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A Passive Islanding Detection Method for Neutral point clamped Multilevel Inverter based Distributed Generation using Rate of Change of Frequency Analysis

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ABSTRACT

Presently renewable energies have taken a special place in the world and most of the Distributed Generations (DGs) used in the interconnected power system are utilized, renewable energy resources. Due to the DG's advantages, including use of renewable energy such as, clean nature, does not pollute environment and having endless nature the use of these renewable resources to produce electrical energy in the world are increasing in day to day life. One problem with such Distributed generators is an unintentional islanding phenomenon. Islanding occurs when a Distributed Generation continues to energize an isolated part of a power system even after it was disconnected from the main grid, which is surrounded by unpowered lines. Since islanding can cause hazardous conditions for people and equipment which is connected to it. As per IEEE 1547 DG Interconnection standards, islanding should be quickly detected within 2 seconds, by protective relays and inverters that are part of the DG system. In this paper, a new passive method to identify islanding states has been proposed, based on the rate of change of frequency analysis (ROCOF) for a multilevel inverter based solar distributed generation systems. This method is efficient for both connecting DGs to the network with or without the Inverter. This method is more efficient than the existing methods and reducing the Non Detection Zone (NDZ), which is the disadvantage of existing passive methods and also clearly differentiating between the Islanding and Non-islanding events. The simulation results, which are carried on the MATLAB/Simulink environment shows the performance of the proposed method

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1. INTRODUCTION

Nowadays, the majority of the country's energy consumption is supplied by burning of fossil fuel resources. In this regard, they have faced with many problems, including environmental pollution and ending of fossil fuel resources. To solve this problem many countries have interest in renewable energy generation to meet their global energy consumption demand. Renewable energy, mostly includes solar energy, wind energy, energy due to the urban waste burning, biomass, streamline water flow and others. A decentralized electrical generation source connected to the distribution level of the power grid is called a Distributed Generation [1]. Major part of DGs in power systems, are from the renewable energy resources. Due to their type and nature, they can generate the energy either in the AC or DC forms. Generally, these DGs interconnect to the power grid through power switching converters [2]. Islanding occurs when a DG unit continues to energize certain part of the power system disconnected from the rest of the power grid. Prolonged islanding can be dangerous and even fatal to field personnel since they may not be aware that a serviced power line may still be energized by a nearby DG source, the main causes of such unintentional islanding are due to the failures detected by the grid, accidental opening of circuit breakers at the grid, intentional opening of CB for maintenance, human errors and an act of nature [3]. Standard regulations such as IEEE 1547 series and UL 1741 requires that, islanding should be detected within 2 seconds and requires the DG sources to shut down if the island load cannot be sustained and leads to variations in the voltage, frequency, current, THD, active, reactive powers outside the standards, which may hazardous to customers connected to it [4], [5]. There has been a considerable research effort to develop quick and robust islanding detection techniques, which are classified as active, passive, machine learning and remote techniques. Remote techniques such as the PLCC and SCADA require collecting information from both the utility side and DG sides to detect islanding.

PLCC monitors signals from the utility side and detect islanding when these signals are disappearing. On the other hand, SCADA detects islanding phenomenon using information from the auxiliary contacts of the circuit breakers. But these methods are costly to implement because of the need to install transceivers and other monitoring devices [6]-[8]. Active Islanding detection techniques continuously inject a form of signal into the system or change the power output reference of the DG source [9], [10]. In a grid-connected system, the grid absorbs local disturbance and no deviations are observed in the system voltage or frequency. However, in case of islanding, the disturbance can be significant, and resulting in noticeable deviation. Active detection techniques are mostly efficient, but can fail to detect islanding under certain conditions and may degrade the power quality due to the constant injection of disturbance [11]-[14].

