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Islanding Detection in a Distribution System with Photovoltaic (PV) System as Distributed Generation

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Abstract

Objectives: One of the most crucial problems of distributed generation is islanding detection in power system. In this paper, the variation of frequency and THD value of voltage waveform at PCC will be studied for islanding detection diagnosis. **Statistical Analysis**: Islanding detection methods are classified as local and remote islanding detection. In that local methods are categorized as passive and active methods. These two methods are based on changing in parameters such as frequency, voltage and current harmonics. But these methods have some challenges such as reduction in power quality and large Non Detection Zone (NDZ) whereas remote methods doesn't contains NDZ but not economically suitable for small networks. The studied system was considered by following the standard IEEE-1547 and UL-1741.This work is performed to determine islanding detection in power system. **Findings:** Whenever the grid disconnects from the power system there will be variations in frequency and THD value of voltage waveform at PCC. These variations will be taken as reference for islanding detection and generates trip signal for DG. **Application/Improvements:** This work is used in various power system applications. Simulation results using SIMULINK software on the power shows the effectiveness of proposed method.

Keywords: Distributed Generation (DG), Grid-Connected, Islanding Detection, Non Detection Zone (NDZ), Point of Common Coupling (PCC), Reactive Power Output, Total Harmonic Distortion (THD)

1. Introduction

Distributed Generation (DG) provides many potential benefits, such as peak shaving, fuel switching, improved power quality and reliability, increased efficiency and improved environmental performance. For DG systems producing a DC voltage, an inverter is used to interface the DG system with the grid. The switching of the inverter is determined based on a certain implemented control strategy[1]. The DG could be designed to supply active power or both active and reactive power. Aside from controlling the DG output power, the DG interface control performs an additional function, which is anti-islanding protection[2].

Islanding is the condition in which a part of system is temporarily isolated from the main grid but still the local load is energized. It may occur intentionally or unintentionally. Traditionally islanding has been considered by utilities as an undesirable condition due to concerns about safety, equipment protection and system control. These concern have been addressed through anti-islanding features in grid interactive inverters and the provisions included in standards similar to IEEE 1547 and UL 1741. Intentional islanding operation may be desired in cases where the central grid is prone to reliability problems. Usually, protective devices must be reconfigured automatically when transitioning between islanded and grid connected modes.

Islanding detection techniques are divided into local and remote techniques. The local techniques further classified into passive, active and hybrid techniques. Remote islanding

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detection techniques are based on communication between the grid and the DG like Supervisory Control and Data Acquisition (SCADA), Power Line Carrier Communication (PLCC). Even though they are more reliable but they are expensive to implement compare to local islanding detection techniques. Local islanding detection techniques are based on the measurement of parameters such as voltage, current, frequency. They are classified as passive, based on the monitoring of these parameters but it suffers with having large Non Detection Zone (NDZ). Hence it is not useful for high DG penetration. The active islanding detection techniques are based on intentionally introduce perturbations in the parameters voltage, frequency or output power and continues monitoring of these parameters to conform the islanding detection condition. Hybrid methods employ both the active and passive detection techniques.

2. Distributed Generation

The distributed generation correlates the energy generation at distribution system near to the load centers less than 10 MW.

These distributed generation technologies categorized as renewable and nonrenewable. Renewable technologies includes

- Solar, Photovoltaic or Thermal.
- Wind.
- Geothermal.
- Ocean.

Nonrenewable technologies includes

- Internal Combustion Engine.
- Combined Cycle.
- Combustion Turbine.
- Micro-turbines.
- Fuel Cell.

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

- The main function of inverter is controlling the DG as a major source of active power.
- Protection of DG and protection of network from islanding.

The inverter can also produce power quality problems such as voltage distortion and harmonics.

