Islanding Detection using Improved SMS Method in Grid Connected Converters

Master of Technology
in
Power Systems

by

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(2014PES5065)

Under the supervision of

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Malaviya National Institute of Technology, Jaipur
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This Dissertation is submitted in partial fulfillment of the requirements
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CANDIDATE'S DECLARATION

I hereby certify that the work which is presented in the Dissertation entitled **"Islanding Detection Using Improved SMS Method in Grid Connected Converters",** in partial fulfillment of the requirements for the award of the **Degree of Master of Technology** is submitted in the **Department of Electrical Engineering**, Malaviya National Institute of Technology Jaipur, under the supervision of Prof. Manoj Fozdar, Department of Electrical Engineering, Malaviya National Institute of Technology Jaipur.

The matter presented in this dissertation embodies the results of own work and studies carried out by me and have not been submitted for the award of any other degree of this institute or any other institute.

Vikram Singh
2014PES5065

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date

Prof. Manoj Fozdar
Supervisor

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Abstract

The increase in electricity demand and global pressure for cleaner energy has encouraged the integration of Distributed Generation (DG) technology in the power system. DG units are increasing expeditiously and majority of them are connected with distribution network to deliver power to the local load as well as the main network**.** However, for maximum utilization of DGs few issues have to be discussed. Islanding condition is a standout amongst the most vital concern in this context. When the supply from the main grid is cut-off due to unpredictable abnormalities such as short- circuit or equipment failure but the DG continues to feed power into the distribution networks, islanding operation of DG occurs. Accurate detection of Islanding and prompt isolation of DG from the distribution network is necessary because of its negative effects such as power quality degradation, out of phase reclosing etc. Various techniques of islanding detection have been suggested in the literature. Remote techniques are accurate but expensive to implement whereas passive techniques tend to have large NDZ (Non-Detection Zone). To eliminate these limitations of remote and passive techniques, active techniques are used which reduces the NDZ considerably. Conventional SMS method is categorized as one of the active method. In this thesis, a comparative study of SMS and its improved variant I-SMS is done. Both methods were tested on utility interactive DG system, consisting of an inverter and a local parallel RLC load. The comparison is carried out on the basis of *run-on time* parameter. The results obtained are found to be promising in nature as time taken to identify islanding is less with I-SMS method. NDZ for I-SMS method was also found to be reduced significantly due to the added phase shift introduced in converter output current of I-SMS. This shows the robustness of I-SMS method and its role in reducing the run-on time and increasing the speed of islanding detection.

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Abbreviations

DG	Distributed Generation
DER	Distributed Energy Resources
IEEE	Institute Of Electrical And Electronics Engineers
NDZ	Non- Detection Zone
PV	Photo-Voltaic
PCC	Point Of Common Coupling
PLCC	Power Line Carrier Communication
Q_f	Quality Factor Of RLC Load
SCADA	Supervisory Control And Data Aquisition
EPS	Electric Power System
Vmax	Maximum Voltage
Vmin	Minimum Voltage
IDM	Islanding Detection Method
PLL	Phase Locked Loop
PJD	Phase Jump Detection
OFR	Over Frequency Relay
UFR	Under Frequency Relay
ROCOF	Rate Of Change Of Frequency
VU	Voltage Unbalance
AFD	Active Frequency Drift
THD	Total Harmonic Distortion
RPS	Reactive Power Shift
SVS	Sandia Voltage Shift
SFS	Sandia Frequency Shift
Cf	Chopping Factor

CHAPTER 1
INTRODUCTION

Recently, more focus is shifted towards non-conventional i.e. renewable resources like wind, solar, fuel cells etc. because of the increase in consumption of energy around the world and the depletion of non- renewable energy resources. Since the last decade, non-conventional energy sources have been comprehensively utilized as Distributed Generation (DG) as they are eco-friendly and cause less CO_2 emission and therefore have less impact on the environment. Thus the concept of DG introduces a transformation from centralized generation of power to distributed generation. Earlier, there was no active source that can generate power in a distribution system. As a result, it cannot get power in condition of an upstream fault in transmission line but with DG, this condition is now possible. DGs are the small-scale power generating resources and may consist of wind, photovoltaic, bio-mass, fuel cells etc. They are mainly utilised to generate power in grid connected as well as off- grid connected mode and can transfer the power to main grid in off-peak hours through grid-connected converters. But, the introduction of DG forms some issues related to the stability and power quality in nearby utility. These issues need to be solved before employing DG as an indispensible component of power utilities. It can lead to certain problems associated with protection such as selectivity problem at the time of faults, failed auto reclosing and sensitivity problems created by decreased fault current because of utilization of DG.

The most problematic issue in the present scenario is islanding condition. Islanding is an "electrical phenomenon that occurs when the energy supplied by the main utility gets interrupted due to several factors but DG continues to energize some or the entire load" [2]. Islanding can be intentional as well as unintentional. Whereas intentional/planned islanding can be used for repair/ maintenance purposes and could potentially bring benefits to the owner of DG by giving additional revenue due to increased power supplied in case of power outage, an unintentional islanding is not desirable as there are various issues associated with it [1].

1.1 Issues with DG penetration

The issues that may arise with the penetration of DG can be summarized as:

1.1.1 Reverse Power Flow

There are many benefits associated with introduction of DGs at the load side i.e. they can supply some or all of the required power for increased demand and reduce the load demand. DGs can lead to the reduction in the line losses. This condition is satisfied as long as the DG generation balances with the load demand so that the net flow of power will be from substation to load. But as the penetration level of DGs increases, there may be time when the power generated by DGs surpasses the local demand resulting the power flow to change its direction from load to substation. This condition is not usually anticipated in design of power system and it will affect the distribution feeder protection schemes equipped with directional over current relays.

1.1.2 Islanded Mode of Operation

Islanding occurs when a section of power system remains energized by DG while remain disconnected from the main utility. Its behaviour is uncertain as the island is not controlled. As a result parameters of power system such as voltage, frequency may violate recommended limits. There is a probability of out-of-phase reclosing and devices may get damaged due to high transient inrush currents. Therefore, it is desirable to de-energize the islanded systems expeditiously.

As per IEEE Standard 1547, for all possible conditions of islanding, DG should be able to sense it and discontinue to feed the region within 2s for small voltage signal variations at PCC, whereas for voltage changes above 1.3 p.u. or below 0.5 p.u. it should be detected within 0.16 sec. as indicated in Table 1.1.

Table 1.1 "DG System Response to Abnormal Voltages" [3]

IEEE Standard 1547	
Voltage Range (%)	**Disconnection time (sec)**
$V \leq 50$	0.16
$50 \leq V \leq 88$	2
$110 \leq V \leq 120$	1
$V \geq 120$	0.16

1.2 Need for Reliable Islanding Detection

[1] **Safety of line worker**- As the line workers are unaware that the DG is still feeding the load after the primary (i.e. main utility) sources have been opened, it poses a serious threat to the maintenance personnel.

[2] **Frequency and Voltage threshold**- After the disconnection of main utility, the voltage and frequency of the DGs cannot be maintained inside the threshold limits and this may result into unacceptable range of voltage and frequency. This may cause damage to the customer equipments as they are designed for specific range of voltage and frequency.

[3] **Power Quality**- When the load is fed power by Distributed Generation in case of islanding, the quality of the power may be inferior to the case when the power is supplied through main utility. Lowered quality of power may affect the loads adversely.

[4] **Out of phase reclosing**- After the island formation out-of-phase reclosing can cause tripping of line or it can damage the distribution system or any other equipment which is connected as the returning voltage after islanding develops considerable amount of mechanical torques and large currents. These are capable of damaging the generators and prime movers.

Due to the above mentioned problems, it is necessary to identify condition of islanding promptly and effectively.

1.3 Organization of Dissertation

This Dissertation consists of six chapters:

Chapter 1 explains the difference between traditional distribution systems and distribution systems including Distributed Generations (DG). It explains the need for integration of Distributed Generations into Distributed systems followed by one of the most important issue associated with the operation of DG i.e. "Islanding". It also addresses the problems associated with islanding and the importance of reliable detection of islanding.

Chapter 2 presents literature review of several islanding detection techniques proposed by various researchers.

Chapter 3 is dedicated to the various techniques used for islanding detection, their advantages and limitations and the assessment of each index used in detection of islanding based on its effectiveness.

Chapter 4 describes the problem formulation i.e. investigation of proposed islanding detection technique. It contains the mathematical formulation of the proposed islanding detection method and comparative study of other method which is used for islanding detection.

Chapter 5 is devoted to simulation model and all subsystems of the model which is used for islanding detection. Simulation results are then presented and discussed.

Chapter 6 summarizes the conclusions obtained from the results followed by some scope for future work.

CHAPTER 2
LITERATURE REVIEW

The various issues associated with islanding necessitate its prompt identification. Several techniques of islanding detection have been proposed earlier. A significant number of research workers have given their contributions in this field. Passive techniques make use of parameters like voltage, frequency etc. to identify islanding. Active methods attempt to inject disturbances at PCC to detect the condition of islanding. Hybrid methods utilize both passive and active methods.

Chiang *et al*. [1] proposed an active detection scheme in which the inverter acts as a virtual resistor with its frequency of operation somewhat more or less than fundamental frequency of main grid voltage. When the utility is connected, the function of virtual resistor is not triggered. But when the grid is lost inverter will work as a virtual resistor with frequency away from the fundamental frequency resulting a change in the amplitude and frequency of load voltage, thus detecting the condition of islanding.

Several islanding control standards like IEEE Std. 929-2000 [2], IEEE Std. 1547.1-2005 [3-4] had been proposed for grid interactive system. These standards contain equipment and functions which are essential to ensure compatible operation of PV systems. It also includes factors related to protection of equipment, safety of personnel and power quality.

A power line signalling scheme for detection of islanding condition is discussed in [6-8]. It includes considerations regarding highest anti-islanding efficiency. An inexpensive receiver is suggested for PLCC system which shows the practicability of PLCC based islanding prevention.

Ropp *et al*. [12] suggested the phase criteria for various anti-islanding techniques like OFR/UFR, PJD, SMS, AFD and SFS and proved experimentally that SFS method is most effective. It also describes the role of NDZ in islanding detection.

Lopes *et al*. [13] discussed a load parameter space utilizing resonant frequency and quality factor (Q_f against f_0) to represent the NDZ for any RLC loads because the NDZ of passive methods can be explained in power imbalance space (ΔP *v/s* ΔQ) but for active techniques it does not give promising results. It suggested equations representing NDZs in Q_f v/s f_0 space.

Kulmala *et al.*[14] discussed the difficulties associated with islanding protection of DG in distribution network. Simulations are performed in PSCAD environment. Some problems were observed regarding sensitivity and the possibility of nuisance tripping is also examined.

Two parameters of islanding detection viz., voltage unbalance and THD of current are described in [15]. The method proposed merges the conventional parameters with new parameters .The techniques were validated using radial network of IEEE 34 bus.

S. J. Huang and F. S. Pai [16] discussed a method of islanding identification depending on the magnitude and sign deviation in $\partial f/\partial P$. This technique does not get effected by disturbances like load change. The results show that possibility of false alarm is low.

Hung *et al*. [17] described a method based on automatic phase shift .The traditional frequency shift methods like AFD and SMS will not be effective in case of certain paralleled RLC loads. To solve this problem APS is projected in this paper. In this scheme phase shift is carried out of inverter current. When grid failure occurs the phase shift method continue to deviate the inverter voltage frequency till protection circuitry is activated.

A. Yafaoui, Bin Wu and S. Kouro [18] addressed an improved version of the Active Frequency Drift Islanding Methods. This scheme develops THD which is 30% less than classic AFD, making islanding detection quick and decreased non-detection zone.

Wang *et al*. [19] attempted a power line signalling scheme to identify the islanding. In this method a signal is transmitted from substation to DG and any interruption in signal results in islanding.

Kirtley *et al*. [20] proposed a method to identify islanding by monitoring P-V characteristics of DG and load and for the protection Over/under voltage relay is used.

In Ref. [21] the author reviewed the various passive islanding detection techniques based on renewable DG. It also investigates the performance of schemes with respect to degraded power quality that takes place due to increased penetration of renewable distributed generators in utility grid. The rate of change of output power [22], rate of change of frequency [23], voltage unbalance [24] and harmonic distortion [25] are some cases of passive techniques.

A. Samui and S. R. Samantaray [26] proposed a new technique of islanding detection by means of rate of change of phase angle difference (ROCPAD) which works satisfactorily where ROCOF fails to identify. It retrieves the current and voltage at DG site and calculates the amplitude, phase and frequency utilizing algorithm based on synchronous transformation. At last, it calculates the difference in phase angle and ROCPAD to indicate islanding detection.

Hanif *et al*. [27] employed the local anti-islanding protection methods in a inverter based DG. It also gives a hint of technique based on wavelet transform which diminishes the NDZ to zero and the need to form accurate algorithm with careful threshold limits to avoid nuisance tripping.

Zeineldin *et al*. [28] discussed a method applicable to both inverter as well as synchronous based DG.A random forest (RF) method is applied to identify islanding conditions. The islanding and non-islanding conditions were created for IEEE 34-bus system. The *k*-fold cross validation is used for the validation of proposed method. Although, the passive methods are easy, but, suffers from the severe limitation of identifying the islanding when the load and generation are nearly closed in an islanded system. This limitation is eliminated by using active methods, which can sense the islanding even when there is a balance between generation and demand. Some of the proposed active methods are as follows: Reactive power export error detection method, Impedance measurement method [23], Slip-mode frequency shift method (SMS) [13], Active frequency drift (AFD) [29], Automatic phase-shift method (APS) [30-31].

Byunggyu *et al*. [32] proposed SMS and RPV (Reactive Power Variation) methods to identify islanding on the basis of NDZ. Both of these schemes are obtained analytically by modelling and validated by simulation. The results show that islanding is detected within 2 seconds with good power quality and power factor above 0.99. In [33] the author proposed an improved version of the SMS by adding additional shift in phase to stimulate the action of islanding detection.

B. Yu *et al*. [34] presented a hybrid novel active anti-islanding technique, combination of active frequency drift and SMS. The proposed scheme validates the results as per the IEEE standard 1547. Hybrid methods utilize both passive as well as active methods to overcome the problems of both techniques.

Mahat *et al.* [35] employed a passive method (rate of voltage change) to initiate an active method (real power shift) in case the passive method is unable to discriminate amid islanding and non-islanding conditions.

Menon *et al.* [36] suggested a hybrid method based on voltage unbalance and frequency set point for synchronously rotating DGs. It combines the principles of positive feedback and voltage unbalance to identify islanding.

Gokay Bayrak [37] presented a novel remote islanding detection scheme for photo-voltaic based DG systems. This scheme supervises and manages the grid and inverter output with the help of circuit breakers. The algorithm was realized by a FPGA board and presents a low cost solution.

Kolwalkar *et al.*[38] proposed NDZ for three common anti-islanding schemes viz. U/O voltage, U/O frequency and PJD for inverter based DGs with their equations obtained analytically and certified by simulation later. A generic system is also described for anti-islanding study.