Machine learning detection (MLD) techniques can detect islanding based on a machine learning algorithm that can be trained to detect islanding using large sets of sample data collecting islanding and non islanding events. The combination of local parameters such as voltage, frequency, power factor, THD, phase angle and others is used for training. Some popular algorithms such as Artificial Neural Networks (ANN) [15], Decision Tree Models (DT) [16], and Support Vector Machines (SVM) [17] are used to distinguish between islanding and non islanding events. In passive techniques, local parameters such as voltage, frequency, current, phase angle are monitored at the PCC level and islanding is detected if there are changes beyond a certain threshold level. Over-under voltage and over-under frequency relays (OUV/OUF) technique is a passive technique that can detect islanding when the voltage or the frequency of the system exceeds a threshold value [18]-[20]. Other popular passive techniques rely on monitoring more elaborate parameters such as rate of change of frequency, phase jump, and rate of change of reactive power [21], [22].

In this paper, a new passive method to identify islanding states has been proposed, based on the Rate of Change of Frequency analysis (ROCOF) and it also differentiates between the islanding and non islanding events. During grid connected mode, the frequency and ROCOF deviations are lesser than the threshold values, once the solar distributed generation is islanded the deviations in the frequency and ROCOF at the Point of Common Coupling (PCC) are observed at more than the threshold values and an islanding has detected. Furthermore, this technique has no NDZ limitation, and can be implemented with the existing modern DG inverters. The rest of the paper is organized as follows. System modelling is discussed in Section 2, The proposed ROCOF technique and its developments are presented in Section 3, The simulated results, and comparison with the existing methods are presented in section 4, and conclusions are drawn in Section 5.

2. SYSTEM UNDER STUDY

The test system considered as per Distribution energy sources interconnection standards, such as IEEE 1547 and UL 1741 is shown in Figure 1. When the CB is closed, the DG together with local load is connected to power network and power produced by DG is injected into the network, but when the CB is opened the DG along with the local load forms an electrical island, and the solar DG alone supplies the load demanded power and causes customer equipment to damage. In these conditions, islanding state has to be identified and power production should be disconnected within 2 Sec after creation of the island as per interconnection standards. The simulation validation parameters are shown in Table 1. The test system shown in Figure 1 consisting of the following major parts.

2.1. 100 KW Solar PV panels with MPPT boost converter

A 100 KW PV array is connected to a 120 KV grid via a DC-DC boost converter, three phase three level Voltage Source Converter (VSC) and a step up transformer. The PV array uses 330 Sun Power modules (SPR-305E-WHT-D) in which 66 strings of 5 series connected modules are connected in parallel to produce 1 KW power (66*5*305.2 W=100.7 KW) with an open circuit voltage of 64.2 V and a short circuit current of

5.96 A at 1000 W/m^2 sun irradiance and 25^{0}C ambient temperature. The boost converter uses Maximum Power Point Tracking technique (MPPT) to extract maximum power from the panel under irregular weather conditions, which is implemented using Incremental Conductance and Integral Regulator technique. The boost converter increases the voltage level to 500 V DC and is given to the input of the inverter.

