

A New Method for Islanding Detection the Grid Connected Inverters in Case of Unbalanced Loads

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Abstract

One of the facing problems in distributed generation is being unintentionally islanded which the detection of this phenomenon is of great importance. Common methods are active and passive islanding detection. These two methods are based on changing in parameters such as frequency, voltage and current harmonics. If, after the islanding occur, this changes are revealing and visible, islanding phenomenon is demonstrated which is detected by passive methods. If the generated power of inverter is equal to local loads consumption and assuming of the generated reactive power of grid connected inverter equal to zero, it should be detected by active methods but these two methods have some challenges such as reduction in power quality or wide Non Detection Zone (NDZ). In this paper, in proposed method, change of a new parameter will be studied for islanding detection diagnosis. With the difference that the studied system is a three phase system and unbalanced load is studied which is more consistent to reality. Because of small changes in parameters, we have to find the right approach toward active methods. Generally there are two views about the islanding performance. At first view, this phenomenon is seems negatively but in fact this is an opportunity. The first view suggests that all generators in the island should bring out of grid within a maximum of two seconds. In this view the concept of anti-islanding protection is proposed to tackle the task of creating such islands. The second view expresses the concept of micro grid. In this case as far as possible, power required by Inner Island loads were provided by distributed generators. The studied system was similar to standard IEEE-1547 and UL-1741. With the difference that we used three phase and local loads are assumed unbalanced. Conventional active detection methods are not able to identify the island with the aim to help keep it stable. They usually try to bring out the electrical parameters such as voltage and frequency from nominal limits. So in micro grids the island should be diagnosed using passive or remote techniques. Note that detection time of 2 seconds which is referred to on standards is not good and the detection time must be lower than this value. However, the proposed method that is one of the active detection methods is capable for use in micro grids. Simulation results using PSIM software on standard network shows the effectiveness of the proposed method.

Keywords: Islanding, Unbalanced Loads, dq-frame, Phase Locked Loop (PLL), Non Detection Zone (NDZ), Micro-grid.

1. Introduction

In accordance with standard IEEE-1547-2003 the island is the part of the network that is separated from the rest

of system and only fed by distribution generation units. According to this standard, island should be identified and removed from the network in a time range of 1 to 2 seconds after formation. Generally, there are 2 views about

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the islanding performance. At first sight this phenomenon is seen negatively but a second opinion can be seen this phenomenon as an opportunity. The first view suggests that all generators on the island should bring out of network within a maximum of 2 seconds. In this view the concept of anti-islanding protection is considered and its task is to deal with such islands. The second view expressed the concept of micro grid, which in this case, as far as possible, required leads in island is provided by DG. Two concepts of the self-governing island and unwanted island are expressed as similar concepts. Thus the unwanted islanding is the case that islands resource should be removed from the network. On the other hand, in an intentional island, the island sources should be able to provide some of the load within an island. In many literatures, reasons to avoid working on island performance that some of them are noted here:

- Create a risk of electric shock to workers
- Asynchronous reclosing
- Power quality disturbances
- Voltage and frequency control

On the other hand, some believe that island phenomenon can be seen as an opportunity. In fact, with island load reliability can be increased. If allowed DG to continue during islanding, we can protect part of the island from extinction. Indeed, the view that it is sometimes referred to as a micro grid, you can take better advantage of certain features of DG. In this approach each source of DG should be recognized an island and based on its way to change the controls that keep the system stable. In addition, conventional active methods can not help to keep stable the network, because they usually try to bring out the electrical parameters such as voltage and frequency from their nominal value. So in micro grids, island should be detected using passive or remote techniques. We should note that the detection time of 2 seconds which is referred to standards is not good and this time must be less than this value. In this paper, an active method is proposed which even has the ability to use in micro grids. The main approach based on standard IEEE-1547 is disconnecting all DG sources after islanding has occurred. In view of the current standard, is the anti-islanding protection. However this standard is expressed as intentional islanding that this issue is under review and will be discussed in future versions of standards. In this paper, we always consider conscious or intentional islanding that is planned to open the breaker with previous planning which can increase the system reliability and helpful in system regeneration.

Many methods have been proposed for the detection of disconnection from infinite network. Islanding detection methods are divided in to two categories: Local and remote methods, and local and remote methods are divided in to active and passive methods as shown in Figure (1). Local methods were divided in to two active and passive methods.

Local methods use the available information and quantities at the output of distributed generations. Passive methods depends on measuring some system parameters such as voltage and frequency and thus do not interfere with the normal operation of system.