Teoh *et al*. [39] analyzed the several anti-islanding techniques used in photo-voltaic grid-connected systems and also compared different schemes with their advantages and disadvantages.

Ashour *et al*. [40] compared passive methods, OUV/OUF and wavelet based method. Although, the OUV/OUF is easy but it has large NDZ zones. On the other hand, wavelet based can detect even if mismatch is small. Also, these schemes have shown no effect on power quality.

2.1 CRITICAL REVIEW

It is challenging to propose a universal scheme for islanding detection as most of the strategies to identify islanding are decided by the type of application and system dependent factors. This study suggested that the cost of operation and equipment are major factors for the selection of anti-islanding scheme so that minimal compromise is achieved between cost and power quality. Also, it must be ensured that the control circuitry is reliable, accurate and minimising the safety risks as well.

CHAPTER 3

ISLANDING DETECTION TECHNIQUES

Islanding is described as the situation when a section of the power system including both the generation and the load gets detached from the remaining system but remain energised with the help of DGs. As per IEEE 1547, IEEE 929-2000,and IEC 62116 Standards [5], DER systems should detect fault condition for the purpose of safety and detach itself within a fixed interval of time, ranging from 0.1-2 second, which depends on the relevant standard and on the category of fault [2-5] .The main ideology of identifying a situation of islanding is to observe the output parameters of DG like frequency, voltage, power etc. and determine whether condition of islanding has occurred or not from shift in the values of these parameters. It is a difficult task to compare various IDM's (Islanding Detection Methods) as each method operates more efficiently than other methods in a particular situation and system. For instance, techniques that depend on frequency shift will work effectively for inverter based DG's, whereas techniques that depend on terminal voltage change will be ideal in case of Synchronous based DG's.

Table 3.1 DG Types

Technology	DG Type
Photovoltaic	Inverter-Based DG
Wind Turbines	Doubly Fed Induction Generator
Fuel Cells	Inverter Based DG
Geothermal	Synchronous Based DG
Gas Turbines	Inverter Based DG
Hydro	Synchronous Based DG

In the recent years, several methods of islanding detection had been suggested with an ultimate objective of curtailing the NDZ. NDZ is the area in active and reactive mismatch of power between the power supplied by the DG unit in the island and the load demand where the islanding will not be detected.

Islanding detection techniques can be broadly classified as remote and local techniques. Local methods are categorised as active, passive and hybrid methods as indicated in Fig. 3.1

Methods based on communication i.e. remote methods are very accurate but are the most expensive as compared to other methods. Active schemes rely on deliberately injecting some disturbance in the system. Passive methods are straightforward and rely on measurable parameters i.e. frequency, voltage etc., at the PCC to identify the Islanding phenomenon.

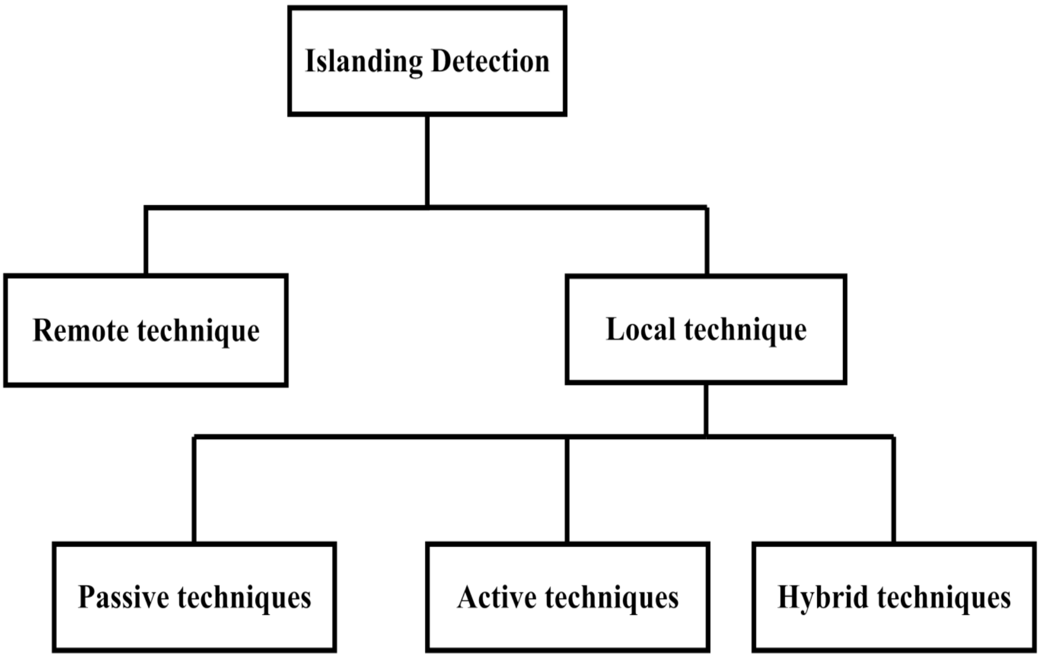

Figure 3.1 Islanding Detection Techniques

3.1 Remote Islanding Detection Techniques

These techniques depend on the interaction between DGs and utilities. Despite the fact that the reliability of remote methods is large as compared to local techniques, they are costly to employ and therefore, not feasible. These techniques may be categorised as:

3.1.1 Transfer Trip Scheme

The main intention of this scheme is to observe the situation of all the circuit breakers and reclosers that could result into islanding of distribution system by SCADA. When there is a disconnection at the substation, the transfer trip scheme find out the areas which gets islanded and forward the suitable indication to DGs to cease the service. This method is advantageous with radial topology that has limited number of circuit breakers and less number of DG sources in which the state of the system can be directed to the DG precisely from every monitoring point. System can be observed in Fig. 3.2.

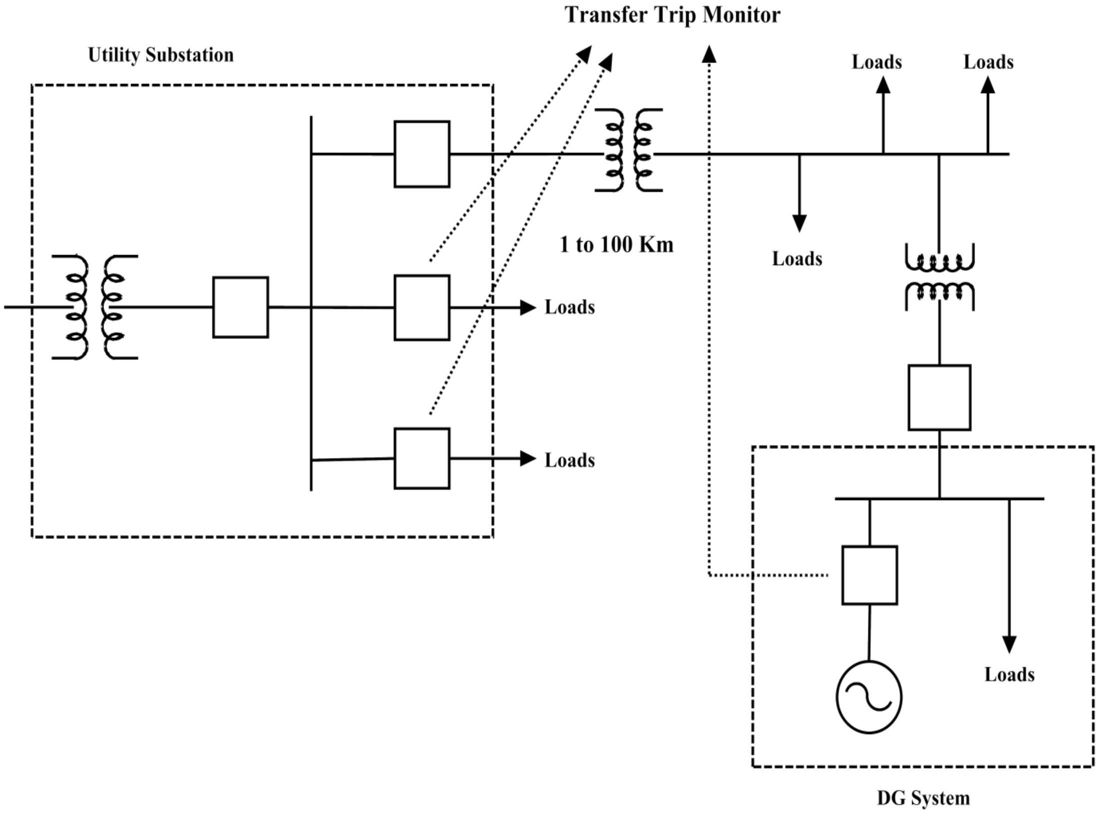

Figure 3.2 Transfer Trip Islanding Detection

The weakness of this scheme is its high cost of implementation. Also, as the complexity in the system increases this method may become obsolete, and need relocation or updating. With a large system and several DG units installed, implementation of this method becomes impractical. If this method is utilised in a correct manner in an uncomplicated network there will no NDZ.

3.1.2 Power Line Carrier Communication (PLCC)

The use of PLCC is to send communication signal of low energy through the power line itself. Since the power line is utilised as a channel of communication, PLCC signal can be utilized to carry out the test of continuity for the line. The existence or non-existence of PLCC signal can be detected by a simple device installed at the PCC on the customer side. In case the PLCC signal does not exist, this implies a break in the line continuity and instruction is given to inverter to cease operation. A PLCC receiver is used to receive the signal from the transmitter along the power line. Whenever there is a loss of PLCC signal, the receiver instructs the inverters to stop its functioning or it unlock its own switch to disconnect the local load and inverter [7-9]. The strength of this method is that it has no impact on the output power quality of PV inverter. Also, it does not get affected by the quantity of inverters and level of penetration with any type of DG.

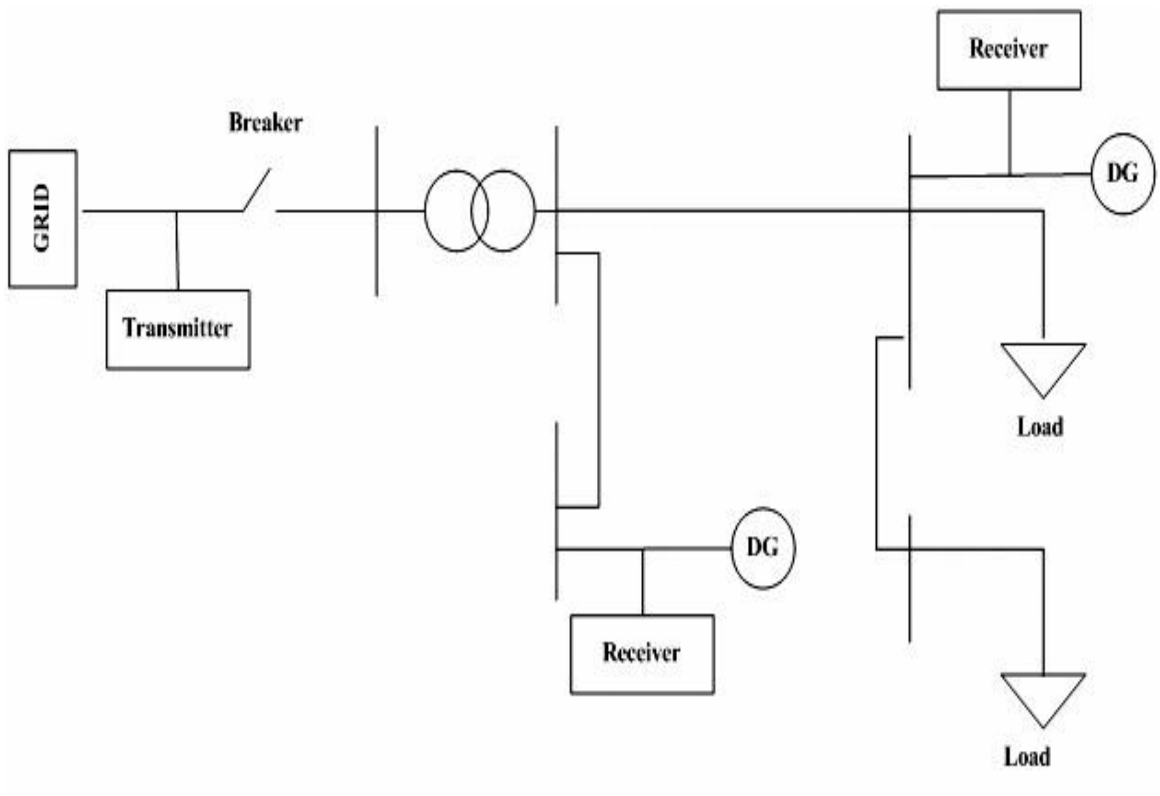

Figure 3.3 Power Line Signalling Scheme

One pre- requisite of this method is utility system must have a PLCC transmitter on the which is capable of sending signals to the inverters through the distribution system as indicated in Fig. 3.3. These transmitters are available but they are slightly uncommon and quite costly as well.

However, similar to TT (Transfer Trip) this method also has practical implementation problems as the system gets larger and complex.

3.2 Local Detection Techniques

These techniques are largely utilized to identify the islanding on the basis of assessment of parameters of the system at DG site. These parameters can be voltage, frequency, current and harmonic distortion. These methods are classified as active, passive and hybrid methods. The usages of these methods have increased briskly during the recent years.

3.2.1 Non-Detection Zone (NDZ)

NDZ are the regions where an islanding detection technique fails to identify the condition of islanding. Practically, there is always some mismatch in power between the load of area electric power system and the DG output. The mismatching in load is given by (R+ΔR, L+ΔL, C+ΔC). In grid connected mode, any imbalance in the power will be taken care of by the grid i.e. $\Delta P \neq 0, \Delta Q \neq 0$. Whereas, in the off-grid mode the new values of voltage and frequency will be V_{new} and f_{new} .

When the mismatch in power $(\Delta P, \Delta Q)$ is large enough the V_{new} *and* f_{new} are outside the specified ranges and U/O voltage and U/O frequency protection will operate to prevent the operation of islanding. The equations showing the correlation between the power imbalance thresholds and voltage/frequency thresholds are established below:

$$\left[\frac{V}{V_{\max}}\right]^2 - 1 \leq \left(\frac{\Delta P}{P}\right) \leq \left[\frac{V}{V_{\min}}\right]^2 - 1 \tag{3.1}$$

$$Q_f\left(1 - \left[\frac{f}{f_{\min}}\right]^2\right) \leq \left(\frac{\Delta Q}{P}\right) \leq Q_f\left(1 - \left[\frac{f}{f_{\max}}\right]^2\right) \tag{3.2}$$

where,

V_{max} - over voltage threshold, V_{min} - under voltage threshold

f_{max} - over frequency threshold, f_{min} – under frequency thresholds.

Usually, V_{max} = 110% of V, V_{min} = 88% of V, f_{max} = 60.5Hz, f_{min} =59.3 Hz.

