Fast and accurate islanding detection technique for microgrid connected to photovoltaic system

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ABSTRACT

Islanding condition means the case of feeding the loads from any distributed generator (DG) with a complete disconnection of the utility grid at the point of common coupling. The main technical issue in DG integration with the primary grid is the islanding condition. Hence, islanding must be detected using an appropriate anti-islanding technique which is needed to be faster in terms of time detection and accuracy. This paper illustrates the phenomenon of islanding and the passive methods which are used for preventing it. The main contribution of this paper is to detect this phenomenon as fast and accurately as possible using the technique of rate of change of power (ROCOP) based on the terminal voltage (TV) (ROCOP-TV) of the Photovoltaic (PV) inverter. The results of the proposed technique have been studied through extensive simulations using the MATLAB/Simulink platform. The ROCOP-TV technique results are compared with various types of passive detection relays after synchronization between the grid side and PV side. Furthermore, the proposed technique was not only able to detect islanding at the instance of its occurrence but also can distinguish between islanding and regular grid faults. The simulation results illustrate the proposed scheme’s effectiveness and flexibility based on the MATLAB/Simulink platform.

1. Introduction

Increasing the demand for energy over the world and in addition to the limited resources of the traditional power-generation methodologies make the different distributed generators (DGs) resources such as wind turbines, water turbine, micro-turbine, solar, and fuel cells are utilized in modern distribution systems (Elshrief, Helmi, Asham et al., 2019), (Penaloza et al., 2021) as shown in Figure 1. Although the benefits for these DGs sources such as reduced power losses, improving the voltage profile, and enhancement of power quality (in some cases), some disadvantages are affecting the safety of the utility grid, and the main dangerous one is the problem of islanding (Abdelsalam et al., 2020), (Amini et al., 2020). The islanding phenomenon occurs by opening the circuit breaker (CB) as shown in Figure 2, where the generation unit and loads will be isolated from the electrical grid. But the problem is that the solar generation system continues to energize these isolated loads. This situation will degrade the quality of power and create an unsafe condition in the system.

There are two main techniques for anti-islanding (AI); local and remote (Elshrief et al., 2019). The remote methods are based on some kind of communication between the grid utility and the DG, as shown in Figure 3. Remote techniques have many different types as impedance insertion, power line carrier communications, a signal produced by disconnect, supervisory control, and data acquisition. The most popular types are phasor measurement units (PMUs) and micro PMUs. The PMU can detect the grid’s loss by the algorithm of a central synchrophasor vector processor, which uses synchrophasor data from two relays, located at the grid side and the DG side as shown in Figure 4. The two relays acquire voltage phasor measurements from their corresponding sites. Relay 1 sends the synchrophasor messages to relay two at specific time intervals (60 messages per second). Relay 2 receives the remote synchrophasor data from relay one and calculates the difference between the local and the remote synchrophasor angle value. The schematic representation of a $\mu$PMU in the distribution system is shown in Figure 5. The $\mu$PMU, similar to PMU, acquires voltage and current signals through a current transformer and a potential transformer, respectively. It also computes phasor with a digital signal processor, timestamps the phasor with a reference time provided by a global positioning system, and then send it to the control center (Elshrief, Abd-Elhaleem, Abozalam, Asham et al., 2021a).
But for the aspect of accuracy, the PMUs can still vary by ±1°, while the μPMU is expected to discern angle differences to an accuracy of better than ±0.05° (Zanjani et al., 2018).

However, the micro-PMUs have significant speed and accuracy, more cheaply than current commercial PMUs. It has some drawbacks as it depends on GPS and communication that lead to some delay, they can be interrupted quickly and high cost compared to local techniques (Elshrief, Abd-Elhaleem, Abozalam, Asham et al., 2021b; Mishra et al., 2021; Pinte et al., 2015). Consequently, these techniques are costly to be used on a small scale as our scale in this paper. Hence, other approaches are appropriate for small scale in the cost, time of detection, and accuracy. These approaches are called local and are divided into active and passive strategies (Elshrief, Abd-Elhaleem, Abozalam, Asham et al., 2021c). Under the two categories, many control techniques are classified depending on the method of detection for each one. Active methods are achieved by

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**Figure 1.** Power distribution system (traditional and modern). (a) traditional distribution system (b) modern distribution system.

