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# A Comparative Analysis between SMFS and Modified SMFS Islanding Detection Methods

Manaskant Mishra <sup>1</sup>, Prof. P. C. Panda <sup>2</sup>, Dr. S. C. Swain <sup>3</sup>, Prof. S. Roy <sup>4</sup>

M. Tech Scholar, School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha, India <sup>1</sup>

Professor Emeritus, School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha, India <sup>2</sup>

Associate Professor, School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha, India <sup>3</sup>

Assistant Professor, School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha, India <sup>4</sup>

**ABSTRACT:** In this paper, a comparison has been made between the performances of original Slip – Mode Frequency Shift (SMFS) and the Modified Slip – Mode Frequency Shift (Mod - SMFS) islanding detection methods. The parameters on the basis of which these methods have been compared are the time of detection of the islanding situation in a grid connected Distributed Generation (DG) system which must lie within the limits as specified by IEEE 1547 and UL 1741 standards and the Non – Detection Zone (NDZ) of these two methods. The simulations have been performed in MATLAB – Simulink software.

**KEYWORDS:** Islanding Detection, Slip – Mode Frequency Shift, Time of Detection, Non – Detection Zone, Comparative Analysis.

### I. INTRODUCTION

It is a well-known fact that Renewable Energy Systems or Distributed Generation is encouraged and given a lot of importance in modern power systems. After the restructuring of the power sector, Individual Power Producers (IPP) came into the power market scenario. These IPP's produce electrical power mostly by using these Distributed Generation systems like Solar-PV energy, Wind energy, Tidal energy, etc [2]. Thus, to sell the power, they connect these Distributed Generation (DG) systems to the main power grid, which gave rise to the grid-tied DG systems of today. But in order to do so, they must comply with certain standards and specifications of their system parameters in accordance with the Grid code and IEEE standards [7] [8]. If any of these codes or standards is violated by the IPP, then the IPP can't sell the power to the main grid.

But even after the DG has been tied to the grid, there are certain technical problems whose probability of occurrence in the power system increases. One of these problems is the Islanding situation [1]. In a grid-tied DG system, when the supply from the main grid is cut-off due to any reason, the DG system still continues to keep some conductors of the system powered up as shown in figure 1. This is known as islanding in a grid-tied DG power system.

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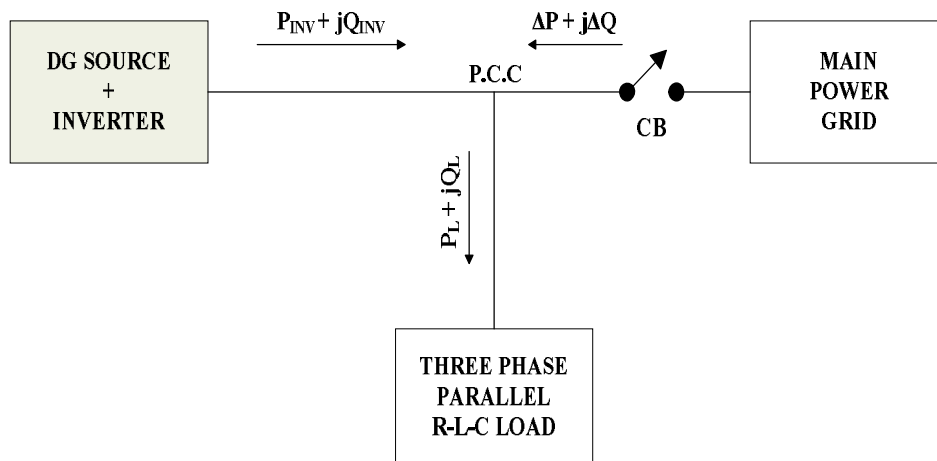


Fig.1. A simple model depicting the islanding situation in a power system

Islanding situation mainly poses a threat to the safety of the maintenance personnel who provide service to the grid conductors from time to time. Other major side effects of this situation are instability in the power system, damage of customer load and equipments, reduction of quality of power being supplied to the customers as well as certain problems in re-closing operations in order to restore system supply [3] [4]. Hence, islanding in a grid-tied DG power system is a highly critical phenomenon and according to IEEE 1547 standard, such a situation must be detected and overcome in a matter of 2 seconds or less [8].