For Quality factor, Q_f = 2.5 we have,

$$-17.36\% \le \left(\frac{\Delta P}{P}\right) \le 29.13\% \tag{3.3}$$

$$-5.94\% \le \left(\frac{\Delta Q}{P}\right) \le 4.11\% \tag{3.4}$$

The equations (3.1) and (3.2) indicates that if the mismatch in active and reactive power exists inside the thresholds mentioned, which are function of frequency and voltage thresholds respectively, the final frequency and voltage will continue to exist within the ranges even in the case of islanding i.e. grid disconnected. Therefore an island is formed and continues to exist without being noticed. The equations (3.1) and (3.2) can create an area that is characterized as NDZ as shown in Fig. 3.4.

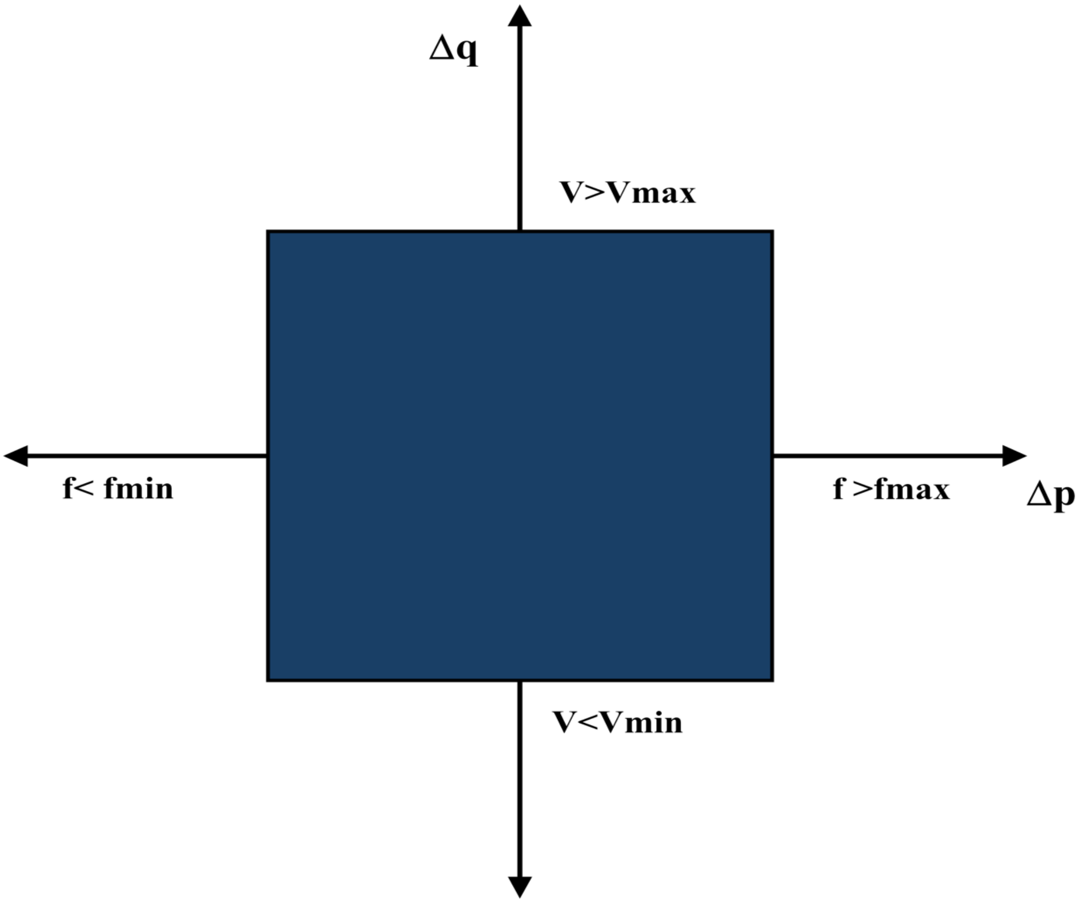

Figure 3.4 NDZ of typical voltage and frequency protection

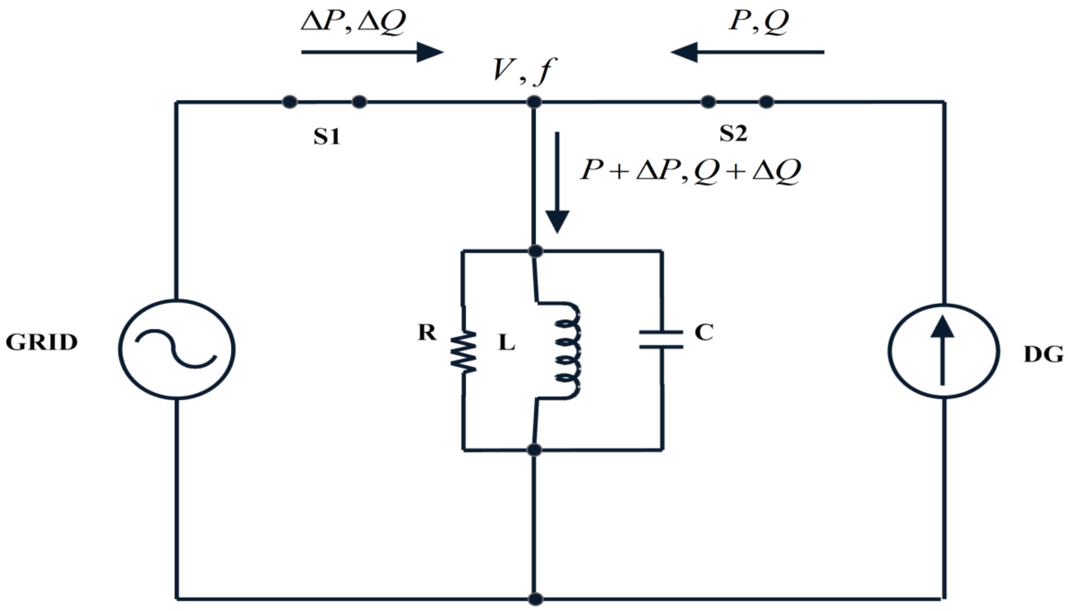

Figure 3.5 System considered for Anti-Islanding Study

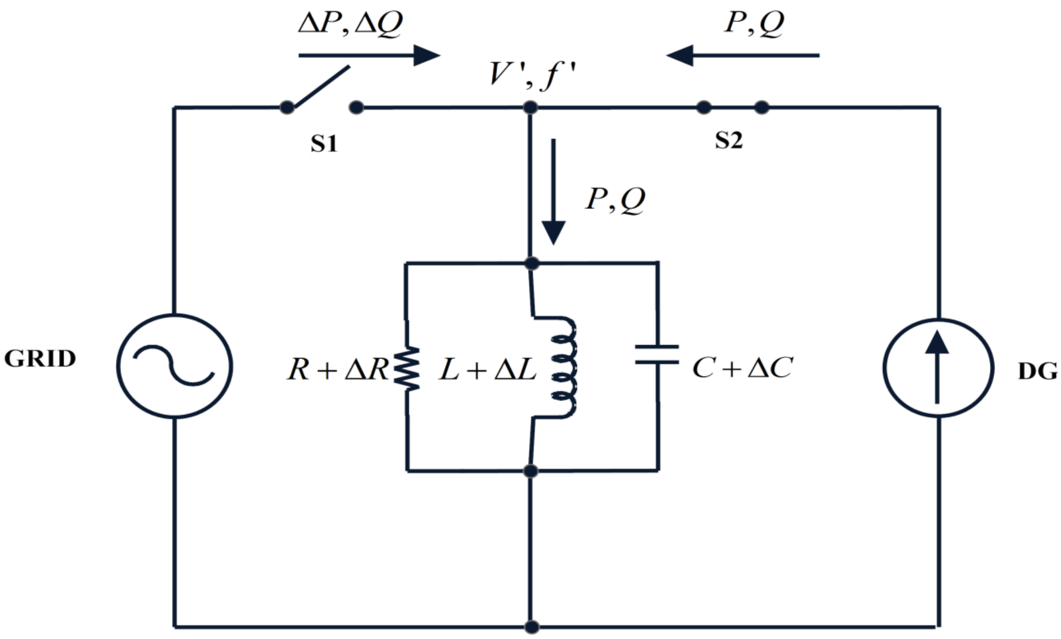

Figure 3.6 DG and RLC circuit post grid disconnection

3.2.2 Passive Techniques

Passive techniques measure current, voltage, harmonics and phase information at PCC or DGs terminals to sense whether an islanding has occurred or not. The values of these parameters differ highly when the system is islanded. The most difficult thing in using passive detection techniques is setting an appropriate threshold that can effectively determine the difference between islanded condition and natural power system variations. Appropriate precautions need to be considered while setting the threshold value for the purpose of discriminate islanding from other perturbations present in the system as small value of threshold setting can lead to nuisance tripping and high value of threshold setting can lead to failure of islanding detection. These techniques are very cost effective. These techniques are quick in identifying islanding. Also, they do not add any perturbation deliberately inside the system but they tend to have a considerably large NDZ.

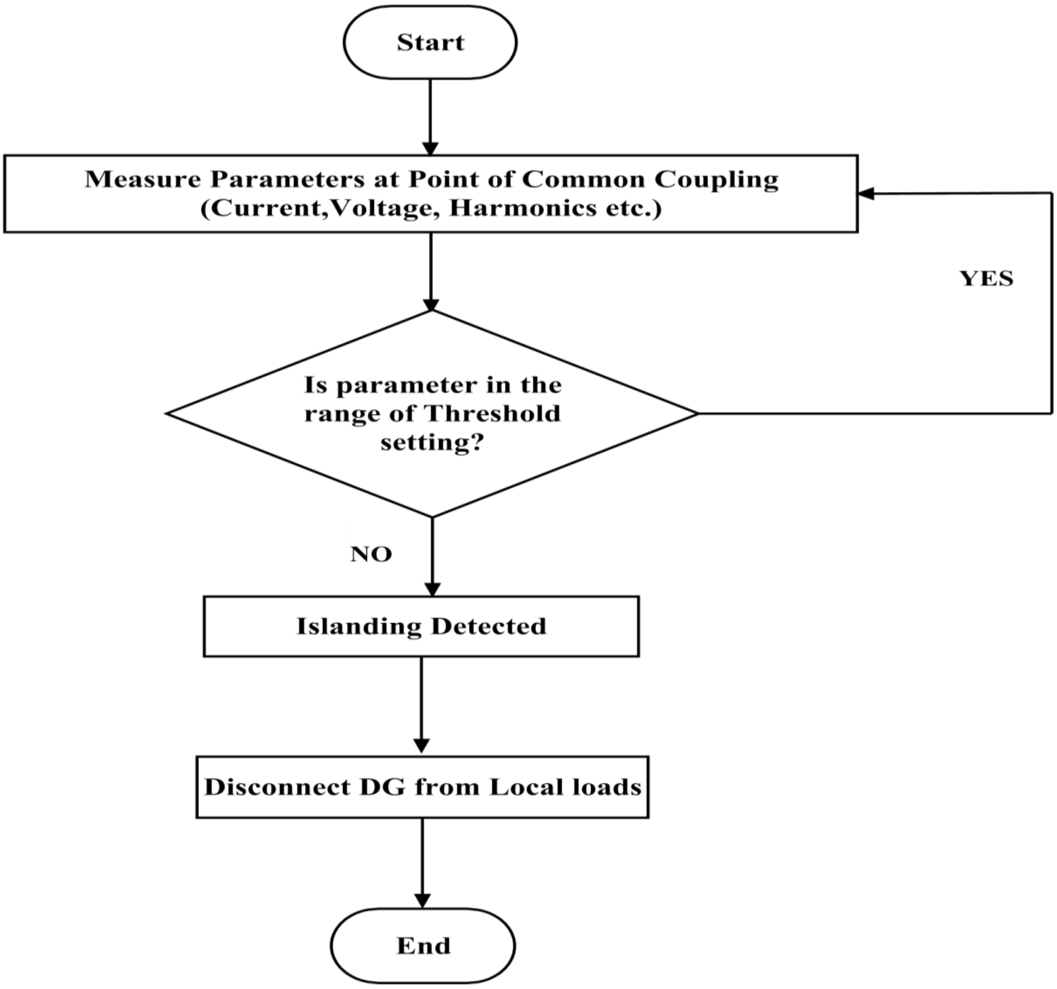

Figure 3.7 Flowchart of Passive method

There are various passive techniques which have been used for islanding detection. Some of them are as follows:

3.2.2.1 Rate of change of power (*dP/dt*) [10]

Once the system is islanded, the ROCOP at the DG side will be much larger as compared to the ROCOP prior to the islanding conditions for the same percentage of change in load.

3.2.2.2 Rate of change of frequency (*df/dt*)

This islanding detection technique relies on the frequency at the PCC to detect islanding. Deviation in frequency depends on the mismatch in reactive power. Under normal operation i.e. in grid connected mode, since there is no mismatch between consumed and generated reactive power, there is no deviation in the frequency. However, in islanding mode there is a mismatch between reactive power developed by DG and consumed by the local load in the island. Depending on the ratio of the mismatch, the frequency will depart to a certain level. In case, there is a large mismatch, then the frequency will depart beyond a pre-defined value of threshold and the relay will trip followed by the disconnection of DG. This method of islanding detection is extremely reliable in case of large power imbalance but it cannot operate if capacity of DGs is same to that of the local loads. When the DG is in the islanded state the ROCOF will be very high.

3.2.2.3 Rate of change of frequency over power (*df/dp*) [11]

For a small system of generation the value of *df/dp* is greater as compared to power system of large capacity. Under conditions of slight power imbalance between the local loads and DG, rate of change of frequency over power is more precise to detect the condition of islanding than ROCOF *(df/dt)*.

3.2.2.4 Voltage Unbalance and Total Harmonic Distortion (THD) [14]

In this method two criterion of islanding detection of DG is discussed viz. Voltage Unbalance and THD of the current.

VU at the DG terminals is defined by:

$$VU = \frac{V_{NS}}{V_{PS}} \tag{3.5}$$

where,

V_{NS}- negative sequence component of DG output voltage

V_{PS}- positive sequence component of DG output voltage.

Also, as a result of disconnection of main utility change of loading occurs .This can lead to variation in the harmonics of current. Total Harmonic Distortion of current is given by:

$$THD = \frac{\sqrt{\sum_{h=2}^{H} {I_h}^2}}{I_1} \times 100 \tag{3.6}$$

where,

I_h is the rms value of h^{th} harmonic component

I_1 is the rms value of fundamental component.

When islanding occurs DG takes control of the local load. As a result, the loading of DG is immediately modified. This immediate shift results into voltage fluctuations and can also leads to current harmonics. At every interval of time voltage unbalance of 3-Ø voltages and THD of phase current are calculated. These calculated values are then compared with threshold. Islanding is detected when these values violate the threshold value. However, for large values of Quality factor this scheme fails to act. Also, the setting of threshold is a cumbersome task.

3.2.2.5 Voltage Phase Jump Detection (PJD)

PJD method involves observation of error in phase between output current of inverter and PCC voltage. The waveform of PCC voltage and output current of inverter are kept in synchronization by utilising an analog or digital PLL. When the islanding takes place, the PCC voltage deviates from the grid voltage in order to compensate for the variation in power and also to manage the phase angle of load. However, the output current of inverter remains invariable as it follows the PLL waveform. This leads to a jump in voltage phase as indicated in Fig. 3.8. The phase slip is calculated and once the phase error surpasses the threshold value condition of islanding is identified.