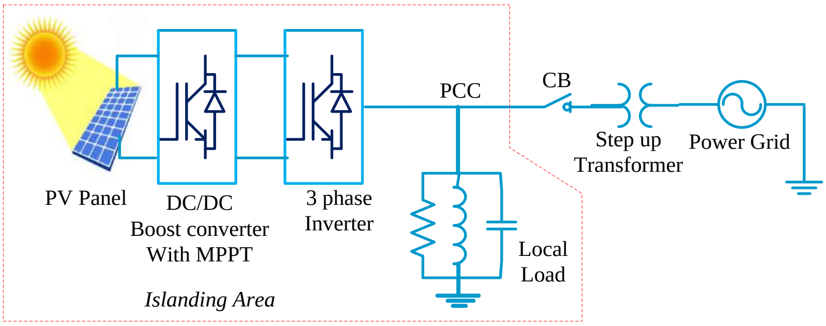

Figure 1. Block diagram of the system under study

2.2. Three phase three level neutral point clamped multilevel inverter

The VSC converts the 500 V DC link voltages to 260 V AC and keeps unity power factor, after which is connected to the grid via the step up transformer. Three level Neutral point clamped (NPC) inverter is shown in Figure 2, is implemented with the space vector modulation technique. On each leg, there are four active switches (Q1a, to Q4a) along with four anti parallel diodes (D1, to D4). The capacitors split the DC input on the DC side and also provide a neutral point N. When switches Q2a and Q3a are ON, the neutral point connects to the output terminal 'A' through one of the clamping diodes. The voltage applied to the capacitors is E, which is V DC. In a switching state of 2, upper two switches in leg A connected and terminal voltage (VAO), then VAO become +E, whereas '0' denotes that the lower two switches are on, then VAO becomes equal to -E. The lower switches Qa2 and Qa3 are connected to the state of 1, VAO becomes zero. Table 2 shows switching status for leg A, Leg B and leg C which have the same concept. A series RL filter is connected to the output terminals of multilevel inverter for eliminating the harmonics presented in it [21].

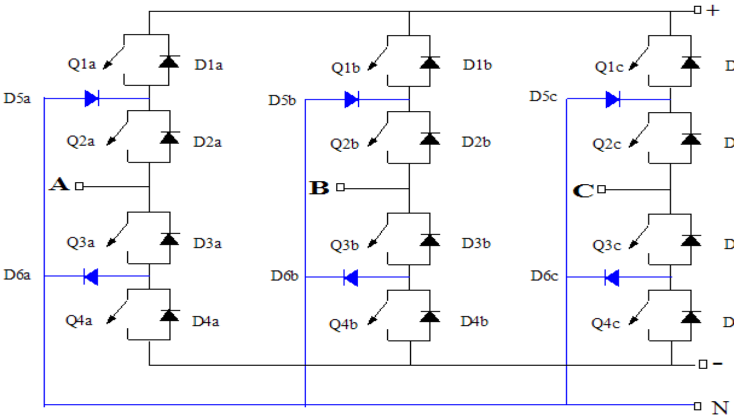

Figure 2. Three level neutral clamped multi level inverter

2.3. Utility grid

The power grid model shown in Figure 3 consists of a 25 KV distribution feeder and a 120 KV equivalent transmission system. The distribution feeder of 19 km is connected to two large loads 2 MW, 30 MW, along with a reactive power supply of 2 MVAR and a 120 KV infinite bus via the substation transformer.

3. PROPOSED INSTALNDING DETECTION ALGORITHM

One of the existing methods for islanding detection is based on the frequency changes at the terminals of solar DG's. The performance of the proposed algorithm is based on the measurement of frequency at PCC. The frequency measurement is done through Phase locked loop. In the cases when the grid system is lost, a change in DG's loading is happening and its instantaneous output frequency is changing called as rate of change of frequency. The Expression for the rate of change of frequency is given by [2].

$$\frac{df}{dt}(k)=\frac{f(t_k)-f(t_k-\Delta t)}{\Delta t}$$

Where

$f(t_k)$ -Measured value of frequency at the time of k^{th} sample i.e. t_k
$f(t_k - \Delta\, t)$- Measured value of frequency, Δt before the k^{th} sample tim e i.e. $t_k - \Delta_t$.

Table 1. Parameters of the Test System

Name of the Parameter	Value
Rated output of PV panels	100 KW
No of solar cells	330
Frequency	50 HZ
OC voltage of each cell	64.2
SC current of each cell	5.96
Transformer rating	100 KVA, 260/25KV
Utility Grid	120 KV, 2500 MVA
Feeder length	19 km
Filter Resistance	3 m ohm
Filter Inductance	0.5 mH
Shunt Capacitor	10 KVAR

Table 2. Switching states of three Phase Inverter

Switching state	Device switching state S1	S2	S3	S4	Output polel Voltage
2	on	on	off	off	+E
1	off	on	on	off	0
0	off	off	on	on	-E

The proposed algorithm is shown in Figure 3, when the rate of change of frequency is more than the threshold value 10, then an islanding is detected. The experimental simulation results show that this method is effectively working in all the cases, even when the generation of DG and load are matched each other.

