) with phase locked loop (PLL) as voltage detection algorithm which output is used to determine decision logic algorithm for switching conditions. The results show that conditions of smart power system flow can be obtained based on voltage source selection in decision logic when fault condition occurs.

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1. INTRODUCTION

Limited power supply capability in Indonesia which is managed by national electricity provider (Pusahaan Listrik Negara / PLN), as preferred source, encourages another electrical energy source to be used as alternative source of electrical energy in the grid. Photovoltaic (PV) is one of alternative source of electrical energy derived from solar irradiation and converted into electrical energy. The use of PV energy in grid-connected system will improve power system quality especially for residential application [1].

Moreover, the fault condition should be anticipated to increase system reliability. Fault conditions in system can affect power quality delivered to the load. Voltage fault, such as voltage sag and voltage swell, can degrade the power quality which could damage electrical equipments [2].

The smart household energy system can be applied for single phase PV grid connected system. The smart household energy system uses PV grid-connected in energy supply and regulates power flow to the load. Smart condition is obtained by detecting and identifying the amplitude, phase angle and frequency of preferred and alternative source. In single phase system, voltage source conditions can be detected using PLL algorithm. The fault condition in the grid can be anticipated based on the voltage source condition. Then, the condition of both supplies is used to determine which supply is connected to load [3].

This paper describes a smart household energy system using photovoltaic (PV) as an alternative source, and the national electricity provider as preferred source. Voltage source detection system is applied by using static transfer switch (STS) to create a smart system for anticipation of fault conditions in the grid. This system is expected to fulfill an ideal condition for electricity generation in accordance with customer needs and create a system that capable to anticipate fault condition on the grid.

2. RESEARCH METHOD

2.1. PV Grid-connected

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are PV grid-connected and PV stand-alone. PV power systems consist of PV generator, inverter, connection-interconnection components and other supporting components [3]. PV generator is a PV module that converts solar irradiation into electrical energy. The inverter is used to convert the DC power source into an AC power source. Connection-interconnection components have function in the process of electrical installations to the load.

Figure 1 shows the condition of PV grid-connected system. Both G_1 and G_2 in the close condition indicate the condition of PV grid-connected system in which photovoltaic and grid work together to supply the load. When G_1 is closed and G_2 is in open condition, it shows the condition of PV stand alone where the load will be supplied entirely by photovoltaic. When G_1 is open and G_2 is in close condition, the load is supplied entirely by the grid. Then, when G_1 and G_2 are in open condition, there is no current flowing into the load. To obtain synchronous condition between photovoltaic and grid, PV takes a synchronization reference for the inverter from the grid so that the conditions derived from the photovoltaic supply to the load will be synchronized with the grid.

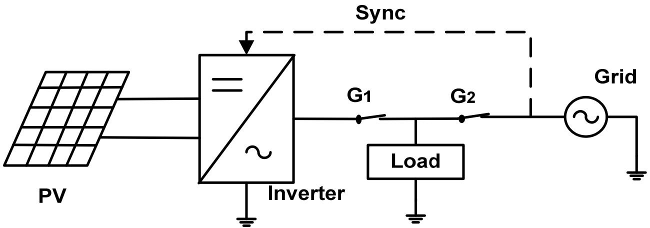


Figure 1. PV grid-connected system

2.2. Single Phase STS System

Static Transfer Switch (STS) is the detection and identification methods which are used to select and set conditions of voltage source for supplying the load based on the switching condition. Figure 2 shows a single phase STS system. STS system consists of the power circuit and control logic [4-10]. In power circuit, a pair of back-to-back GTOs (Gate Turn Off) are used as switching which connect or diconnect a source to load [4], [5]. Control logic provides a gating signal to switching G_1 and G_2 based upon the power conditions of the sources. The control logic circuit is responsible for monitoring the quality of sources and performing the transfer of the load from the preferred source to the alternative source, and vice versa.

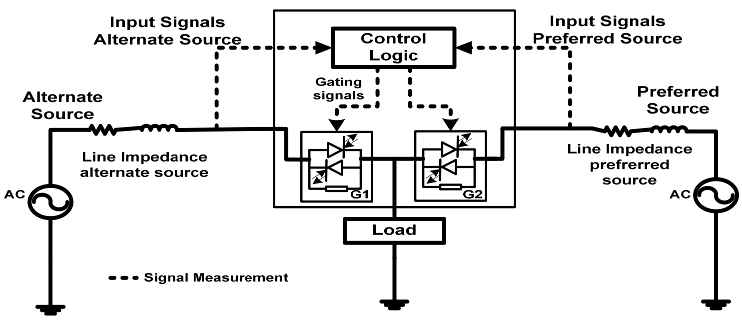


Figure 2. Single phase STS system

2.3. Proposed Smart Household Energy System

Figure 3 shows the proposed smart household energy system with applications of single phase PV grid-connected. The system consists of a PV grid-connected system as an alternative source, national electricity grid system (from PLN) as the preferred source, STS, and household appliances which are described in AC load. Conditions of smart household energy system can be viewed from switching conditions G_1 and G_2 that can be set automatically. The decision of switching conditions is determined by the control logic of STS.

