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PERFORMANCE COMPARISON OF DIFFERENT PASSIVE METHODS FOR THE DETECTION OF ISLANDING CONDITION IN GRID CONSORTED PV SYSTEM

B. Ponmudi[1] and G. Balasubramanian[2]
[1]Department. of Electrical and Electronics Engineering, SASTRA University, SRC, Kumbakonam, India
[2]School of Electrical and Electronics Engineering, SASTRA University, Thanjavur, India
E-Mail: balu_eie@eie.sastra.edu

ABSTRACT

Solar energy plays a vital role in distributed generation system for micro grid applications. The interconnection of Photovoltaic (PV) systems with the grid is a difficult task and it requires multiple conditions to be satisfied. One of the major issues in grid connected PV system is islanding; it is a condition where distributed generation system supplies to local loads during grid failure condition. It also creates disturbances in controlling voltage and frequency at the point of common coupling and also degrades the power quality of grid connected PV system. Hence, islanding has to be detected by a suitable anti islanding technique which has faster detection time and smaller non detection zone. Anti islanding techniques are classified into active, passive and hybrid methods. When compared to passive techniques, the active islanding detection techniques have smaller non-detection zone but active methods are not easy to implement and reduces the power system quality. Passive methods are preferred for island detection with reduced non detection zone. This paper compares and analyzes five different passive methods for islanding detection viz. Over and Under Voltage, Current, Frequency (OUVIF) relays Rate of Change of Frequency (ROCOF) relays and Voltage Phase Shift Relays (VPSR) and suggests making them an integral part of islanding detection in the PV system. The proposed passive anti islanding techniques for islanding detection is tested for grid connected distributed generation system by simulation in MATLAB/Simulink platform. The response time of each technique for islanding detection is observed along with non detection zone and the fastest method is identified by comparing the response time of all proposed anti islanding techniques.

Keywords: distributed generation, electrical grid system, photovoltaic array, rate of change of frequency relay, voltage phase shift relay, voltage source inverter.

INTRODUCTION

In recent years a rapid growth has been witnessed in the field of PV based distributed generation system interconnected with the grid. Due to increasing energy demand over the world and with limited resources for conventional power generation methodologies, integration of different distributed energy resources like solar, wind turbines is inevitable. Introduction of more number of DG's into the utility grid increases the possibilities of islanding condition in a grid connected DG system, which degrades the power system quality and creates an unsafe condition in the system. Islanding is nothing but a phenomenon which occurs when the utility grid fails and mains circuit breaker is open which cuts the power supply to load. Still loads are powered through DG's which does not know any information regarding grid failure. This condition led to unsafe condition for electrical maintenance people working on line; it can also damage the protection devices installed in the grid and DG's loses the control over generated voltage and frequency. Due to the problems stated, unintentional islanding must be detected within the time limit specified as per standards and islanded power must be isolated with the help of breakers. Established islanding technique should detect grid failure quickly and must have smaller non detection zone.

The island detection method in grid connected PV systems can be classified in to remote and local techniques. Remote [1-2] techniques utilize data from SCADA to detect islanding and it founds to be costly whereas local [3-5] techniques can be implemented within the DG system. Local techniques are further classified into active, passive and hybrid methods. Active methods [6-7] have smaller non detection zone and works faster compared to passive methods; but it adds harmonics in the power system and degrades power quality. Hybrid method [8-10] is combination of passive and active method it works based on injecting a signal into live line and monitors the grid side parameters like voltage, current and frequency to detect islanding. It also has more advantages in similar with active method but both are not easier to implement and degrade power quality. Passive methods [11-13] are easier to implement but it suffer from larger non detection zone. It does not have effect on power system quality and shows robustness in detecting between islanding and safe modes. This paper discusses and analyzes various passive islanding methods based on parameter measurements at the point of common coupling. Passive technique like over/under voltage relay, over/under current relay, over/under frequency relay, ROCOF relay and VPS relays are employed for island detection and the fastest method [14-16] is identified using simulation results. The proposed island detection method can be easily implemented in a renewable energy based distributed grid. It helps to achieve better response times when compared to conventional methods. Passive methods

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measure parameters like voltage, current and frequency at point of common coupling and based on threshold values helps to bring out the differences between islanding and non-islanding conditions under a wide range of operating conditions. The present system topology is designed and verified with simulation results by using MATLAB Simulink Platform.