2.1 Photovoltaic (PV) System

A solar cell is the most fundamental component of a Photovoltaic (PV) system. The PV array is constructed by many series or parallel connected solar cells to obtain required current, voltage and high power. Each solar cell is similar to a diode with a p-n junction formed by semiconductor material[3]. When the junction absorbs light, it can produce currents by the photovoltaic effect. It can be seen that a maximum power point exists on each output power characteristic curve. The Figure 1, 2 shows the (I-V) and (P-V) characteristics of the PV array at different solar intensities. The equivalent circuit of a solar cell is the current source in parallel with a diode of a forward bias. The output terminals of the circuit are connected to the load.

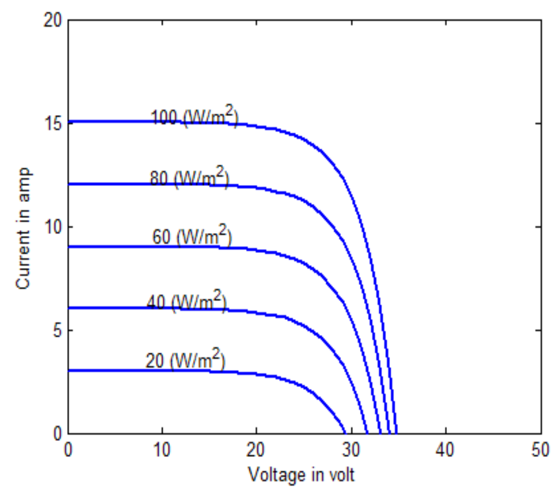

Figure 1. I-V characteristics of the PV array at different solar intensities.

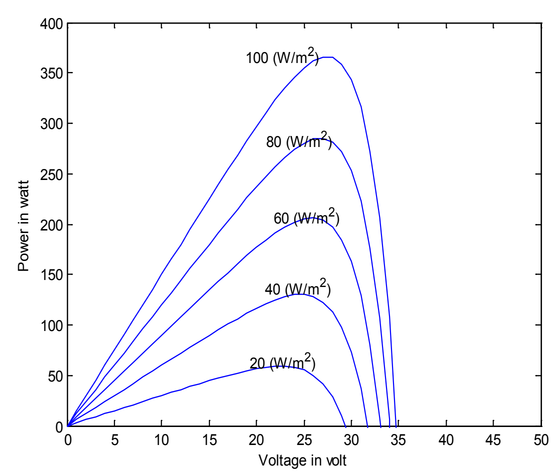

Figure 2. P-V characteristics of the PV array at different solar intensities.

3. Proposed System Islanding Detection

The proposed system is shown in Figure 3. It is consists of RLC load, DG source and inverter, power transformer, utility breaker. It also indicates the point of common coupling (PCC) at node "a", which is the contact point of DG source to the utility grid[4]. The power delivered by the grid to load is the difference between the powers generated by the DG source to the power consumed by the load.

$$\Delta P + j\Delta Q = \left(\left(P_{\rho\upsilon} + jQ_{\rho\upsilon} \right) - \left(P_{load} + jQ_{load} \right) \right)$$

Where P_{load} and Q_{load} represent the active and reactive powers of the *RLC* loads at the grid-connected condition, respectively, $P_{\rho\upsilon}$ and $Q_{\rho\upsilon}$ represent the output active and reactive powers of the inverter in the DG side and ΔP and ΔQ represent the active and reactive powers delivered by the grid.