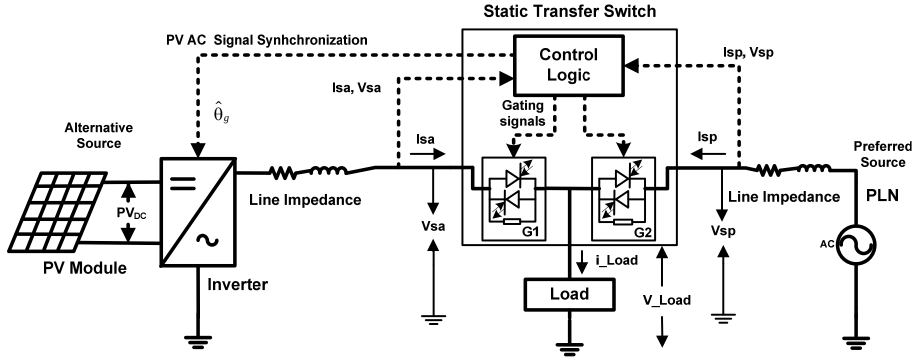


Figure 3. Proposed smart household energy system

2.3. 1. Control Logic of STS

The control logic of STS, as shown in Figure 4, is consisting of two sections; source detection and decision-making logic sections. The control logic is responsible for monitoring the quality of the source voltges and performing a smart decision which source that the load should be transfered. The preferred and alternative sources will be measured in the form of voltage and current measurement. These voltage and current from each source are the required input signals to the source detection block. Here, the measurement results will be processed to be detected and identified by using PLL and than they were compared with reference values given conditions on the system. Further, these conditions of the source detection will be input to the decision-making logic block. In the decision-making logic, G_1 and G_2 will be set automatically according to the conditions from the source detection block.

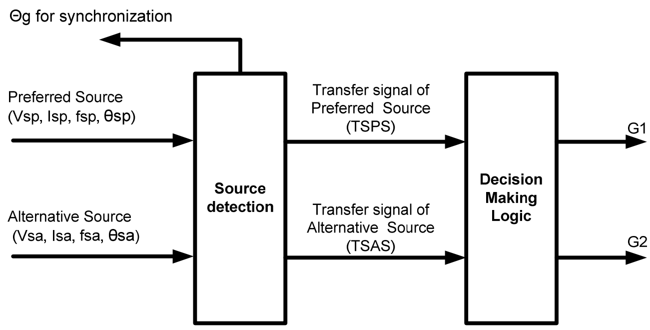


Figure 4. Block diagram of the control logic of a STS.

A. Source Detection

Source detection algorithm is the algorithm that used to detect the condition of both preferred and alternative power source. Source detection algorithm use phase locked loop algorithm (PLL) to detect the condition of amplitude, phase angle, and frequency of preferred and alternative power. The Source Detection algorithm's block diagram is shown in Figure 5, and the flow chart of transfer signal determination is shown in Figure 6.

PLL has three outputs, signal amplitude, frequency, and phase angle. Source detection algorithm use the voltage amplitude and frequency output from PLL algorithm to determine the condition of power source by comparing them to the voltage and frequency reference. The output of voltage and frequency comparison is then filtered using low pass filter to attenuate transient and noise from input signal. Then the output of low pass filter from voltage and frequency of both preferred and alternative source is compared to determine whether current condition is under tolerable range. If each voltage and frequency output under tolerable range then the transfer signal for each source will be set to 0, else it will be set to 1.