**Figure 2.** Model of a grid-disconnected DG source (islanding phenomenon).
injecting disturbances continuously into the system. Hence, these disturbances lead to a noticeable deviation. Although active detection methods are more efficient, they degrade power quality. On the other hand, in passive methods, local parameters such as frequency, voltage, and current are measured at the point of common coupling (PCC), and if there are changes around the threshold values, islanding is detected (Abokhalil et al., 2018; Xie et al., 2021).

The mechanism of detecting islanding for passive techniques is shown in Figure 6. Several passive methods make decisions based on some local measurements proposed in literature such as under/over voltage (UOV) and under/over frequency (UOF) (John et al., 2004), rate of change of frequency (ROCOF) relay (df/dt) (Hashemi et al., 2017), phase displacement monitoring, output power speed changing (Bright, 2001), comparison of the ROCOF, unbalanced voltage, and total current (or voltage) harmonic distortion (THD) (El-Arroudi et al., 2007)

Based on the references mentioned above and their shortcomings, the previous papers do not focus on the relation between accuracy and fast detection time for each method. Hence, the proposed technique which integrates the rate of change of power (ROCOF) and terminal voltage (TV) ROCOP-TV is presented. The proposed technique can detect the islanding condition based on the parameters which are measured at the PCC. Islanding condition is detected firstly by calculating the value of the ROCOP. Hence, if the ROCOP value exceeds the threshold value, the decision is taken by the TV. Different islanding and non-islanding events are simulated. Synchronization is performed between the PV systems and utility grid to prevent the abnormalities of parameters between the PV system and the grid in the proposed method. It can also differ between the islanding state and the other faults in grid-connected disturbances. These faults are single-phase fault, double-phase fault, double phase with the ground, three-phase fault, and three-phase with the ground. So, the proposed method achieves an appropriate speed and accuracy compared to the other passive techniques.

The contributions of this paper can be summarized as follows:

1. The proposed algorithm is an integrated detection system that accurately detects islanding faster than

Figure 3. The general structure of the remote AI technique.

Figure 4. Schematic representation of working of μPMU (Dutta et al., 2019).
the other techniques and proves its superiority. As shown in the results section, the other relays with the same detection times are not accurate in differentiating between islanding and faults. In contrast, the rest of the techniques are neither fast nor accurate.

(2) Since the proposed method is simple, based on common protection relays and hence, it can be easily implemented practically.

(3) The proposed method is a passive technique. Thus, it can be applied for all types of DGs without degrading the system’s power quality.
Figure 7. NDZ in $\Delta P$ versus $\Delta Q$ for over/under frequency and voltage.

Figure 8. RLC load between DG and utility.

The rest of the paper is organized as follows: issues of islanding are discussed in section II. The proposed method of ROCOP-TV is presented in section III. The discussion of the results for various operating conditions is introduced in section IV. Finally, the conclusions are collected in section V.

2. Issue of islanding

There are two types of islanding: intentional and unintentional. The intentional one is occurred by humans who have authority on the system for maintenance or emergencies, but there is unintentional islanding that is happened without any interference from humans. The last one has some disadvantages, such as listed:

- Safety issues for the humans working on the power line and are exposed hazards from the generated power coming from DG sources in case of disconnection of power from a utility grid.
- The values of frequency and voltage may vary away from the standard permissible level and lead to several problems.
- Unintentional reclosing may lead to a desynchronization of DG, which causes unexpected mechanical torques that can destroy the generators (Zheng et al., 2018).

Because of all these reasons, islanding must be detected quickly and accurately.