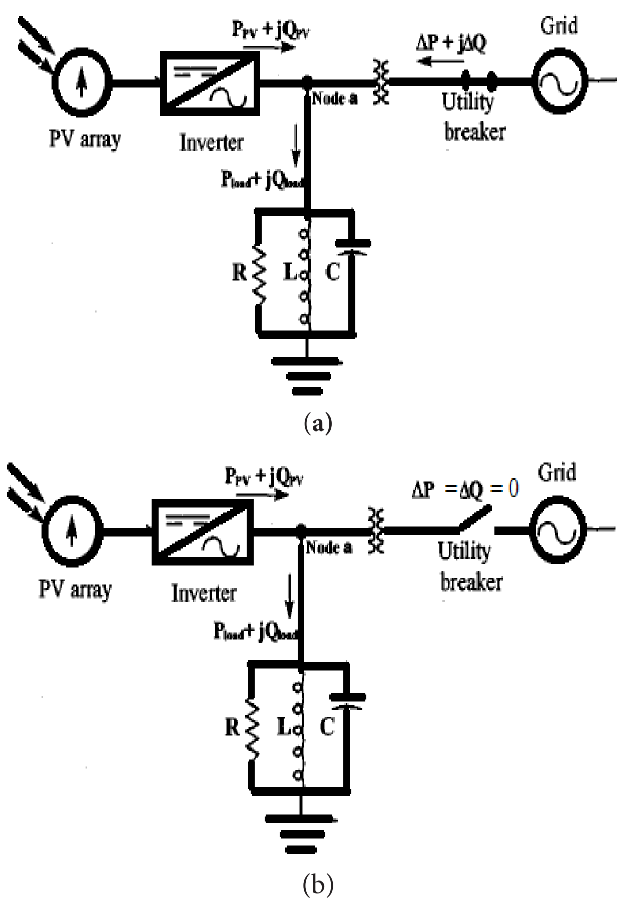

Figure 3. **(a)** Grid connected system. **(b)** Isolated mode of the system.

Under the ideal condition, when the utility breaker opens, the DG and the RLC load will resonate at nominal voltage and frequency and forms an island.

The active and reactive power of the three phase RLC load is given by

$$P_{load} = 3\frac{V_{PCC}^2}{R}$$

$$Q_{load} = 3\left(\frac{V_{PCC}^2}{2\pi fL} - V_{PCC}^2 2\pi fC \right)$$

where V_{PCC} represents the voltage of PCC; is the PCC frequency.

With the parameters of three phase RLC load the resonant frequency and quality factor is expressed as

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$Q_f = R\sqrt{\frac{C}{L}}$$

Mathematically, the RLC load can be represented as

$$R = \frac{V^2}{P}$$

$$L = \frac{V^2}{2\pi fQ_f P}$$

$$C = \frac{Q_f P}{2\pi fV^2}$$

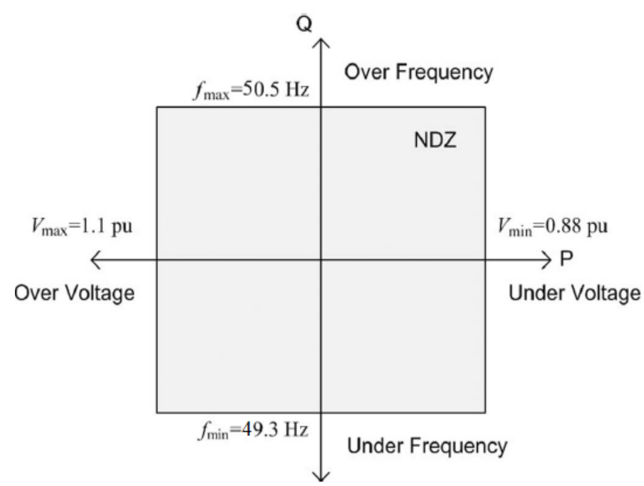

Figure 4. Non Detection Zone of Passive IDM.