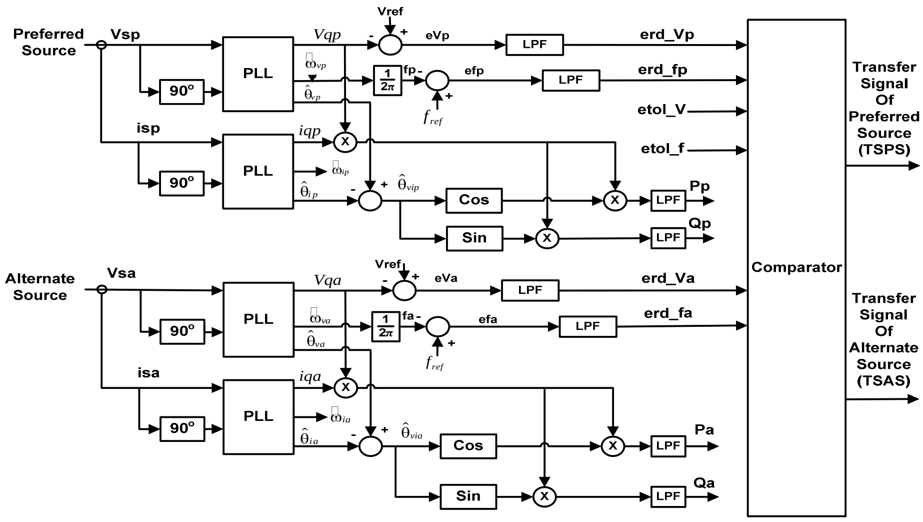


Figure 5. Block diagram of source detection

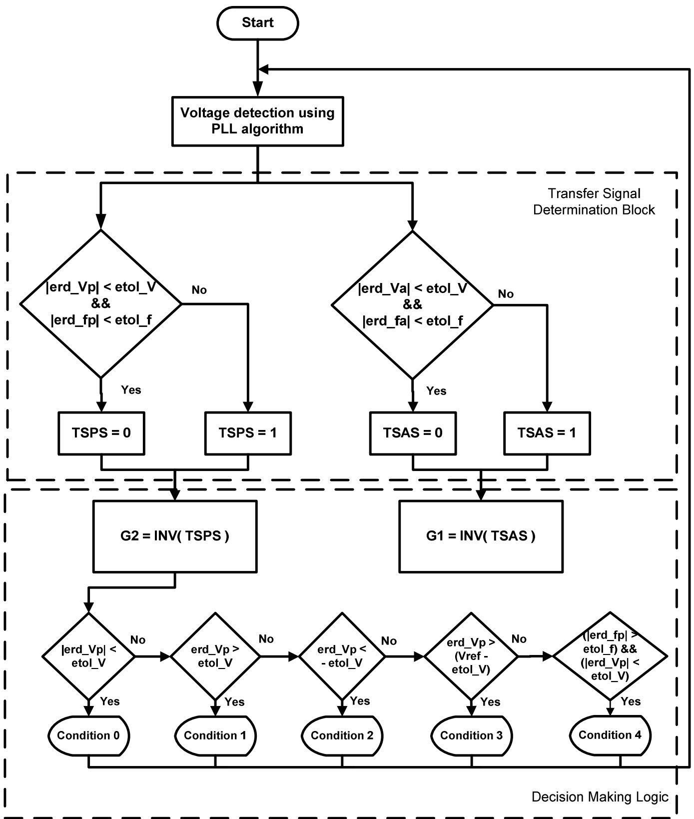


Figure 6. Flow chart of transfer signal determination

B. Decision Making Logic

Decision making logic is used to generate gating signals for G_1 and G_2. The logic is done by simply check which source has good output quality then connect load to one or both source. The logic implementation is done by using the TSAS and TSPS output logic from transfer signal determination block to determine gating signal for G_1 and G_2 by inverting the TSAS and TSPS value.

2.3.2. PV- Grid Synchronization

The AC power output from photovoltaic inverter (PV_{AC}) synchronization with grid is required to provide synchronous condition on the power system network. In order to keep PV inverter output synchronous to the grid, the PV inverter must be fed by synchronous angle ($\hat{\theta}_g$). In this system, a strategy for synchronization and protection system is developed. A conventional PLL algorithm use grid voltage as a phase angle reference, but with use only a conventional PLL algorithm the output of PV inverter will keep synchronous to the grid whether the grid power quality is under tolerable condition or greater than tolerable condition. In this paper a phase angel reference generator is developed. The phase angel reference use $\hat{\theta}_{vp}$ generated from PLL algorithm. However, when the preferred power source quality is outside of tolerable condition, the phase angel reference is generated using free running timer. The diagram block of proposed algorithm is shown in Figure 7 and the phase angel reference selection algorithm is described by flow chart in Figure 8.