Layout of Photovoltaic (PV) model

Solar cell is a pollution-free renewable energy resource. In a grid connected system, it ensures high reliability and high power quality. The current flow in the PV model can be represented as shown in equation (1). The corresponding circuit is shown in Figure-1.

$$I = I_{PV,array} - I_{0,array}\left[\exp\left(\frac{qv}{aKT}\right) - 1\right] I_{diode} \quad (1)$$

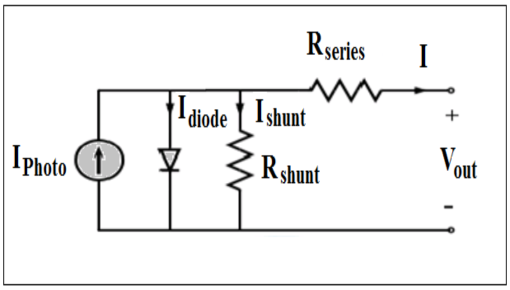

Figure-1. Equivalent circuit of PV module.

The expression for the current in the PV array is represented in equation (2)

$$I = I_{PV,i} - I_{diode,0}\left(e^{\frac{q(V + IR_{series})}{nKT}} - 1\right) \quad (2)$$

where $I_{PV,i}$ represents photo voltaic current, $I_{diode,0}$ represents diode saturation current, R_{series} is the series current charge of electrons, K is constant temperature and n the number of PV modules.

$$I = I_{PV,i} - I_{diode,0}\left[\exp\left(\frac{V + R_{series}I}{V_{ta}}\right) - 1\right] - \frac{V + R_{SI}}{R_p} \quad (3)$$

Here, $I_{pv,i}$ and $I_{diode,0}$ are the photovoltaic and saturation currents of PV array respectively. It can be denoted as $V_{ta} = N_s$ KT/q. It is composed of N_p parallel connection of photovoltaic array and the saturation current and can be stated as

$$I_{pv,i} = I_{pv,cell}N_p,\ I_{diode,0} = I_{0,cell}N_p.$$

Configuration of the Grid connected system

Grid connected DG energy systems are intended to function in parallel and interrelated ways with the electric utility grid. It converts the generated solar DC power into AC power considering the voltage and power quality requirements of the utility grid. In addition, the exposed power to the grid can be stopped automatically when the conditions of grid is not satisfied. The schematic of the PV based utility grid configuration is shown in Figure-2.

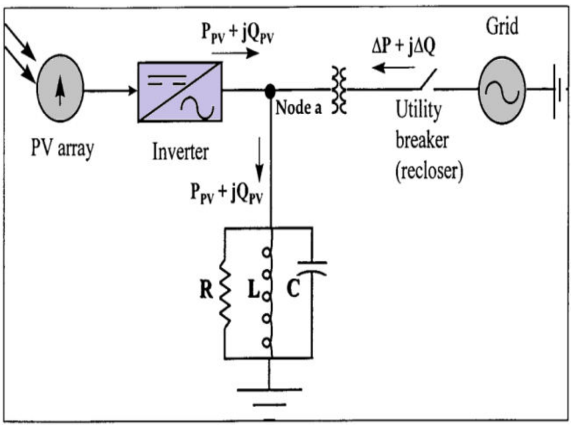

Figure-2. Schematic of the PV system with utility grid.

In Figure-2, the PV based feeder line is connected in reverse to the utility grid by a transformer and a switch and it includes a re-closer, fuse and breaker. The PV is connected to the local load and it is disconnected from the grid when the switch is on.

$$\Delta P = P_{load} - P_{PV} \quad and \quad \Delta Q = Q_{load} - Q_{PV} \quad (4)$$

$$P_{load} = \mathrm{Real}\left[\vec{V_a} * \vec{I}^{\bullet}_{load}\right] = 2V_a I_{load}\cos\phi \quad (5)$$

$$Q_{load} = \mathrm{Img}\left[\vec{V_a} * \vec{I}^{\bullet}_{load}\right] = 2V_a I_{load}\sin\phi \quad (6)$$

Consumption of real and reactive power is expressed in the equation stated above. Here, cosφ is defined as the displacement of load power factor.

Islanding detection techniques

Detecting islanding operation is important and it is developed for continuous supply from PV to the grid until the grid is disconnected from the load. A block diagram of the islanding detection scheme is shown in Figure-3.