As a result, many Anti-Islanding Protection (AIP) schemes have been proposed since the discovery of this power system phenomenon. These schemes are mainly divided into 3 types: active schemes, passive schemes and remote schemes. Active schemes generally detect islanding by injecting a certain perturbation into the system parameters and recording their response to the perturbation. These schemes have the merit that their Non-Detection Zone (NDZ) is very small and have low Error Detection Ratio (EDR) [2] [4]. The de-merit of these schemes is that they reduce the power quality in the system because of the fact that they introduce perturbations into a system that is already stable.

Passive schemes, on the other hand, monitor the various system parameters continuously and check for abnormalities in their variation with time. The merits of these methods are that they are cheap and easy to implement and they don't introduce any kind of perturbations into the system to detect islanding situation unlike the active schemes. The de-merit of these schemes is that they are highly sensitive with large NDZ and high values of EDR as compared to active schemes [2] [4].

Remote schemes are mainly based upon the communication between inverter on the DG side and the main power grid so as to monitor the breakers on each side. The merit of these schemes is that they have very low or almost zero NDZ and EDR. But the de-merit is that these schemes need very large investments in order to implement them and are thus, suitable only for major power stations or industries i.e. they aren't economically viable on a smaller scale [2] [4].

Hence, in order to counteract the individual de-merits of these AIP schemes, a combination of these schemes is used to detect islanding in a power system and are thus known as Hybrid Islanding Detection schemes. These schemes generally employ one active and one passive scheme to overcome each other's de-merits for the purpose of islanding detection in the system [5] [6].

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In this paper, the two methods that have been compared i.e. original Slip – Mode Frequency Shift (SMFS) and the Modified Slip – Mode Frequency Shift (Mod - SMFS), are both active islanding detection methods and thus, the following section deals with the simulation models developed for the above mentioned purpose as well as the simulation data needed to obtain the necessary results.

## II. SIMULATION MODEL AND DATA

The simulation for making the comparative study between the SMFS and Mod – SMFS islanding detection methods has been done in MATLAB - Simulink based on the model in Fig.1. The simulated model is shown as follows:-