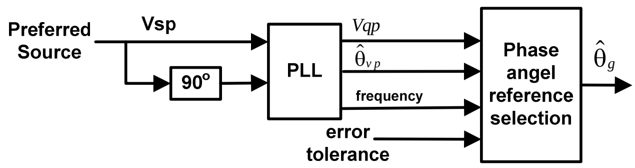


Figure 7. Block $\hat{\theta}_g$ which is generated by PLL from preferred source reference

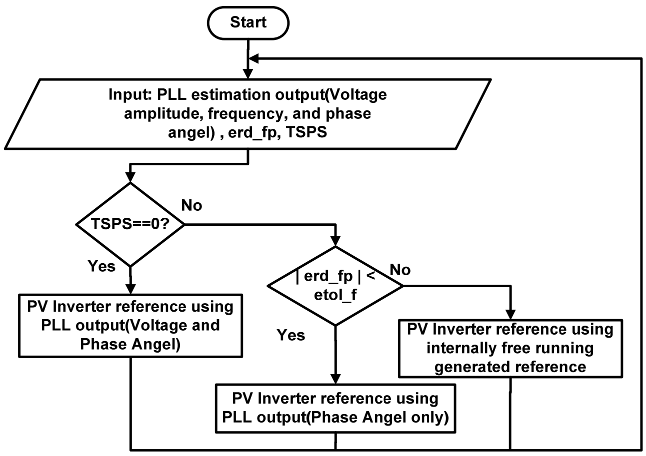


Figure 8. Flow Chart Flow chart algorithm to generate $\hat{\theta}_g$ in PLL from preferred source reference

3. RESULTS AND ANALYSIS

The system simulation is implemented using C language programming in Matlab Simulink. Detection time shows required time to detect the fault conditions in the grid, based on transfer signal conditions and gating logic on switching components. The system will provide the logic 1 (closed) or 0 (open) on gating logic to activate or deactivate the switching components on the preferred source (G_2) and alternative sources (G_1) in fault conditions. System fault conditions given are voltage sag, voltage swell, voltage momentary interruption, and variation of frequency. Table 1 gives parameter value used in the system:

Table 1. System parameters of smart household energy system

System Quantity	Value
Preferred Source	220 Volt
Alternative Source	220 Volt
Frequency System	50 Hz
Impedance Line Preferred Source	1,518 + j 0,7067 Ohm
Impedance Line Alternative Source	2.53e-4 + j 1,117e-4 Ohm
RL Load	18 + j 10,8 Ohm

GTO Specifications:
Ron = 0.01 Ω, Forward voltage Vf = 1 V
Current Fall Time 10% Tf = 10μsec
Tail Current Time Tt = 20 μsec
Snubber Circuit Parameters:
Resistance Rs = 5000 Ω
Capacitor Cs = 0.05 μF.
Parameters of Low Pass Filter:
Cut off Frequency = 100 Hz

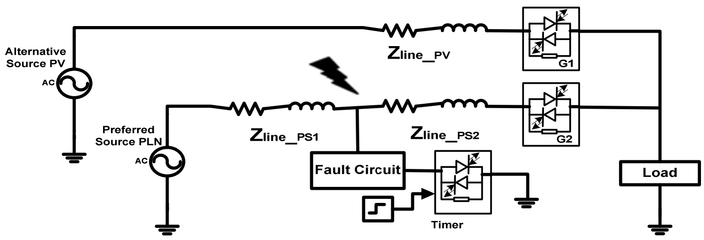


Figure 9. The schematic of fault conditions on preferred source

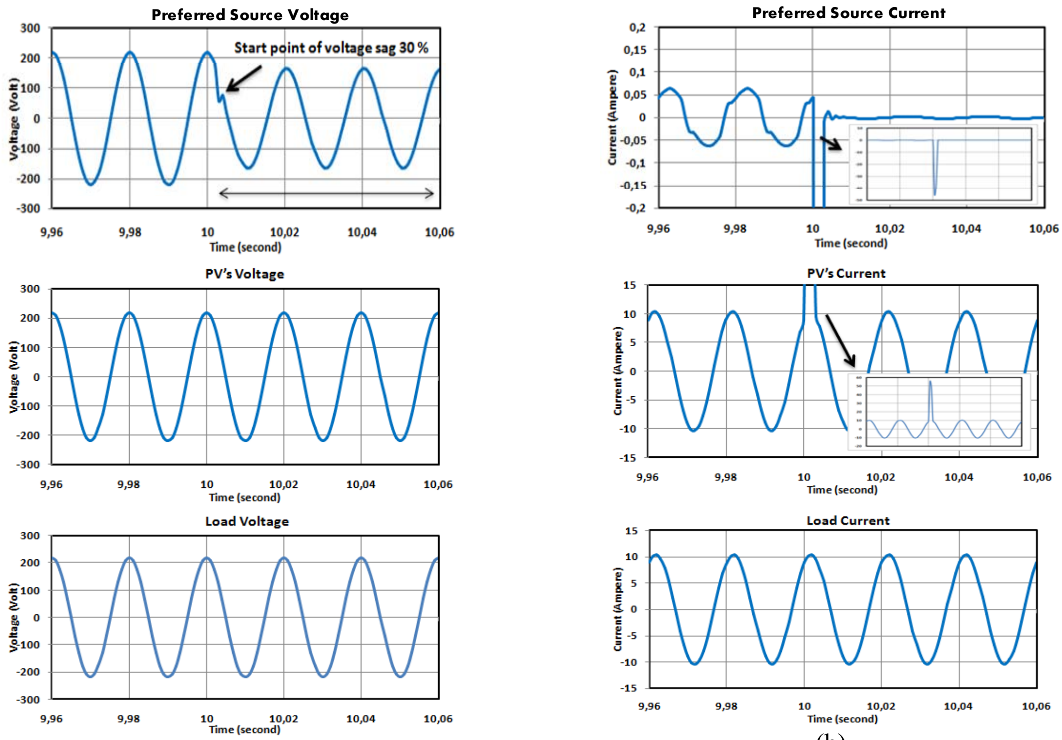
Figure 9 shows the schematic of fault condition occurs on preferred source. The transmission line is modeled by line impedance of preferred source from the value of line Z_{line_PS1} and Z_{line_PS2}. The value of line impedance based on the location of fault condition. The value of Zline_PS1 is 1.518 + j0.7065 Ohm and value of Z_{line_PS2} is 3.79e-4 + j 1.76e-4 Ohm. This system uses time sampling of 1ms and the fault condition occurs at 10 second.

