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A new passive islanding detection technique for different zones in utility grid

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ABSTRACT

Distributed generation (DG) has reformed the meaning of traditional generation of power from large-scale to small-scale generation. The main issue of connecting the DG to the utility grid is the detection of unintended islanding. This paper shows the impact of the islanding phenomenon in the case of grid-connected photovoltaic arrays and how to develop a convenient technique to detect this phenomenon. A passive islanding detection algorithm is proposed for all types of DGs by varying and analyzing the DC-link voltage for voltage source converter in the photovoltaic inverter. The proposed algorithm is applied on the low and medium voltage scales. Furthermore, a comparison for applying the proposed technique with resistance load on the two scales is presented. In addition, the proposed technique for anti-islanding protection is performed and compared with a lot of techniques such as underfrequency, overfrequency, and rate of change of frequency according to the detection time of islanding. The simulation results using MATLAB/ SIMULINK platform illustrate the effectiveness of the proposed method.

Keywords: Anti-islanding methods; Distributed energy; DC-link voltage; Islanding detection; Photovoltaic; Rate of change of frequency (ROCOF).

INTRODUCTION

Recently, the distributed energy resources (DERs) have witnessed increasing contributions in the field of power generation all over the world and alter the conventional passive distribution system to an active network. Nowadays, various distributed generation (DG) systems have penetrated the electric power system (EPS) generation by using the smart grid. The DG introduces the bidirectional flow of electricity and information, reduces network losses, and protects the electric machines and equipment from a complete failure caused by natural disasters and wrong operations. Besides, saving the investment costs required for network upgrades enhances the overall power system reliability, security, efficiency of generation, transmission, and distribution (A.G. Abo- Khalil., 2020 & Y.A. Elshrief et al., 2019.).

In this context, a vital condition for the integration of DG structures in the EPS is the ability of DG to detect the islanding condition. Islanding can be defined as a portion of the utility system that contains both load and distributed resources, which remain energized while being isolated from the remaining utility system (Y.A.Elshrief et al., 2019, Y.A.Elshrief et al., 2021). It may lead to malfunction of the protection devices, reduction of power quality levels, safety hazards to the operating personnel, and equipment damage (A.G. Abo- Khalil., 2020 & Y.A. Elshrief et al., 2021). Consequently, islanding is a major issue to DG users and utility, since, in recent years, the possibility of islanding occurrence has increased with the DG penetration (Y. Tang et al., 2018 & D. Voglitsis et al., 2018).

There are two types of islanding: planned and unplanned. Planned islanding is performed to improve the reliability and the power quality of the EPS or for maintenance purposes. The other type, called unplanned islanding, occurs due to equipment failure or faults resulting in the opening of circuit breakers that interconnect the island with the rest of the power grid. So, unplanned islanding causes the potential danger for human safety, electrical equipment fault possibility, and power quality issues. Consequently, the IEEE standard 1547-2008 (Y.A. Elshrief et al., 2020) recommends isolating energized DERs within 2 seconds after the occurrence of an unplanned islanding event. Therefore, it is essential to detect unplanned islanding conditions as quickly as possible.

In general, islanding detection methods can be classified into two groups: local methods and remote methods. Remote methods detect the islanding situation using communication links between the DG and the point of common coupling (PCC), and when islanding is detected, signals for warning and disconnecting DGs from the distribution network are issued (T. Zheng et al., 2018 & Y.A. Elshrief et al., 2019). Remote methods are extremely reliable, detect the islanding with a negligible or even zero non detection zone (NDZ). But they are expensive to be implemented because of the need to install transmitters, receivers, and other monitoring devices, in addition to the backup protection problem, and the risk of loss of communication links.

Local methods can be divided into active and passive ones. The active method attempts to detect a grid failure by injecting small signals into the power line and then observing whether the signals change or not (M.U. Zaman et al., 2018). In a grid-connected system, the grid absorbs local disturbance, and no deviation is observed in the system voltage or frequency. However, in the case of islanding, the disturbance can be significant resulting in noticeable deviation. Examples of active islanding detection methods are active frequency drifting (A. Abokhalil et al., 2018), slip mode frequency shift (A. Pouryekta et al., 2018), impedance measurement (H. Abdi et al., 2020), frequency jump (H. Xu et al., 2020), Sandia voltage shift (SVS) (M.F.N. Khan. 2020), and Sandia frequency shift (R. Haider et al., 2018). Active techniques can interfere with other devices that inject the disturbance into the system, can fail to detect islanding under certain conditions, and may degrade the power quality due to the constant injection of disturbance.

In passive techniques, the monitoring of electrical quantities of network parameters, i.e., voltage, current, frequency, and phase angle, is done and used for islanding detection purposes. When it is found that the magnitude of the measured parameter is greater than the predefined threshold, then islanding is done by opening the circuit breaker (CB) located at PCC. Some of the important islanding detection techniques, i.e., rate of change of voltage, over/under voltage (R. Nale et al., 2018), over/under frequency, rate of change of frequency (ROCOF) (Y.A. Elshrief et al., 2020), average absolute frequency deviation (S.B.A. Bukhari et al., 2018), rate of change of output power, and voltage unbalance (S. Dutta et al., 2018), are amongst the most preferred ones, since these methods do not produce any disturbance in the grid parameter. However, all the previous methods have a large NDZ and fail when the power mismatch between load and generation within the microgrid is relatively small.