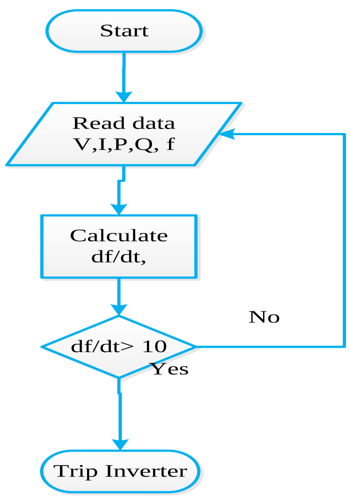

Figure 3. Flow chart of proposed algorithm

4. SIMULATION RESULTS OF THE TEST SYSTEM

In this section of the paper, the results of the proposed method to detect islanding states in different modes of the network are shown, and the ability of an algorithm to detect the islanding states as well as the non islanding cases is presented with the results. All the simulated islanding cases were chosen to lie within the NDZ of the OUV/OUF techniques currently used for protection in modern PV inverters.

4.1. Grid connected mode

In grid connected mode under normal operating conditions the three level output voltage wave of the inverter, PCC voltage, current, frequency and rate of change of frequency are shown in Figure 4, Figure 5, Figure 6, and Figure 7 respectively. From Fig.6 the frequency is varied from 50.08 to 49.02 which are completely within the non detection zone. The rate of change of frequency is varying from +5 Hz/Sec to -5 Hz/Sec which is shown in Figure 7. As per islanding detection algorithm presented in this paper, the variations in frequency and rate of change of frequency are within the threshold values and the system is working in grid connected mode. If these values are more than the threshold values then an islanding state occurs.