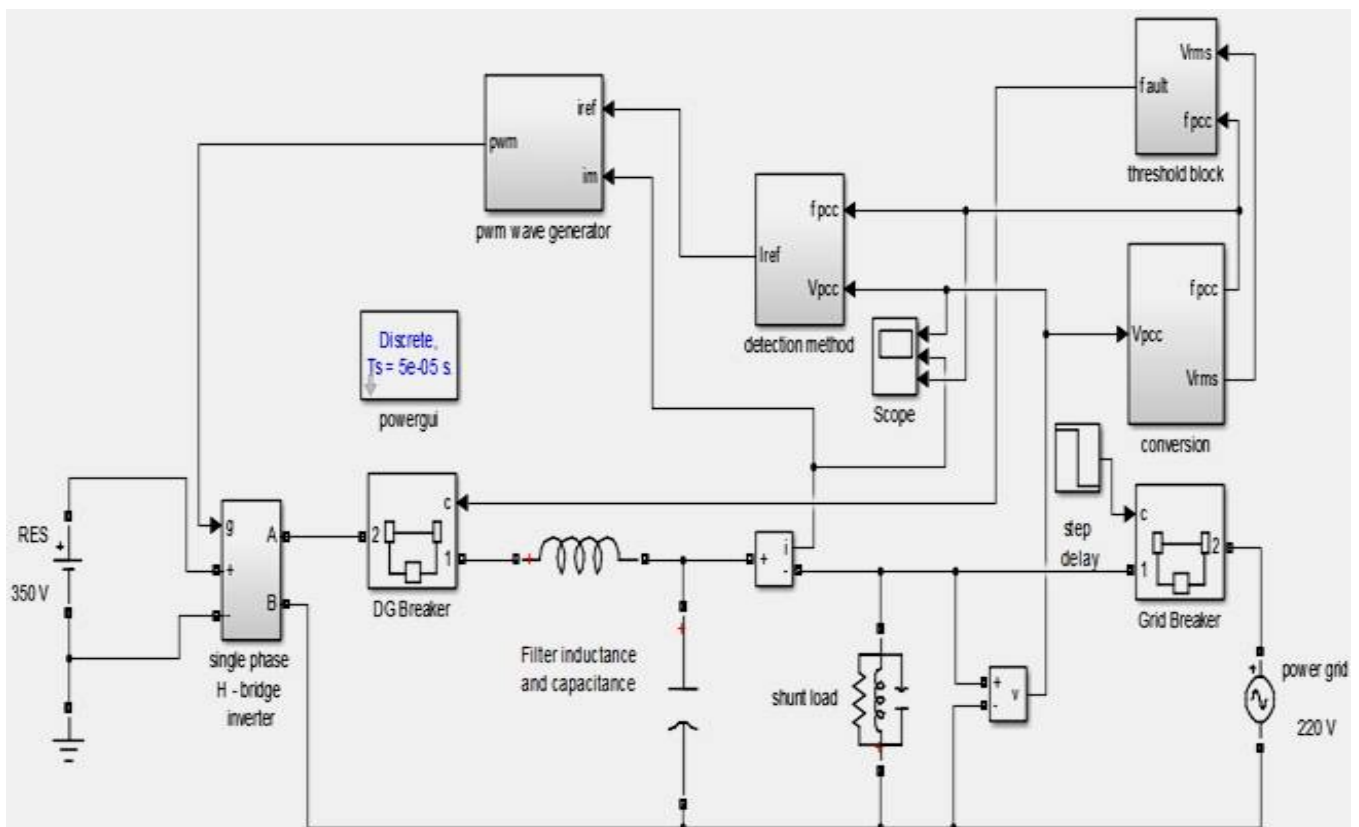


Fig.2. Simulation model for SMFS and Mod – SMFS islanding detection methods

In this model, the DG side consists of a renewable energy source that provides its DC output as input to a PWM based single phase H – bridge type inverter which in turn gives single phase AC output from the DC input. The output AC wave is then passed through an L – type LC filter to remove any dominant harmonics. The DG is connected to the AC voltage source that acts as a grid in this case and the RLC parallel load is connected at the Point of Common Coupling (PCC). These methods introduce perturbations in the phase angle of the reference current and then measure

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the response to these perturbations in order to detect an islanding condition. The phase perturbations for SMFS and Mod – SMFS methods are shown respectively in equations (1) and (2) below:-

$$\theta_{SMFS} = \frac{2\pi}{360} \theta_m \sin\left(\frac{\pi}{2} \frac{f - f_n}{f_{max} - f_n}\right) \quad (1)$$

$$\theta_{Mod-SMFS} = x(f - f_n) + \phi(f - f_n)\theta_0 \quad (2)$$

where,  $\theta_m$  = maximum phase shift

$f_{max}$  = frequency at which maximum phase shift occurs

$f$  = measured frequency at PCC

$f_n$  = nominal system frequency

$x$  = accelerating gain factor of Mod – SMFS method

$\theta_0$  = additional phase shift introduced in Mod – SMFS method

The function  $\phi(f - f_n)$  is made in such a way that it gives a phase advance when measured frequency is less than nominal frequency and gives a phase delay when measured frequency is more than the nominal frequency. The function is shown as in equation (3) below:-

$$\phi(f - f_n) = \begin{cases} +1 & f \geq f_n \\ -1 & f < f_n \end{cases} \quad (3)$$

The PWM wave for the single phase inverter is generated by comparing the measured current with the reference current given respectively for SMFS and Mod – SMFS methods by the equations (4) and (5) below:-

$$I_{refSMFS} = I_m \sin(2\pi ft + \theta_{SMFS}) \quad (4)$$

$$I_{refMod-SMFS} = I_m \sin(2\pi ft + \theta_{Mod-SMFS}) \quad (5)$$

After islanding occurs, the frequency will change iff the following condition is satisfied:-

$$\left. \frac{d\theta_{load}}{df} \right|_{f=f_n} < \left. \frac{d\theta_{shift}}{df} \right|_{f=f_n} \quad (6)$$

where,  $\theta_{shift}$  can be substituted with equations (1) and (2) for the respective methods.  $\theta_{load}$  is the angle by which current of the parallel RLC load leads the load voltage and is given as:-

$$\theta_{load} = \tan^{-1} Q_f \left( \frac{f}{f_0} - \frac{f_0}{f} \right) \quad (7)$$

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where,  $Q_f$  = load quality factor =  $R \sqrt{\frac{C}{L}}$

and,  $f_0$  = load resonant frequency =  $\frac{1}{2\pi\sqrt{LC}}$

From the above equations, the Non – Detection Zone can be found for both methods by equating  $\theta_{load}$  and  $\theta_{shift}$  given by:-

$$f_0 = \frac{1}{2} \left[ -\frac{f_{is} \tan(\theta_{shift}(f_{is}))}{Q_f} + \sqrt{\frac{f_{is}^2 \tan^2(\theta_{shift}(f_{is}))}{Q_f^2} + 4f_{is}^2} \right] \quad (8)$$

where,  $f_{is}$  = maximum or minimum islanding frequency for maximum or minimum resonant frequency respectively. The simulation data for which the results have been obtained are given in the following table:-