The problem in this case is that if the mismatch of power (active/reactive) is specified in the threshold range that is a function of voltage, frequency and Q_p , the resultant voltage and frequency will remain in nominal range even after opening the breaker. So the result is an island and continues to operate without being detected. This problem caused formation of a region presented as non detection zone (NDZ). Disadvantage of local methods is NDZ. Also in active methods, disturbances were applied to distributed generation units and from the response of disturbances; changes can be used to detect network outages. This method was more effective than passive methods but in terms of economic cost, they are not affordable. The main idea of islanding detection is changing the output parameters of DG and other system parameters in order to show the different conditions in an island state. A more complete classification method of islanding detection is shown in Figure (2).

The threshold value and the tripping time can be chosen in accordance with one of the standards IEEE-929-2000, IEEE 1547-1-2005, VDE 0126-1-1. This is necessary

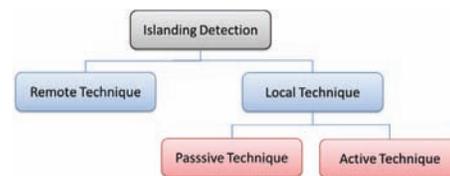


Figure 1. Classification of islanding detection methods.

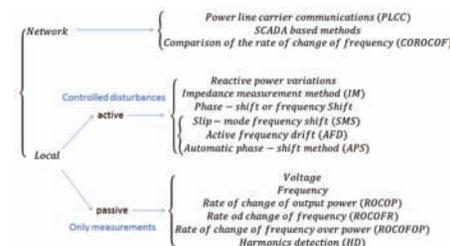


Figure 2. Detailed classification of islanding detection methods.

to explain that standards are for single phase system that in practice it is far from reality.

In section 2 modeling of studied system are described. In section 3, the proposed structure of the voltage sourced converters are discussed. In section 4, the result of simulations conducted to evaluate the effectiveness of the proposed method is presented. Section 5 is allocated to conclusion resulting from simulation with PSIM software. To improve the quality of waveforms, plot menu of MATLAB software is used for plot.

2. Modeling of System Elements

2.1 Introduction

As can be seen from the following Table 2 according to IEEE-1547 standard, for various capacities of DG, the diagnose time and also trip time is changes.

Table 1. Classification of different standards ($P < 30$ KW)

Q_f	Frequency	Voltage	THD	Standard
$Q_f < 2.5$	$59.3 < f < 60.5$	$V < 50$ $50 \leq V \leq 88$ $110 \leq V \leq 120$ $V \geq 120$	THD < %5	IEEE 1547
$Q_f < 2.5$	$f_{n-1} < f < f_{n+1}$	$V < 50$ $50 \leq V \leq 85$ $110 \leq V \leq 135$ $V \geq 135$	THD < %5	IEC 61727
$Q_f < 2.5$	$47.5 < f < 50.2$	$110 \leq V < 85$	THD < %5	VDE 0-126-1-1

Table 2. Classification of IEEE-1547 Standard

Clearing Time (second)	Voltage Range (% of base voltage)
0.16	$V < 50\%$
2.00	$50\% \leq V \leq 88\%$
1.00	$110\% \leq V < 120\%$
0.16	$V \geq 120\%$

Clearing times (second)	Frequency range (Hz)	DR size
0.16	> 60.5	} ≤ 30 KW
0.16	< 59.3	
0.16	> 60.5	} > 30 KW
Adjustable 0.16 to 300	$< \{59.8 - 57.0\}$ (adjustable set point)	
0.16	< 57.0	

Studied network is similar to network available in stand-ard UL-1741. With the difference that system is three phase and loads are assumed to be unbalanced. The system consists of a voltage-sourced converter (e.g. PV, wind or FC) and connected to grid by a three phase VSC. An RLC load with quality factor of 1.5 and a network that is shown in Figure (3).

Conventional system according to three phase system is shown as single line which includes a DC voltage source model as a DG source and an inverter connected through a transformer (for voltage amplification and isolation) and a filter comprises a local RLC load and a transmission line to a network Figure (4).

This system can be modeled as shown below. In this model filters and resistances are modeled by R_f and L_f Figure (5).

Finally, the system studied in this paper is modeled as shown in Figure (6). As can be seen in the Figure (11), transformer is not possible like single line diagram.

Note that the studied network is the same as the network used to detect an island in most relevant articles. With the distinction that in all of the papers, system was considered as single line diagram system. For this reason the system was a single phase system but in this paper system is

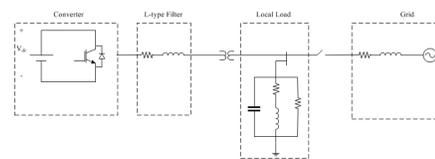


Figure 3. Single line diagram of studied system in Standard UL-1741.