3.1. Fault Condition in Preferred Source

When preferred source and PV supply the load in normal condition, then 30% voltage sag occurs on preferred source. The smart system then will detect the fault in 2 ms as shown in Figure 10. Because the fault only occurs on preferred source, so G_1 remains closed and the G_2 will be opened as shown in Figure 11.

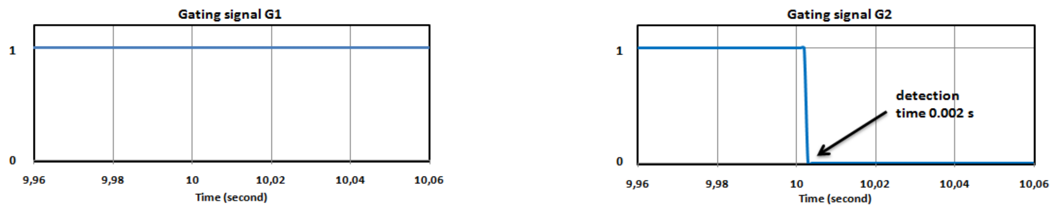
These conditions provide a load current and load voltage in stable condition. The results of the display system conditions are shown in Figure 12. They show that the system detects fault conditions when voltage sag occurred.

Condition system display (Figure 12) shows the condition based on the detection and identification of PLL on the preferred source and photovoltaic alternative source. The result of the system conditions in fault conditions varies according to the type of fault. At the start of fault condition, the system shows transient conditions. In this period, a display system condition doesn't show the exact conditions. But after passing through transient conditions, it can display the true system conditions in accordance of fault conditions on the grid.



(a) (b)

Figure 10. The conditions for voltage sag of 30% on preferred source (a) voltages system (b) currents system



(a) (b)

Figure 11. The conditions for transfer signal on switching components during voltage sag of 30% on preferred source (a)gating signal component G_1 (b)gating signal component G_2

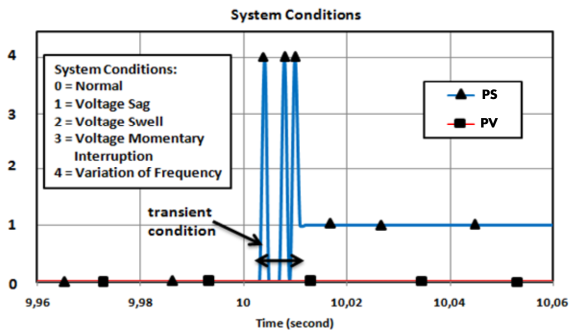


Figure 12. The display system conditions when voltage sag of 30% on preferred source

Simulation results of the fault conditions of 15% voltage swell, voltage momentary interruption, and variation of frequency on the preferred source can be seen in Figures 13, 14, and 15 respectively. Detection time that is required by the system to detect these all conditions is in 0.002 second.