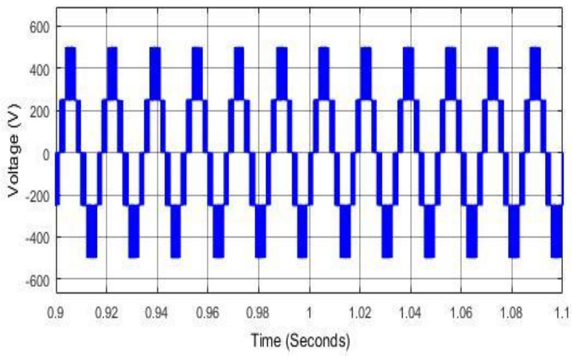

Figure 4. Simulated three level output of inverter under grid connected mode

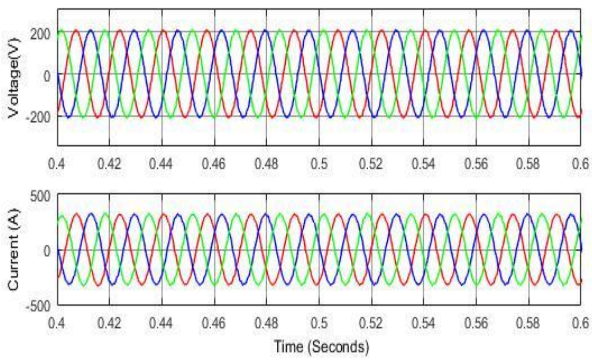

Figure 5. Simulated wave forms of Voltage and current under grid connected mode

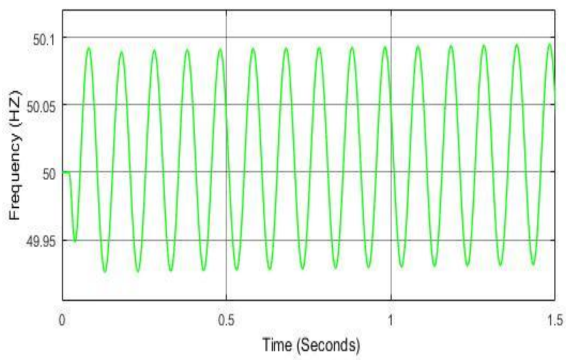

Figure 6. Simulated wave form of frequency under grid connected mode

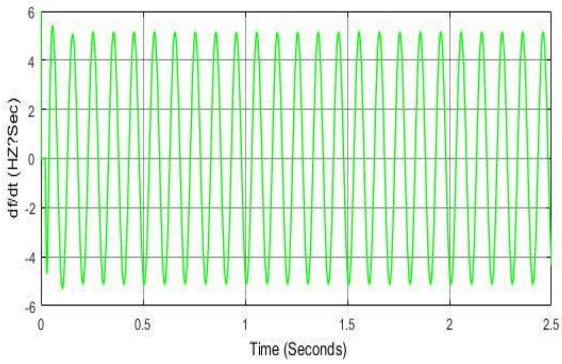

Figure 7. Simulated wave form of rate of change of frequency under grid connected mode

4.2. Islanding mode of operation of test system

The islanding events in this paper are simulated by considering the following cases

4.2.1. When generation of solar DG is more than the local load

In this test the load is considered as 10 KW, which is very less than the generation, 100 KW. At first when the CB is closed, the system is working in the grid connected state. At t=1 Sec CB is opened and solar photo voltaic DG together with the local load is separated and an electrical islanding condition was established as shown in Figure 1 with dotted lines. The simulation results of the three level output voltage, voltages, currents, frequency and ROCOF are shown in the Figure 8, Figure 9, Figure 10 and Figure 11 respectively. From Figure 8, when an islanding is developed at t= 1 Sec, we observed the rise in voltages, which leads to the rate of rise of voltages shown in Figure 9. Due to the occurrence of islanding the currents at PCC are falling down after t= 1 Sec. Hence, from the Figure 10 and Figure 11 the frequency and ROCOF changed, and it is observed that the ROCOF is more than the threshold value setting 10. So islanding is detected and the proposed algorithm is working well when the load is less than the generation.

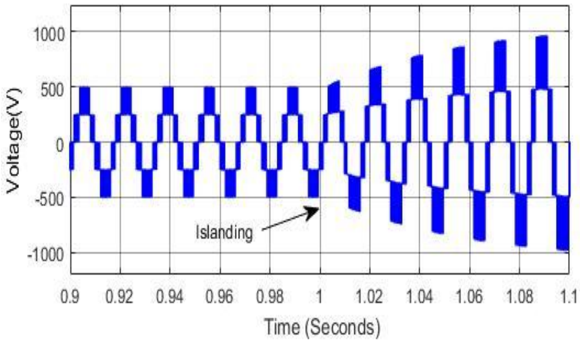

Figure 8. Simulated wave form of three level output under islanding mode when load= 10 KW

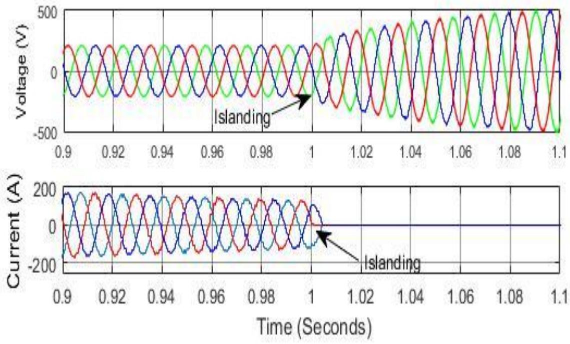

Figure 9. Simulated wave forms of voltages and currents at PCC under islanding mode when load= 10 KW

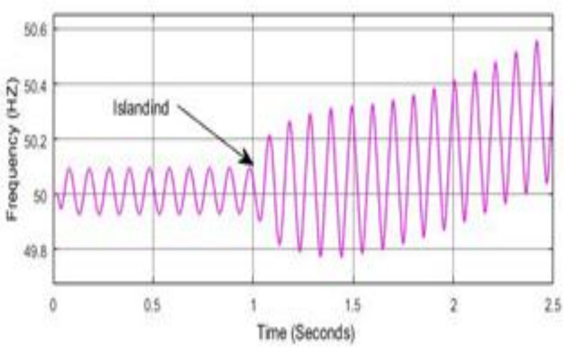

Figure 10. Simulated wave form frequency at PCC under islanding mode when load=10 KW