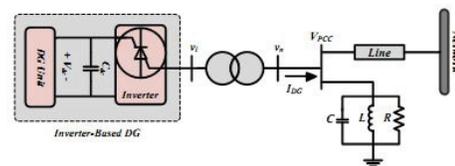


Figure 4. Connecting converter to network by filter and transformer.

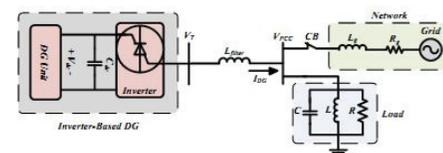


Figure 5. Single line diagram of the conventional system consist of DG, network and RLC load.

considered as a three phase real system. Several distinguishing features are as follows:

1. Use of multilevel converters if needed.
2. Forcely use a 3-phase PLL.
3. Use of unbalanced loads as needed.
4. The importance of transformation in 3-phase system is obvious.

2.2 Inverter Modeling

As we know, most of DGs such as PV systems, FC and wind turbines use power electronics converters such as inverter as an intermediate connection to grid. DC input of inverters is supplied by direct DC voltage producers or rectifiers.

Generally inverters are divided in to two categories as shown in the Figure (7).

2.2.1 Line Commutated Inverters

These inverters used thyristors as switching elements. Thyristor is turn on with a signal and to shut off need an external circuit to make zero the flow current. These inverters are connected voltage for switching and therefore do not have the ability to work independently. In addition these types of inverters need expensive filters to filter output and reduce power quality problems.

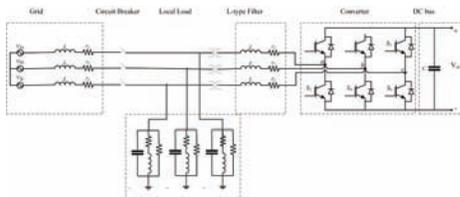


Figure 6. Studied 3-phase network.

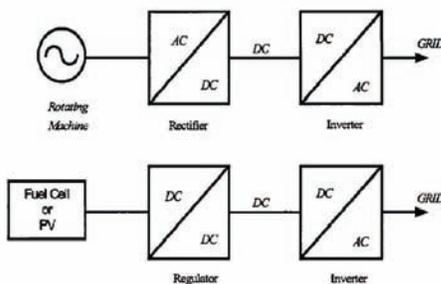


Figure 7. DG inverter topologies with different technologies.

2.2.2 Self Commutated Inverters

Such inverters use switches such as MOSFET and IGBT which able to turn on and off with gate pulses. The main advantage of these inverters is the ability to control voltage and current and hence there are suitable for connection to network or operating independently. Depending on the nature of inverter DC side inverter, they are classified in to two categories. Voltage sourced inverters (VSI) and current sourced Inverters (CSI). Voltage sourced inverters have a capacitor on DC side for voltage stabilization and acts as a voltage source. However, current sourced inverters acts as a current source and have an inductor in DC side for current stabilization. In DGs VSC is used more to bring a Voltage controlled source Figure (8).

In this paper we used a 3-phase 2-level PWM VSC with 6 power electronics switches shown in Figure (9).

2.3 Filter Modeling

Used filters in connection of DG sources are the simple RL that is series with VSC. Common forms of filter shown in Figure (10).

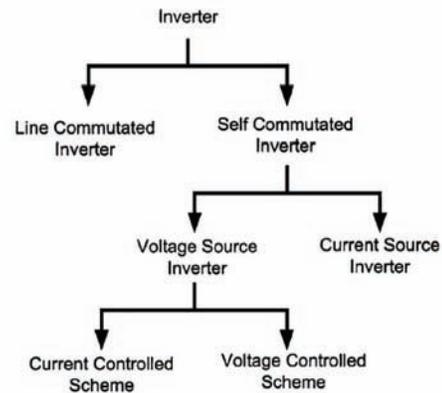


Figure 8. Inverter classification.

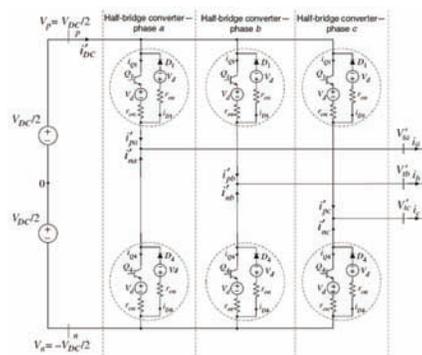


Figure 9. Schematic diagram of the used inverter in non ideal mode.

2.4 Transformer Modeling

The problem in simulating such network is that here is no zero point to close the current of inverter. In studied network, a transformer is used as a point of zero. Overall structure of the transformer shown in Figure (2).