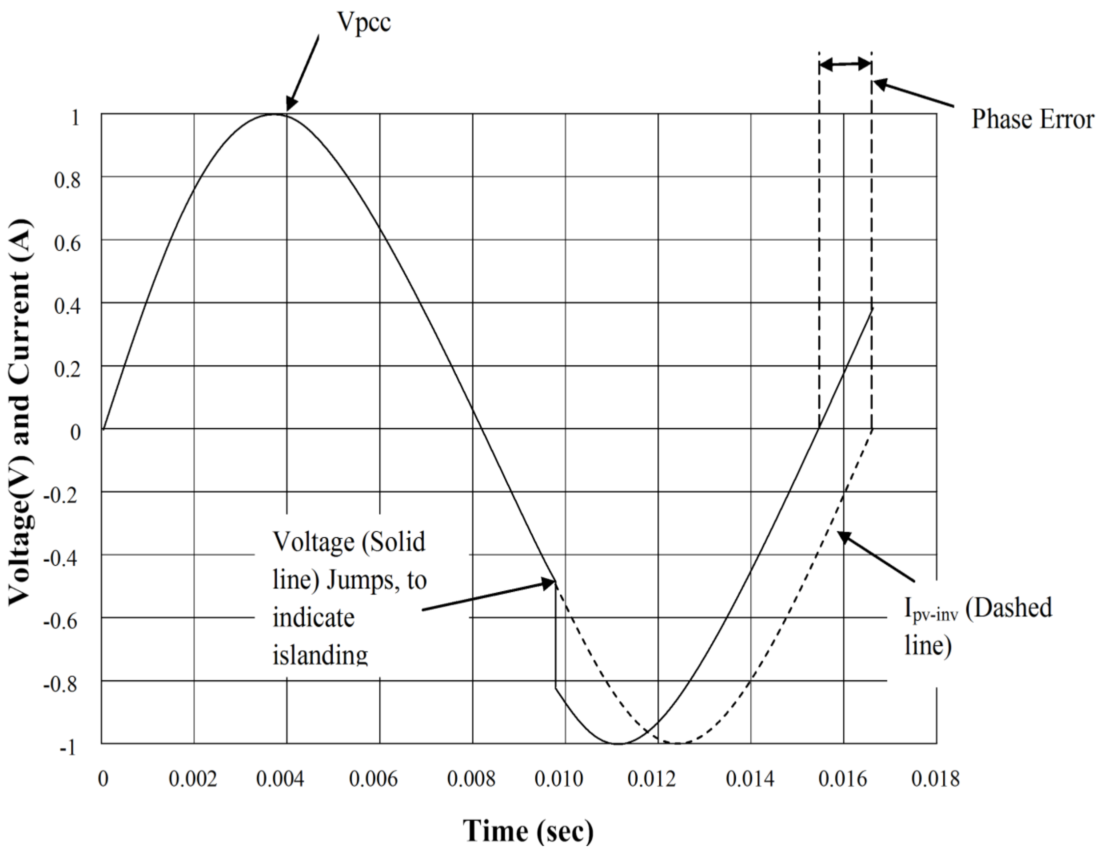

Figure 3.8 Phase Jump Detection Method

PJD method is simple to use as PLL required for the synchronization of DG's with the utility mains is available. But this method have some issues regarding nuisance tripping because fixing of threshold point is a challenging task. Also this scheme of islanding detection does not affect transient response of system and power quality.

3.2.3 Active Techniques

These techniques are based on intentionally injecting disturbances with power systems operation. Islanding can be identified even in case of exact match between load and generation with the help of active methods, which would not be possible with passive techniques. The operation of these techniques includes injection of a disturbance or perturbation signal. This perturbation is introduced in the current waveform which in turn forces the parameters of system out of the limits in case of islanding. The basic concept behind these techniques is that a little disturbance can cause a considerable shift in parameters of the system in case of islanding, though the effect of perturbation will be small before islanding phenomenon occurs i.e. when DG is working in parallelism of grid. For the purpose to curtail NDZ, especially when the DG systems have almost the same capacity to that of the local loads i.e. almost perfect load generation condition, active techniques are utilised to identify the condition of islanding.

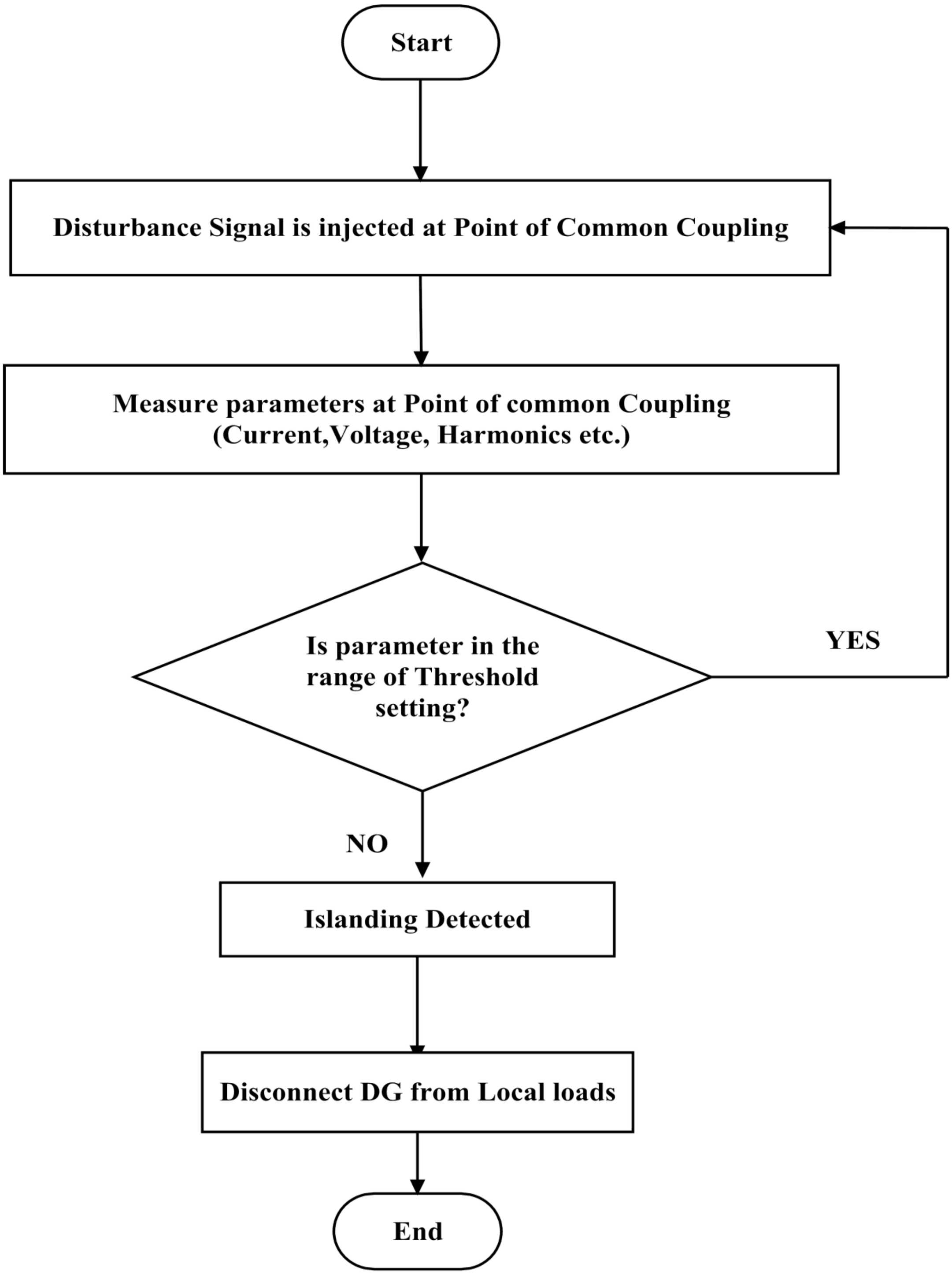

Figure 3.9 Flowchart of Active Method

3.2.3.1 Impedance Measurement Method

The basic concept remains similar to the passive technique where under conditions of islanding, system impedance changes. For direct measurement, an inductor is coupled across supply voltage in parallel and reduction in supply voltage and short circuit current is utilised to evaluate the impedance of source of the power system. But, in case of indirect method a signal of large frequency is introduced into the terminals of DG with the help of voltage divider. This signal of large frequency gets more powerful when the main utility is cut-off [12].

3.2.3.2 Reactive Power Export Error Detection (REED)

This method of islanding detection operates on the basis of flow of reactive power which is generated by DG at the PCC or the connection point of reed relay. The flow of reactive power can be managed until the main utility is attached. Islanding condition is detected when the level of reactive power falls below the pre-defined value. In case of synchronous generator based DG, the condition of islanding is identified by raising the internal induced voltage of DG meagrely and observing the corresponding change in the flow of reactive power and voltage at the junction where DG is attached to the distribution system. A significant variation in the terminal voltage while the flow of reactive power nearly staying at fixed value represents condition of islanding.

The main disadvantages of this technique includes it cannot be utilised where DG has to operate at unity pf condition. Also, the time required to sense islanding is large as compared to other active techniques.

3.2.3.3 Slip Mode Frequency Shift (SMS)

SMS is an inverter based method of islanding detection that utilizes a positive feedback control to make the source inverter unstable when an islanding condition occurs.

The variation in phase between the PCC voltage and output current of inverter is made to be zero normally in a PV inverter (i.e. unity pf). However, with SMS method, rather of being controlled to zero, this phase difference between voltage and current of the inverter is designed as a function of PCC voltage frequency.

SMS curve can be given by the equation:

$$\theta = \theta_m \left(\frac{\pi}{2} \frac{(f^{(k\text{-}1)} - f_n)}{(f_m - f_n)} \right) \tag{3.7}$$

where,

θ_m - maximum value of phase shift that exist at frequency f_m.

f_n - nominal frequency

$f^{(k-1)}$ - frequency of prior cycle.

SMS curve with θ_m=10 and f_m=53 Hz, is indicated in Fig. 3.10. The curve is designed in such a way that slope of the SMS curve should be larger as compared to the phase of load curve in the unstable area.

When the main grid gets cut-off the operation will shift towards the stable operating point via unstable region (indicated by red dots in Fig. 3.10). When the frequency of the inverter exceeds the setting value, islanding is detected.

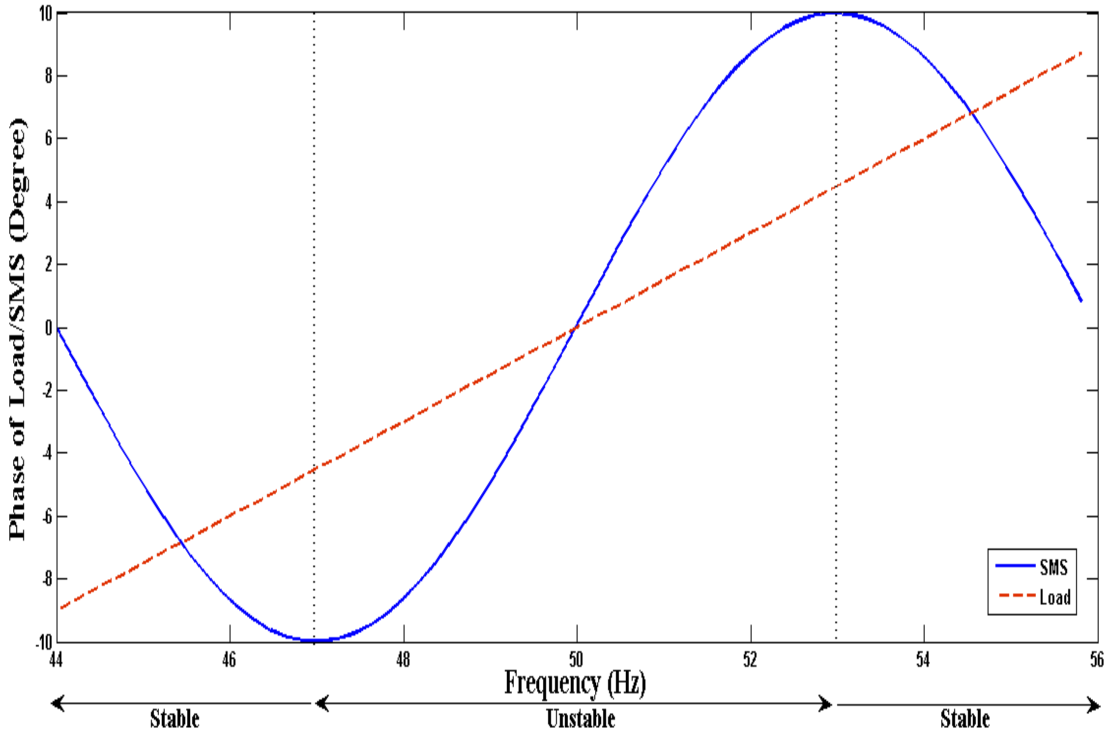

Figure 3.10 Phase response of DG and local load

The limitation of this method is that if the slope of the SMS line is larger than the phase angle of the load, condition of islanding may go unnoticed because of the presence of stable operating points inside the unstable region [13].

3.2.3.4 Active Frequency Drift(AFD)

The technique involved in the AFD or frequency bias technique involves forcing variations in the inverter's output utilising positive feedback so as to enhance the inverter current frequency.

This method uses the inverter current waveform which is inserted at the PCC. AFD method is only advantageous for pure resistive loads. During the period of grid connection, the voltage frequency is kept within the limits but otherwise,(i.e. during islanding) the voltage frequency at PCC will try to shift towards higher value thus attaining values more than f_0 .In both the conditions, the voltage lags by the fundamental component of current by angle θ_{AFD} .

When AFD is used with unvarying frequency drift, each cycle current is given by:

$$i_k = \sqrt{2}I \sin[2\pi(f_{vk-1} + \delta f)]t \tag{3.8}$$

Under islanding conditions and in the steady state, the inverter phase angle, θ_{inv} can be given by

$$\theta_{inv} = \frac{t_z / 2}{T_v} = \frac{\theta_{AFD}}{2\pi} \tag{3.9}$$

where,

t_z - dead time

T_v - duration of grid voltage.

where,

$$t_z = \left(\frac{1}{f_v} - \frac{1}{f_i} \right) = \left(\frac{1}{f} - \frac{1}{f + \delta f} \right) = \frac{\delta f}{f(f + \delta f)}$$

The inverter angle θ_{AFD} is given by

$$\theta_{AFD} = \pi f t_z = \frac{\pi\delta f}{f + \delta f} \tag{3.10}$$

Now, using the phase criterion $(\theta_{load} = \theta_{AFD})$

$$-\tan^{-1}\left[Q_f\left(\frac{f_0}{f_{is}}-\frac{f_{is}}{f_0}\right)\right]=\frac{\pi\delta f}{f_{is}+\delta f} \quad (3.11)$$

Therefore,

$$f_0^{\,2}-\frac{f_{is}\tan[\theta_{AFD}(f_{is})]}{Q_f}f_0-f_{is}^{\,2}=0 \quad (3.12)$$

For the purpose of calculating the NDZ of the AFD technique, the frequency of islanding is modified to the frequency of threshold (f_{min} or f_{max}) .Then, the Q_f value is changed and resonant frequency of load at the threshold of the NDZ is evaluated.