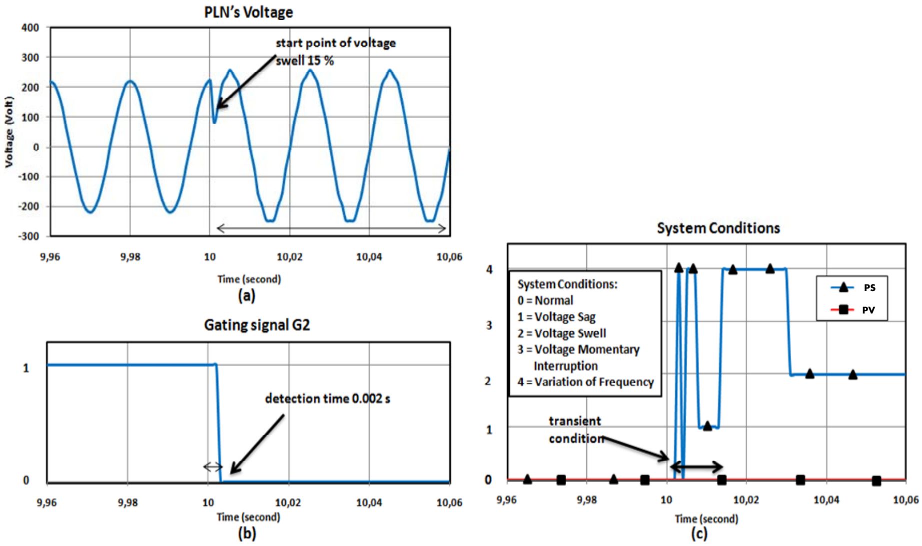


Figure 13. The conditions for voltage swell of 15% on preferred source

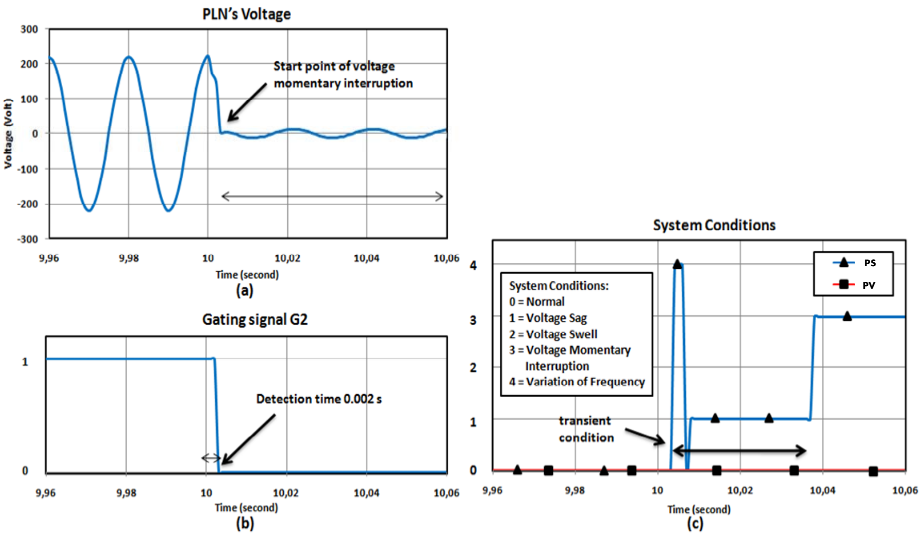


Figure 14. The Conditions for voltage momentary interruption on preferred source

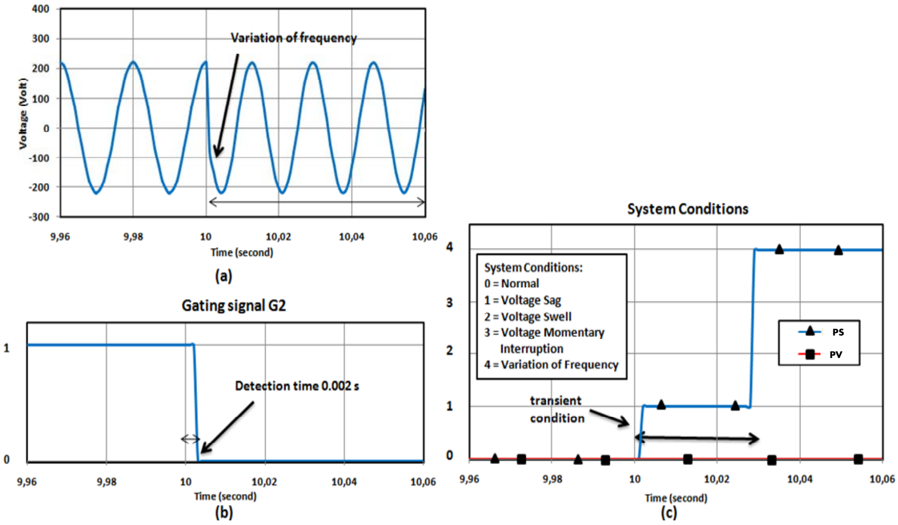


Figure 15. Condition for variation of frequency on preferred source.