2.5 Load Modeling (Unbalanced Load)

In studied network we used 3 unbalanced RLC loads for creating unbalanced voltage Figure (12).

The infinite bus voltage source is modeled in 2 ways.

2.6 Inverter Control Modeling

The main function of the inverter for DG system can be summarized as follows:

1. The main function of inverter is controlling the DG as a major source of active power and also the inverter can produce power quality problems such as voltage distortion and harmonics especially used in operation of micro grid.
2. Protection of DG and protection of network from islanding.

The standard IEEE 929-2000 requires DG is equipped with an anti-islanding detection algorithm that can be

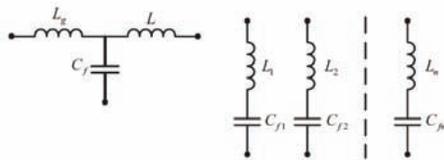


Figure 10. Filter classification.

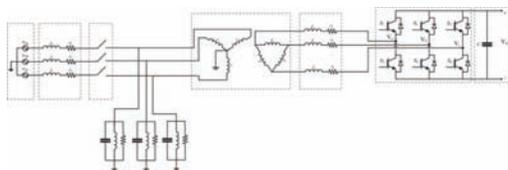


Figure 11. Schematic diagram of the used transformer.

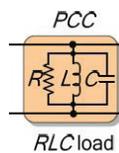


Figure 12. General structure of the local load.

performed by inverter control. These methods are known as active methods. Different methods of converter operations are divided in to 2 categories:

1. When connected to grid behaves like a current source and our control is on current which is delivered to the network Figure (13).
2. As shown in Figure (14), After islanding detection there are two views. When a network connection is interrupted named micro-grid and acts as a voltage source and the voltage are controlled, or in this case inverter is disconnected named anti islanding mode Figure (15). Common point of view in these two views is the fast islanding detection. Passive methods does not have the ability to work in micro grid mode.

2.7 Modeling of Current Control

The major and minimum requirements of inverter are control of active and reactive power injected to grid. The converters are able to connect to grid with 2 voltage and output current control. When the voltage is controlled inverter is controlled like that it should generate the reference voltage on its terminal. The sinusoidal PWM (SPWM) is used for switching. The method of switching is based

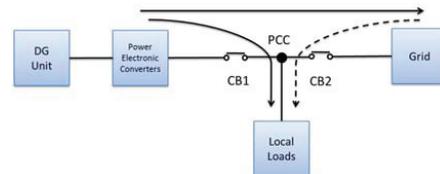


Figure 13. Grid connected mode.

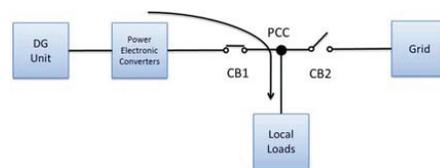


Figure 14. Island Mode (Micro Grid).

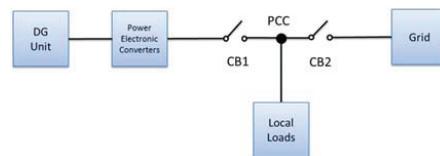


Figure 15. Anti-islanding Mode

on comparison between high frequency triangular carrier wave and produce pulses with different amplitude and bandwidth. In the current control mode, the inverter output current is controlled in such a way that is consistent with the desired reference. How to control the inverter or how to determine the reference voltage/current is depending on how the inverter is used.

Inverters in distributed generation systems can be used as 3 control ways. The following are 3 ways to control the inverter:

1. Voltage-sourced inverter with constant current control
2. Voltage-sourced inverter with constant PV control
3. Voltage-sourced inverter with constant PQ control

In this paper, function of current control in normal operation can be done when connected to an infinite bus and control is on the current that injected to network. As we know in general, current control methods are classified in to VOC, DPC and hysteresis. In this paper, conventional current control with consistent power is used with VOC method like block diagram of Figure (16). In modulator,

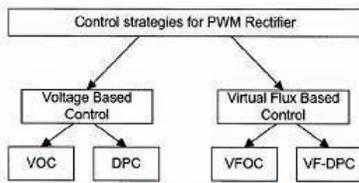


Figure 16. Classification of different control strategies.

