Implementation of Passive Anti-islanding Detection Scheme for Solar PV Integrated Microgrid Network

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Abstract- Microgrids incorporated with Distributed Energy Resources (DER's) offer various reimbursements to the electric power grid like high Power quality, Energy efficiency and reduced carbon dioxide emissions. Microgrids can be operated in grid-connected mode as well as islanding modes. The main technical problem in a microgrid is unintentional islanding, where failure to trip the microgrid may lead to serious consequences in terms of protection, reliability, voltage imbalance, and frequency fluctuation, which requires fast and effective detection of islanded mode is essential for reliable microgrid operations. This paper proposes a new Passive Anti-Islanding Protection [PAIP] including distributed generation by considering the parameters like frequency , voltage , current at the Point of Common Coupling (PCC). The proposed algorithm differentiates between the island state and non-island disturbances, such as short-circuit faults, and load switching properly, avoiding the unwanted operation of protective devices. The performance of the algorithm has been tested in 3Φ grid-connected 100kW PV system under different scenarios in MATLAB /Simulink.

Keywords Island detection, distributed generation, microgrid network, solar PV.

1. Introduction

The power systems remain facing high complications and sensitivity due to the high penetration of renewables and storage systems. Islanding detection is a major aspect of study in microgrid networks. In an islanding scenario, one or more Distributed Generations (DG's),a section of the connected area detach at the utility grid and the islanded network is operated [1]. The system has placed a high priority on islanding detection since it addresses several issues, including safety risks, and out-of-phase reclosing. The *IEEE* 1547 [2] and the recloser procedure both state that the islanding should be identified in less than 2 seconds. Since the re-closer constant time is typically a lesser amount than that of 500ms, the time of detection is a critical factor in distinguishing the island preceding to recloser's action. Grid codes [3] also suggest these the DG's need to be able to keep running in the islanded mode. As a result, the islanding is identified to separate the DG from the grid and allow it to continue operating even after the islanding has occurred. In general, there are two types of detection of island methods: remote and local. Using communication channels between DG and the PCC, which joins the connected area to the upstream grid, remote approaches can identify an islanding situation [4]. Islanding is identified in [4] using Phasor Measuring Unit (PMU) measures. By transmitting a small signal from the DG-connected busbar and receiving it in the circuit-breakers' opinion, power line signalling is used [5] to identify the islanding. None Detection Zone (NDZ), remote methods can find islands. These methods are also quick at identifying islanding situations and separating islanding from grid-connected disturbances [6]. The foremost disadvantages of isolated approaches, however, are their higher cost, the possibility of communication link breakdown, in addition, the need for backup protection. The two types of local approaches are active and passive. To purposely notice the islanded scenario in the active methods, a disturbance is intentionally supplementary to the system [5,7]. As a result, active methods can be created according to the classification of DG. Additionally, the faulty signal is not additional to the