TABLE 1

SIMULINK BLOCK PARAMETERS

Simulink Block	Parameters
Power grid	220 V, 50 Hz
RES	350 V (DC)
Frequency threshold	$50 \pm 0.2$ Hz
Voltage threshold	$200 \pm 20$ V
Load	R = 40 $\Omega$ , L = 20.54 mH, C = 493 $\mu$ F
SMFS method	$\Theta_m = 10^0$ , $f_{max} = 53$ Hz
Mod – SMFS method	$x = 11.5$ , $\Theta_0 = 0.5^0$

The following section deals with the results obtained for both islanding detection methods with a comparative analysis between them.

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## III. RESULTS AND DISCUSSION

### Case – 1: Simulations with SMFS Method

The waveform for instantaneous voltage and measured current are respectively shown as follows in figure 3:-

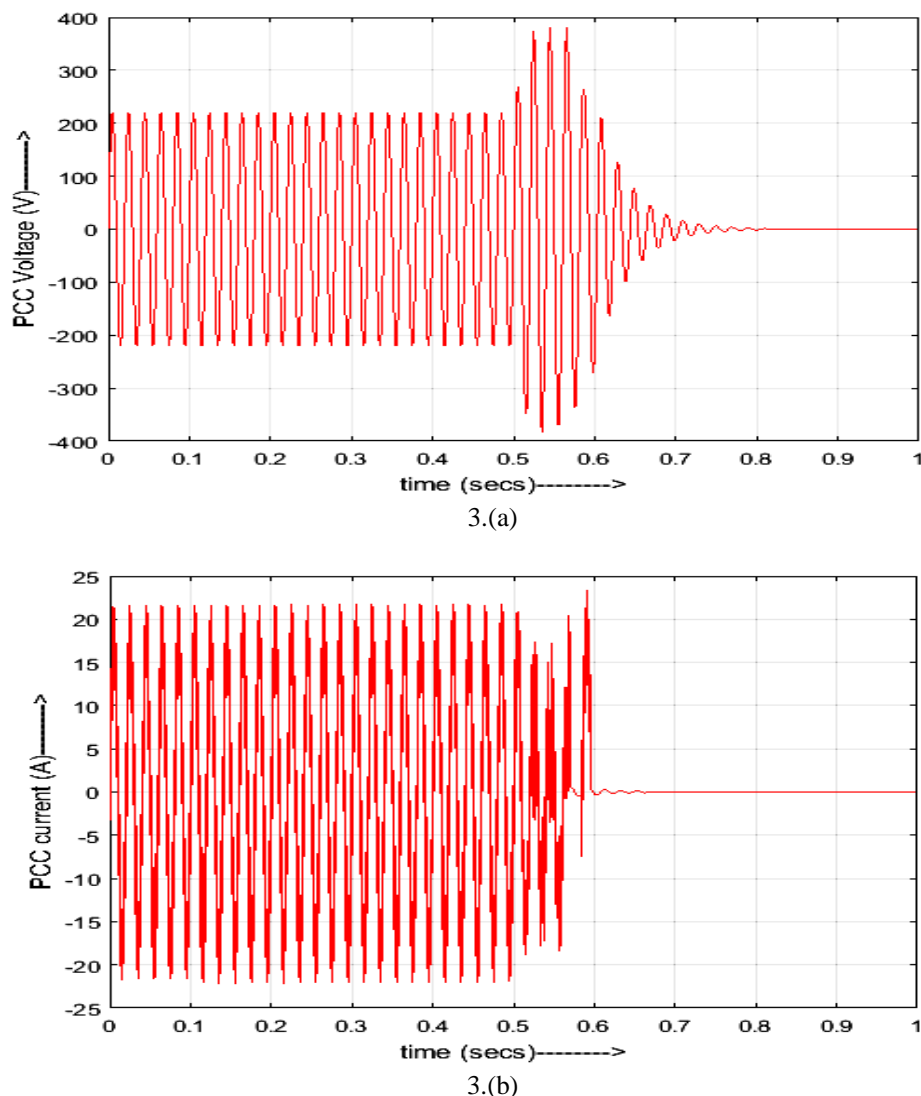


Fig.3. (a) Instantaneous voltage and (b) instantaneous current at PCC after detection of islanding using SMFS method

In the above two figures, it is seen that with the SMFS islanding detection method, the detection time for voltage at PCC is 0.3 seconds and that for current is 0.15 seconds. After islanding, the voltage wave in this case shows three to four major peaks above the nominal value. This is because of the nearly un-noticable phase change in the reference

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current wave (as given by equation 4) after islanding and re-closing of the DG side breaker as shown in figure 4. Because of the above two reasons the detection time is relatively more than Mod – SMFS as will be shown later in case – 2.