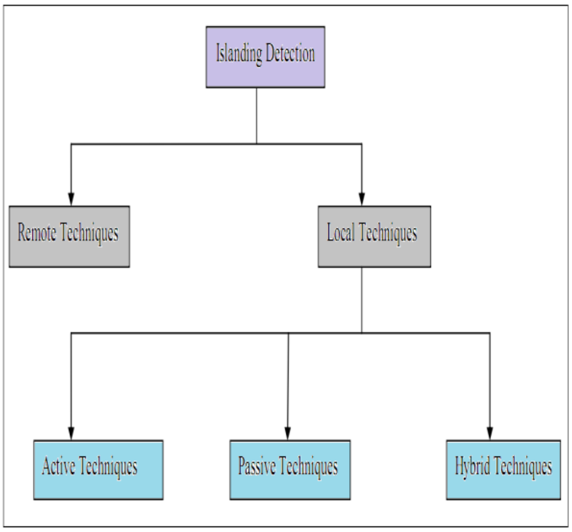

Figure-3. Block diagram of island detection methods.

Utility networks employ automatic circuit reclosing condition to cope with short circuits. When a short circuit occurs, the grid is disconnected and after that particular time, the switching device closes down the circuit. Before setting the various methods of islanding detection, it is significant to foreground two key characteristics in order to realize the islanding process. The first one is Non- Detection Zone (NDZ), which can specify the range consisting of different power quality issues in the proposed inverter and the load. The second one is consorted with the nature of loads, which can be prototyped as a parallel RLC circuit.

Islanding passive detection technique is used to evaluate voltage, current and phase information of the DG terminals. It is used to decide whether an island condition has happened. Some of these methods are cost efficient as the relay in place meets most safety requirements. The main drawback of the passive island detection techniques is its adjusting reserve sensor threshold that can be described as the difference between the islands and natural variation of power system.

Design of proposed control strategy

The present paper proposes different passive control techniques to detect islanding in a grid connected PV system. It consists of under and over voltage, current, frequency range, changing frequency relay and it considers voltage phase shift methods. However, the grid is incoherent and the voltage and frequency may be pressed to their newer values, if the propagated generation is prohibited in a steady power system. The breaker acts as a defense and it is introduced at the generation side to maintain the island operation. A graphical representation of the three passive detection methods is depicted in Figure-4.

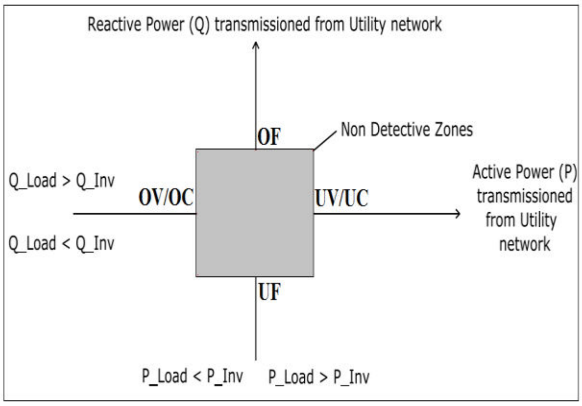

Figure-4. Detection relay of over/Under voltage, current, frequency in NDZ.

The threshold values are obtained for over/under voltage, current, frequency, and they are stated below in the equation. The passive method based effective NDZ is improved if the standard of islanding condition improves and to coordinate with the circuit breaker reclosing position.

$$\left(\frac{Volt}{Volt_{max}}\right)^2 - 1 \leq \frac{\Delta Power}{Power} \leq \left(\frac{Volt}{Volt_{min}}\right)^2 - 1 \tag{7}$$

$$\left(\frac{I}{I_{max}}\right)^2 - 1 \leq \frac{\Delta Power}{Power} \leq \left(\frac{I}{I_{min}}\right)^2 - 1 \tag{8}$$

$$Q_{freq}\left(1 - \left(\frac{freq}{freq_{min}}\right)^2\right) \leq \frac{\Delta Power}{Power} \leq Q_{freq}\left(1 - \left(\frac{freq}{freq_{min}}\right)^2\right) \tag{9}$$

If the distributed generation becomes islanded, the source starts to feed a larger load or smaller load, because of current supplied by the power grid is suddenly interrupted. In order to increase or decrease this current induces a change in the DG terminal voltage (V_t). This Voltage Phase Shift (VPS) relay is very fast compared to ROCOF. However, it is more sensitive to grid connected network faults and it has larger non-detection zone for islanding detection condition.