3.2. Fault Condition in Photovoltaic

In certain conditions, the photovoltaic voltage is in unstable condition. This condition occurs because the photovoltaic is influenced by temperature and sunlight as the energy source. When the photovoltaic get enough light then ideally the voltage produced will be stable but, on the contrary, if the sunlight received by the photovoltaic is less and the ambient temperature condition is extreeme, it will affect the supply of photovoltaic to the load.

Figure 16(a) shows the current condition when PV has voltage drop condition but still in the state of tolerance, and preferred source is in normal condition. PV current decreases from normal condition when the PV voltage decreases. This yields an increase in preferred current condition and the load current isn't affected.

Figure 17 shows the condition when the preferred source and alternative source are in fault condition. This is in a drop condition so there is no current flowing into the load based on condition from signal transfer. If the preferred source is in normal condition and the PV is still in fault condition, the supply conditions of the load will be supplied entirely by the preferred source.

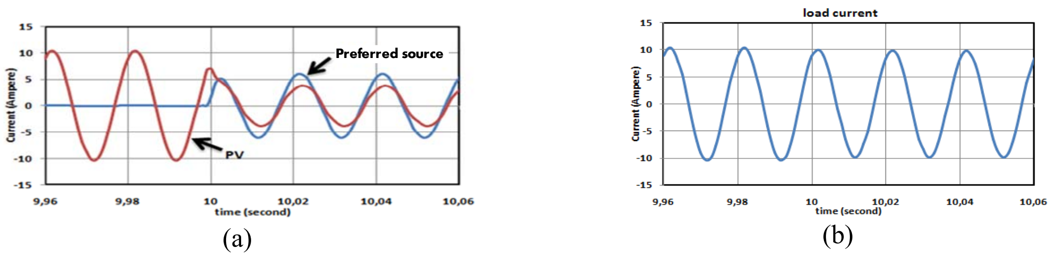


Figure 16. Condition of current when the PV alternative source voltage decreased from 220 volt to 210 volt, and while preferred source is in a normal condition:
(a) Preferred source and PV currents (b) load current

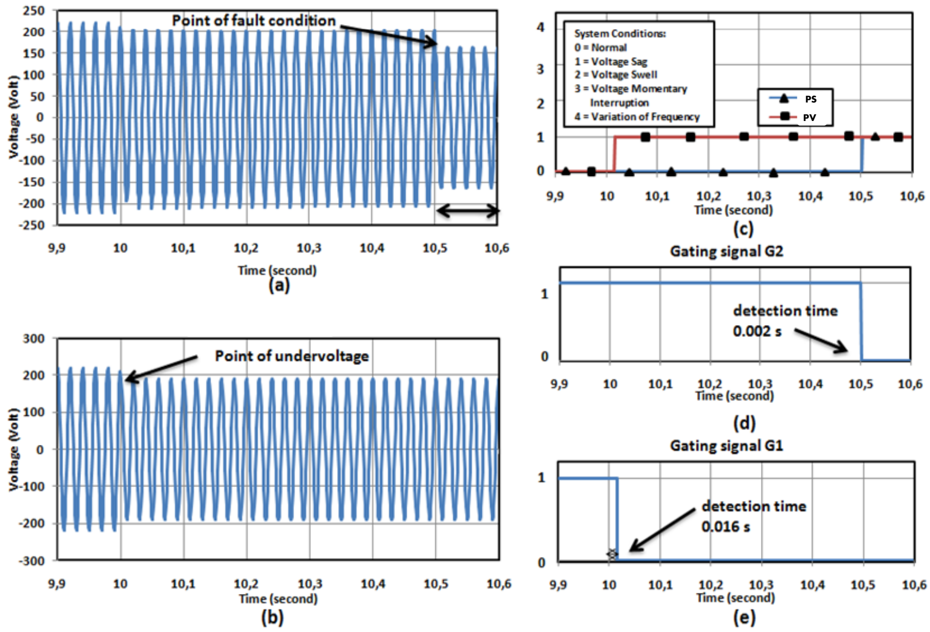


Figure 17. (a) preferred source voltage (b) PV's voltage (c) system conditions (d) gating signal G2 (e) gating signal G1

3.3. Impact of Transient on Detection System

When the fault condition occurred at preferred or alternative source, the system will respond by using signal transfer to determine the condition of the switching component of each STS. Detection time is the time required by the system to detect fault conditions that occur in the system. When the system is in fault conditions as shown in Figure 18, the system will respond with the gating logic switching conditions as Figure 19(a). Gating logic condition 1 (closed) shows the condition of the source is in active condition while supplying the load, Gating signal condition 0 (open) shows the condition of the source is off or drop. The condition of oscillation gating signal that occurs as in Figure 19(a) is caused by transient condition of the system. Transient conditions comes from fault conditions in the system. This condition will affect the system loading conditions. To overcome this condition, it requires a time delay for system loading conditions exist in a stable condition. The result is shown in Figure 19(b). The maximum time delay is the total of sampling time for a wave period of 20 sampling times.