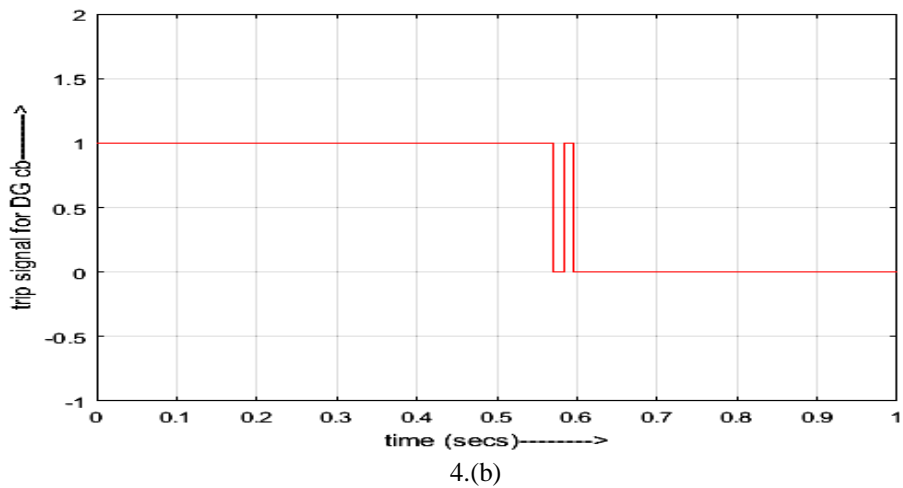
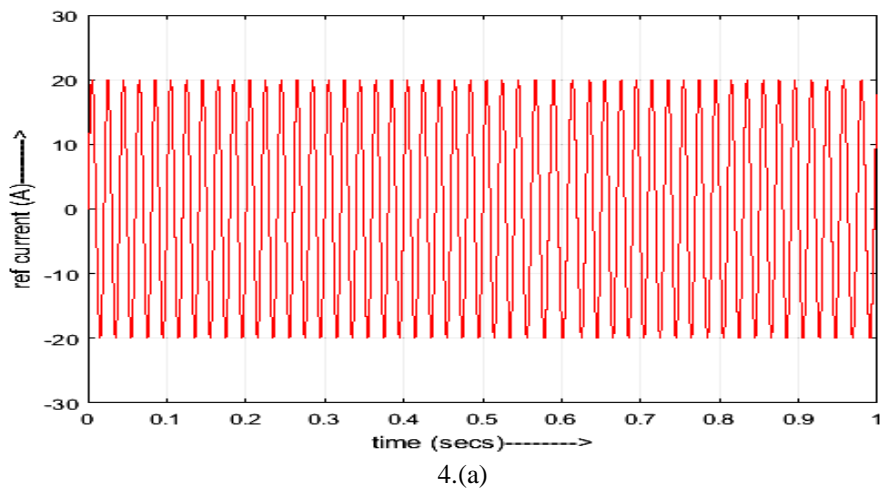


Fig.4. (a).Reference current waveform and (b).trip signal of the DG side circuit breaker for SMFS islanding detection method

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The Non – Detection Zone (NDZ) of this islanding detection method is shown as follows in figure 5:-