In this paper, a passive islanding detection technique based on analyzing the DC-link voltage (Vdc) of the photovoltaic inverter is presented for detecting an islanding state in presence of DGs in low and medium voltages. The proposed technique is compared with other passive techniques such as under frequency (UF), over frequency (OF), and the ROCOF. The main contributions of this paper can be summarized as follows:

1. The detection time of islanding conditions is improved significantly using the proposed islanding detection method.
2. The proposed method can be easily implemented practically, as it is simple and based on common protection relays.
3. The proposed method can be applied for all types of DGs without degrading the power quality of the system.

The rest of the paper is organized as follows: the system description and proposed islanding detection method are presented in section 2. In section 3, simulation results of islanding cases are introduced. The conclusions are collected in section 4.

SYSTEM DESCRIPTION AND PROPOSED ISLANDING DETECTION METHOD

A. System Description

Figure 1 shows the Matlab model for a three-phase grid-connected PV system built from 330 SunPower SPR-305-WHT modules (66 strings of 5 series-connected modules connected in parallel) and expected to provide a 273.5V and 100.7kW at maximum in standard test conditions (STC) (Y.A. Elshrief et al., 2020). The inputs of the PV Array are the sun irradiance (W/m2) and the cell temperature (°C). Figure 2 shows the three-phase grid-connected PV system connected to a 20kV distribution system that exports the power to a 110kV power grid, via a DC-DC boost converter and a three-phase three-level voltage source converter (VSC).

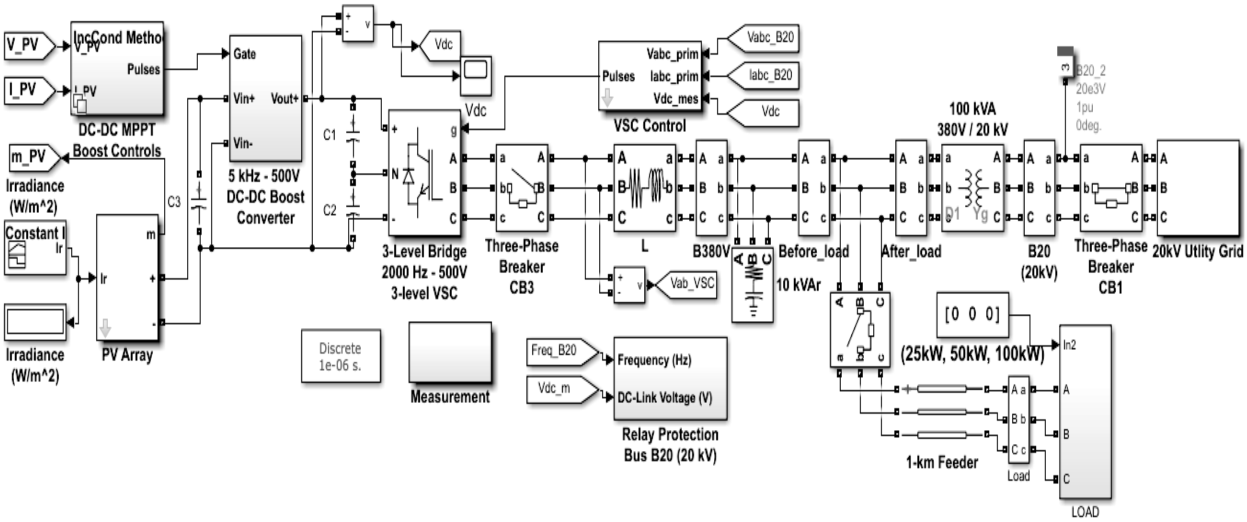

Figure 1. Model of PV-Grid Connection System for 100 kW in detail.

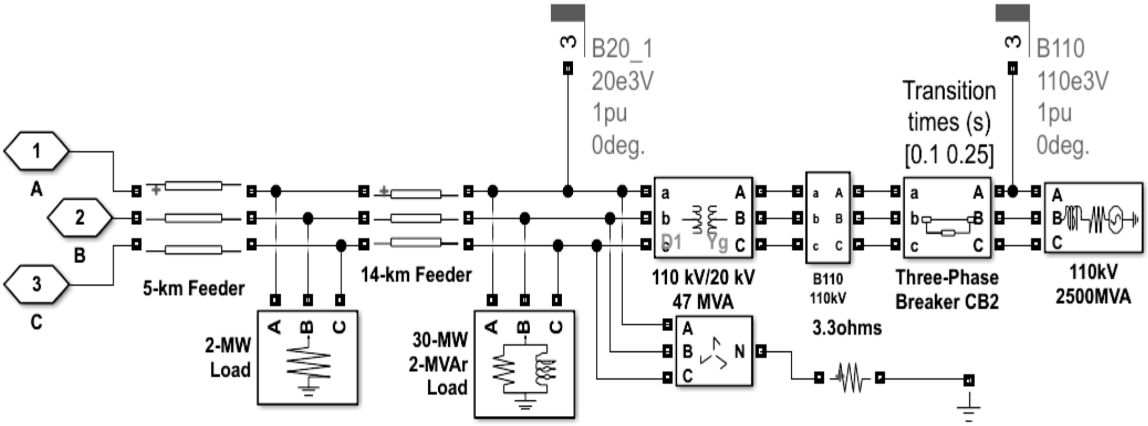

Figure 2. Simulation of 20KV for utility grid by Matlab/Simulink.

B. Traditional Islanding Detection Methods (IDMs)

Many methods have been used for islanding detection. The main concept of most passive islanding detection methods is a great change in islanding mode, while there is no change significantly when the DG system is grid-connected. In some cases, these methods do not recognize islanding mode and cause disoperation in power system disturbances like short circuit faults. In this paper we apply some traditional methods such as UF, OF, and ROCOF and compare their results with the proposed technique. The Matlab implementations of these relays are clarified below.