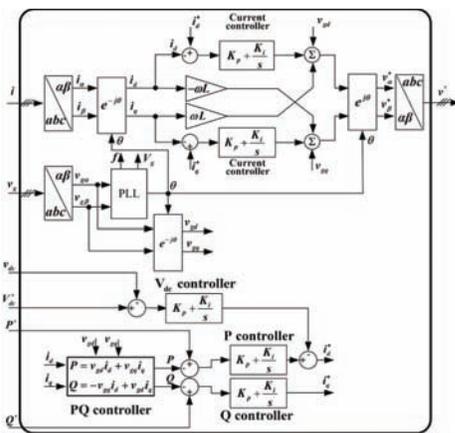


Figure 17. VOC current control in dq-frame. (Constant power control strategy)

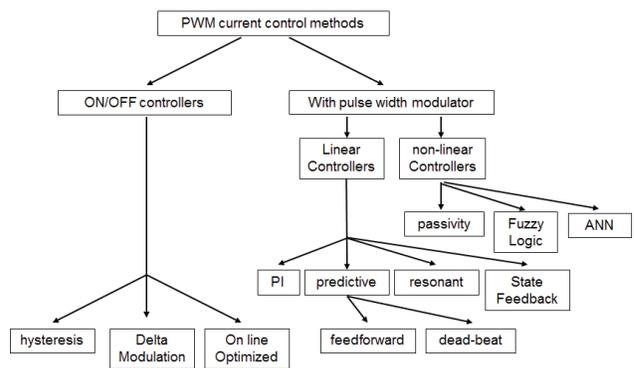


Figure 19. Classification of current control methods.

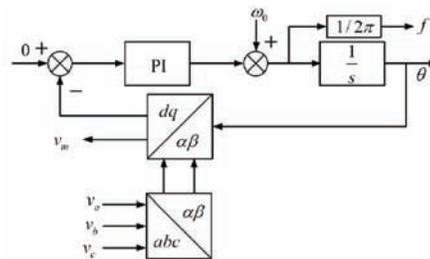


Figure 20. Synchronous reference frame phase locked loop.

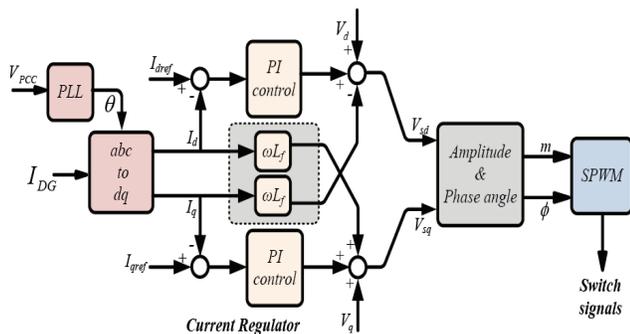


Figure 18. Current control with constant current strategy.

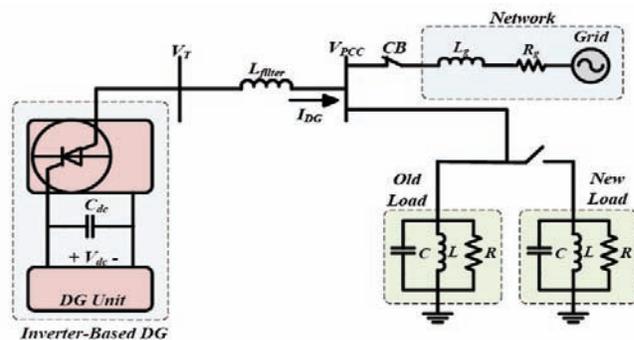


Figure 21. Studied system considering the load switching.

control method of modulator is used index modulation (m_d and m_q). Figure (17), (18) show the control strategies.

In this type of controller, various control methods in Figure (19) can be used.

In this paper, the PI control is used in the control loop because it was the first time to consider 3-phase system. In order to synchronize the voltage sourced converters to grid, 3-phase PLL is used in accordance with the following:

2.8 Modeling of Phase Locked loop

As Figure (20) shows, three phase voltage is entered the PLL control loop after converting frames and then phase and frequency are extracted. Also, V_m showed in Figure (20) is the amplitude of voltage.

Finally, simulations are carried out in accordance with the system parameters in the Table 3.

2.9 Modeling of Studied System Considering the Load Switching

As we know, because of load switching, we have affiliation in voltage and frequency. These changes must have been in standard limitation, which does not lead to falsely detection Figure (21).

3. The Proposed Structure of Islanding Detection (The Proposed Rule)

In general, voltages in unbalanced mode can be simulated in 2 ways:

Considering the unbalanced load and considering the source with neglect of loads and in general is like equation (1).