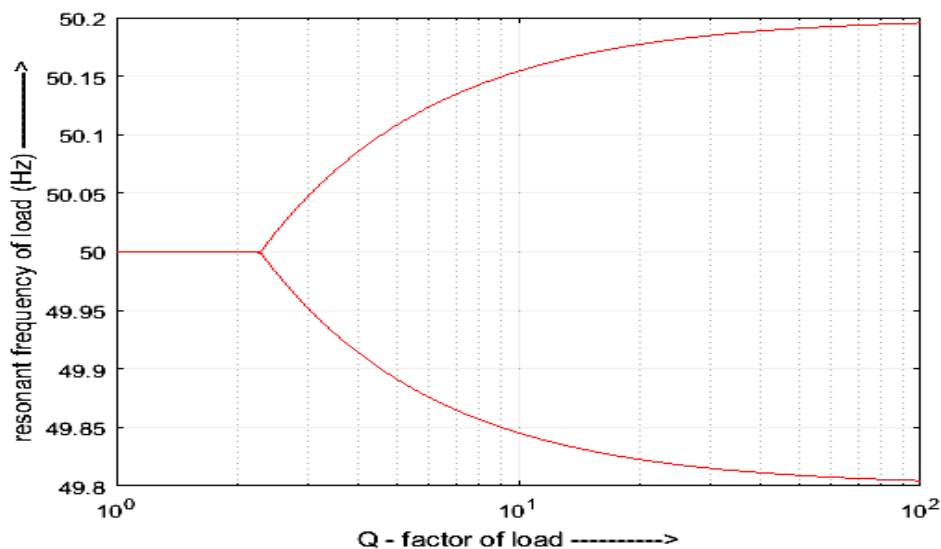
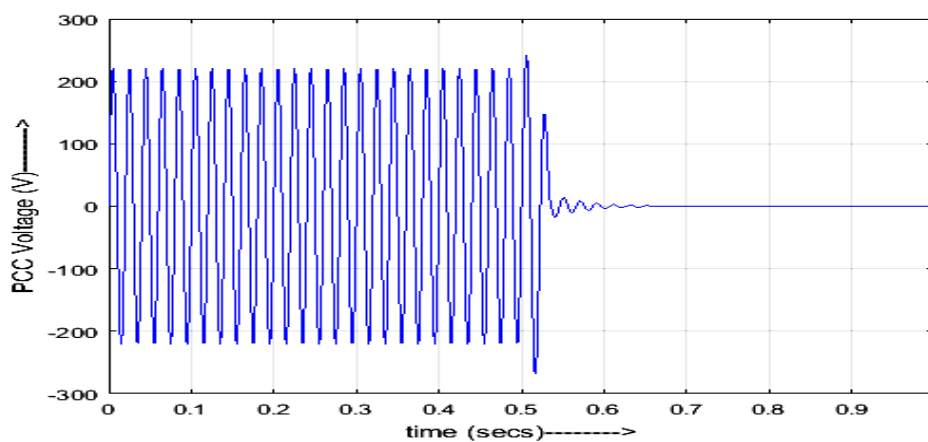


Fig.5. NDZ of SMFS islanding detection method

The NDZ of SMFS islanding detection method has been plotted by using a semi-log scale on x – axis and a normal scale on y – axis. The NDZ for this detection method is very big and increases if Q – factor of load goes above 2.5.

### Case – 2: Simulation using the Mod – SMFS method

The waveform for instantaneous voltage and measured current are respectively shown as follows in figure 6:-



6.(a)



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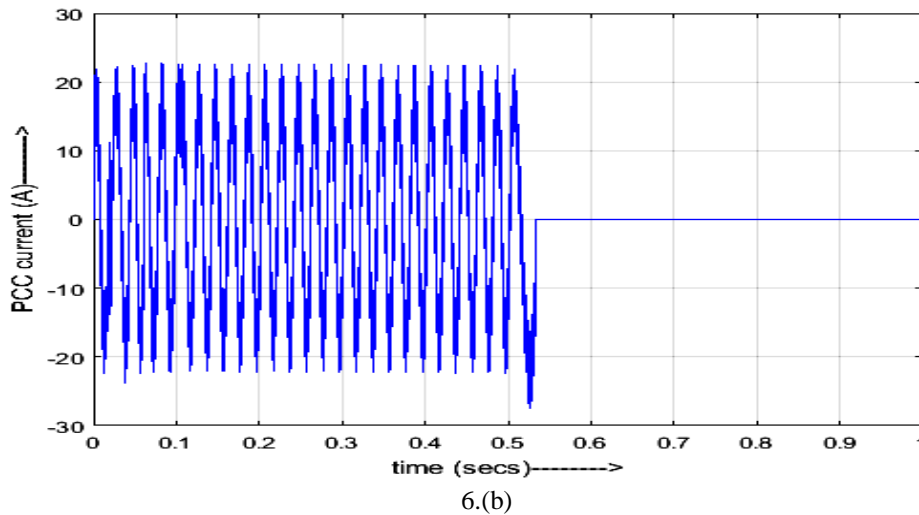
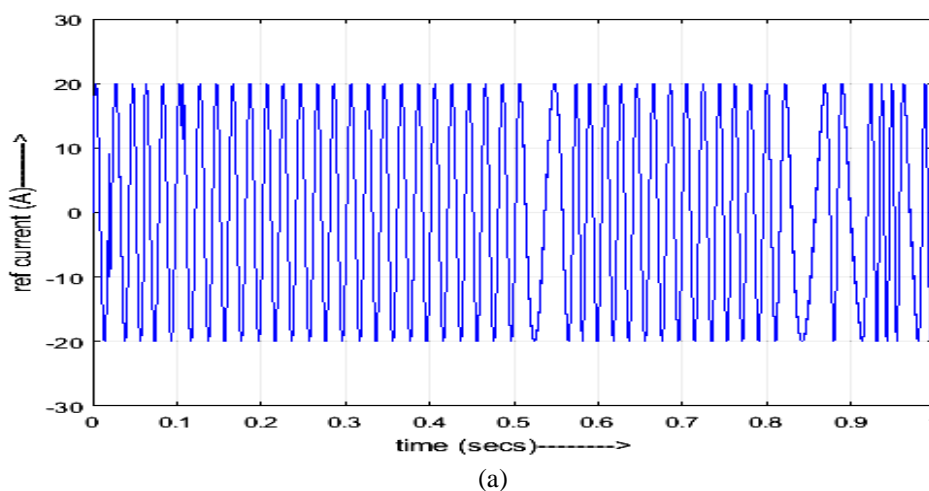