The existing current controller regulated both active and reactive power. Here, the Phase Locked Loop (PLL) is used to track the grid side frequency and to generate the gate pulse signal. In this paper, frequency regulation based gate pulse generation of inverter controller using real/reactive power for achieving better performance is proposed.

SIMULATION RESULTS AND DISCUSSION

The present paper proposes islanding detection for grid connected PV system using different passive methods. Single diode photovoltaic array is designed in Simulink platform using MATLAB. All the five methods are developed one by one and the closing time of the breaker for each is observed. It should be remarked that

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for the present simulation, the generation of power is larger than the load local power. The overall layout of the proposed system configuration is shown in Figure-8. At simulation time of t = 0.3 seconds, an islanding condition is produced by assuming a three-phase fault in the grid side, inducing the first breaker to close and by a grid side tripping off situation. The output voltage and current waveforms are noted at the Point of Common Coupling (PCC) and the corresponding simulation results are described in Figures 5-7.

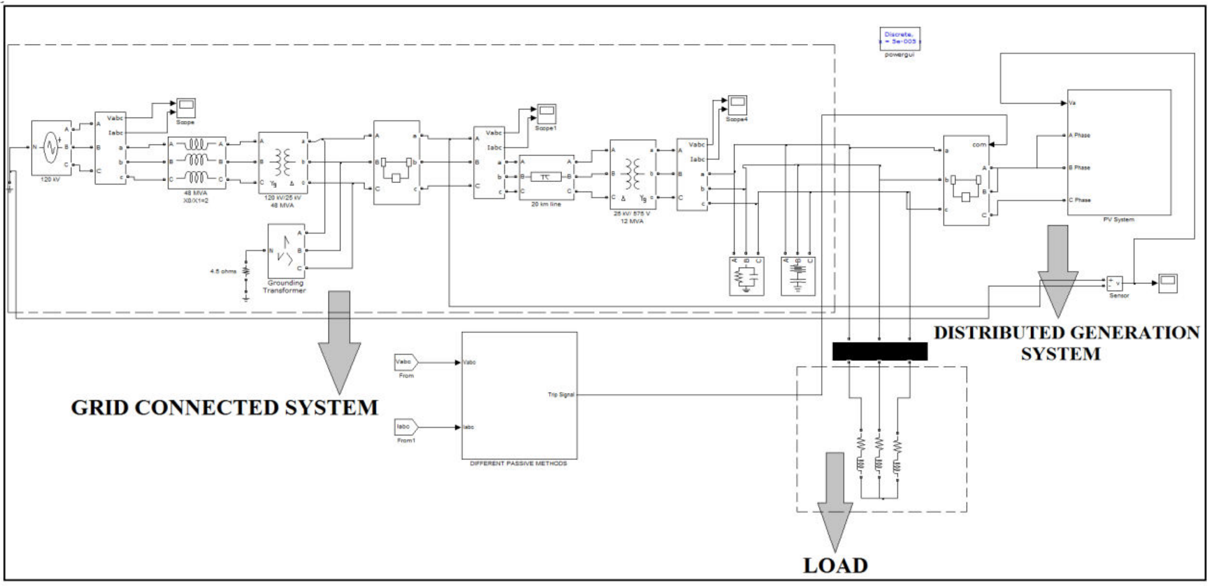

Figure-5. Overall layout of the proposed system configuration.

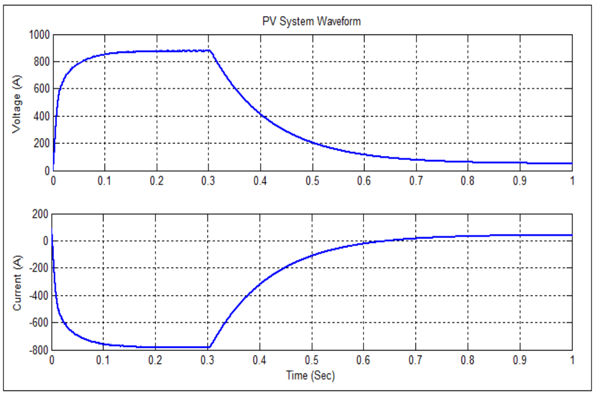

Figure-6. Input source of PV system based voltage and current waveform.