Table 3. Information of grid, controllers and load parameters

Inverter parameters	
Switching frequency	8000 Hz
Input DC voltage	900 V
Filter Inductance	2.1 mH
Voltage (line to line)	480 V
DG output power	100 KW
Load parameters	
Resistance	1.15, 1.1, 1.1 Ω
Reactance	3.45 mH
Capacitance	2037 μF
Grid parameters	
Frequency	60 Hz
Grid inductance	0.3056 mH
Grid Impedance	0.012 Ω

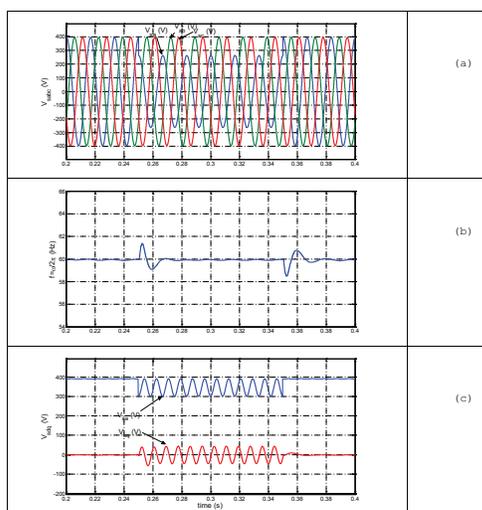


Figure 22. PLL Response to Unbalanced Load.

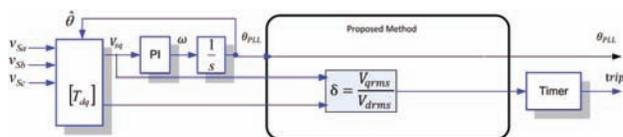


Figure 23. Proposed Mechanism.

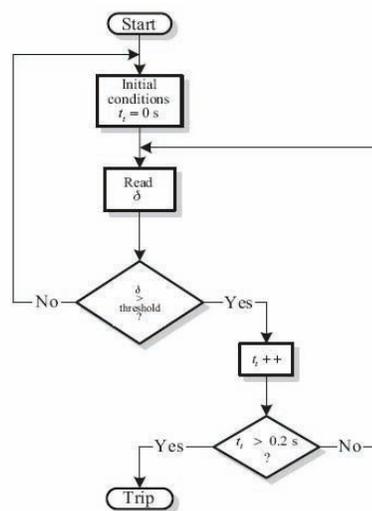


Figure 24. Proposed algorithm.

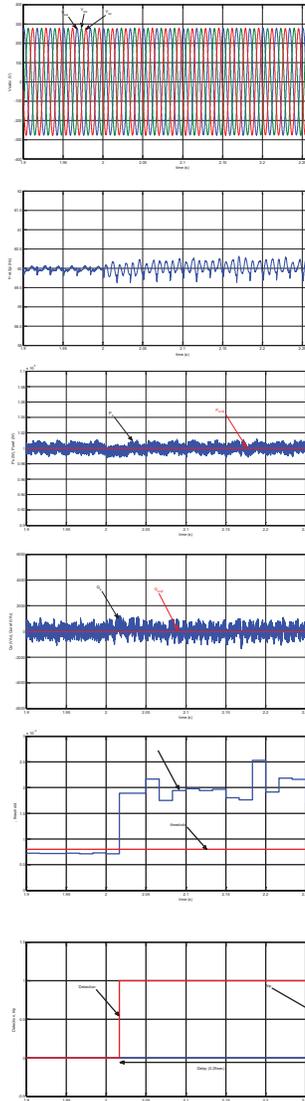


Figure 25. Simulation results of proposed method.

$$\begin{aligned}
 V_{sd}(t) &= \hat{V}_s \cos(\omega_0 t + \theta_0) + K_1 V_s \cos(\omega_0 t + \theta_0) @ \\
 V_{sb}(t) &= \hat{V}_s \cos\left(\omega_0 t + \theta_0 - \frac{2\pi}{3}\right) + K_1 V_s \cos\left(\omega_0 t + \theta_0 - \frac{4\pi}{3}\right) @ \\
 V_{sc}(t) &= \hat{V}_s \cos\left(\omega_0 t + \theta_0 - \frac{4\pi}{3}\right) + K_1 V_s \cos\left(\omega_0 t + \theta_0 - \frac{2\pi}{3}\right) @
 \end{aligned}
 \tag{1}$$

The second term represents the unbalanced voltage with negative sequence component. If PLL is under steady state conditions, i.e., $\rho = \omega_0 t + \theta_0$, then V_{sd} and V_{sq} will be as follows:

$$V_{sd} = \hat{V}_s + K_1 \hat{V}_s \cos(2\omega_0 t + 2\theta_0) \tag{2}$$

$$V_{sq} = -K_1 \hat{V}_s \sin(2\omega_0 t + 2\theta_0) \tag{3}$$

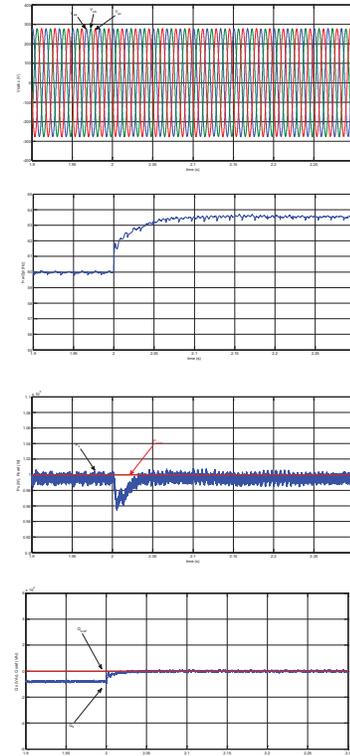


Figure 26. Simulation of Active method (SFS).