Fig.6. (a).Instantaneous voltage and (b).instantaneous current at PCC after detection of islanding using Mod – SMFS method

From figure 6, it is seen that the Mod – SMFS method detects islanding in a power system much faster than the SMFS method because of the additional phase shift as seen in equation 2. The damping out of the disturbance after islanding is significantly increased thereby causing the detection time of voltage and current waves to 0.15 and 0.05 seconds respectively. Here also as seen in figure 7, the reference current waveform has a notable phase shift after islanding and the trip signal for the DG side does not show any signs of re-closure unlike that of the SMFS method.



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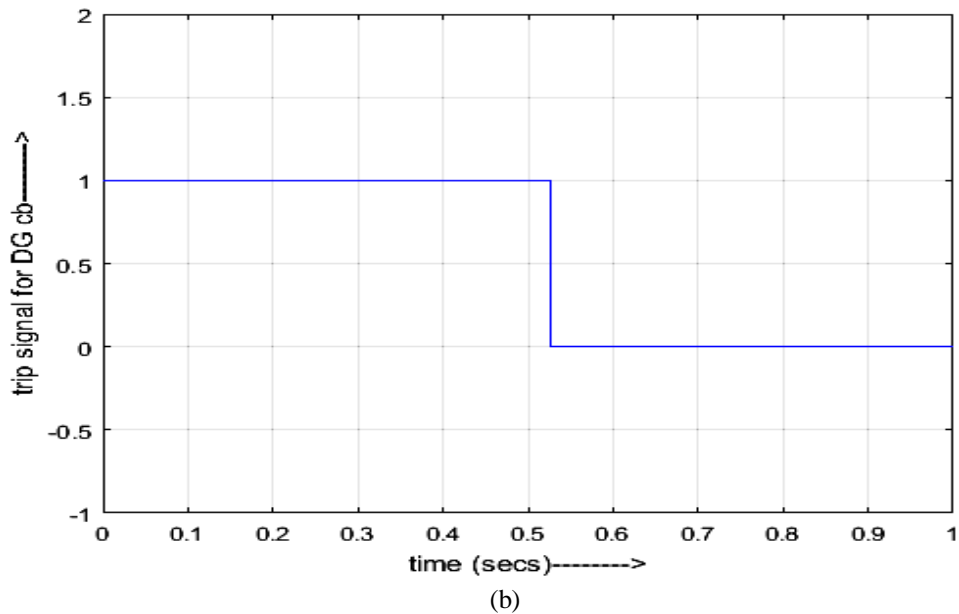


Fig.7. (a).Reference current waveform and (b).trip signal of the DG side circuit breaker for Mod – SMFS islanding detection method

The Non – Detection Zone (NDZ) of this islanding detection method is shown as follows in figure 8:-