1) The under/over frequency (UOF) Relays

The relays of UOF display the value of frequency in the photovoltaic inverter and perform a comparison between this value and the predefined threshold values that are defined according to the Egyptian grid requirements (M.S. Kim et al., 2019).

Figure 3 describes the algorithm of this comparison, and Figure 4, shows the algorithm of the phase-locked loop (PLL) method that is used for measuring frequency. (Va, Vb, and Vc) are the normalized signals of the primary three-phase and are considered as input on the form of a vector, and the measured frequency is the output as (Hz) = ω / (2π).

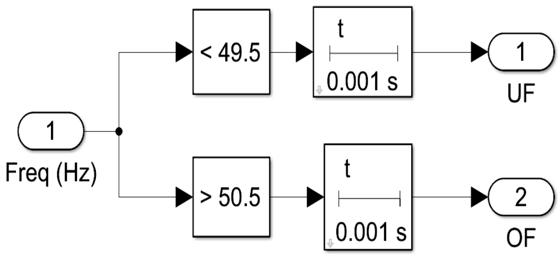

Figure 3. Implementation of UF/OF protection relays by Matlab.

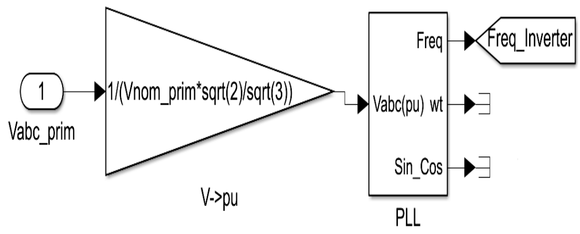

Figure 4. Measuring Frequency by Matlab.

2) The ROCOF Relay

Figure 5 shows the process of implementing ROCOF relay in Matlab/Simulink. The input of this relay is the frequency that is calculated using PLL. This frequency is used to determine the ROCOF, which is compared with its threshold. This threshold is determined according to IEEE international standards. The relay is energized as soon as this situation is pleased, then the power of the PV array is accidentally disconnected from the utility grid.

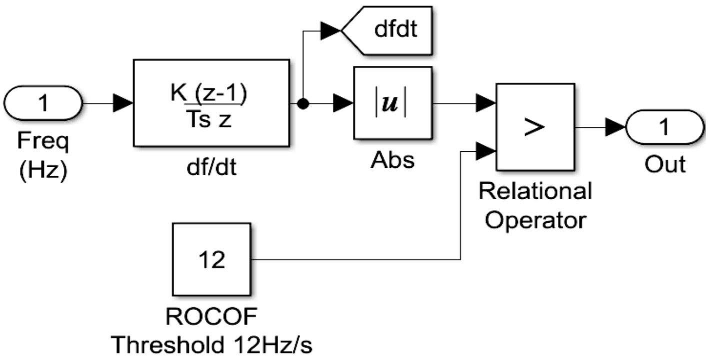

Figure 5. Implementation of ROCOF relay by Matlab.

C. Proposed Islanding Detection Method (*Dc Link Voltage*)

This paper provides a new algorithm that has better results for islanding detection; it is called the DC-link voltage that mainly depends on the value of DC voltage of the photovoltaic inverter. V_{dc} is considered the output of the DC-DC boost converter, DC-link mean voltage (V_{dc_m}) is calculated using the VSC control. Its detection process is represented in Fig. 6. Its value is compared with a threshold to ensure the decision of detecting islanding is convenient or not and this relay is energized as soon as its value is higher than its threshold value. The proposed islanding detection algorithm can easily be integrated into the area of VSC control, which belongs to the inverter of photovoltaic and is simulated under various load conditions.

Dc link voltage threshold (V_{dc_TH}) is determined according to 10% variation of Vnom_dc (T. Ghanbari et al., 2018 & T. Gush et al., 2018) as analyzed that the more we increase the (V_{dc_TH}), the more increment in the time of detection. In this case, the time of detection time for the V_{dc} relay will be large compared to the ROCOF relay. So, we can select the optimal (Vdc_TH) by the way that we can guarantee that Vdc is low as we can, for decreasing switching losses of VSC (Y.A. Elshrief et al., 2019).

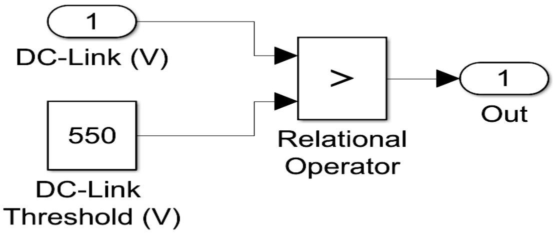

Figure 6. Model of V_{dc} relay by Matlab.

THE MATLAB SIMULATION RESULTS OF ISLANDING CASES

Figure 7 shows the Simulink of protection relays used for preventing islanding; there are two scenarios for detecting islanding:

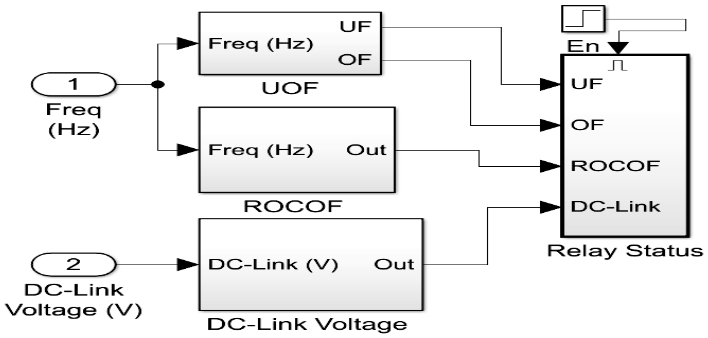

Figure 7. Model of islanding prevention relays by Matlab.