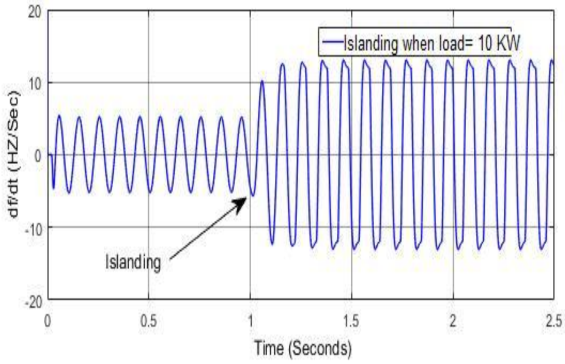

Figure 11. Simulated wave form of ROCOF at PCC under islanding mode when load=10 KW

4.2.2 When Generation of solar DG is equal to the local load

In this simulation test the load is considered as 100 KW, which is equal to the generation, 100 KW. The simulated frequency and ROCOF are shown in the Figure 12 and Figure 13 respectively. From

Figure 12, during islanding is developed at t= 1 Sec, we observed the rise in frequency, which leads to the rate of rise of frequency shown in Figure 13. In this test also the ROCOF is more than the threshold value setting 10. So islanding is detected and the proposed algorithm is working well when load closely matches with the generation. The disadvantage of previous ROCOF analysis methods is, it is failing to detect islanding when load matched. Due to the use of three level inverters this difficulty is completely eliminated.

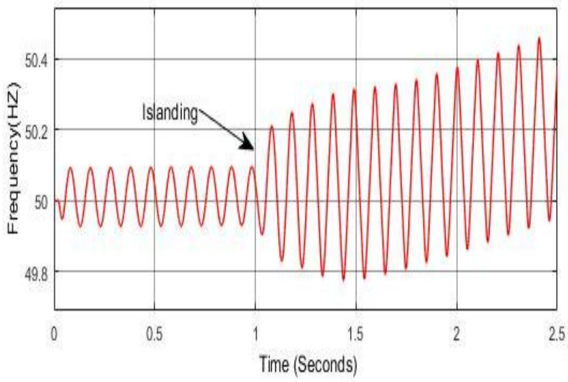

Figure 12. Simulated wave form of ROCOF at PCC under islanding mode when load= 100 KW

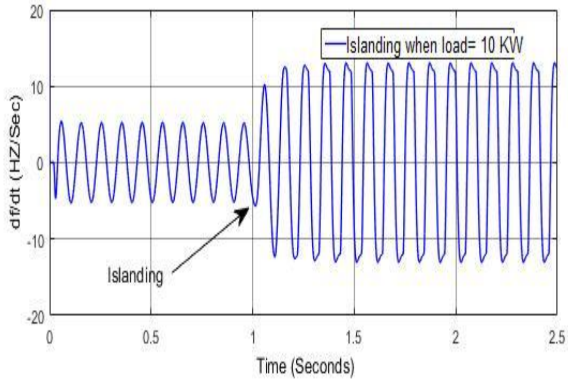

Figure 13. Simulated wave form of ROCOF at PCC under islanding mode when load= 100 KW

4.2.3. When Generation is less than the local load

In this simulation test the load is considered as 200 KW, which is more than the generation, 100 KW. In this case if we failed to detect the islanding the DG cannot sustain the load and allows to flow of excessive currents which damages the DG unit. So as per IEEE 1547 standards we have to detect islanding within 2 Sec after it was island. The simulated frequency and ROCOF are shown in the Figure 14 and Figure 15 respectively. From Figure 14, when islanding is developed at t=1 Sec, we observed the rise in frequency, which leads to the rate of rise of frequency shown in Figure 15. In this test also the ROCOF is more than the threshold value setting 10. So islanding is detected and the proposed algorithm is working well, even when load is more than generating.