So, in unbalanced grid voltage, a component is generated in V_{sd} and V_{sq} with a frequency twice the frequency of the grid voltage. As can be seen in Figure (22), in unbalanced mode, they are not DC yet and have a sinusoidal oscillation frequency twice the grid frequency.

Implementation of proposed method is shown in Figure (23). In order to detect island, double frequency component is used and we will work on the following algorithm Figure (24).

In used algorithm, time is named by t that is initially 0 second. If δ exceeds the threshold value for more than 0.2 seconds, trip command is given to inverter and if δ is going down the threshold value for less than 0.2 seconds, timer is reset to zero.

Threshold and trip time is selected in accordance of one of the standards IEEE-929-2000, IEEE-1547-2005 or VDE-0126-1-1. Trip is dependent to which view we are studying. Trip in micro grid view, have been lead to disconnection of DG from infinite bus and DG will continue to supply the local loads in this case the control strategy is changed to voltage control strategy. In other hand Trip in anti-islanding view, DG have been turned off from supplying the load.

In this algorithm, δ is calculated from the following equations:

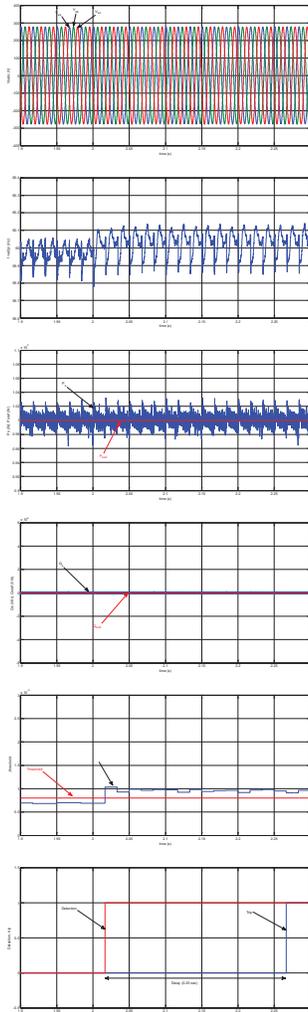


Figure 27. Simulation results of proposed method.

$$\delta = \frac{V_q(rms)}{V_d(rms)} \tag{4}$$

It should be noted that, when we are connected to system, voltage and frequency is composed from grid. After islanding due to unbalanced load, voltages are often slightly different but again are located in the rated limit.

4. Simulation Results

4.1 Comparing the Results of Proposed Method with Active Method (SFS)

In this section simulation results of proposed method have been compared with one of active islanding detection methods (SFS). Simulation results are based on Constant current Current control strategy.

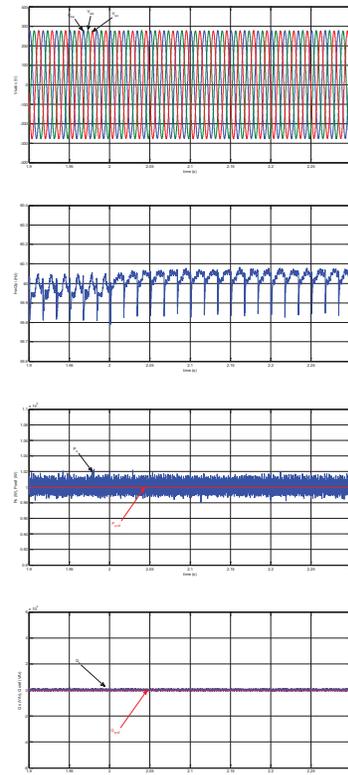


Figure 28. Simulation results of Active method (SFS).

These two methods have the ability of detection. But because of frequency affiliation in SFS method can't be used in micro-grids. And also as shown in simulation results, SFS method have undesired reactive power which lead to reduction in power quality Figure (25), Figure (26).

4.2 Comparing the Results of Proposed Method with Active Method (SFS) in Constant Power Current Control Strategy

As shown in these figures Figure (27), Figure (28) Active method don't have the ability of islanding detection in current control with constant power strategy.