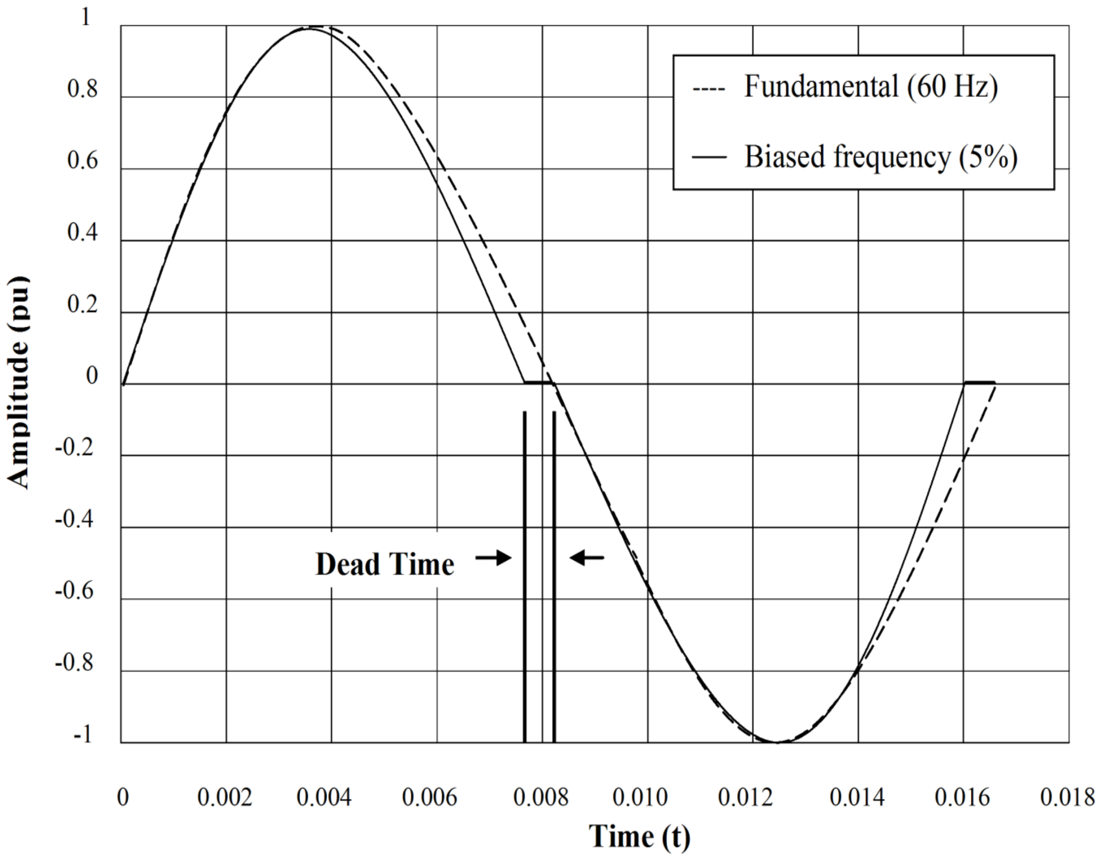

Figure 3.11 AFD Islanding Detection

In case of several inverters, all should use same type of AFD technique i.e. if one inverter utilises upward AFD then the rest of the inverters should also utilise upward technique. In case they use techniques which are contradictory to each other, it will result in cancelling the effect and method will be unsuccessful to identify the islanding. Also, the non-detection zone is comparatively large in contrast to other active methods.

3.2.3.5 Sandia Frequency Shift

This technique is an improved version of AFD method where a positive feedback is utilized to determine the chopping factor as in equation (13).

$$Cf = Cf_0 + K(f - f_0) \tag{3.13}$$

where,

Cf_0 - chopping factor in grid connected mode when there is no variation in frequency.
K - Positive feedback gain, f_0 -nominal frequency (60 Hz), f is measured frequency

When the main grid is linked the change in frequency is very minute and $(f - f_0)$ is almost negligible so the value of chopping fraction is small and can be neglected. But, during islanding DG unit comes in control and due to this frequency will vary to match the load resonance frequency. As a result chopping factor will increase until the inverter trips as per the above equation.

3.2.3.6 Sandia Voltage Shift

In this technique of islanding detection positive feedback is applied to the magnitude of voltage. This method is usually used in conjunction with SFS (Sandia frequency shift). This technique decreases the power output of inverter in order to reduce its voltage. Under ordinary circumstances i.e., during grid-connected mode, reduction in power has trivial effect on the output voltage. However, during islanding, there is a drop in voltage because of the reduction in power. This reduction in voltage is enhanced by the positive feedback until the under-voltage relay trips and detaches the DG unit from the system.

The main limitations associated with this technique are the decreased power quality due to positive feedback and reduction in efficiency of DG. Sandia voltage shift method can detect the islanding effectively when used with SFS and can be implemented with ease. Active techniques have advantage of small NDZ and accurate results but certain limitations are also associated with it like reduced power quality and slow detection time.

3.2.4 Hybrid Techniques

Hybrid islanding detection schemes include both the passive as well as active detection techniques. The hybrid method consists of a couple of stages to detect islanding to eliminate the limitations of active and passive techniques so that higher effectiveness can be guaranteed. The active method is applied only after passive method confirms the occurrence of islanding. Some of the hybrid techniques are as follows:

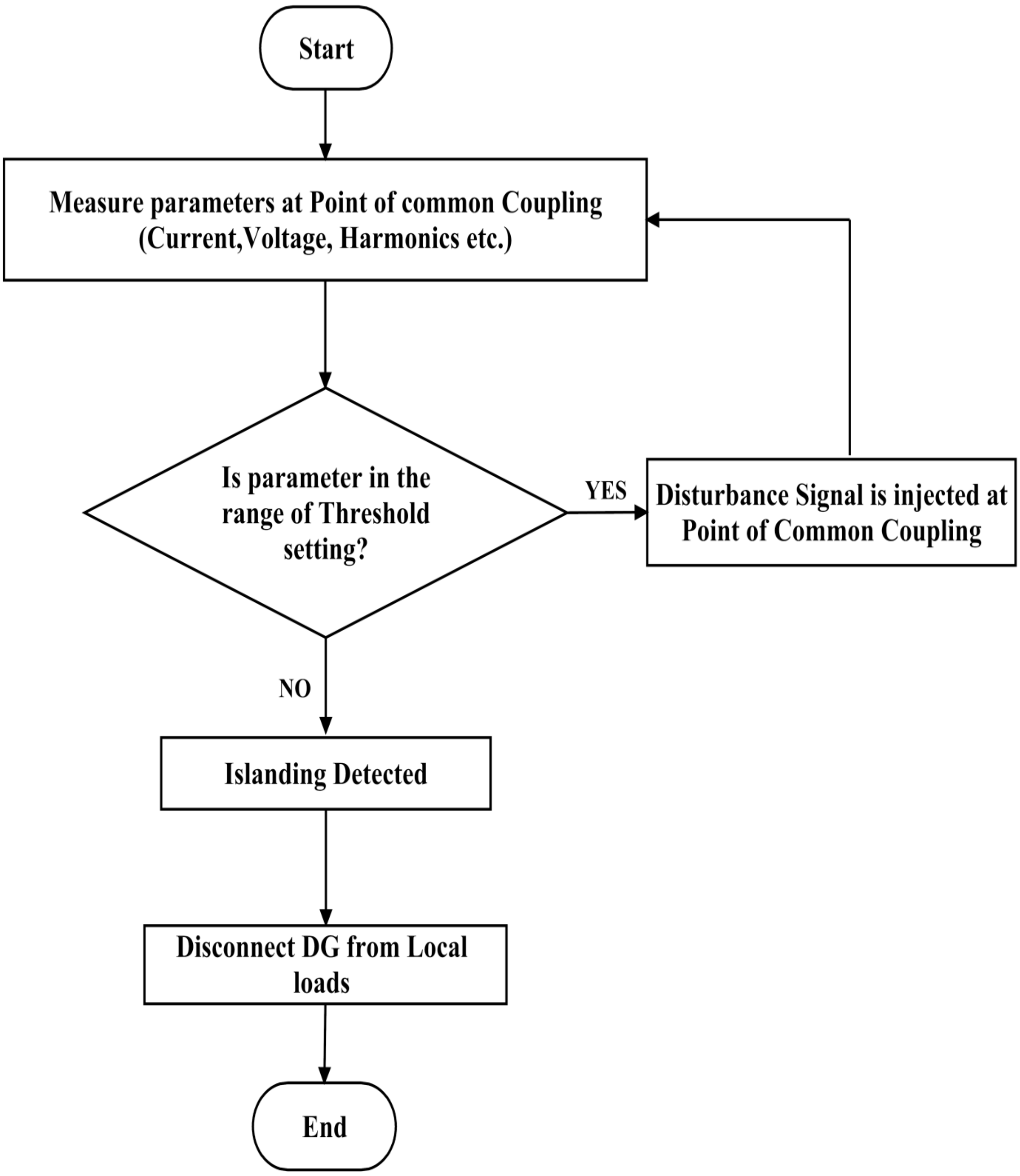

Figure 3.12 Flowchart of Hybrid Method

3.2.4.1 Positive Feedback and Voltage Unbalance (VU)

This method includes positive feedback (i.e. active method) and voltage unbalance (i.e. passive method).This method monitors the 3-Ø voltages repeatedly to evaluate VU.

Voltage Unbalance is given as,

$$VU = \frac{V_{+S_Q}}{V_{-S_Q}} \tag{3.14}$$

where,

V_{+S_Q} - Positive sequence voltage

V_{-S_Q} - Negative sequence voltage.

Spikes in voltage will be noticed in case of islanding, change of load, switching action etc. When the voltage unbalance spike exceeds the preset value, set point of DG's frequency gets changed. Therefore, frequency of the whole system gets change when the DG is islanded.

3.2.4.2 Voltage and Reactive Power Shift (RPS)

This technique uses an average rate of the voltage change and deviation of real power to remove the shortcomings of the active and passive techniques in islanding detection. This method can detect the condition of islanding with multiple units of DG working at unity pf.

However, RPS is applied to the system if the passive technique cannot perfectly detect the islanding condition.

There is no individual islanding detection method which will perform accurately under all situations for all systems. The preference of which method should be used will rely on the system characteristics and also the type of DG's. Recently, hybrid techniques have been suggested in which the passive schemes detect the islanding when the changes in system parameters are vast and triggering the active schemes in case there is slight change in system parameters for which the passive schemes fail to have a sheer discrimination between islanding and non-islanding condition.

Table 3.2 Classification of Islanding Detection Techniques with their Advantages, Limitations and Examples

Islanding Detection Techniques	**Advantages**	**Disadvantages**	**Examples**
1.) Remote Techniques	Reliability high	Costly to implement these techniques	I. Transfer Trip Scheme II. Power Line Carrier Communication
2.) Local Techniques			
A. Passive Techniques	I. Do not Disturb the System Intentionally II. Fast Detection Time III. Suitable when there is large imbalance between local demand and generation in islanded system. IV. Large Non-Detection Zone (NDZ).	I. Setting of threshold is difficult. II. Difficult to detect the islanding in case of small power imbalance between generation and load.	I. Rate of change of Frequency II. Rate of change of Power III. Rate of change of Frequency over Power IV. Voltage Phase Jump detection V. Voltage Unbalance and THD
B. Active Techniques	I. Overcome the limitation of passive techniques. II. Identify islanding	I. Add disturbance into the system to detect islanding. II. Perturbation	I. Impedance Measurement Method II. Reactive Power

	even under perfect balance between generation and local load in islanded system. III. Small NDZ	results into degradation of power quality and can even lower the system stability. III. Detection time is large as compared to the passive techniques.	Export Error detection III. Slip Mode Frequency Shift IV. Active Frequency Drift
3.) Hybrid Techniques	Perturbation is injected only when islanding is detected by passive techniques.	Time to identify islanding is large as both active and passive techniques are used.	I. Positive feedback and Voltage Unbalance II. Voltage and Reactive Power shift.

Table 3.3 Comparison of Local (Active and Passive) & Remote methods

S. No.	Detail	Local		Remote
		Passive	**Active**	
1.	Operating principle	Uses current, voltage, frequency and harmonics sensing.	Deliberately introduces some disturbance in DG to shift the point of operation to the frequency or voltage thresholds.	Utilises communication between main utility and DGs.
2.	Non-Detection zone (NDZ)	Vast	Narrow	None
3.	Run-on time	Slightly longer	Short	Shortest

4.	Mal-operation	When small mismatch between main utility and local load it is challenging to decide the threshold.	Rare	Very rare
5.	Cost	Low, Minimal hardware	High, Require additional circuitry	Extremely high
6.	Impact on Distribution System	None	Direct impact on power system i.e. voltage fluctuations.	None
7.	Efficacy	Less effective in balanced condition	More than passive	Most
8.	Types of DG involved	Synchronous & inverter based DGs	Inverter based DGs	Applicable to all types of DGs
9.	Multiple DG operation	Possible	Not Possible	Possible
10.	Additional Equipment	Minimum Equipment Required	Requires some Equipment	Communication devices
11.	Power Quality	No degradation	Power Quality is degraded because of disturbance added.	No deterioration

Table 3.4 Comparison of SMS and PJD techniques

S. No.	Detail	Phase Jump detection (PJD)	Slip Mode Frequency Shift (SMS)
1.	Type	Passive technique	Active technique
2.	Operating principle	Monitor phase error between output current and terminal voltage.	Introduce a shift in phase to shift the frequency of output voltage.

3.	Non-Detection Zone	Large	Small
4.	Implementation Cost	Low	High
5.	Response time	Cannot predict. Problematic to decide the phase error threshold.	Fast as compared to PJD
6.	Load condition designed for islanding protection	Small power mismatch between DG and local load.	Large power mismatch between load and DG.
7.	Effect on power system	Does not affect the power quality output and transient response of system.	Requires small degradation in the power quality.
8.	Ease of implementation	Easy	Moderate
9.	Effectiveness	Effective	Highly effective with exception of small inductive and high capacitive loads.

CHAPTER 4
PROBLEM FORMULATION

Islanding occurs when DG continue to feed a section of the power system even though it remains detached from the main utility as shown in Fig. 4.1. The nature of island cannot be predicted because the island is not regulated and voltage, frequency and other parameters of power system can have limits which are not acceptable. Balancing of active and reactive power between DG and load is done by the newly established operating points, which will determine the complexity of the islanding condition. The out-of-phase reclosing is possible and devices may get damaged due to high transient inrush currents. Therefore, the power supply to the islanded systems has to be ceased quickly.