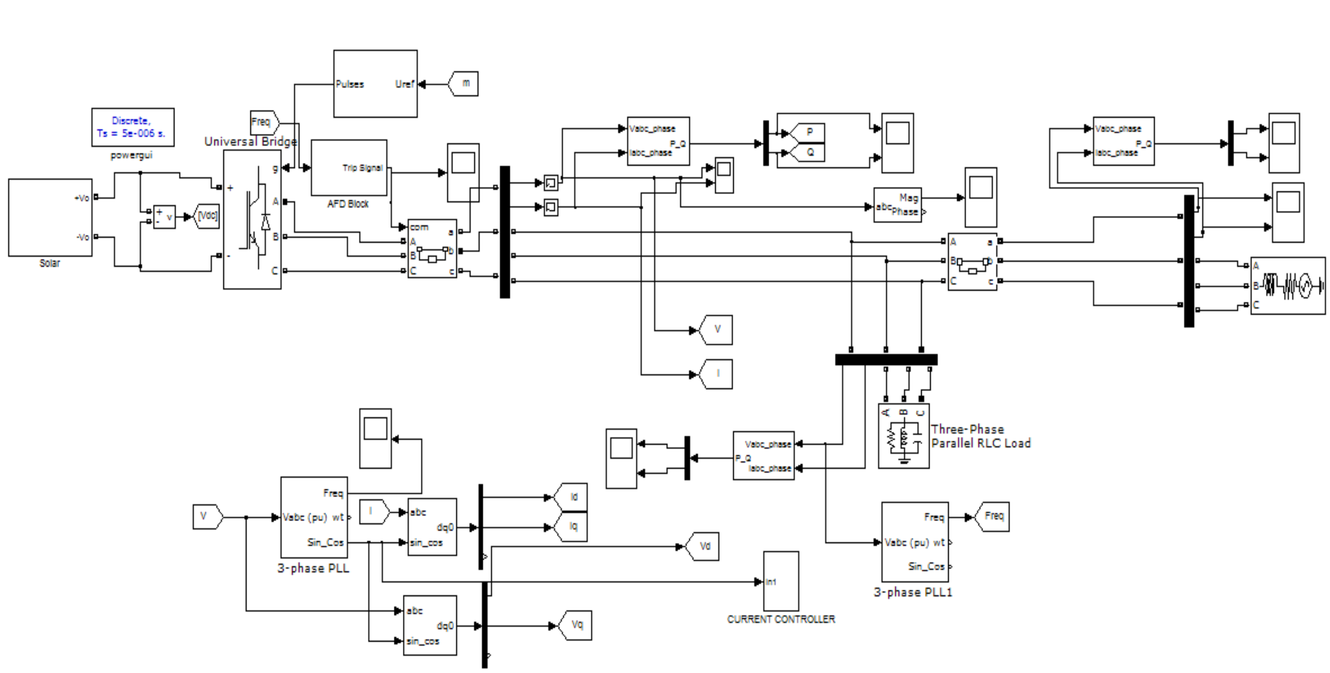

Figure 5. Simulink diagram of the system.

Where

- R Effective load resistance in Ohm;
- C Effective load capacitance in Farad;
- L Effective load inductance in Henry;
- P Real power in W;
- Q_f Quality factor;
- f Grid frequency in Hz.

4. NDZ of Under/Over Voltage and Under/Over Frequency

Non Detection Zone (NDZ) is defined as the loading condition for which an islanding detection method would fail to operate in a timely manner.

In practical situations, there will be power mismatch between the DG output and the RLC load. This mismatched load can be represented by (R + ΔR, L + ΔL, C + ΔC). Before the grid is disconnected, the power mismatch will be compensated by the grid.

When grid is disconnected, the voltage and frequency will be forced to new values of voltage and frequency. If the DG is controlled as a constant power in the system.

When the power mismatch is large enough, the values of voltage and frequency may be out of nominal ranges and under/over voltage/frequency protection will trip the circuit breaker present at the DG side to prevent continued island operation. The relationship between the power mismatch thresholds and voltage/frequency thresholds can be derived as below.

$$\left(\frac{V}{V_{max}}\right)^2 - 1 \le \frac{\Delta P}{P} \le \left(\frac{V}{V_{min}}\right)^2 - 1$$

$$Q_f\left(1-\left(\frac{f}{f_{min}}\right)^2\right) \le \frac{\Delta P}{P} \le Q_f\left(1-\left(\frac{f}{f_{min}}\right)^2\right)$$

Where are under/over voltage and under/over frequency thresholds, respectively.