Scenario 1: Disconnecting the CB1 (low voltage cutoff)

The tripping signals of some relays are activated by disconnecting the CB1. We can apply the conditions of islanding on the network shown in Fig.1, by opening CB1 at a time (t) = 0.2 Sec. That is mean, CB1 cut off the power of the utility from the residue of the network (low voltage cutoff). Any changes in the values of the connected loads have an impact on detection time, so we will apply the effect of changing load as in the following cases:

Case A: Load has a Greater value than the Power Generated when CB1 cutoff

The value of all tripping relays will change by applying resistive load equal to 2e6 Ω with the utility model. The effect of this change on the relays Vdc, UOF, and ROCOF are described in Figures 8- 10 sequentially. As analyzed from these Figures, there is a reduction in frequency for a minimal time and this rapid variation in frequency will lead to some variations of ROCOF until it exceeds the ROCOF threshold then islanding is detected. The sign of frequency is an indication for increment (+) or decrement (-), and about Vdc, it will detect islanding rapidly. Figure 11 shows the detection time by seconds and status of the anti-islanding protection relays as each one of the protection relays has two monitors, one for the status of each protection relay (0 for De-energize / 1 for energize) and the other shows the islanding detection times.

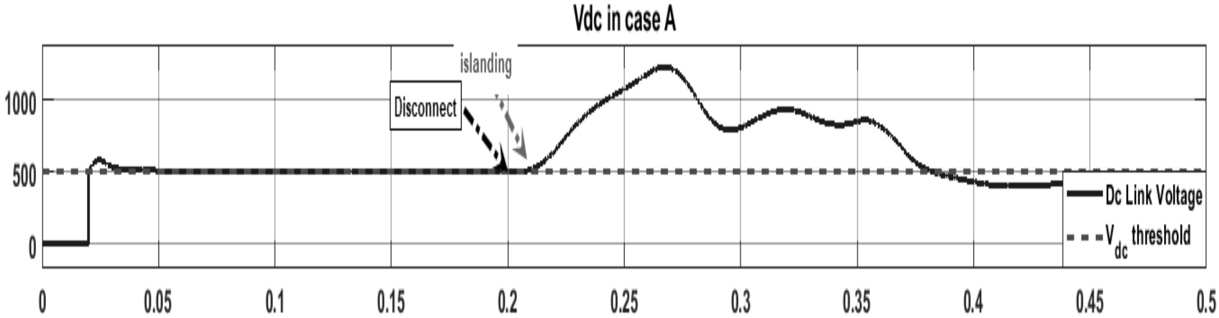

Figure 8. Effect of DC-link voltages for islanding detection in case A.

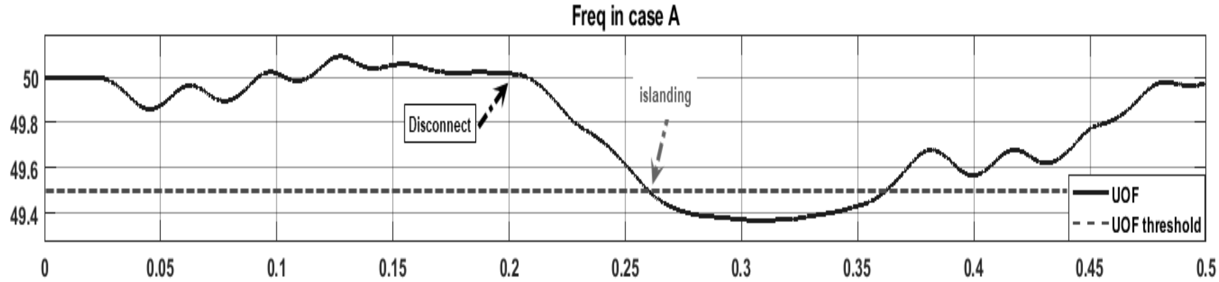

Figure 9. Effect of UOF for islanding detection in case A.

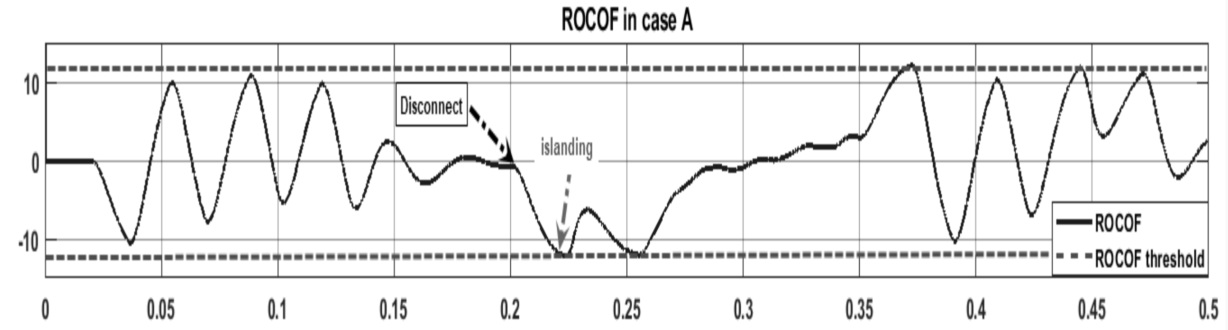

Figure 10. Effect of ROCOF for islanding detection in case A.