The active and reactive power imbalance is the difference in active and reactive power developed by DG and absorbed by the local load.

$$\Delta P = P_{DG} - P_L \tag{I}$$

$$\Delta Q = Q_{DG} - Q_{L}. \tag{II}$$

where,

P_{DG} – active power developed by DG

P_L– active power dissipated by the local load

Q_{DG} – reactive power developed by DG

Q_L– reactive power used up by the local load

The local load is presumed to be parallel RLC load and active and reactive power dissipated by the load may be calculated as:

$$P_L = \frac{V^2}{R} \tag{III}$$

$$Q_L = V^2 \left[\frac{1}{2\pi fl} - 2\pi fc \right] \tag{IV}$$

The active power mismatch at the time of system disconnection from the grid has an effect on the voltage magnitude at PCC, while reactive power mismatch at the time of system disconnection from the grid has an effect on the frequency magnitude at PCC. The parameters of the system will increase or decrease and finally gets settled to newly establish operating points depending on the mismatch.

In the case of positive active power mismatch (more active power is developed by DG than consumed by the local load), voltage magnitude at PCC will increase and may stabilize at the higher level after disconnection from the grid, while for negative active power mismatch (more active power is dissipated by the local load than generated by DG) voltage magnitude will decrease and may stabilize at lower value. Similarly, for positive reactive power mismatch (more reactive power is developed by DG than consumed by the local load) frequency will decrease and may stabilize at the lower level, while for negative reactive power mismatch (more reactive power is dissipated by the local load that it is generated by DG) frequency will increase and may stabilize on the higher level.

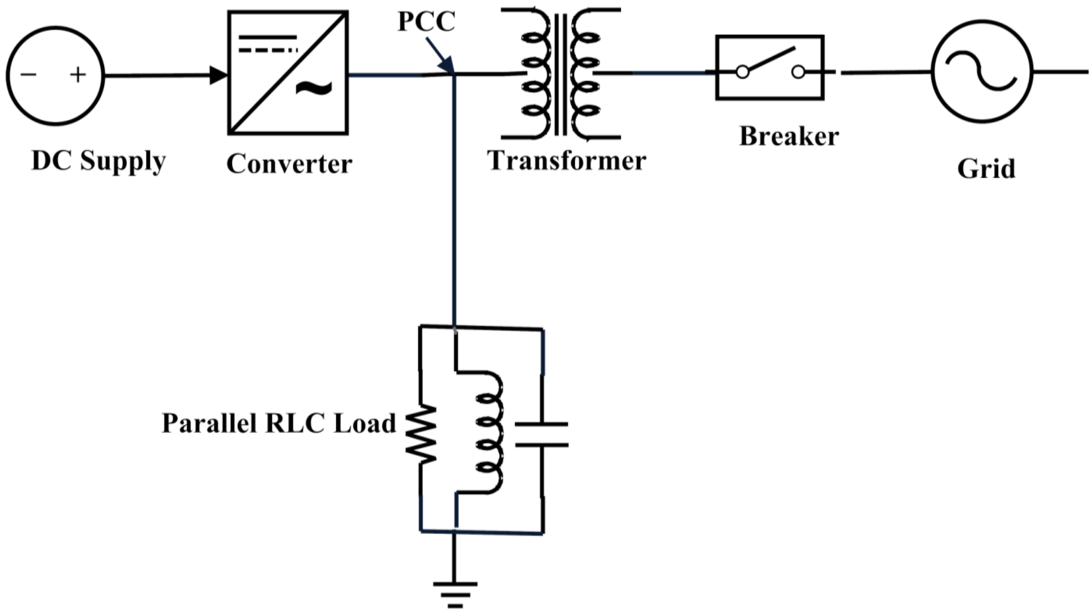

Figure 4.1 Configuration used for understanding anti-islanding features of grid connected inverters

4.1 Investigation of SMS Method

SMS technique applies positive feedback to the voltage phase at the PCC. This results in shifting of phase and thereby the short-term frequency. The phase angle of current is made to be a function of the divergence of frequency for last cycle f_{vk-1} against the normal frequency of operation of the main grid f_g . The output current of converter can be written as

$$i_{con} = I \sin(2\pi ft + \theta_{sms}) \tag{4.1}$$

where,

f -frequency of PCC voltage

θ_{sms} - phase angle for SMS method.

The phase angle is made to be a sinusoidal function of nominal frequency of grid f_g.

$$\theta_{sms} = \frac{2\pi}{360}\theta_m \sin\left(\frac{\pi}{2}.\frac{f - f_g}{f_m - f_g}\right) \tag{4.2}$$

where, θ_m - maximal value of phase angle in degrees

f_m - frequency at which θ_m occurs.

From (4.2), when the frequency of main grid is kept at rated value, θ_{SMS} is practically zero. At the time of disconnection of grid, the SMS technique is entirely driven by an uncontrolled, externally provided disturbance produced by noise, incorrect measurement and quantization error. In case this disturbance is microscopic, then this technique cannot identify the islanding within the time established by IEEE Standard 929-2000 [1].

4.2 Investigation of Improved SMS (I-SMS) Method

For the purpose of eliminating the limitations of the SMS method a modified version of it with an additional phase shift called I-SMS is recommended as

$$\theta_{I-SMS} = n(f - f_g) + F(f - f_g)\theta_0 \tag{4.3}$$

Where, n and θ_0 are constants

$F(f - f_g)$ - signum function of frequency error.

$$F(f - f_g) = \begin{cases} 1 & f \geq f_g \\ -1 & f < f_g \end{cases} \tag{4.4}$$

Compared with SMS method as in equation (4.2), a phase shift of $F(f - f_g)\theta_0$, in addition is recommended in the I-SMS method. As a result of the added phase shift in I-SMS technique when the frequency of grid is at its nominal value *fg*, it still remains and aid to accelerate the frequency positive feedback. As a result, the islanding detection technique becomes more reliable.

The phase error between current and output voltage of converter is decided by the load when the main grid is not connected. In order to examine the islanding detection a parallel RLC load is considered. The resulting phase angle of current advancing the voltage is given by

$$\theta_{load} = \tan^{-1}\left(R\left(\omega C - \frac{1}{\omega L} \right) \right)$$

or, $$\theta_{load} = \tan^{-1}\left(Q_f \left(\frac{f}{f_0} - \frac{f_0}{f} \right) \right) \quad (4.5)$$

where, Q_f - Load Quality Factor

and, f_0 - Resonant frequency

The Quality Factor, Q_f for a parallel RLC circuit is given by

$$Q_f = R\sqrt{\frac{C}{L}} \quad (4.6)$$

The main objective of I-SMS technique is to make sure there will be no stable point of operation within the threshold frequency after the grid disconnection. For this to happen, the phase angle of converter need to be accelerates at a fast rate than the phase angle of parallel RLC load. The frequency of resonance has to be kept near grid frequency in order to ensure that the I-SMS scheme can obtain result accurately in such condition. Therefore, the following condition should be ensured for $f = f_0 = f_g$.

$$\left. \frac{\mathrm{d}\theta_{load}}{\mathrm{d}f} \right|_{f=f_0} \leq \left. \frac{\mathrm{d}\theta_{\text{I-SMS}}}{\mathrm{d}f} \right|_{f=f_g} \quad (4.7)$$

Ignoring the added phase shift and putting (4.3) and (4.5) into (4.7), the following condition is attained.

$$n \geq \frac{360 Q_f}{\pi f_g} \quad (4.8)$$

As per [2] $Q_f \leq 2.5$ can take all feasible configuration of distribution line. Therefore, putting Q_f =2.5 in (4.8), value of parameter n is found to be 6. Depending upon the values of Quality factor and resonant frequency [14] (Q_f against f_o) the load parameter space is utilised to determine the NDZ of the I-SMS scheme. The relation between islanding frequency f_{is} and frequency of resonance f_0 is given by

$$f_0 = \frac{f_{is}}{2Q_f}\left[-\tan\theta_{inv}(f_{is}) + \sqrt{\tan^2\theta_{inv}(f_{is}) + 4{Q_f}^2} \right] \quad (4.9)$$

Where, θ_{inv} - phase angle between current of converter and voltage.

Setting the threshold of frequency protection at $50 \pm 0.5\text{Hz}$ and (4.3) into (4.9), the NDZ can be portrayed without consideration of θ_0. The area inside the contours is the NDZ. As the value of parameter n increases NDZ is reduced. The quality factor of load is usually limited to 2.5 [2] and the proposed technique apparently has minimum area of NDZ with n equals to 6.

CHAPTER 5

SIMULATION RESULTS

To demonstrate the design feasibility of the proposed I-SMS method, a SIMULINK model of the utility-connected converter system is implemented in MATLAB R2013a to carry out a digital simulation and authenticate the efficacy of the I-SMS technique. The simulation model is indicated in Fig. 5.1. The parameters of system considered are indicated in Table 1.

Table 5.1 System parameters for digital simulation

Utility Mains	220V,50Hz
Converter Rated Power	3kW
Specifications of LC filter	3mH,4.7μF
Frequency threshold	50.5Hz(Uppermost), 49.5Hz(Lowermost)
Voltage threshold	242V(Uppermost), 193.6V(Lowermost)
SMS parameters	$\theta_m = 10^0$, f_m=53Hz
I-SMS parameters	n=6 , θ_0=0.5
Parallel RLC Load	R=57.6Ω, L=36.67mH, C=276.31μF

In case of SMS technique, the disturbance in phase is accomplished by (4.2) with the help of a trigonometric function, whereas in the I-SMS scheme the computation of phase shift is realized by (4.3) with a simple algebraic operation. Putting this value of phase perturbation in (4.1), the value of reference current (I_{ref}) is obtained.