Non Detection Zone is shown in Figure 4. In the NDZ the islanding detection is not possible. The effective NDZ of passive IDMs is increased if the criterion is fast detection of islanding condition, so as to coordinate with circuit breaker reclosing.

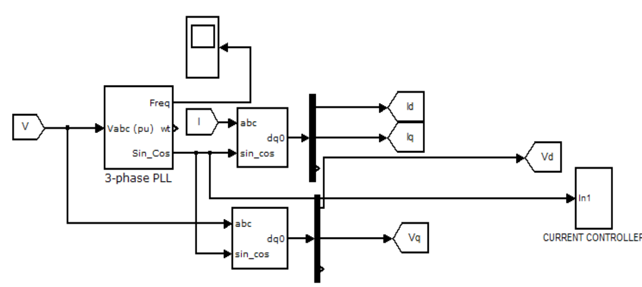

Figure 6. Outer control loop of DG interface controller.

5. System Description

The system which has been studied in paper, modelled in Simulink. The system consists three phase source, constant RLC load, DG system modelled with controlled DC voltage source with an inverter. The system parameters are taken from the reference paper[5]. The rating of the inverter is 100 kW.

The DG interface controller is the constant power control in which both voltage and current controller will takes place.

Figure 5 shows the control scheme based on *dq* synchronous reference frame. In this system, the input power extracted from the DG unit is fed into the dc link. Therefore, active power controller fed up with reference power and active power from DG. The output of the controller is given to gain for the generate reference currents[5].

The reactive power controller specifies the reference value for the *q* component of the converter current. The reactive power reference value Q_{ref} is set to zero in order to model a unity power factor DG operation. It also consists two Proportional-Integral (PI) controllers for the *d* and *q* axis current controls. The outputs of these controllers obtain the reference voltages for the PWM signal generator. The main features of the current control strategy are the limitation of the converter output current during a fault condition, providing overcurrent protection and reducing the fault current contribution of the unit.

The DG interface controller is the constant power control in which both voltage and current controller will takes place.

The outer control loop of DG interface controller is shown in Figure 6. The outer controller is the constant voltage controller.

The d-q transformations of the Phase Locked Loop (PLL) is given below

$$V_d = \frac{2}{3}\left(V_a \sin(\omega t) + V_a \sin\left(\omega t - \frac{2\pi}{3}\right) + V_a \sin\left(\omega t - \frac{4\pi}{3}\right)\right)$$

$$V_d = \frac{2}{3}\left(V_a \cos(\omega t) + V_a \cos\left(\omega t - \frac{2\pi}{3}\right) + V_a \cos\left(\omega t - \frac{4\pi}{3}\right)\right)$$

$$V_0 = \frac{1}{3}(V_a + V_b + V_c)$$

The inner control loop of DG interface controller is the constant current controller[6].

The reference real power is taken as P_{Ref} which is the function of terminal voltage and the reference reactive power is taken as $Q_{Ref} = 0$ kW for unity power factor. The error signals are given to the PI controllers and generates d-q reference currents. It generates modulation index given to PLL block and produces pulse signals for the inverter.

5.1 Frequency Detection Model

The OUF relays monitors the frequency in the DG inverter and compare this value with some present threshold limits. In Figure 7, the frequency relay model and its settings according to grid standards.

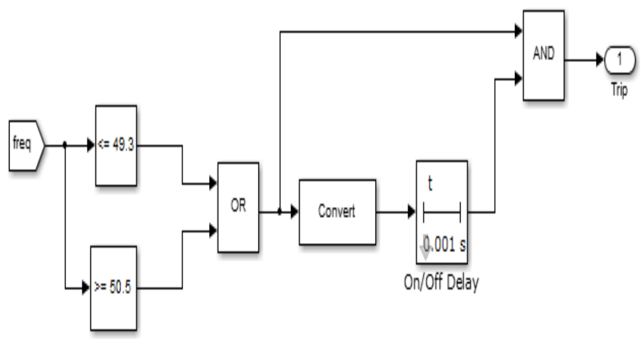

Figure 7. Frequency detection model.