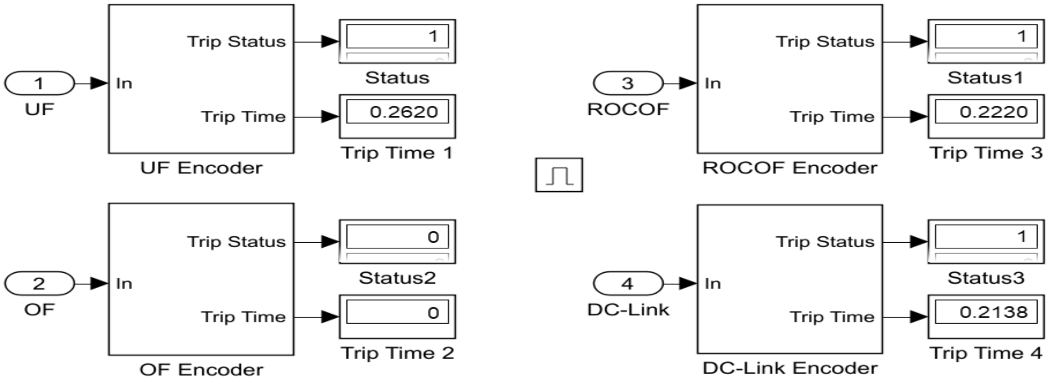

Figure 11. Detection Time and status for the AI protection relays in case A.

Case B: Local Load has the same value as the Local Power Generated when CB1 cutoff

The value of all tripping relays will change by applying a resistive load equal to 103e3 Ω that nearly matches the power generated from DG. The effect of this change makes the relays of Vdc, UF/OF, and ROCOF unable to detect islanding in this case (NDZ) as the values of these relays did not exceed the predefined thresholds, which are described in Figures 12–14 sequentially. Figure 15 shows the detection time by seconds and status of the anti-islanding protection relays.

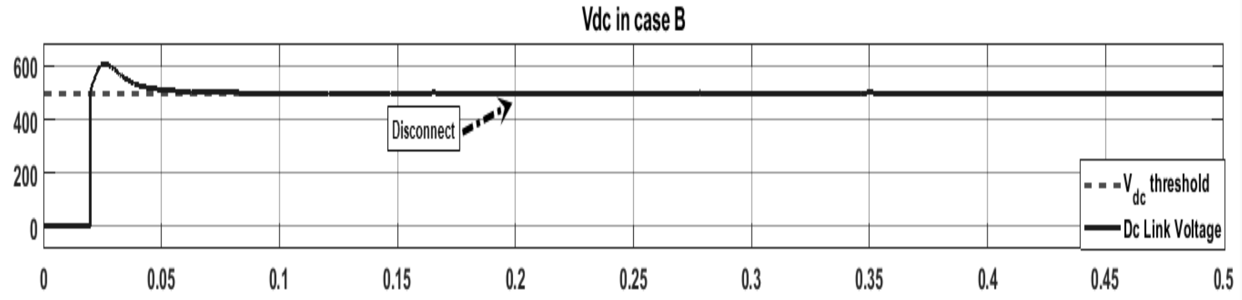

Figure 12. Effect of DC-link voltages for islanding detection in case B.

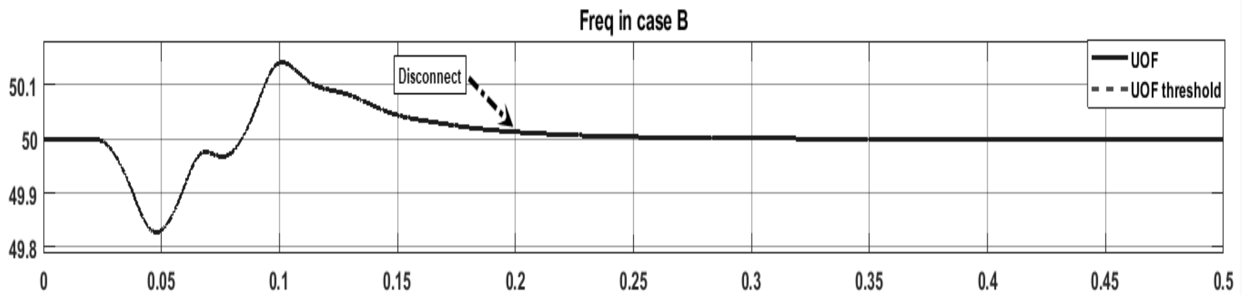

Figure 13. Effect of UOF for islanding detection in case B.

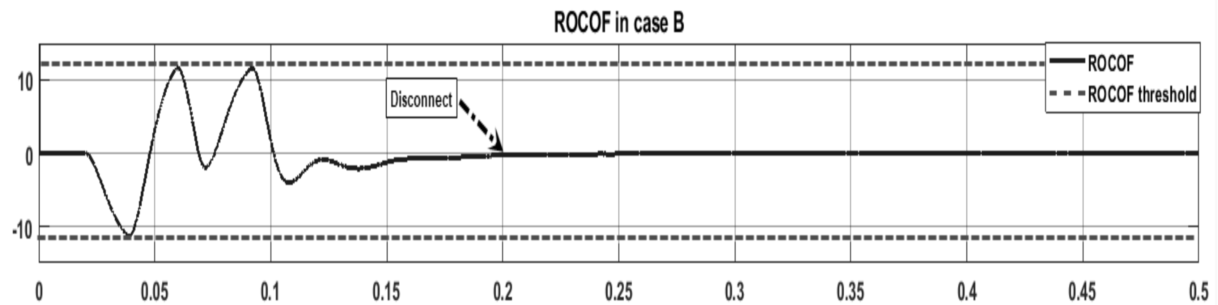

Figure 14. Effect of ROCOF for islanding detection in case B.