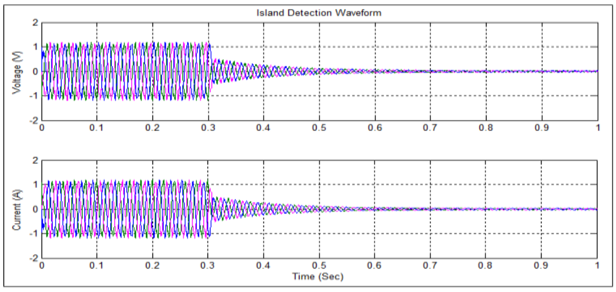

Figure-7. Islanding detection waveforms without using control strategy.

In this network, for the over/under voltage, current, frequency based control signal is applied on the second breaker for detecting the islanding condition. Thus, all the three methods aggressively decrease power quality issues as soon as the islanding passes. The monitor of the ROCOF relay is used to calculate the change of frequency when compared to the threshold value of the ROCOF and the extreme voltage of the PV inverter. If both conditions are satisfied, the tripping relay is actuated. The tripping signal of these five techniques based on simulation results are shown in Figures 8-11.

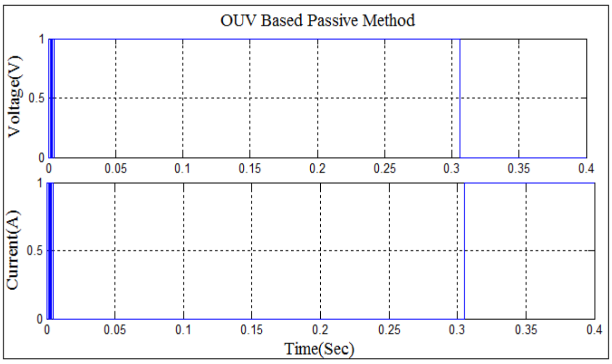

Figure-8. Tripping signal for OUV based passive detection method.

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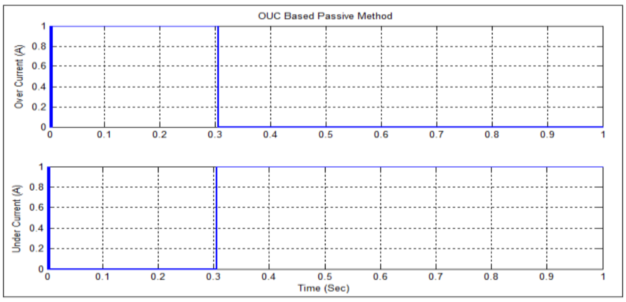

Figure-9. Tripping signal of OUC based passive detection method.

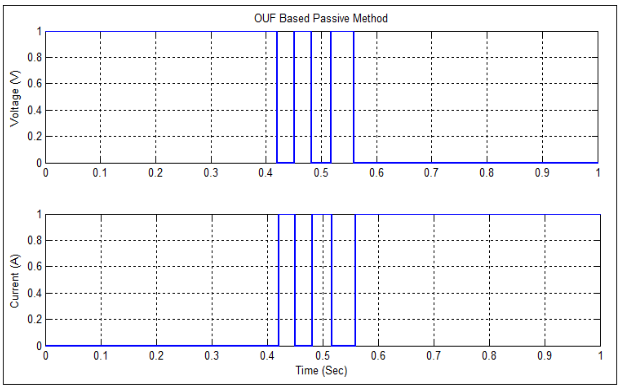

Figure-10. Tripping signal of OUF based passive detection method.

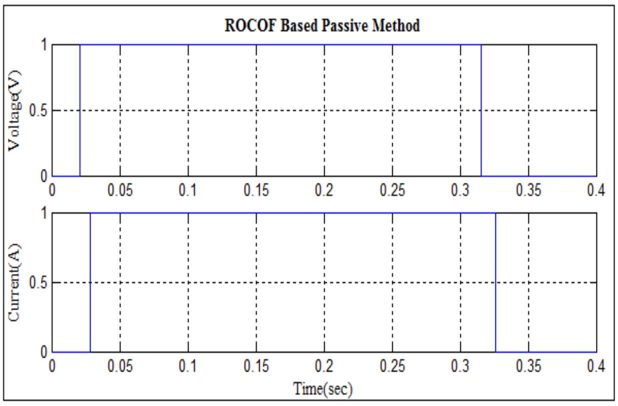

Figure-11. Tripping signal for both ROCOF and VPS based passive detection method.