6. Results

Simulation results for PV system interconnected to grid with 100 kW inverter is carried out using SIMULINK. When the Grid is connected to the system the output of three phase voltage and current is stable but with the opening of CB at grid side, the system becomes isolated mode. The simulation time period is 0.5 sec. Initially the system will be in grid connected mode thus voltage at PCC is steady state. At t = 0.3 sec the circuit breaker at grid side is opened and island occurs.

Whenever island is formed, the controller circuit detects and generates trip signal for circuit breaker at DG side

Whenever the Grid is disconnected at t = 0.3 sec the the output of voltage and current was distorted and becomes zero. The output waveforms of voltage and current at PCC and grid is shown Figures 8, 9.

Due to the opening of CB at t = 0.3 sec the frequency at PCC will change continuosly shown in Figure 10. Due to the change in frequency the trip signal is generated and given to CB at DG side.

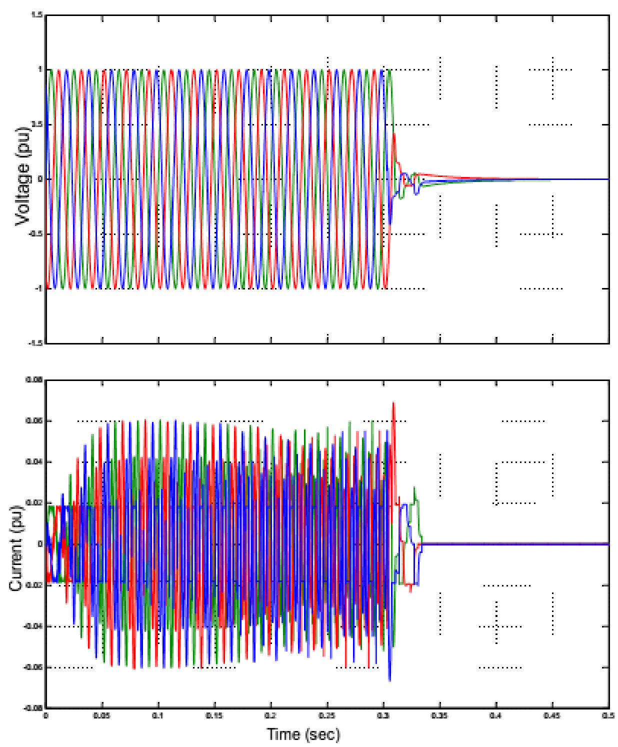

Figure 8. Voltage and current at PCC.

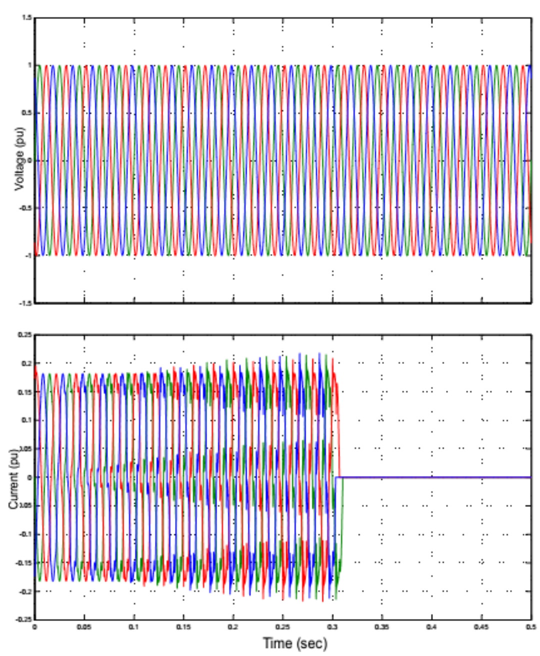

Figure 9. Voltage and current at grid.