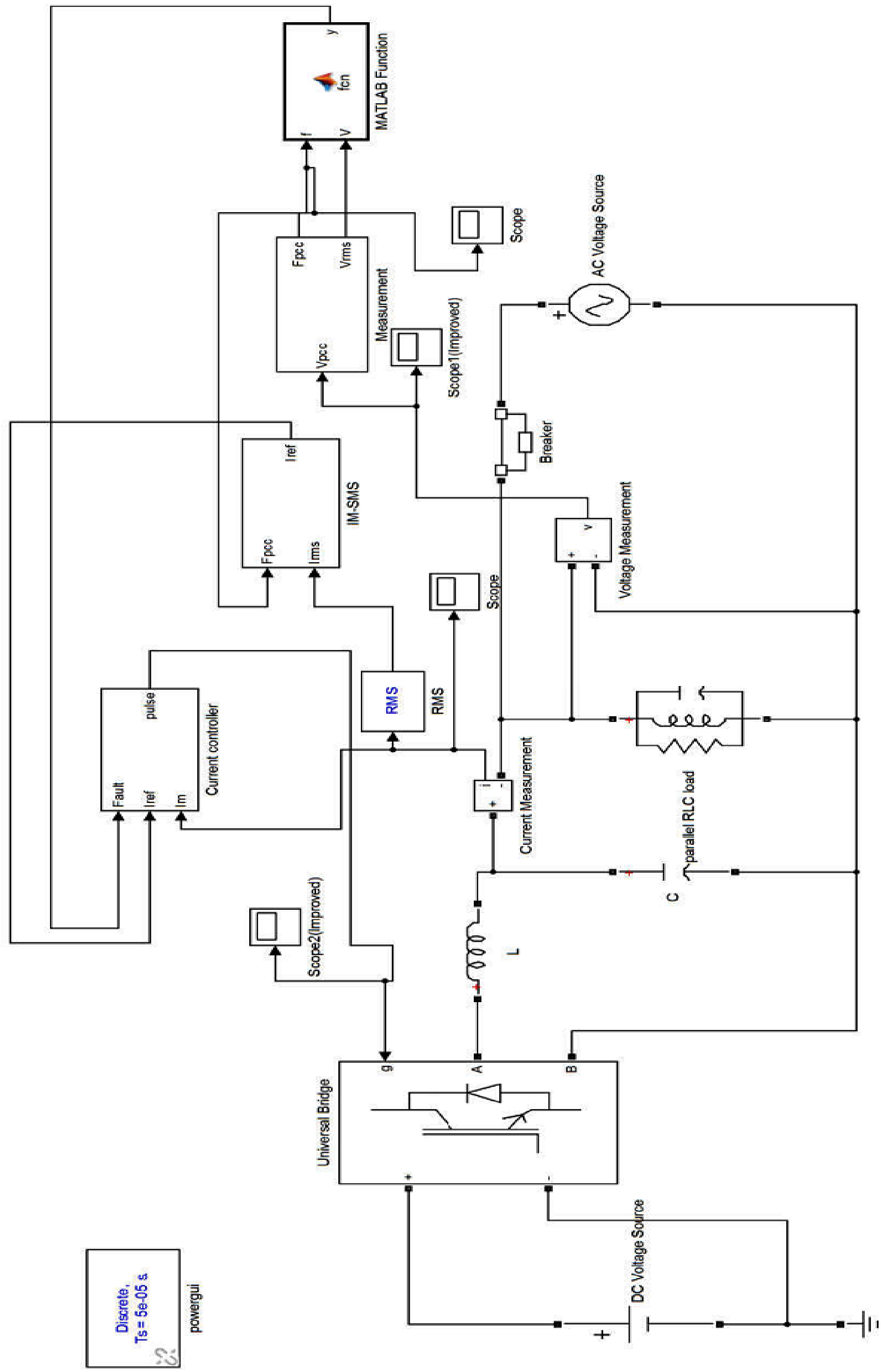

Figure 5.1 SIMULINK Model of a Grid-Connected Converter

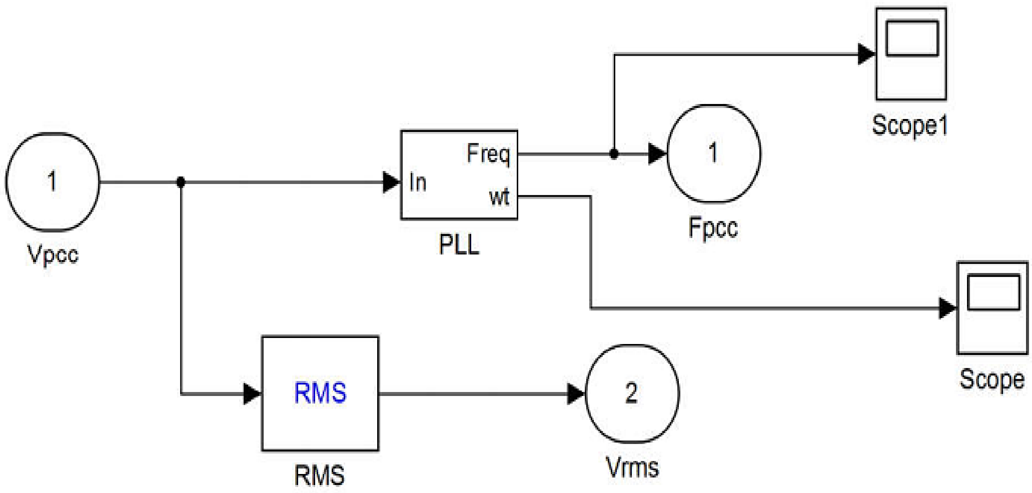

Fig 5.2 Subsystem of “Measurement” block

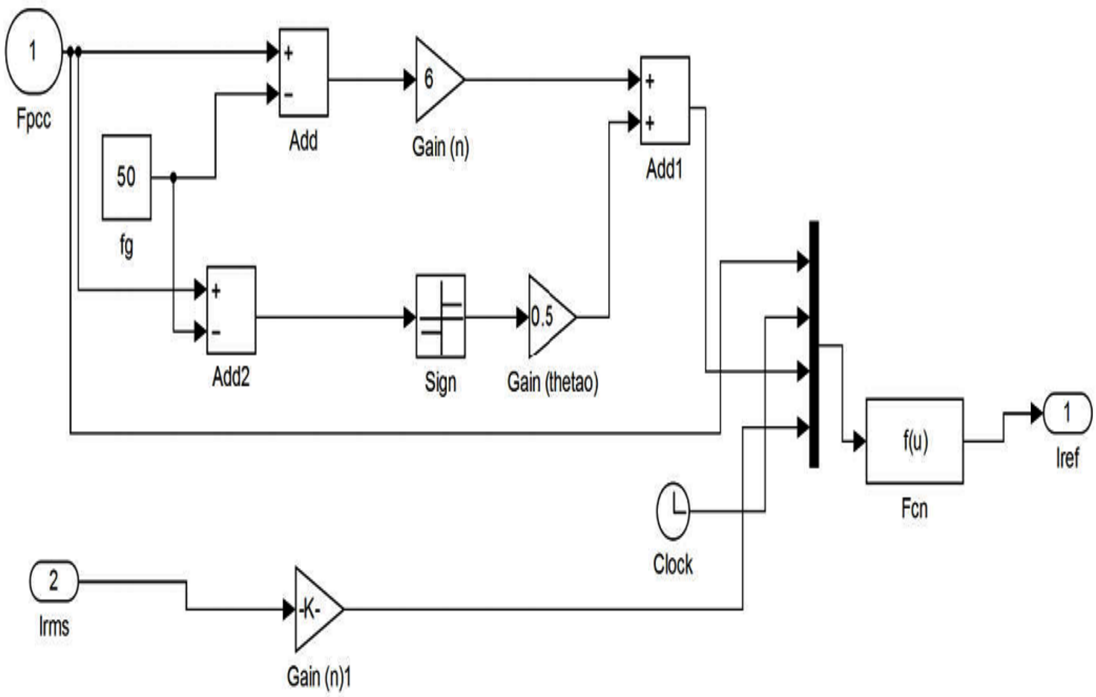

Fig 5.3 Subsystem of “I-SMS”

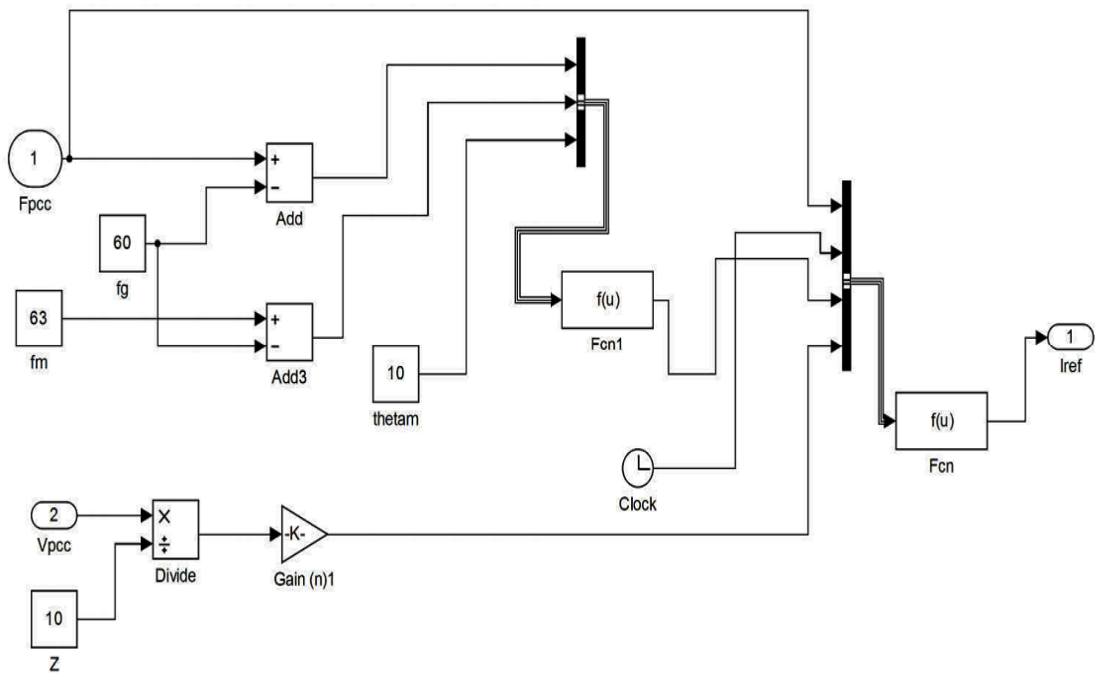

Figure 5.4 Subsystem of “SMS”

Table 2 indicates the simulated run time for different values of Quality factor, Q_f of a DG inverter to illustrate all possible values for a distribution line. The run-on time is defined as the time instant between the main utility disconnection and the instant the inverter gets tripped to stop feeding the RLC loads. For $Q_f < 2.5$ the average tripping time is less whereas, in case of RLC circuit with $Q_f \geq 2.5$ the identification time is larger. As the value of load Quality Factor is raised, it can be seen that run-on times are enhanced.

Table 5.2 Simulated Run-On Times For SMS and I-SMS Method

Q_f	L(mH)	C(μF)	Run-on time SMS (sec)	Run-on time I-SMS(sec)
0.1	1833.4	5.526	0.016	0.002
0.3	611.16	16.57	0.015	0.005
0.5	366.6	27.63	0.017	0.008
1.0	183.35	55.26	0.05	0.04
1.5	122.23	82.89	0.062	0.053
2.0	91.67	110.52	0.129	0.06
2.5	73.34	138.15	0.167	0.09
3.0	61.10	165.8	0.189	0.128

5.0	36.67	276.31	0.223	0.192
10.0	18.33	552.62	0.41	0.378

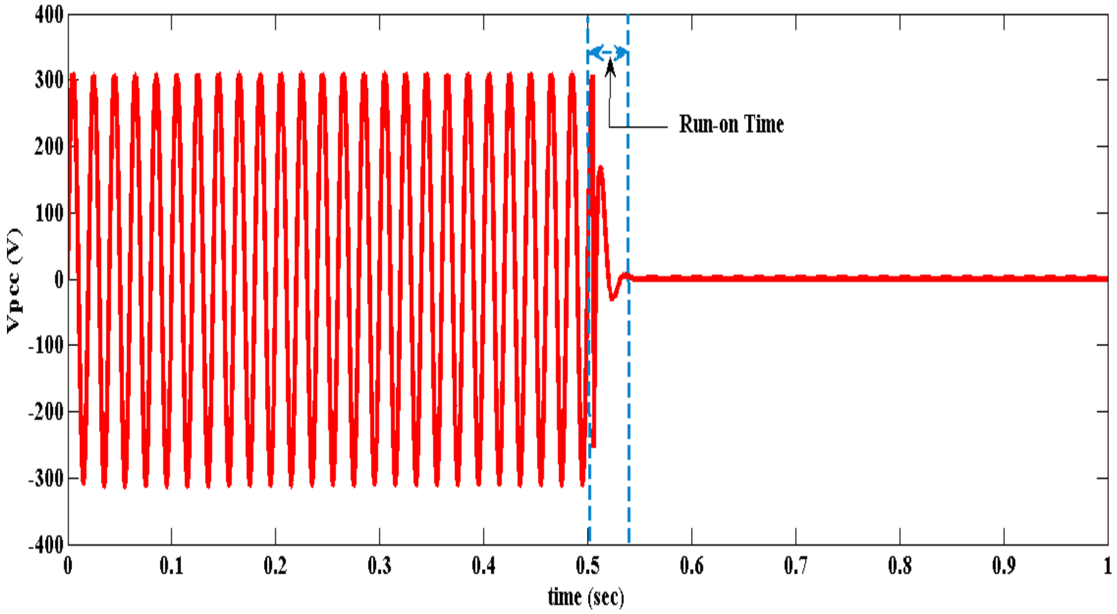

Figure 5.5 PCC voltage with I-SMS and parallel RLC load (Q_f = 1.0, f_o=50 Hz)

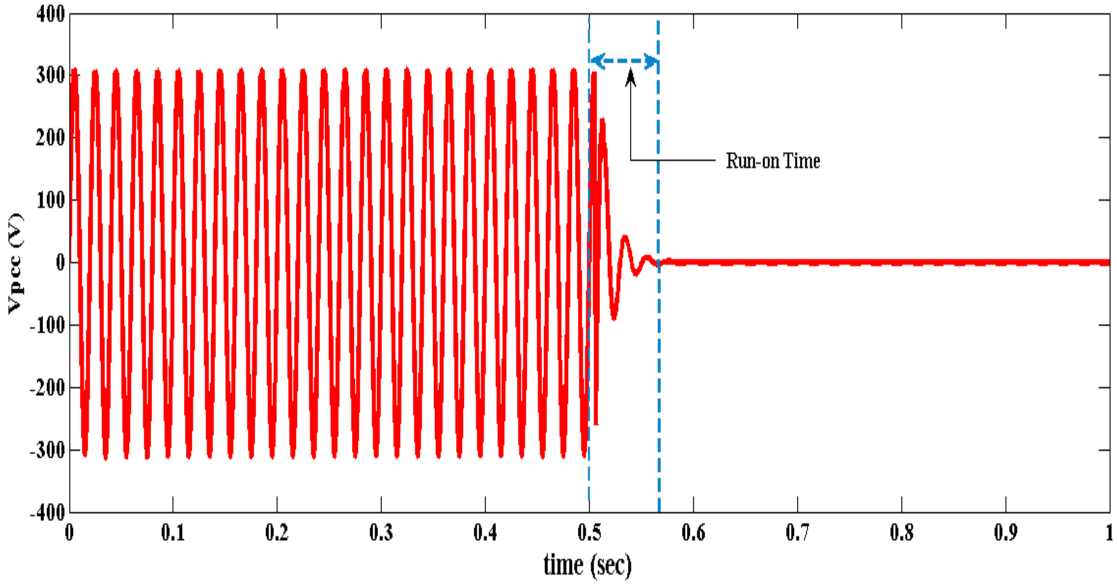

Figure 5.6 PCC voltage with I-SMS and parallel RLC load (Q_f = 2.0, *fo*=50 Hz)

In Fig. 5.6 islanding takes place at 0.5 s and the trip signal is produced at 0.51 s to shut down the inverter at 0.6 s.

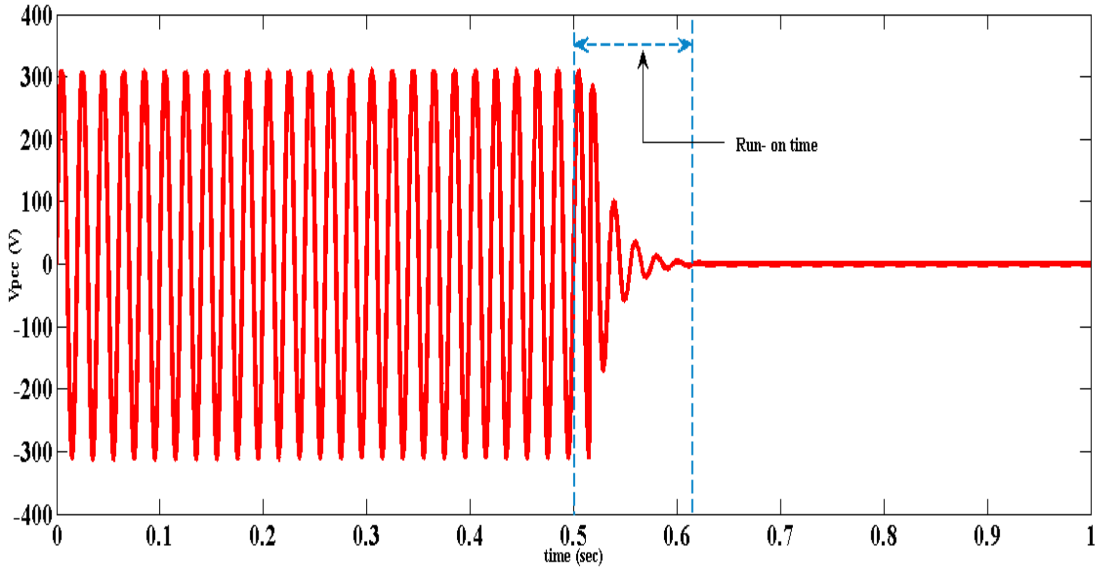

Figure 5.7 PCC voltage with I-SMS and parallel RLC load (Q_f = 3.0, *fo*=50 Hz)

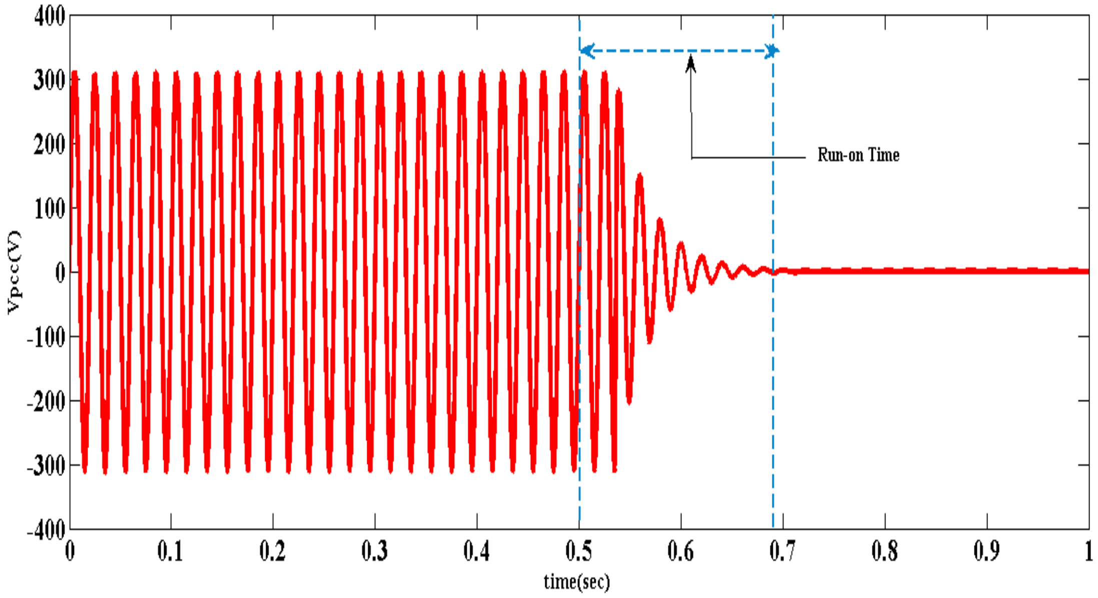

Figure 5.8 PCC voltage with I-SMS and parallel RLC load (Q_f = 5.0, *fo*=50 Hz)

Fig. 5.8 shows the output voltage at PCC with Quality factor equals to 5.0. Here, islanding occurs at 0.5 s and the trip signal is developed at 0.55s to shut down the inverter at 0.7 s.