Finally, the last control method of Voltage Phase Shift (VPS) is developed and analyzed for islanding detection. It is used to examine the three-phase voltage (Vabc) and extreme voltage (Vt) p.u of the PV inverter, that is equated to a entry range. The three-phase waveform is controlled and is used to calculate each complete cycle by examining the increasing edge of the waveform. The output voltage and the current waveform of the passive detection based control technique using point of common coupling are indicated by Figures 12-16.

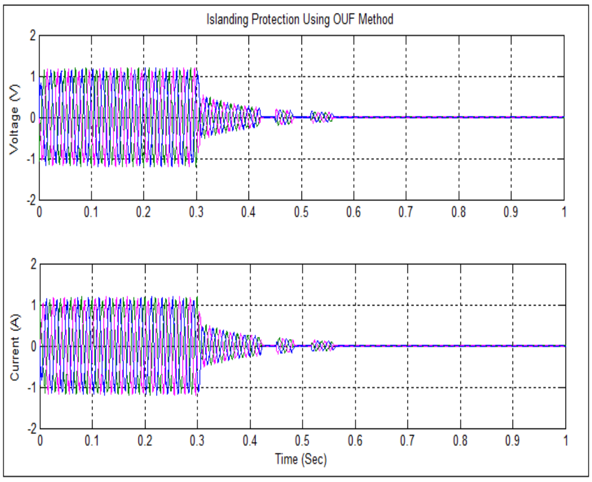

Figure-12. Over/Under frequency based passive detection waveform.

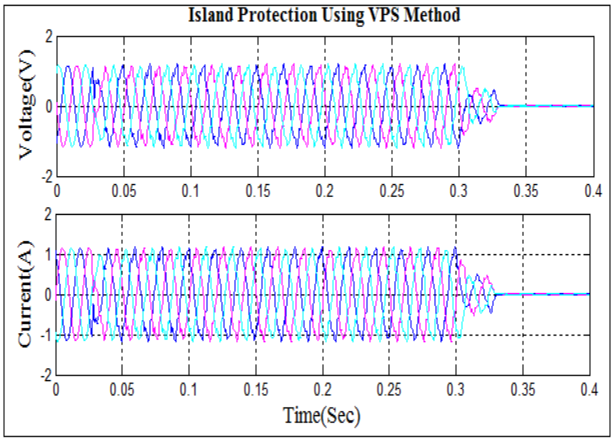

Figure-13. Voltage phase shift based passive detection waveforms.

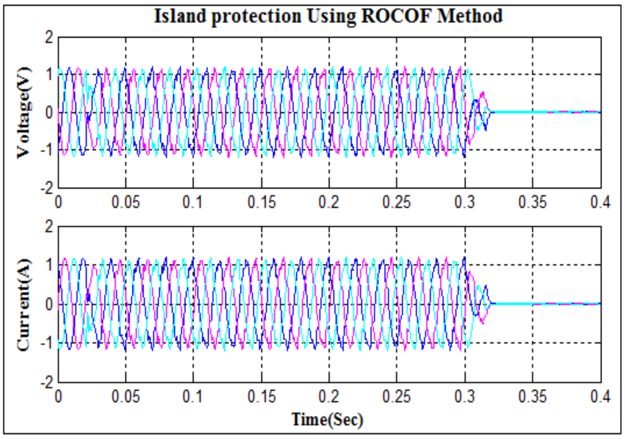

Figure-14. Rate of change of frequency relay based passive detection waveforms.

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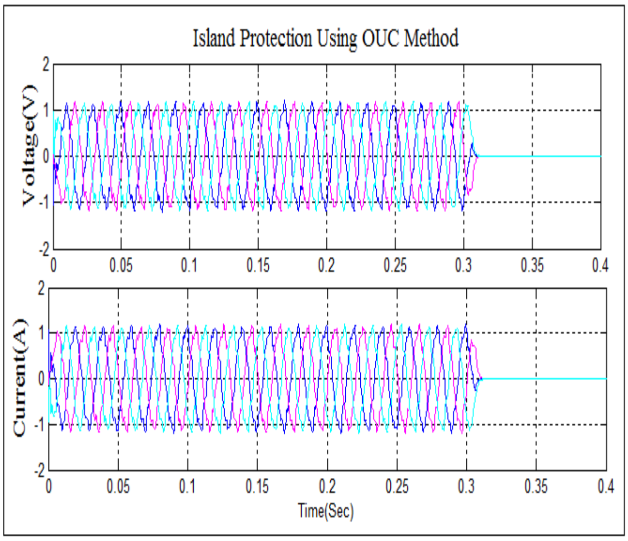

Figure-15. Over/Under current based passive detection waveforms.