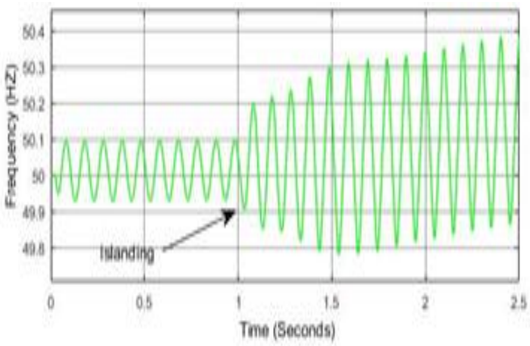

Figure 14. Simulated wave form of at PCC under islanding mode when load= 200 KW

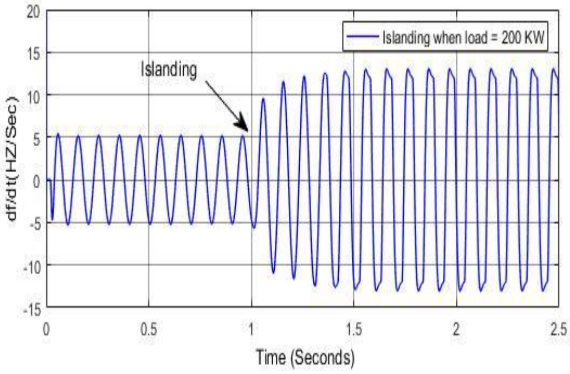

Figure 15. Simulated wave form of ROCOF at PCC under islanding mode when load= 200 KW

4.3. Non islanding events

In this section, the response of the proposed technique to non-islanding events are presented. The selected Non islanding events were known to cause nuisance tripping in passive detection techniques because of the high non detection zone. The major Non-islanding events in this paper are simulated by considering the following cases.

4.3.1. Capacitor bank switching and load switching

In this part of the paper, to distinguish between islanding and non islanding cases and to check the performance of the proposed algorithm proposed in this paper, a non islanding case of star connected capacitor bank of 500 KVAR and a load of 50 KW was opened at t=1 Sec and closed at t=2 Sec independently. Figure 16 shows output frequency changes at PCC during switching the capacitor bank and load independently. From both the wave forms we observed that, it should not go beyond the threshold value, strictly said that it is same as grid connected mode. Hence, this state was detected properly for switching of capacitor banks and loads, so the proposed method of rate of change of frequency analysis does not act wrongly.

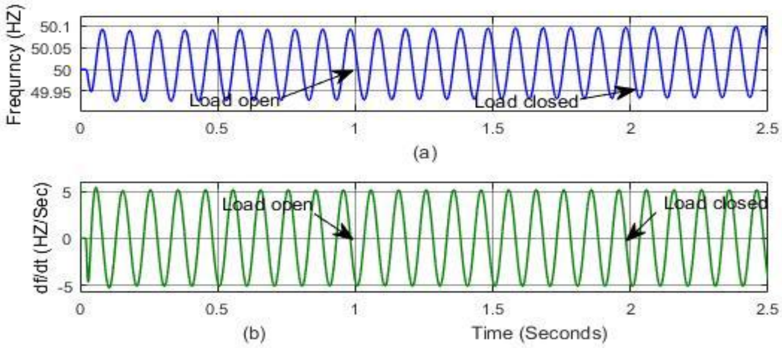

Figure 16. Simulated wave form of frequency and ROCOF at PCC during load switching

4.3.2. Starting of induction motor

One of the other important cases in which the proposed algorithm may wrongly detect is, starting of the Induction motor drive. In this case, an intense condition has been considered and it was shown that the algorithm in the intense modes will not mistake and could distinguish the islanding state from the other conditions. In this test, a 150 H.P induction motor is considered for the simulation. At t= 1 Sec the motor was switched and connected to the network and is opened at t= 2 Sec. We observed the frequency and rate of change of frequency are same as shown in Figure 16. So, this state is detected perfectly and the system will continue to work. In this test also, the proposed algorithm shows good performance as the previous non islanding cases.