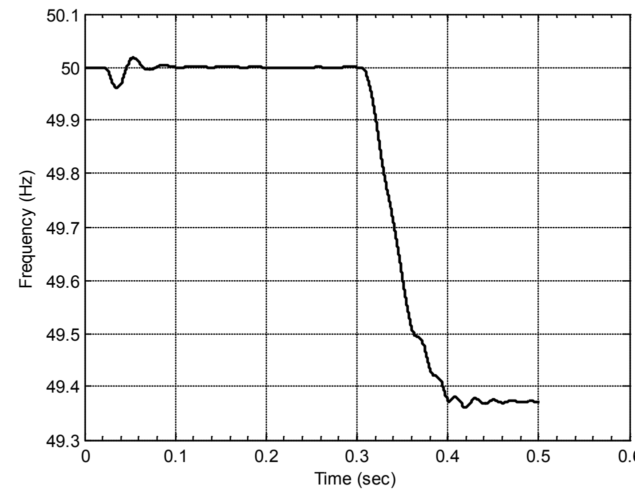

Figure 10. Frequency at PCC.

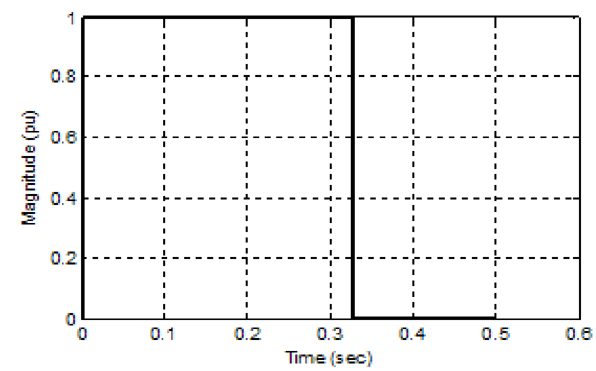

Figure 11. Detection signal for CB at DG.

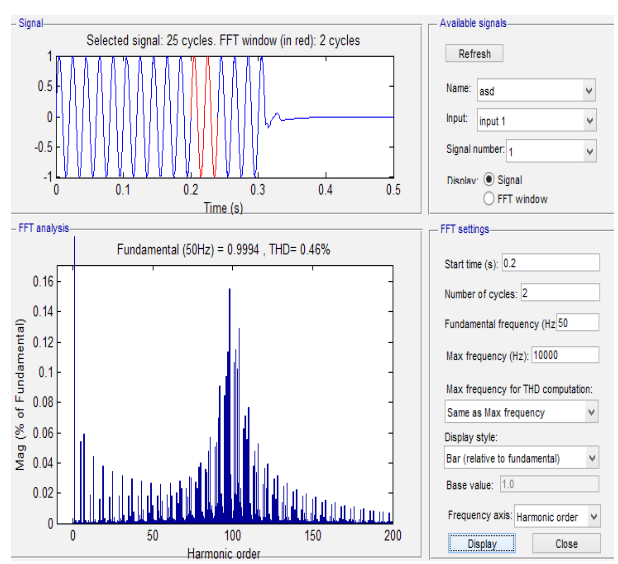

Figure 12. THD value of voltage waveform before islanding event.

As per IEEE std, the DG is disconnected with in 0.02 sec from the rest of system and the trip signal provided to the CB at DG shown in Figure 11.

The THD values for voltage waveform is measured and shown in Figures 12, 13 for the before and after islanding events occurred.

7. Conclusion

The change in THD value of voltage waveform at PCC is observed by disconnecting the grid for RLC load. This work will be carried out for the different loads and observe the change in parameters for different load when islanding is formed. Those variations will be taken as reference for the islanding detection.

8. Acknowledgement

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