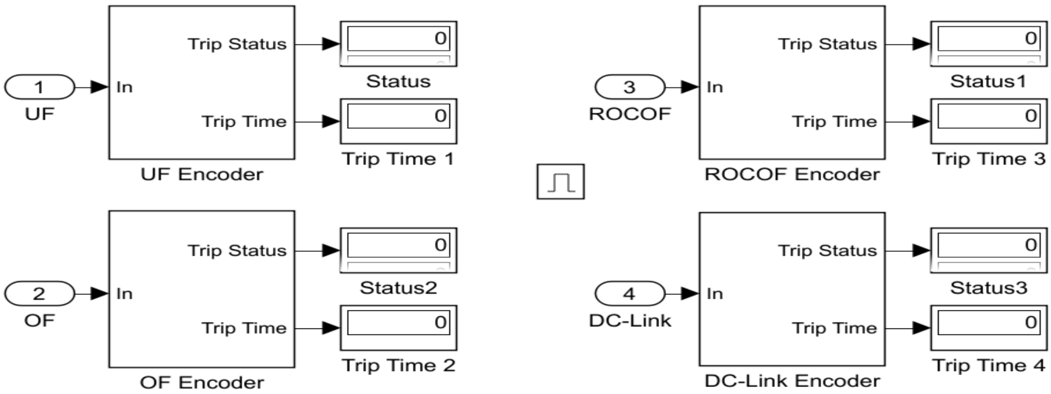

Figure 15. Detection Time and status for the AI protection relays in case B.

Case C: Load has a lower value than the Local Power Generated when CB1 cutoff

The value of all tripping relays will change by applying a resistive load equal to 50e3 Ω with the utility model. The effect of this change on the relays Vdc, UF/OF, and ROCOF is presented in Table 1, as we analyzed that Vdc will detect islanding rapidly than the other relays.

Scenario 2: Disconnecting the CB2 (Medium voltage cutoff)

Islanding detection in medium voltage on the network shown in Fig. 3, cam be occurred by opening CB2 at a time (t) = 0.2 Sec. That is mean, CB2 cut off the power of the utility from the residue of the network (Medium voltage cutoff). Then, applying the same values of loads in scenario 1, the detection time of islanding will be changed, and that is presented in the following cases:

Case D: Load has a Greater value than the Power Generated when CB2 cutoff

The value of all tripping relays will change by applying resistive load equal to 2e6 Ω with the utility model. The effect of this change on the relays Vdc, UF/OF, and ROCOF are described in Figures 16-18 sequentially. As analyzed from these Figures that there is an increment in frequency for a minimal time and this rapid variation in frequency will lead to some variations of ROCOF until it exceeds the ROCOF threshold then islanding is detected. The sign of frequency is an indication for increment (+) or decrement (-) and about Vdc, it will detect islanding rapidly. Figure 19 shows the detection time by seconds and status of the anti-islanding protection.

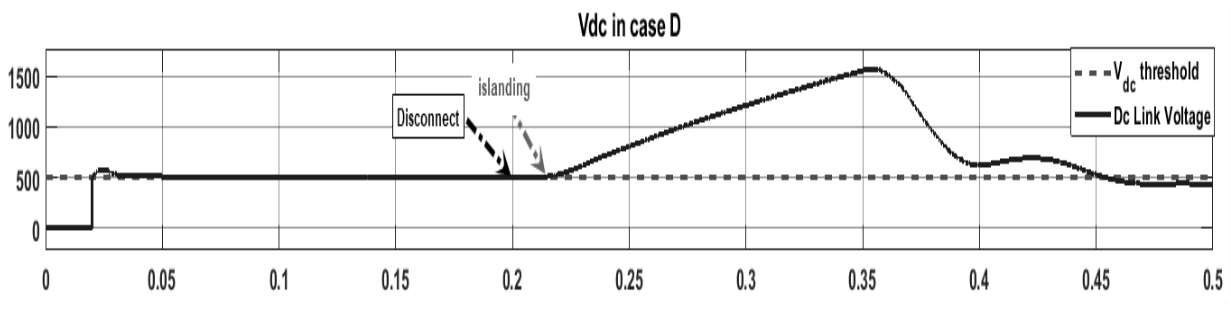

Figure 16. Effect of DC-link voltages for islanding detection in case D.

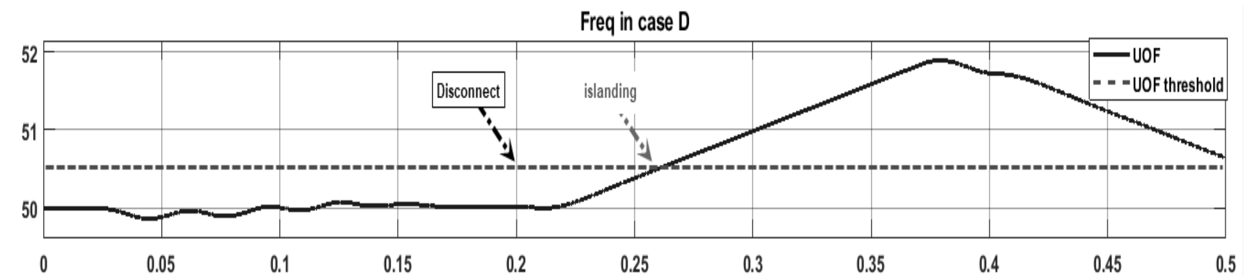

Figure 17. Effect of UOF for islanding detection in case D.