4.3.3. Switching of parallel feeders

One of the important cases in which the proposed algorithm may wrongly detect is, switching of parallel feeders. In this case, an intense condition has been considered and it was shown that the algorithm in the intense modes will not mistake and could distinguish the islanding state from the other conditions. At t=1 Sec the parallel feeder was switched and connected to the network and is opened at t=2 Sec. We observed the frequency and rate of change of frequency are shown in Figure 17. Here also they are within the threshold values. So, this state is detected perfectly and the system will continue to work. In this test also, the proposed algorithm shows good performance as the previous non islanding cases.

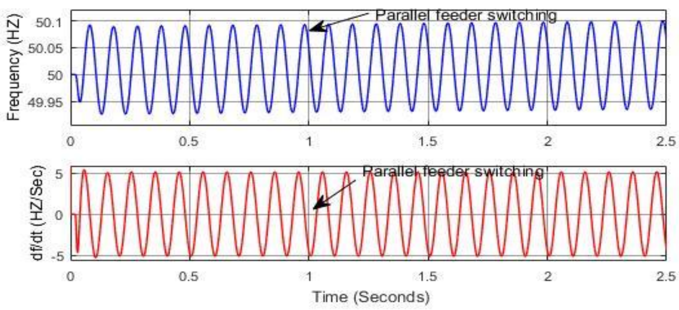

Figure 17. Simulated wave form of frequency and ROCOF at PCC during parallel feeder switching

4.3.4. Three phase to ground fault at PCC

Here a three phase fault associated with the ground at the PCC is simulated. From Figure 18 it is observed that at t=1 Sec the fault is simulated, and the changes in frequency and rate of change of frequency are observed but they do not go beyond the threshold value mentioned. So this case also detected correctly by this method. The different cases of islanding and non islanding events and with, results which are simulated in this paper are listed in Table 3.

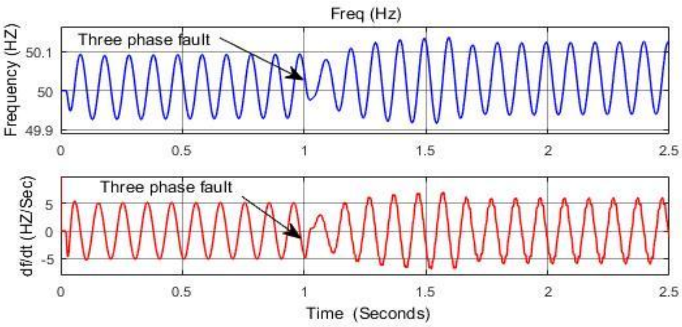

Figure 18. Simulated wave form of frequency and ROCOF at PCC during three phase fault

Table 3. Result Analysis of different Islanding and Non Islanding Events

Sl.No	Case	Result
1	Load less than generation	Islanding
2	Load equal to generation	Islanding
3	Load more than generation	Islanding
4	Switching of capacitor bank	Non Islanding
5	Switching of loads	Non Islanding
6	Switching of parallel feeder	Non Islanding
7	Induction motor operation	Non Islanding
8	LLLG fault at PCC	Non Islanding

5. CONCLUSION

In this paper a new passive method to detect islanding conditions for multilevel inverter based solar DGs was proposed. This method is essentially passive and makes decisions based on the local measurement of frequency and rate of change of frequency at PCC. This technique was modelled and implemented on a grid-connected PV system. A wide range of islanding and non islanding events such as generation matches with the load, less than the load, greater than the load, capacitor bank switching, starting of the induction motor, parallel feeder switching, three phase fault on DG terminals are tested in a realistic manner. The results show the effectiveness of the proposed method because the previous methods are wrongly worked for non islanding cases and causes nuisance tripping of inverter, but this method can easily identify and distinguish between the islanding and non islanding cases and a proper decision was sent to protect the system. The non detection zone is completely eliminated and strict islanding detection is achieved with this method.

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