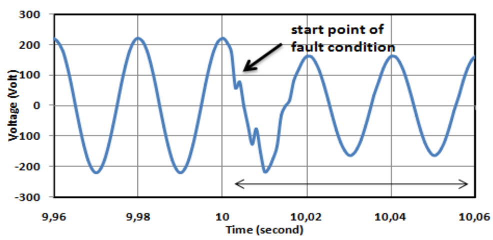


Figure 18. Fault condition on preferred source

(a) (b)

Figure 19. The conditions of gating signal: (a) G_2 before a given delay, (b) G_2 after a given delay

4. CONCLUSION

In this paper, an algorithm of Smart household energy systems to anticipate fault conditions in power system grid has been proposed. Fault conditions can be anticipated by selecting the appropriate voltage sources to supply the load. The condition of smart system is described in power flow regulation to the load by detection and identification of amplitude, phase angle, and frequency of the voltage source compared to the system reference. The results show that conditions of smart power system flow can be obtained based on voltage source selection in decision logic when fault condition occurs. Fault occurs on preferred source such as 30% voltage sag, 15% voltage swell, voltage momentary interruption and variation of frequency can be detected in 0.002 second. Voltage drop occurs on PV source can be detected in 0.016 second. The oscillation of gating signal as impact of transient on detection system is overcome using a time delay.

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REFERENCES

[1] Conty S, Raiti S & Tina G. *Simulink Modelling of LV Photo Voltaic Grid-connected Distributed Generation*. 18th International Conference on Electricity Distribution, Cired, Turin, June 6-9, 2005.
[2] Meena P, Rao KU & Ravishankar DA. *Modified Simple Algorithm for Detection of Voltage Sags and Swells in Practical Loads*. Third International Conference on Power Systems, Kharagpur, INDIA, 2009.
[3] Castaner L & Silvestre S. *Modelling Photovoltaic System Using Pspice*. John Willey & Sons Ltd, England, 2002.
[4] Pachar RK & Tiwari HP. *Performance Evaluation of Static Transfer Switch*. 2008; 3(3): 1991-8763.
[5] Pachar RK, Tiwari HP, Jhajharia N & Surana SL. *Simulation Study of GTO Based Static Transfer Switch Using MATLAB*. 6th WSEAS International Conference on CSECS, Cairo, Egypt. 2007: 264-269.
[6] Mokhtari H, Dewan SB & Iravani MR. Benchmark Systems for Digital Computer Simulation of A Static Transfer Switch. *IEEE Transactions on Power Delivery*. 2001; 16(4): 724-731.
[7] Mokhtari H, Dewan SB & Iravani MR. Performance Evaluation of Thyristor Based Static Transfer Switch. *IEEE Transactions on Power Delivery*. 2000; 15: 960-966.
[8] Mokhtari H, Dewan SB & Iravani MR. Analysis of a Static Transfer Switch With Respect to Transfer Time. *IEEE Transactions on Power Delivery*. 2002; 17(1): 190-199.
[9] Mokhtari H. Impact of Feeder Impedances on the Performance of a Static Transfer Switch. *IEEE Transactions on Power Delivery*. 2004; 19(2): 679-685.
[10] Pachar RK, Tiwari HP & Ramesh C. *Performance Analysis of High Speed Power Quality Disturbance Recognition Scheme for Static Transfer Switch Application*. 2008; 7(12).
[11] Mok HS, Choe GH, Kim SH, Lee JM & Suh IY. Current THD Reduction and Anti-islanding Detection in Distributed Generation with Grid Voltage Distortion. *ICSET*. 2008.
[12] Min S, Yongdong L, Jian W & Xinghua T. A New Synchronous Frame Single-Phase PLL Algorithm With A Decoupling Network. Tsinghua University, Beijing, China.
[13] Chung SK. A Phase Tracking System for Three Phase Utility Interface Inverter. *IEEE Transaction on Power Electric*. 2000; 15(3).
[14] Alonso MA, Sanz JF, Sallán J & Villa JL. *Comparison of different voltage dip detection techniques*. International Conference on Renewable Energies and Power Quality (ICREPQ'09), Valencia, Spain, April 15-17, 2009.

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