system by way of the DG in some active ways. For instance, a condenser or capacitor may be added to purposefully disrupt power imbalances to identify an islanding situation [7,8].FS(Frequency-shift) [9], AFD (Active Frequency Drift), VD (Voltage drift) approach, and PF(Power factor) method are a few of the active methods for inverter-handled generators [10]. A remedy to the current injection method's capability issue is introduced in [11] and is based on the idea that only specific high-frequency components should be considered as injected current. Similar islanding detection techniques aimed at synchronous-based generators are given in [11,12]. Two real power and reactive power control loops with positive feedback are shown in [13] to make the system unstable in an island scenario. New active and passive power control loops are suggested in [13] to simultaneously increase the synchronous generator's ability to ride through circumstances and identify islanding. To render the system unstable in an islanding condition, integrated controllers are additional to the governor, and the excitation system of the synchronous generator is further in [12,13]. To make the system slightly unbalanced in an islanding situation, two modified real power and reactive power control loops of synchronous DG are described in [14]. Moreover, a feature that designates the islanding conditions is found using a signal processing technique. Two probabilistic phase-neutral network controllers are used in [15] to manage real power (P) and reactive power outputs of inverter-based DGs.Monitoring the system's electrical quantities forms the basis of passive approaches. By going against the preset thresholds, the islanding is thus discovered. Another form of passive island detection method is the use of vector surge relays [16]. ROCOF(Rate of change of Frequency), which has a large NDZ, is a crucial metric for the islanding detection method. A straight cooperation between decreasing the NDZ and maloperation in non-islanding occurrences is reached when the ROCOF threshold is established. Additionally, approaches relying on voltage measurement, such as ROCOV(Rate of change of voltage) [16], fail to distinguish between islanding conditions, particularly when reactive power imbalance is present. The primary flaw in these approaches is short circuit fault malfunction. Other passive technologies that have lately been presented are signal processing techniques [16,17]. In [17], the wavelet transform is employed to detect islanding and reduce NDZ. [16,17] introduces a passive approach for inverter-based DGs by intergrating a high-frequency impedance monitoring technique with close-loop frequency management. Machine-learning techniques have been developed to extract the elements that identify the modes of operation, namely islanding and grid-connected operations, according to [18].To categorise islanding and grid-connected generations, several features are first examined by signal processing techniques, and then these features are used in a deep learning-based Machine learning algorithm. The islanding situation for power imbalances, the line current measured to disconnect loads, and shifting into islanding operation have all been detected using a voltage index and effects of MG can be studied in local national grids to know the control of MG in [19,20]. To increase detection accuracy, this research suggests a PAIP technique.Considering the connection PV (Photovoltaic) incorporated island system have various conditions like volatge sag,voltage swell and external distrubances. Therefore proper droop control method is implemented[21, 22] and is one of the elements required for the identification of the island, it has predictive control of function. The suggested method uses measured values of the Frequency, Voltage , and Current to differentiate between islanding and non-islanding conditions[23,24]. Additionally, the integration of distributed generation into the power system allows for the implementation of the suitable detection of islanding[25,26]. The summary of the work are as follows:

- Effective islanding requires the development of passive anti-islanding strategies that incorporate well-coordinated protection plans.
- The passive anti-islanding detection approach considerably reduces the time required to detect islanding.

It also detects grid-connected disturbances such as short circuit faults. The paper is organized as follows: Section 2 presents the proposed methodology under various types of protection relays. The recommended methodology of a Passive Anti-Islanding Protection scheme is implemented in Section 3. Section 4 presents a discussion of the simulation results of 3Φ grid connected 100kW PV system under different scenarios and the conclusions are provided in Section 5.

2. Proposed Methodology

The passive anti-island protection method is based on continuous monitoring of voltage, frequency, and harmonic distortion as these parameters vary during the islanding condition. These variations are directly influenced by the power mismatch between the supply and the loads. Due to passive methods of islanding detection being dependent on the changes in the aforementioned parameters, the efficiency is thus dependent on the threshold set. The rate of change of voltage/frequency relies on the fact that power imbalance causes transients in an islanded system and causes the voltage and frequency to vary. The over/under voltage and frequency, however, deal with the thresholds of the voltage and frequency, respectively, to detect an islanded system Figure 1 shows the suggested Passive Anti-Islanding Protection, which comprises coordinated protection. Trip signals from the grid-connected PV system are provided to the 3Φ circuit- breaker on the 20kV side of the PCC to start as numerous relays as possible and associate their islanding detection timings. The traditional voltage-based anti-islanding, over/undercurrent, frequency, ROCOF, and dc voltage approaches are developed. Figures 2 to 4 show the conventional overcurrent, undercurrent, overvoltage, under voltage and frequency, and under frequency relays for grid-connected PV systems' passive anti-islanding protection. Similar to other relays, these work by comparing measured 3Φ current, voltage, or system frequency characteristics to predetermined thresholds. The least or determined elements of the inputs are output by minimum and maximum current and voltage threshold blocks in Figure 2,3. The Overcurrent and Undercurrent relay logic

blocks are being traversed by the measured three-phase current.

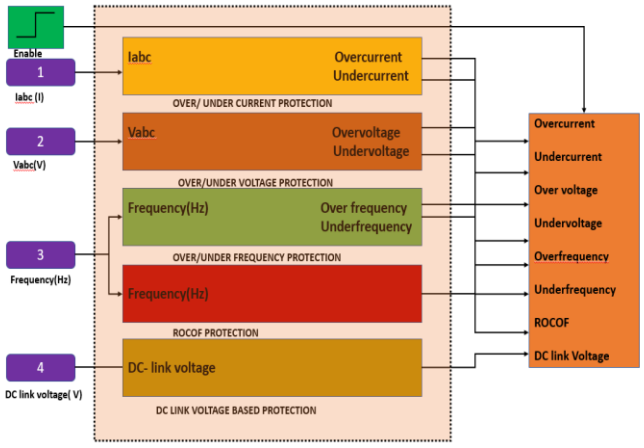


Fig. 1. Proposed passive-anti-island coordinated protection.