4.3 Simulation of Studied System Considering the Load Switching

At time of t=1 sec, a balanced load is connected to system and at time of t=3 sec it is disconnected from system. At last, in time of t=5 sec system is islanded. Simulation results show the constant load voltage.

With considering the impact of load switching in proposed method, detection time have been increased. Figure (29), Figure (30).

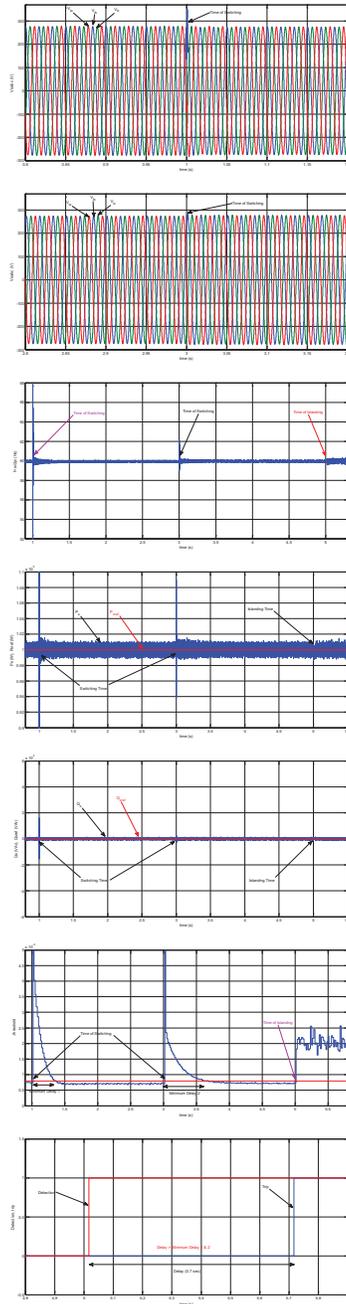


Figure 29. Simulation Results of proposed method.

5. Conclusion

Following results and Table 4 have been performed based on simulation:

1. In this method, there is no injection in inverter current so there is no unwanted reactive power.

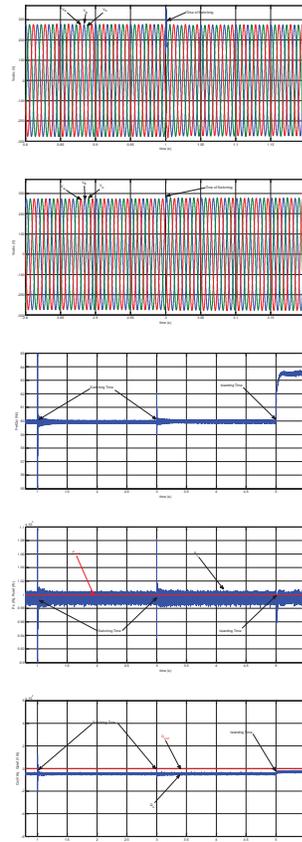


Figure 30. Simulation Results of active method (SFS).

2. The proposed islanding detection method is having a high speed.
3. Simulations have been performed using PSIM software in real environment.
4. In this method we do not have non detection zone (NDZ).
5. Studied system is similar to standard UL-1741 with the difference that is used with 3-phase and local loads are assumed to be unbalanced.

Conventional active detection methods are not able to detect the island with the aim to keep it stable. Because they try to leave electrical parameters such as voltage and frequency from their rating value. So in micro grids, island should be detected by using passive or remote methods. We should note that the detection time of 2 seconds which is referred to in standard is not appropriate and detection time must be less than this value. The proposed method which is in group of active methods is capable for use in micro grids.

Table 4. Performance comparison of Proposed method and active method (SFS)

Method	Speed of detection	Ability to use in micro grids	Ability to use in anti-islanding	Impact in power quality reduction	Non Detection Zone (NDZ)	Ability to use in constant power control strategy	Ability to use in constant current control strategy	Impact of load switching in islanding detection	Ability to reconnect to grid
Active (SFS)	Excellent(Depend on implementation parameters due to method)	X	✓	✓	✓	X	✓	X	X
Proposed method	Excellent (Depend on system parameters e.g. impact of load switching)	✓	✓	X	X	✓	✓	✓	✓

6. Studied network is similar to network of related articles and for islanding detection with the distinction that in all papers three phase system was considered as a single line. For this reason, the system was single phase PLL but in this paper a three phase system is considered that several features are as follows:

1. Take advantage of multilevel converters if needed.
2. Forcely use a three phase PLL.
3. Use of unbalanced loads as needed.
4. The importance of three phase transformer is obvious.

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