To achieve the best AI technique, two main issues must be studied, the non-detection zone (NDZ) and time detection (Ye et al., 2004). The NDZ is defined as the interval that the islanding phenomenon is failed to be detected by some AI techniques (Elshrief et al., 2020). From Figure 7, the NDZ is the zone formed in case of similarity between the consumed power of local loads and the DG generated power.

In this paper, the fastest and accurate time detection is achieved in regular operation and grid faults without considering NDZ. Hence, the concept of passive methods will be used. This technique’s implementation is fast, easy, more uncomplicated, and has no disturbance in the system.

To implement this technique, the connection between DG sources such as solar energy in our case and utility grid through PCC is executed as declared in Figure 8. Hence, the measurement at this PCC can detect whether it is an islanding case or not using the relays of under/over frequency, current, and voltage (Pedrino et al., 2019). The threshold limits of the relays are determined by equations (1-4) which matches with IEEE 1574 presented in Table 1 (Teodorescu et al., 2011). These limits are used to ensure that the DGs must stop feeding power to the utility if a value of any parameter at PCC exceeds the predefined thresholds (Elshrief, Helmi, Asham et al., 2019). The proposed technique is compared with many passive methods in terms of the detection time by varying load and applies some grid faults.

\[
\left( \frac{V}{V_{\text{max}}} \right)^2 - 1 \leq \frac{\Delta P}{P} \leq \left( \frac{V}{V_{\text{min}}} \right)^2 - 1 \tag{1}
\]

\[
1 - \left( \frac{f}{f_{\text{min}}} \right)^2 \leq \frac{\Delta Q}{Q} \leq 1 - \left( \frac{f}{f_{\text{max}}} \right)^2 \tag{2}
\]

where $(V_{\text{min}},V_{\text{max}})$ are the UOV thresholds, respectively, $(f_{\text{min}},f_{\text{max}})$ are the UOF thresholds, respectively, $(V,f)$ are the nominal voltage and frequency, respectively, $(\Delta P,\Delta Q)$ are the real and reactive power. The $\Delta P$ and $\Delta Q$ are declared by the following:

\[
\Delta P = P_{\text{DG}} - P_{\text{LOAD}} \tag{3}
\]

\[
\Delta Q = Q_{\text{DG}} - Q_{\text{LOAD}} \tag{4}
\]

where $P_{\text{DG}}$ and $Q_{\text{DG}}$ are the DG source real and reactive powers, respectively. Similarly, $P_{\text{LOAD}}$ and $Q_{\text{LOAD}}$ are real and reactive powers of the loads, respectively.

3. Proposed method

The ROCOP detection method is based on the real power imbalance, which causes transients in an islanded system. When that happens, the system’s frequency drifts up or down, making the system’s frequency deviate from its nominal value according to IEEE and IEC standards (IEEE

| Parameters                      | Standard               |
|--------------------------------|------------------------|
| Range of voltage               | $88\% \leq V \leq 110\%$ |
| Range of frequency             | $49.5\ \text{HZ} \leq f \leq 50.5\ \text{HZ}$ |
| Maximum time for islanding     | 2 second               |
| THD %                          | $\leq 5\%$             |
Furthermore, the range of the frequency can be changed from 18% to 25%. In our case study, the threshold value has been taken to be 20%. When the relay of frequency is triggered, the ROCOP relay is activated. Hence, ROCOP can be used as a detection index under this islanding situation. The TV relay is based on the reactive power imbalance that causes transients in an islanded system, and its value starts to vary dynamically during the islanding operation. The TV drifts up or down in these instances, making the TV deviate from its nominal value according to IEEE and IEC standards (IEEE Standard Requirements for Instrument Transformers, 2008).

Moreover, the range of TV can be changed from 0.1% to 3%. In this paper, the threshold two value has been taken to be 1%. When the relay of TV is triggered, TV can be used as a detection index under this islanding situation. As shown in Figure 9, the proposed combines the advantages of ROCOP and TV techniques. Hence, the ROCOP-TV of PV inverter is fast, easy, more accurate, and has no disturbance.