The maximum and lowest threshold currents have overcurrent and undercurrent, and the three-phase current can be transformed into an RMS discrete value. The Overcurrent exceeds the constant by 3.5 times. It will trip the overcurrent relay. The Undercurrent is compared to a constant and is less than 2.5 times and It will trip undercurrent relay. The on-time delay for both the OC and UC is 0.001 seconds.

2.1. Protection based on Over/ Under voltage Relay and Under/Over Frequency Relay

The method of detection of the islanding problem is the simplest of the available methods where the voltage and/or frequency is continuously measured and when the voltage or frequency is measured to be outside the predetermined acceptable limits, the connection between the DG and the power grid is disrupted. In case that the power rating of the DG is less than the power rating of the load, the mismatch of the power will be compensated by the grid. However, when the islanding occurs, there will not be any power supply from the grid, so in this case the voltage and frequency will deviate. That is, in this case, when there is an islanding effect, the voltage at the Point of Common Coupling (PCC) should increase until active power = Real Power of the load P (load). The Non-Detection Zone (NDZ) refers to the zone within which the islanding condition is not detected by the islanding detection method.The frequency should also change such that the reactive power Q (DG) is equal to the reactive power of the load Q of load of generation. This happens because the DG inverter will seek a frequency where the current–voltage phase angle of the load equals that of the DG inverter as follows

$$P(load) = (V^{\wedge 2}\,(PCC))/R, \tag{1}$$

$$Q(load) = (V^{\wedge 2}\,(PCC)(1/((2 * pi * f * L)) - 2 * pi * f * C) \tag{2}$$

Where P = Real power of load in kW Q= Reactive power of load in kVar

The equation (1) and (2) can then be effectively measured to find the islanding situation. Furthermore, the detection time of the over/under voltage is found to be 0.03 and 0.05 s and that of the over/under frequency is found to be 0.02 in both cases.

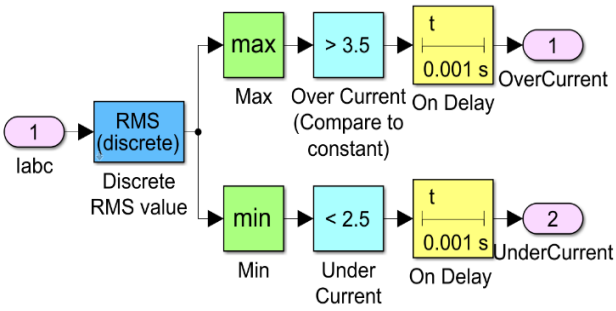


Fig. 2. Under/Over current protection logic.

The main drawback of the over/under voltage and over/under frequency anti-islanding method is its vast NDZ. This range is given by the equation (3) and (4).

For active power,

$$(V/V_{\max})^2 - 1 \le \frac{\Delta P}{P} \le (V/V_{min})^2, \tag{3}$$

Where
V= Voltage at PCC in volts
V_{max} = Maximum voltage at PCC in volts
V_{min} = Minimum voltage at PCC in volts

For reactive power,

$$Qf(1 - (f/fmin)^2) \le \Delta\, Q/Q \le (1 - (f/fmax)^2) \tag{4}$$

Where
f= frequency at PCC in Hz
f_{max} = Maximum frequency at PCC in Hz
f_{min} = Maximum frequency at PCC in Hz
These two ranges act as the limiting value of the voltage and frequency for the detection of the islanding condition in the net metering.

The logic behind under and oer-voltage / Frequency relays is explained in Figures 3 and 4. The OC and UC relays' logic blocks process the observed three-phase voltage. The maximum and minimum threshold voltages have overvoltage and undervoltage, respectively.The undercurrent relay will trip if the UV is not compared to a constant since it is less than 18000 times. The on-time delay for both the OV and UV is 0.001 seconds. Over-frequency prevention continuously compares the rate of the PV inverter's frequency to specified preset thresholds. The frequency is computed using a phase-locked loop. The unique 3-PLL (Phase-locked Loop) block receives its input vector fromV_a,V_b regularized 3Φ primary grid voltages and evaluates its output at frequency f = $\omega/(2\pi)$.