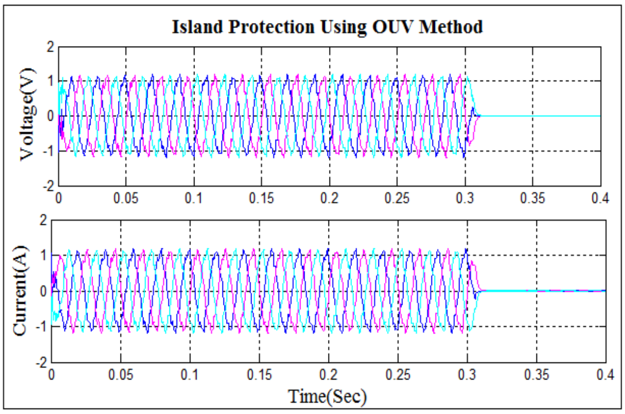

Figure-16. Over/Under voltage based passive detection waveforms.

The main advantage of passive detection is that it does not include any undetected zone and it is stable. The comparative study and simulation results of the islanding detection zone are represented graphically in Figure-17.

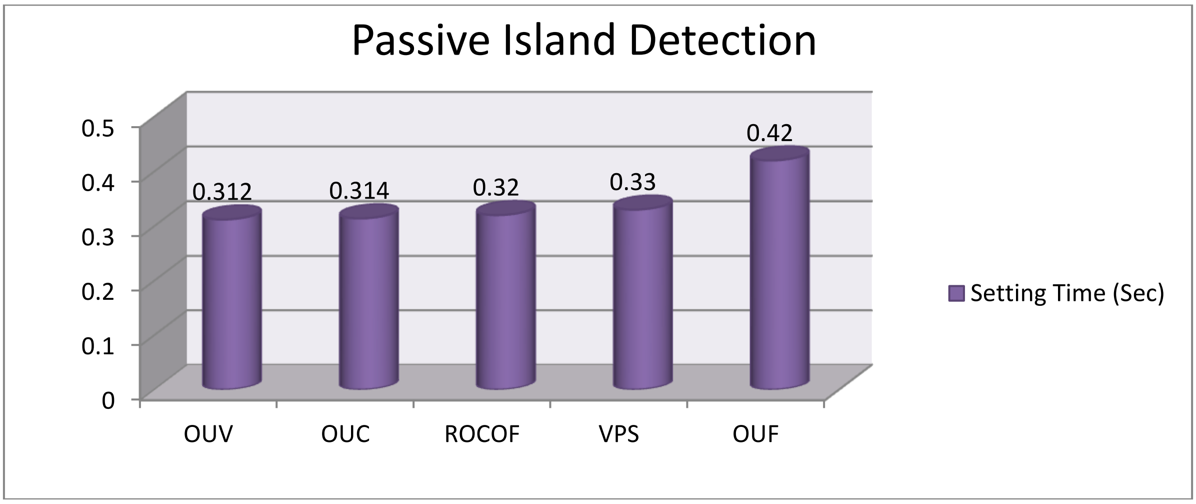

Figure-17. Graphical representation of different passive island detection methods.

The circuit breaker closing time (in sec), matching to the speed of island detection is preferred as the performance indicator parameter for evaluating the five methods. As required, the islanding should not be exposed by un islanding system and the system should continually deliver power to the load while tending of reactive power during improper frequency flow and the cross over frequency in that standard operating situation.

CONCLUSIONS

This paper analyzes the performance of various passive islanding detection methods for grid connected PV power generation system. Passive anti islanding techniques are based on predefined threshold values and can detect grid failure by sensing the changes in grid side parameters. Passive methods have smaller effect on power system quality and have smaller non detection zone with the use of proposed inverter control strategy based on modified reference frequency. A power system model which consists of PV based Distributed generation system interfaced with utility grid and supplying local loads is build in MATLAB/Simulink to verify the performance of proposed passive anti islanding techniques. From the results furnished, it was noticed that by using relays for passive islanding detection such as OUV and OUC produced the better performance with observe to sensing time of islanding detection conditions. Other anti islanding techniques such as ROCOF relay, vector phase shift relay and OUF relay able to sense the islanding within the time specified by IEEE standards. But these techniques take more time to sense islanding compared to OUV and OUC relays.

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