4. PV-grid connection system and its proposed ai scheme

The Matlab model for PV-GRID connection system of a total power 100 kW and the simulation of 20 kV for the utility grid is presented in Figure 10. The PV array constructed from 330 sun power modules can provide 273.5 V and 100.7 kW at maximum in standard test conditions (Khodaparastan et al., 2015).

The network represents a connection between a 100 kW photovoltaic array and a 20kV power grid depicted in detail in Figure 10. In addition to a 380 V/20kV three-phase coupling transformer with 50 Hz primary frequency through a 100kVA. The value of the DC voltage from the PV array can be increased from 272 V to nearly 500 V by using a 5 kHz-500 V DC-DC Boost/step-up converter, and the 500 Vdc can be converted to 380Vac by using the three-level bridge. Using a state flow implementation with incremental conductance methods, we can get the DC-DC maximum power

Figure 9. The flowchart of the proposed technique.

Figure 10. Model of PV-Grid connection system for 100 kW.
point tracking. The dc-link voltage is implemented and adapted to be 600 V using the 3-phase voltage source converter control. The MATLAB implementations and results can be clarified as follows:

41. The matlab implementation of AI schemes

Figure 11 shows the Simulink of UOF, UOV, under/over current (UOC), ROCOF, and ROCOP-TV protection relays to prevent the islanding on PCC. All these relays are activated only once in simulation, and the MATLAB implementations of each relay are clarified below:

1) The Under/Over Frequency (UOF) Relays

Frequency can be obtained by applying the normalized voltage signals Va, Vb, and Vc to the phase-locked loop (PLL) in a vector. The values of UOF relays at the PCC are compared with these predetermined threshold values according to IEEE standard and equation 2.

2) The ROCOF Relay

Implementing ROCOF relay in MATLAB/Simulink depends on the frequency at the PCC as an input; which is calculated using a PLL. This frequency is differentiated and compared with its threshold. This threshold is determined according to IEEE international standards. Hence, the relay is energized as soon as this situation is achieved and the power of the PV array is accidentally disconnected from the utility grid.

3) The Under/Over Voltage (UOV) Relays

The relays of UOV compare the value of the voltage of PV inverter and the predefined threshold values defined according to IEEE standard.

4) The Under/Over Current (UOC) Relays

As in UOV, the relays of UOC compare the value of current PV inverter and the predefined threshold values defined according to IEEE standard.

5) The proposed method (ROCOP-TV) Relays

The ROCOP is combined with a TV protection relay. If both conditions are satisfied, the relay is activated.

4.2. Matlab results of different values of load for islanding phenomenon

The simulations for the PV-grid connection system in Figure 10 are performed using MATLAB in the following different cases. The islanding condition can be applied to the network after guaranteeing the synchronization between PV and grid by means of the PLL at time $t = 0.16$ second. Islanding is achieved by opening CB2 at time $t = 0.3$ second illustrated by the green color and synchronization by red color. This means CB2 cut off the power of the utility from the residue of the network.

Case I: Load has a consumed power more significant than the generated power

In Figure 12, when the load consumes power more than the generated from DG, it is observed that there is a rapid variation in ROCOP-TV and an under-voltage (UV) relay until they exceed their threshold, then islanding is detected. In this case, it is observed that ROCOP-TV and UV relays are similar in time detection.

Case II: Load has a consumed power lower than the generated power

In this scenario, the connected load has a power less than the PV generation. Figure 13 shows a rapid variation in ROCOP-TV, ROCOF, UC, and over voltage (OV) relays until they exceed their threshold then islanding is detected. It is observed that ROCOP-TV and OV relays are similar in time detection and faster than ROCOF and UC relays.

Case III: The consumed power equal to the generated power

Figure 14 shows the impact on all relays when the consumed power from loads and power generated from DG is nearly matched. During islanding conditions, the behavior of the relays from this figure can be analyzed. It is observed that there is a variation in the behavior of each relay, but it does not exceed the thresholds, so islanding is not detected.