2.2. Protection Based on ROCOF Relay

The ROCOF detection method is based on the feature that the real power imbalance causes transients in an islanded system and the system frequency starts to vary dynamically during the islanding operation. Such system behaviour can be used to detect an islanding condition.

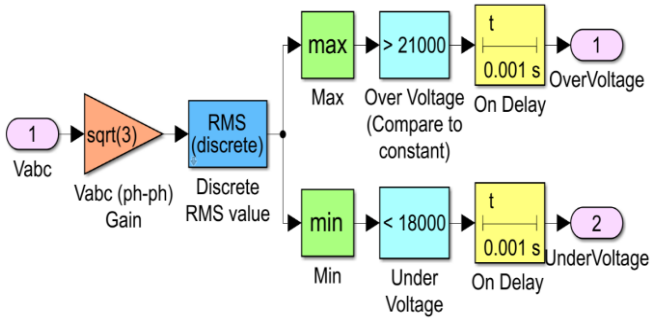


Fig.3. Logic for under/over-voltage protection.

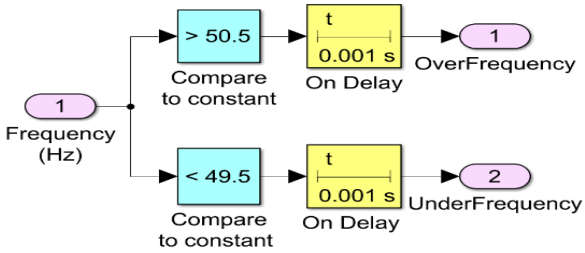


Fig.4. The logic for over/under Frequency protection.

Therefore, measuring the ROCOF would show whether the DG is operating in parallel with the grid or functioning independently of the grid as follows

$$ROCOF = \frac{df}{dt} = \frac{\Delta P}{2H} f \quad (5)$$

Where
$\frac{df}{dt}$ = derivative of frequency in Hz
ΔP = mismatch power of the DG
H = moment of inertia for DG/ System

As seen in the above equation (5), when the real power imbalance ΔP causes transients in the islanded system, the frequency of the system drifts up or down, making the frequency of the system deviate from its nominal value until the frequency relay is triggered. However, if the power imbalance ΔP in the islanded system is small, then the frequency will change slowly. The logic behind the ROCOF is explained in Figure 5.Different configurations of the connected feeder loads have a different effect on dc-link voltage The frequency variations and their ROCOF or $DF\ /\ DT$, during island conditions for the same configurations of connected feeder loads. As can be observed, for default loads and the resistive loads these two quantities are quite close. For capacitive reactive loads, the PV inverter loses control of the frequency. During the islanding condition, the frequency decreases in a very short time. The rapid change in frequency implies a certain variation of ROCOF. The islanding conditions are detected when a ROCOF threshold of 12Hz/s is exceeded as shown in Figure .5. The minus sign indicates the frequency decrease.

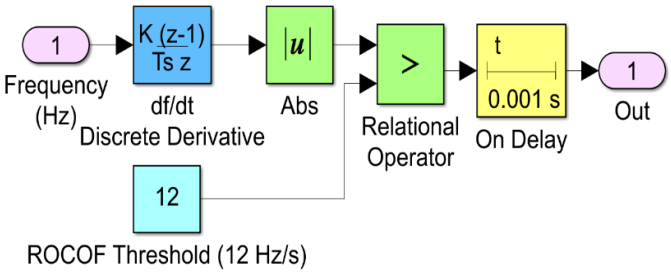


Fig.5. Logic for ROCOF protection.

2.3. Protection Based on DC-Voltage Relay

The DC _Voltage is assessed by the PV system's VSC main controller. The reference DC voltage is 500 V, or the nom DC busbar voltageV_{normal_dc}. The ideal threshold trip of the DC-Voltage technique remained fixed at 10% of the usualV_{normal_dc}. by working at a minimum DC voltage to reduce converter switching losses. After numerous simulations, it was discovered that the time of the island directly rises as the DC link-voltage threshold does**.**

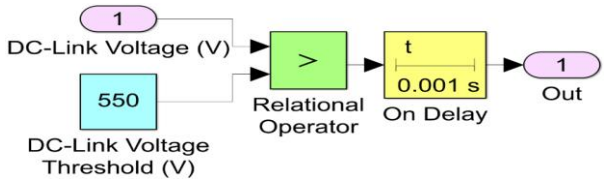


Fig.6. DC, link-voltage protection.