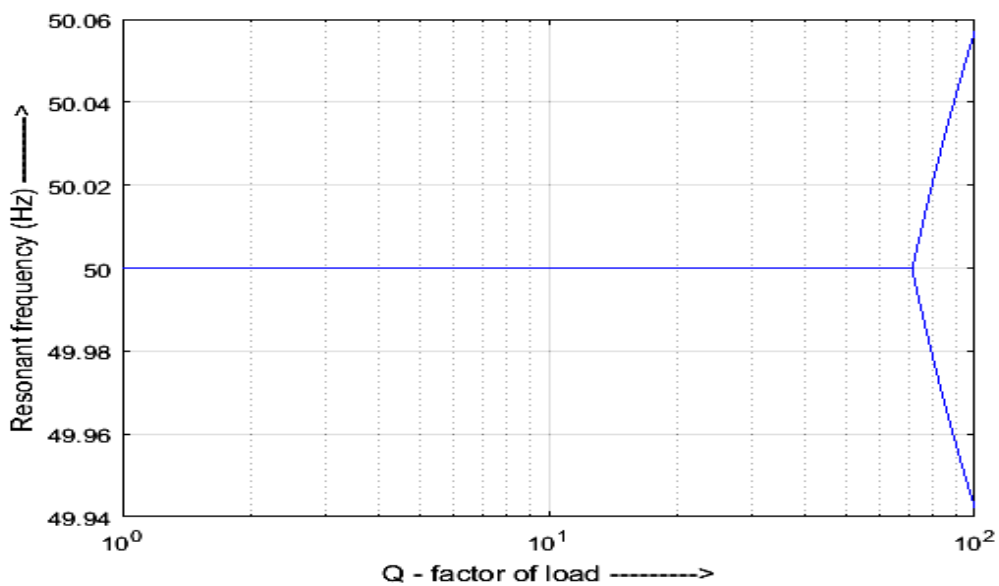


Fig.8. NDZ of Mod – SMFS islanding detection method

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In this case, the NDZ is very small as compared to that of the SMFS method as shown in figure 5. The NDZ increases beyond  $Q_f$  – factor of 70. Also in this method, the accelerating gain ‘ $x$ ’ has a certain range of values within which re-closure of the circuit breaker on the DG side will not occur. This optimum range of accelerating gain will vary with the quality factor of the load connected at the PCC. In this case, for the given load value in table 1, the optimum range of accelerating gain is 7.5 to 11.5. The detection time and damping ability of this method improves as the value of ‘ $x$ ’ increases progressively from 7.5 to 11.5. Beyond this range of ‘ $x$ ’, the circuit breaker on the DG side re-closes which gives rise to greater disturbances that can’t be allowed to flow into the load. The results for Mod – SMFS method is shown for  $x = 11.5$  which gives the best detection time and ability to damp out disturbances after islanding.

Thus, the following table summarizes the various parameters or criterion based on which the comparison between the SMFS and Mod – SMFS islanding detection methods has been done:-

TABLE 2

COMPARATIVE STUDY BETWEEN SMFS AND MOD – SMFS ISLANDING METHODS

Comparison criteria	SMFS Detection Method	Mod – SMFS Detection Method
Detection Time for voltage wave	0.30 seconds	0.15 Seconds
Detection Time for current wave	0.15 Seconds	0.05 Seconds
Non-Detection Zone	Big NDZ (increases beyond $Q_f = 2.5$ )	Small NDZ (increases beyond $Q_f = 70$ )
DG side CB re-closing	Re-closing occurs (disturbance is more)	No re-closing for $x = 7.5$ to $x = 11.5$ for given RLC load
Phase shift in reference current wave	Not noticeable after islanding occurs	Noticeable after islanding occurs
Transient Stability	Less	More

## IV. CONCLUSION

Thus, from the above comparative analysis between SMFS and Mod – SMFS islanding detection methods, it has been found that Mod – SMFS method is much better as compared to the original SMFS method as it detects an islanding situation in the grid in almost half the time taken by SMFS method due to the additional phase shift  $\Theta_0$  and the accelerating gain ‘ $x$ ’. Because of these two extra factors, the phase shift in the reference waveform is much more conspicuous after islanding as compared to that of the SMFS method where the phase shift after islanding in the reference current wave is very small, hence resulting in slower detection speed. Also, the Mod – SMFS method shows better transient stability than SMFS method and hence, the power quality is hampered to a relatively lesser extent.

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Further work on this can be carried out by analysing the Mod – SMFS method by studying the effect of the various parameters in equation 2 on the NDZ and detection time.

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