4.3. Matlab results of different types of faults impact

Applying some faults can be used to illustrate the accuracy of the proposed method compared to the other AI methods by observing each method’s performance according to each fault. These faults are applied on the network, as shown in Figure 10 after the synchronization between PV and grid is guaranteed by means of PLL at
time $t_0 = 0.16$ second. The faults are connected at time $t = 0.3$-second each time by connecting each fault's CB. The behavior of each relay when the fault is applied is shown according to the type of each fault as:

Single-phase fault can be detected using UV and ROCOF relays as presented in Figure 15. The UV, OC, and ROCOF relays can detect the double-phase fault, as shown in Figure 16. Furthermore, the UV and OC relays can detect double-phase fault with the ground as presented in Figure 17. The three-phase fault can be identified through the relays of ROCOF, UV, and OC, as shown in Figure 18. Finally, Figure 19 illustrates the three-phase fault with ground detection using ROCOF, UV, and OC relays as all faults are clarified by yellow color and synchronization by red color.

The effect of changing load and faults can be summarized in Table 2, where the detection time by seconds and the status of the AI protection relays (0 for de-energize/1 for energize). It is observed from this Table that the proposed ROCOP-TV has the same detection time as UV relay in case I. For case 3 ROCOP-TV has the fastest detection time similar to OV. Besides its superiority at
Figure 13. Effect of case II on islanding detection relays.

Figure 14. Effect of case III on islanding detection relays.

Figure 15. Effect of single-phase fault on islanding detection relays.

Figure 16. Effect of double phase fault on islanding detection relays.
the cases of applying various types of faults, it did not energize for any fault. So we conclude that the ROCOP-TV protection relay has the fastest detection time and accuracy compared with the other relays.

5. Conclusion

Fast and accurate detection of islanding phenomenon is one of the main challenges in today’s power system. Hence, the proposed technique ROCOP-TV is introduced to achieve good speed and accurate detection compared to some passive anti-islanding detection techniques such as UOF, UOC, UOV, and ROCOF. The comparison is achieved according to varying loads and injecting faults in the power system. The simulation results have clarified that the proposed technique is adequate and the most convenient under any conditions except equality between the power generated and the load requirement. Moreover, the proposed method can detect islanding at its occurrence and distinguish between islanding and regular grid faults. Some future topics of interest are to extend the results of this paper to use a hybrid technique that incorporates local and smart techniques such as adaptive fuzzy controller (Asham, Badr, Hassan et al., 2006; Asham, Badr, Sultan et al., 2006; Elshrief, Atlam et al., 2016; Elshrief et al., 2017; Elshrief, Elakbawy et al., 2016; Hamdy et al., 2018, 2017).

Figure 17. Effect of double phase fault with the ground on islanding detection relays.

Figure 18. Effect of three-phase fault on islanding detection relays.

Figure 19. Effect of three-phase fault with the ground on islanding detection relays.
Table 2. Detection Time (s) Of Anti-islanding Protection Devices.

| Cases        | UF DT(s) | OF DT(s) | ROCOF DT(s) | OV DT(s) | UV DT(s) | OC DT(s) | UC DT(s) | ROCOP-TV DT(s) |
|--------------|----------|----------|-------------|----------|----------|----------|----------|----------------|
| Load Change  | 0  0  0  0  0  0  0  0  0.0082  0  0  0  0.0082 |
| Faults       |          |          |             |          |          |          |          |                |
| Single-phase fault | 0  0  0  0  0  0  0  0  0.0200  0  0  0.0074 |
| Double-phase fault | 0  0  0  0  0  0  0  0  0.0350  0  0  0.0093 |
| Double-phase to ground fault | 0  0  0  0  0  0  0  0  0.0073  1  0.0073  0  0  0  0.0073 |
| Three-phase fault | 0  0  0  0  0  0  0  0  0.0254  0  0  0.0073  0  0  0  0.0073 |
| Three-phase to ground fault | 0  0  0  0  0  0  0  0  0.0253  0  0  0.0073  0  0  0  0.0073 |

ST: Status DT (s); Detection Time

Disclosure statement

No potential conflict of interest was reported by the author(s).

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