The PAIP method of protection combines all of the anti-islanding relays that have previously been available, and the following section demonstrate, the DC-Voltage method detects the island mode under all circumstances with reduced switch voltage stress without affecting the quality of the electric power.

3. Description of Test System

This section describes the simulation arrangement for the proposed PAIP protection for the grid-connected PV system.

3.1 Solar Microgrid under Grid-connected Mode

The 3Φ and 100kW grid-connected solar system that is used in the simulations is shown in Figure 7. PV construction includes the PAIP protection relay, which is situated in the 20/kV bus. Under standard evaluation conditions (STCs) of 1000 W/m2 solar irradiance, 25° sun temperature, 1.5 airmass, and ASTM G173-03 solar insolation, the 330 SunPower module PV solar array generates an estimated output of 100.7 kW and 273.5 V. It produces 22.6 kW and

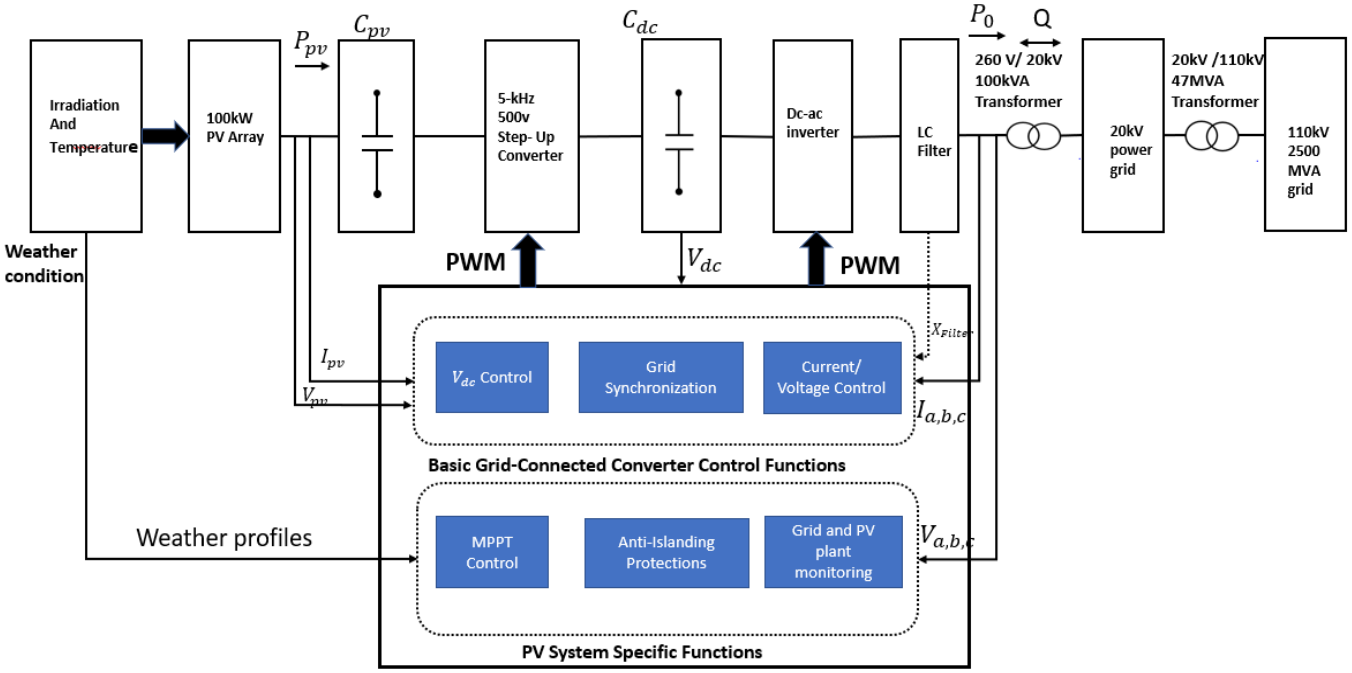


Fig.7. Protection module in 100kW PV connected 3Φ grid connected system.