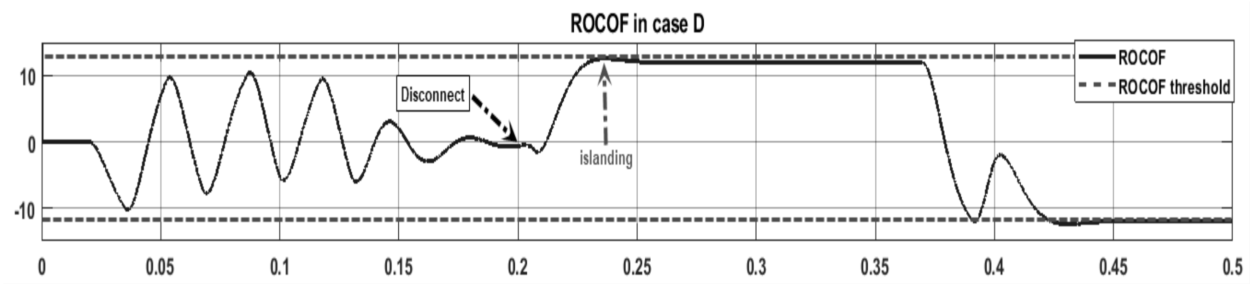

Figure 18. Effect of ROCOF for islanding detection in case D.

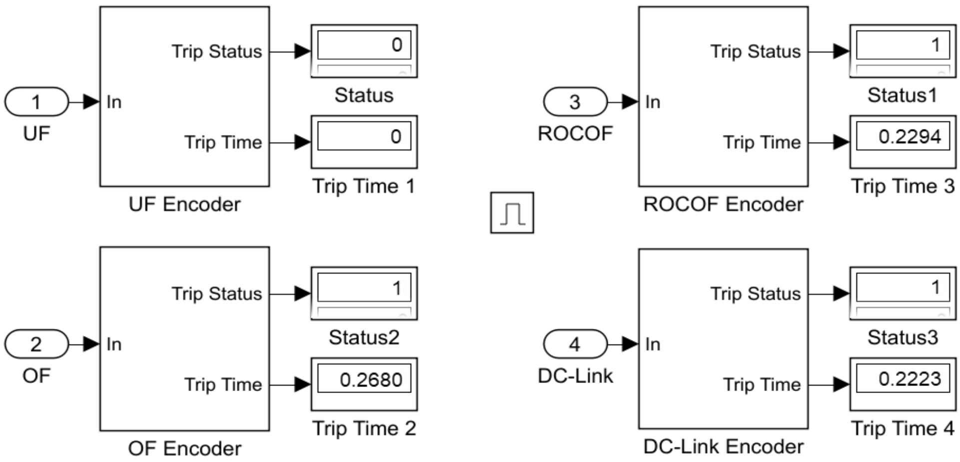

Figure 19. Detection Time and status for the AI protection relays in case D.

Case E: Local Load has the same value as the Local Power Generated when CB2 cutoff

The value of all tripping relays will change by applying a resistive load equal to 103e3 Ω that nearly matches the power generated from DG. The effect of this change on the relays Vdc, UF/OF, and ROCOF are presented in Figures 20–22 sequentially, as we analyzed that Vdc has the superiority for detecting islanding in this case (NDZ).And the detection time by seconds and status of the anti-islanding protection relays are presented in Fig. 23.

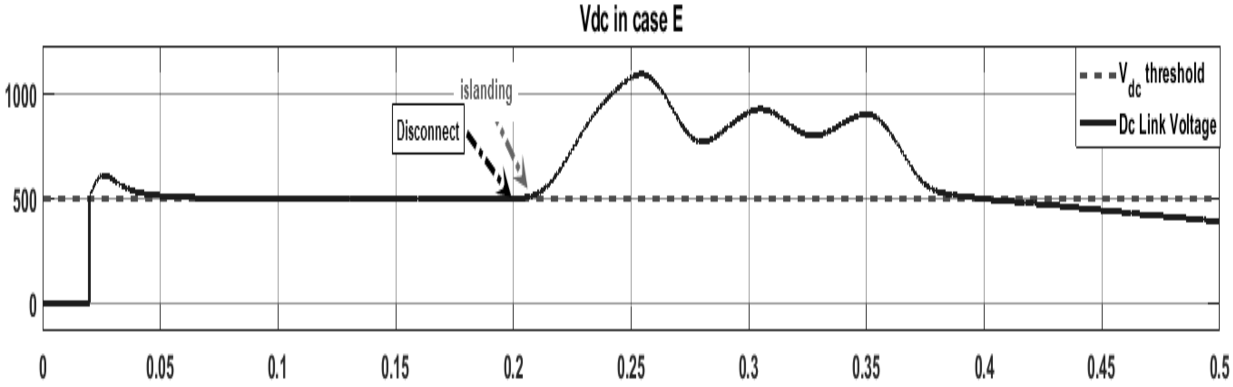

Figure 20. Effect of DC-link voltages for islanding detection in case E.

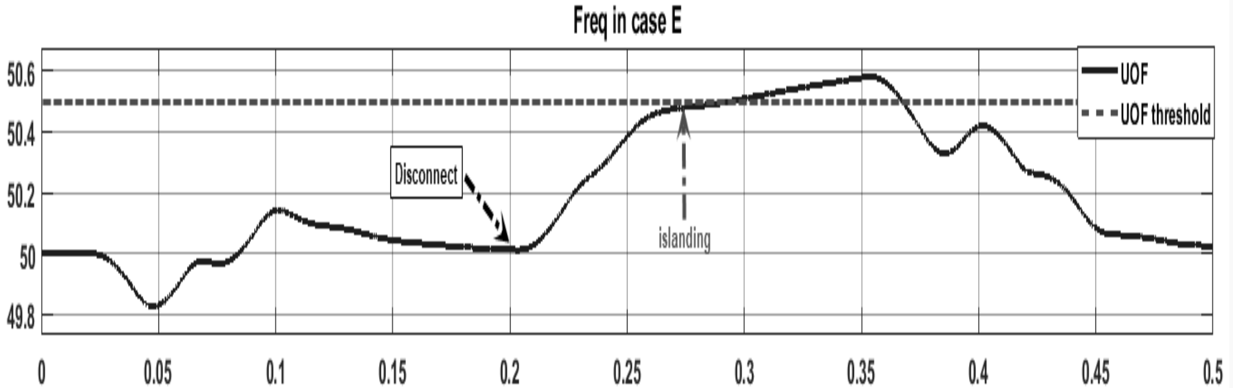

Figure 21. Effect of UOF for islanding detection in case E.