252.4 V at 250 W/m2 [21]. The standard 20 kV utility grid is connected to a standard 50 Hz main frequency using a 100kVA 260V/20 kV 3 coupling transformer, a 2-stage inverter PV using a 5kHz step-up boost converter and a 2kHz 3 - 3 level voltage source converter (VSC), and a 100 kW PV array. The highest natural voltage of the PV, which is 272 V, is raised to 500 V by the step-up converter. The Maximum Power Point Tracking (MPPT) control system, uses the incremental-conductance-MPPT procedure to automatically change and optimise the power-converter's transferring duty cycle to extract the most energy and supply necessary volt. The boost converter controls the MPPT independently while the VSC controls the DC voltage. The 3PV inverters regulate 500 V DC voltage. When converting from 500Vdc to 260 Vac, the three-level VSC converter, which is made up of 25H inductor L filters and 10kvar capacitor bank C-filters, keeps a unity power factor. The effectiveness of the suggested technique in various islanding scenarios is evaluated using the simulation data produced by the proposed model. The suggested PAIP protection method intended for a 100kW grid-connected PV system was developed in the MATLAB Simulink environments for 0.4 seconds at 1000W/m2 irradiance level and 25º Celsius. The original three circuit breakers on the 110kV grid side (see Fig. 7) in dynamic simulation cases caused an islanding scenario, many grid faults (short circuits) to manifest 5km from the PV system's PCC. When the 110kV grid-side circuit breaker opens at time(t) = 0.1 seconds, an islanding operating mode is started. A circuit breaker turns off when there is less locally produced power in the first 150 milliseconds circuit- the breaker cuts off the power grid.

4. Discussion on Simulation Results

The efficiency of the recommended PAIP protection technique is examined in this part together with the timings for islanding detection. The three instances that are being looked into are (i) grid failures, and (ii) islanding operation mode brought on by the 3Φ circuit-breaker opening on the 110 kV grid side.

Case 1: Performance of opening the 3Φ circuit-breaker

Table 1 demonstrates that islanding detection should be performed based on Overcurrent, Undercurrent, Overvoltage and Undervoltage conditions. According to the results of Table 1, Undervoltage relay was shown to be the most reliable protection.The performance of a circuit breaker during open conditions, three different scenarios should be studied. Load is higher than PV generation. In this scenario, the overcurrent relay will trip at 0.0103ms and the under voltage relay will trip at 0.0064ms rather than UC and OV not tripped in this scenario. In the second scenario load closely matches with PV generation, the OC relay will trip at 0.0123ms UV will trip at 0.0085ms and the remaining relays do not trip. The last scenario namely load is less than PV generation. In this OC will trip at 0.0126ms and UV will trip at 0.0088ms again UC and OV is not tripped. According to the different scenarios mentioned in Table 1, the UV relay has comparatively less detection time. Therefore it is concluded the UV relay has a reliable detection time. Table 2 demonstrates that islanding detection that depends on Overfrequency, Underfrquency, ROCOF and DC Voltage conditions.

Table 1. Detection time of PAIP Protection under Overcurrent, Undercurrent, Overvoltage, Undervoltage conditions

Test Case	**PAIP Methods**								
	Different scenarios	**Overcurrent**		**Undercurrent**		**Overvoltage**		**Undervoltage**	
		Relay status	***Detection Time in ms***	***Relay status***	***Detection Time in ms***	***Relay status***	***Detection Time in ms***	***Relay status***	***Detection Time in ms***
Performance of Circuit breaker during open condition	load is higher than that of PV generation	1	0.0103	0	-	0	-	1	0.0064
	Load closely matches with PV generation	1	0.0123	0	-	0	-	1	0.0085
	load is lesser than that of PV generation	1	0.0126	0	-	0	-	1	0.0088

Table 2. Detection time of PAIP Protection under Overfrequency, Underfrequency, ROCOF, DC Voltage conditions

Test Case	**PAIP Methods**								
	Different scenarios	**Over frequency**		**Under frequency**		**ROCOF**		**DC Voltage**	
		Relay status	***Detection Time in ms***	***Relay status***	***Detection Time in ms***	***Relay status***	***Detection Time in ms***	***Relay status***	***Detection Time in ms***
Performance of Circuit breaker during open condition	load is higher than that of PV generation	0	-	1	0.0536	1	0.0159	1	0.0146
	Load closely matches with PV generation	1	0.0632	0	-	1	0.029	1	0.0222
	load is lesser than that of PV generation	1	0.0632	0	-	1	0.0286	1	0.0232

According to the results of Table 2, the DC voltage relay is shown to be the most reliable protection. Whenever the performance of a circuit breaker during open conditions, three different scenarios should be studied. Load is higher than PV generation. In this scenario, under frequency will trip at 0.0536ms, ROCOF will trip at 0.0159ms and the DC voltage relay will trip at 0.0146ms and only the over frequency will not trip in this scenario. In the second scenario in which load closely matches with PV generation, the OF relay will trip at 0.0632ms UF will not trip and the remaining ROCOF and DC voltage relays will trip at 0.029ms, and 0.0222ms respectively. The last scenario namely load is less than PV generation. In this OF will trip at 0.0632ms UF will not trip and the remaining ROCOF and DC voltage relays will trip at 0.0286ms, 0.0232ms respectively. According to the different scenarios mentioned in Table 2, the DC voltage really should have comparatively less detection time. Hence it is concluded.

The performance evaluation of passive anti-island protection with active island detection is explained in Table 3 and it shows the detection time for the load with different capacities and also the capacity of inverter output and detection time in ms.

The load capacity can be varied from 25% to 125% concerning inverter output. In 25% the capacity of inverter output is 25% active island detection time is 28ms and

passive island detection is 0.0064ms. For 50% capacity of inverter output is 50% active island detection time is 29ms and passive island detection is 0.0085ms. For 75% capacity of inverter output is 75% active island detection time is 35ms and passive island detection is 0.0088ms. For 100% capacity of inverter output is 100% active island detection time is 39ms and passive island detection is 0.0146ms. Finally, for 125% capacity of inverter output, 100% active island detection time is 20ms and passive island detection is 0.0232ms. Compared to active islanding detection time, the passive anti-island method has the least detection time. PAIP is the most promising and reliable method for grid-connected photovoltaic generation systems. In Figure 8, the resistive loads are directly compared in terms of DC volts and frequency.

Table 3. Island- Detection time under different load conditions.

Loading Conditions	**Island *Detection time(ms)* [23]**	**Proposed Island *Detection time(ms)***
25%	28ms	0.0064ms
50%	29ms	0.0085ms
75%	35ms	0.0088ms
100%	39ms	0.0146ms
125%	20ms	0.0232ms

Due to its greater slope and range during the operation of the island, the dc-voltage fluctuation is noticed more quickly than that of frequency change. According to Fig. 8, in all three circumstances, the islanding operating mode's DC voltage increases dramatically without DC-voltage protection, which indirectly results from a considerable rise in electric power losses on the PV inverters. Therefore, the overall dependability of the solar system is enhanced by limiting the dc-voltage level towards reduce switching losses, which leads to a lesser junction temperature mean, and operates with the controlled reference DC-Voltage is higher (10%) than that of threshold to 550 Vdc, as shown in Figure 8.

Case 2: Sequences Under No Islanding

In this instance, grid faults without an islanding scenario show the efficacy of planned PAIP. Several grid faults, including ABC-G faults, AB faults, AB-G faults, and A-G faults lasting 150ms, have been carried out in the 20/kV grid of the solar system situated 5km away from the PCC at the time (t) = 0.1 s. Figure 9 illustrates the frequency and ROCOF df/dt variations of the grid-connected mode photo-voltaic system during the islanding operation mode. Figure 9 may illustrate how the islanding method affects the frequency of solar power systems. In islanding techniques, the Frequency in Hz rapidly reduces. Rapid frequency changes cause an audible shift in ROCOF. As seen in Figure 9, the ideal range of the ROCOF limit of threshold that is exceeded afterwards the mode of the island is 12 Hz/s. The information provided in Figs. 9 and about anti-islanding protection relate to the effects of island mode the behaviour of Frequency in Hz, Rate of change of frequency and DC-voltage methods respectively, and the effects of island mode on the difference provided by the deliberate methods.