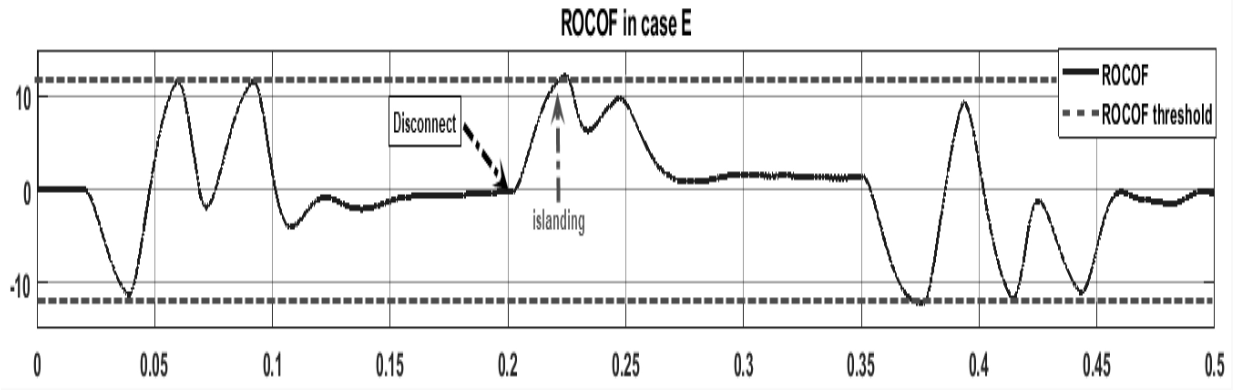

Figure 22. Effect of ROCOF for islanding detection in case E.

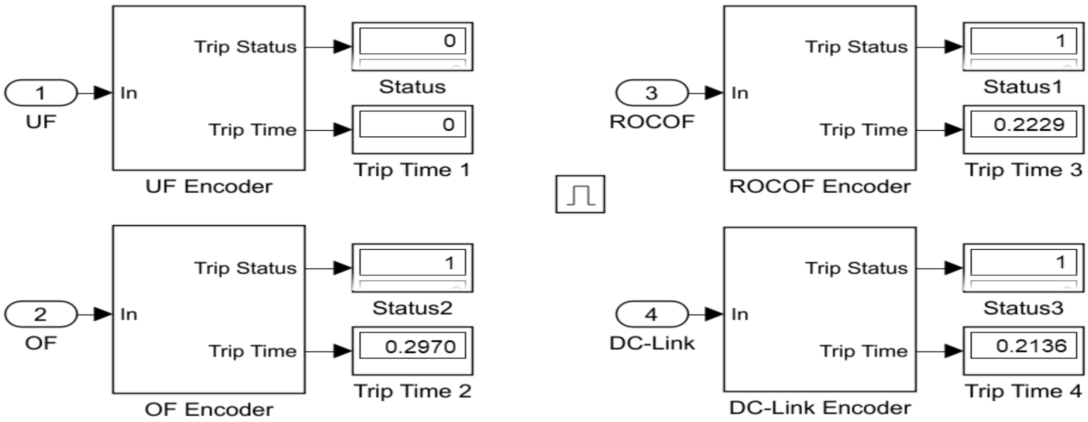

Figure 23. Detection Time and status for the AI protection relays in case E.

Case F: Load has a lower value than the Local Power Generated when CB2 cutoff

The value of all tripping relays will change by applying a resistive load equal to 50e3 Ω with the utility model. The effect of this change on the relays Vdc, UF/OF, and ROCOF are presented in Table 1, as we analyzed that Vdc will detect islanding rapidly than the other relays.

The comparison between all anti-islanding methods discussed in this paper according to its detection times, which are presented in previous different cases is shown in Table 1. From this table, the importance and effectiveness of the proposed Vdc technique in detecting islanding are better than other techniques.

Table 1. Time of Detection of AI Methods for different cases.

	Cases	Time of Detection (Seconds) of AI Relays			
		UF	OF	ROCOF	Dc link
Scenario 1 (CB1 cut off)	Case A	0.0620	--	0.0220	0.0138
	Case B	--	--	--	--
	Case C	--	0.0710	0.0245	0.0220
Scenario 2 (CB2 cut off)	Case D	--	0.0680	0.0294	0.0223
	Case E	--	0.0970	0.0229	0.0136
	Case F	0.0923	--	0.0293	0.0284

CONCLUSION

In this study, a new method of AI prevention in a PV-grid connection system is presented depending on monitoring and analyzing the V_{dc} of the PV inverter. The comparison between the UF, OF, ROCOF relays, and the proposed DC-link voltage protection relay based on the detection time in case of low voltage and medium voltage is discussed. This comparison declares that the proposed V_{dc} protection relay is the most convenient under any conditions except the case of similarity between the power generated and consumed in low voltage disconnection, and the simulation results in other cases show that the islanding detection time was about 20 mSec, which is very much faster than the required detection time of 2 Sec.

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