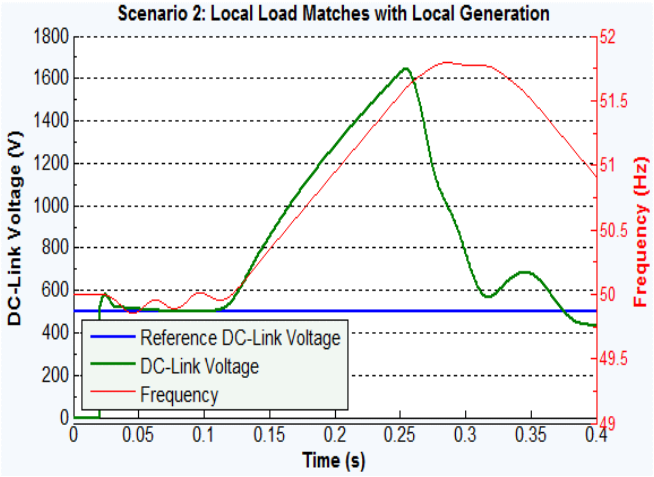


Fig.8. Frequency and ROCOF under island mode of operation.

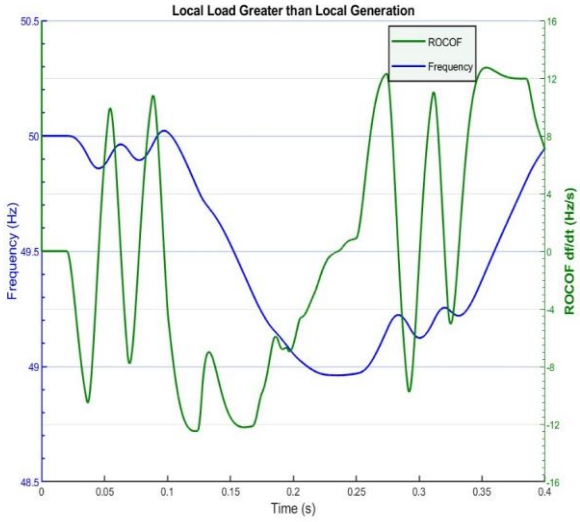


Fig.9. DC voltage and variations of frequency.

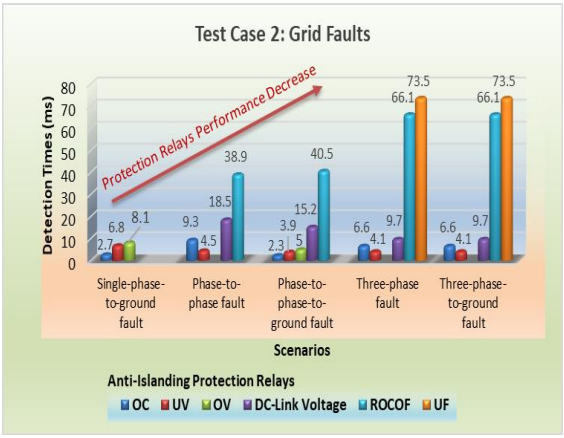


Fig.10. Detection time under no islanding(grid-faults).

This information is necessary to ascertain whether a passive type can identify this variation in the standings of detection time of the island. These figures show that, when used in islanding mode, coordinated islanding approaches function effectively. Figure 10 compiles the outcomes of passive-anti-islanding relay identification faults during grid mode and on no-account islanding scenarios. The suggested PAIP can discriminate amongst the islanding operating mode and grid failures such as short circuits based on the events' detection times. To lessen the effects of grid faults and unintended islanding operation mode and to comply with grid code requirements, passive-anti-islanding measures are essential to be installed in areas where islanding operating mode may happen.

5. Conclusion

This research presented a novel PAIP for two-stage 3Φ grid-connected solar systems with reduced switching losses. In different situations and conditions, the proposed method's islanding detection time is compared. According to the analysis, employing the recommended protection greatly improves concert in terms of the detection time of the island. The suggested PAIP method can also recognise an island mode when there are grid faults. Depending on the time the abnormal event is detected, the PAIP protection differentiates between the islanding operation manner required new grid codes. The suggested anti-island protection can work through the islanding mode which can strengthen the resiliency of the electric power grid. The conclusion is that given that the suggested anti-islanding protection has a short detection time, lower voltage stress, is efficient and is simple to install, it may be used to detect islanding in solar systems under various conditions. The future scope of the work is proposed islanding detection method will be implemented in microgrid network considering protection issues like reverse power flow, blinding of protection and sympathetic tripping. The model will also be tested tripping . The model will also be tested in different test systems considering multiple renewables like wind and battery systems.

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