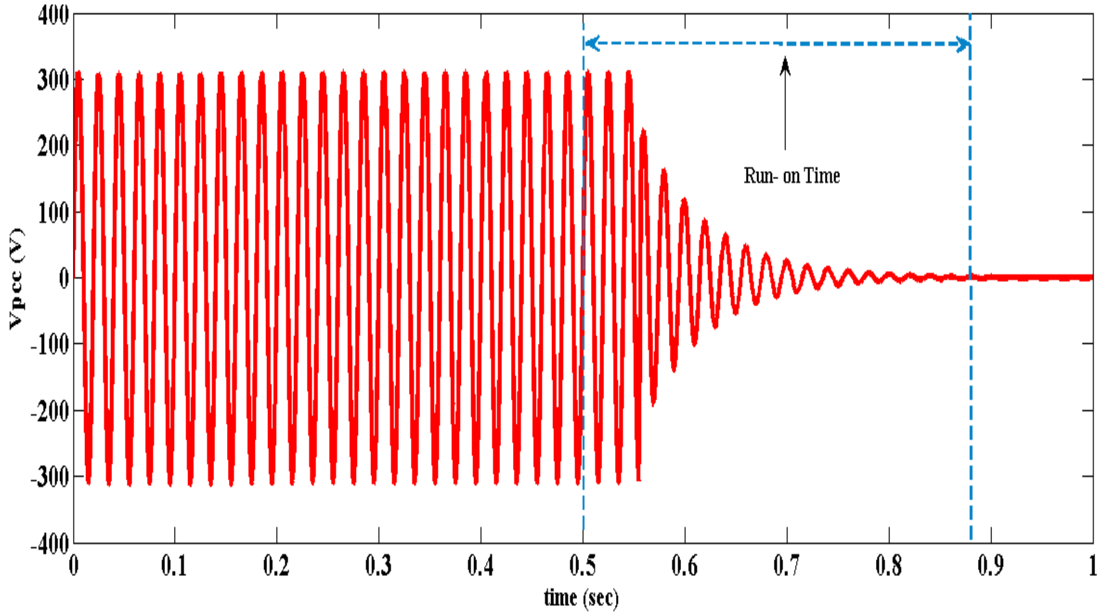

Figure 5.9 PCC voltage with I-SMS and parallel RLC load (Q_f = 10.0, *fo*=50 Hz)

For different values of Quality factor (i.e. Q_f =1.0, 2.0, 3.0, 5.0, 10.0) voltage at PCC is observed for Improved Slip Mode Frequency Shift method and it is found that as the value of Q_f increases run-on times are increased i.e. higher the Quality factor of parallel RLC load, more is the difficulty to identify islanding. Keeping the parameters same PCC voltage is again observed for SMS method and the following waveforms are obtained.

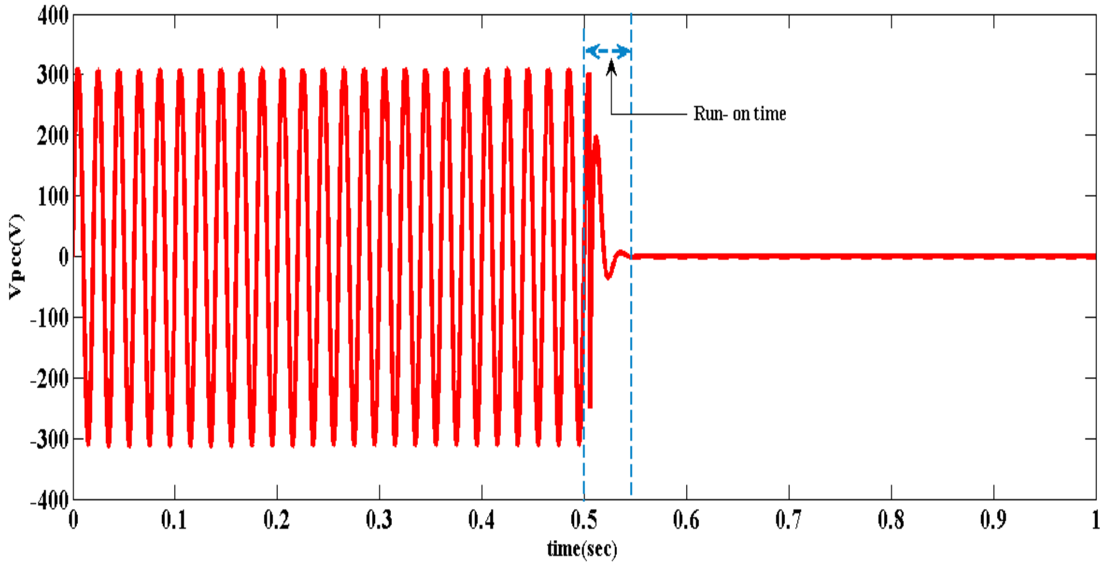

Figure 5.10 PCC voltage with SMS and parallel RLC load (Q_f = 1.0, *fo*=50 Hz)

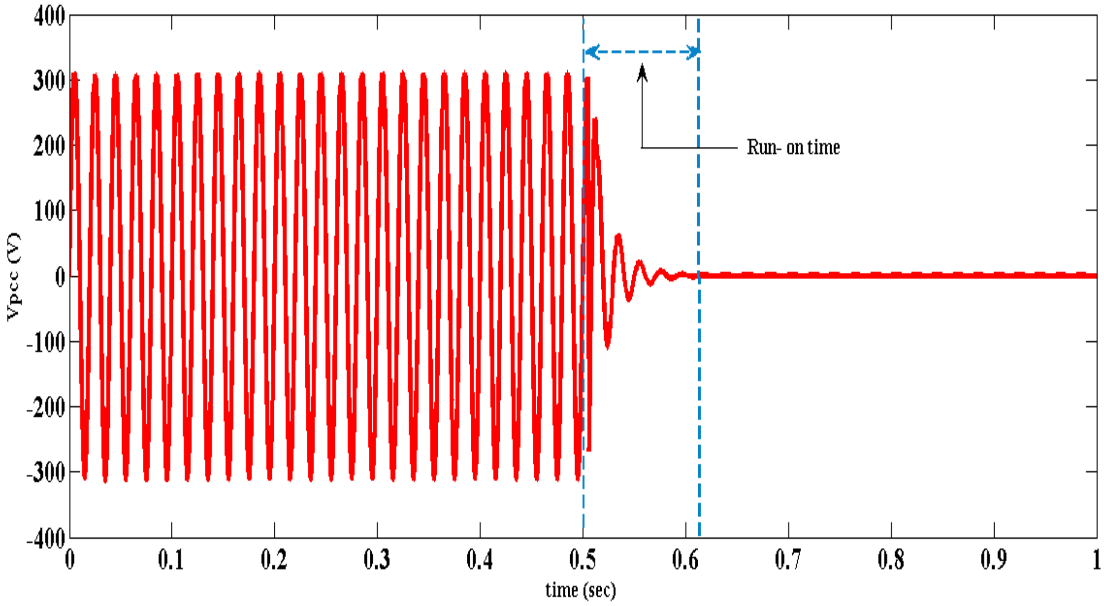

Figure 5.11 PCC voltage with SMS and parallel RLC load (Q_f = 2.0, *fo*=50 Hz)

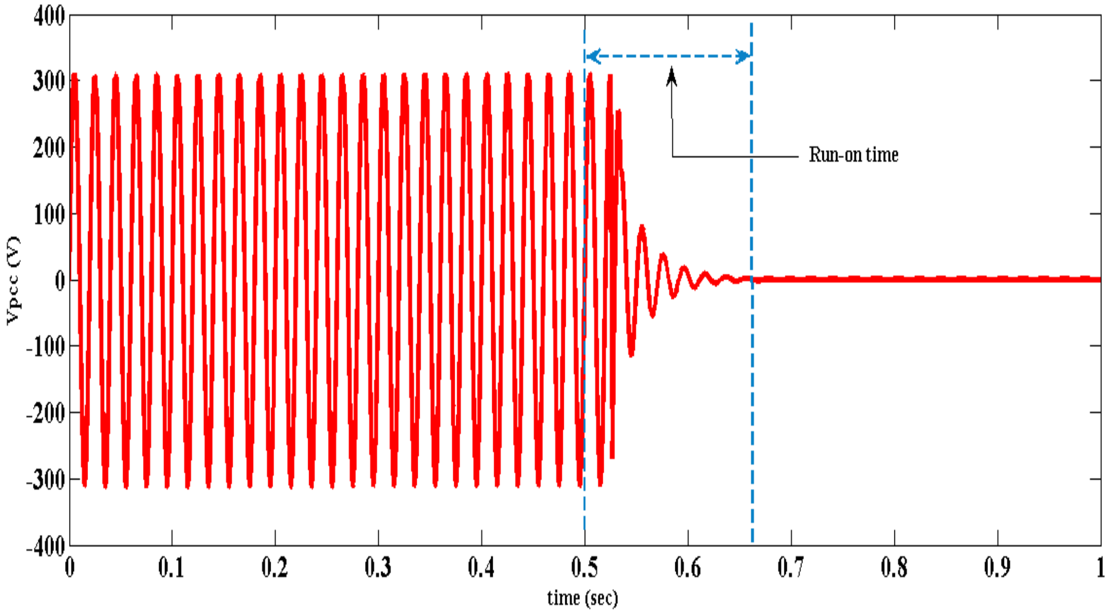

Figure 5.12 PCC voltage with SMS and parallel RLC load (Q_f = 3.0, *fo*=50 Hz)

The output voltage at PCC is shown in Fig. 5.12 with Quality factor equals to 3.0. Here, islanding occurs at 0.5 s and the trip signal is developed at 0.53s to cease the inverter operation at 0.68 s.

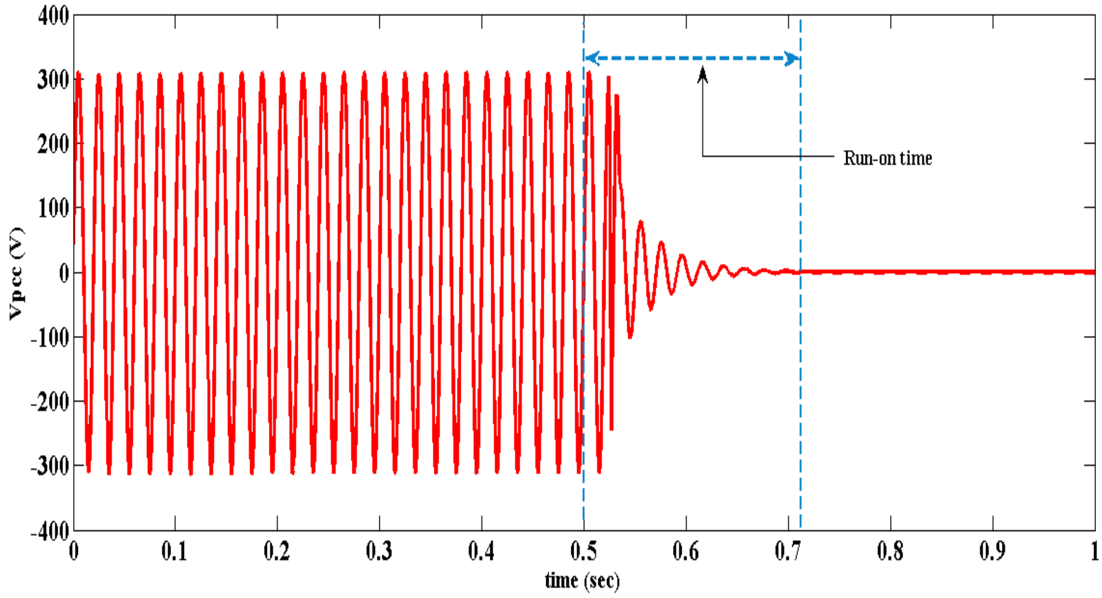

Figure 5.13 PCC voltage with SMS and parallel RLC load (Q_f = 5.0, *fo*=50 Hz)

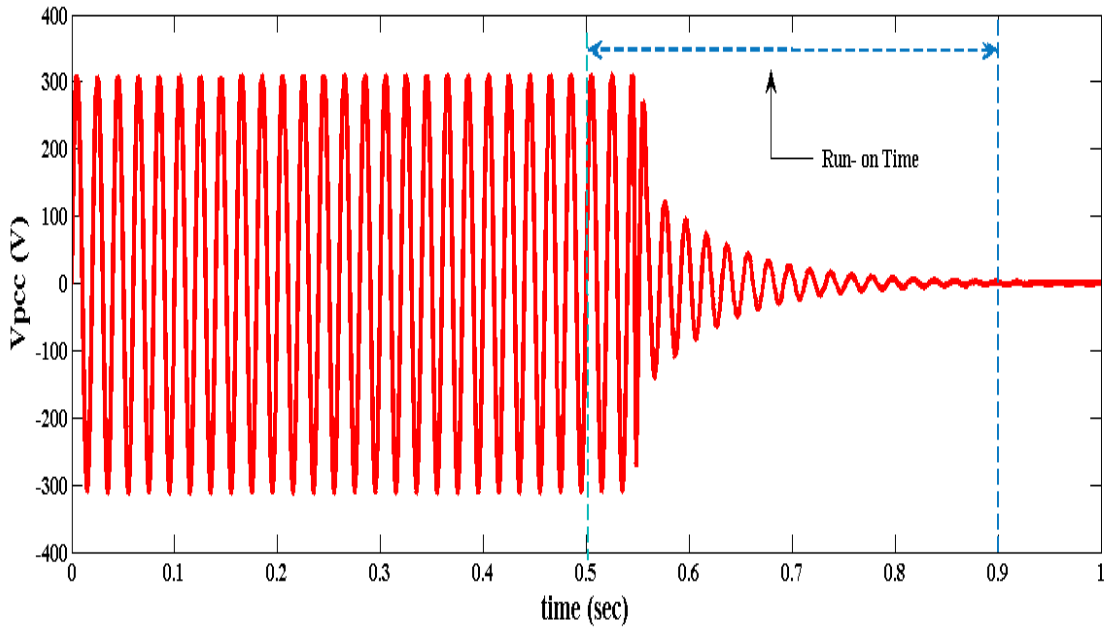

Figure 5.14 PCC voltage with SMS and parallel RLC load (Q_f = 10.0, *fo*=50 Hz)

From the waveforms obtained, it can be observed that the run-on time for SMS technique is larger than Improved-SMS for each and every value of Quality factor, resulting in slower islanding detection.

Depending on the values of Run-on Time for Slip Mode Frequency Shift (SMS) and Improved Slip Mode Frequency Shift (I-SMS) method, a comparison has been made between them by plotting a graph taking Quality factor, Q_f as abscissa and Run-on time as ordinate.

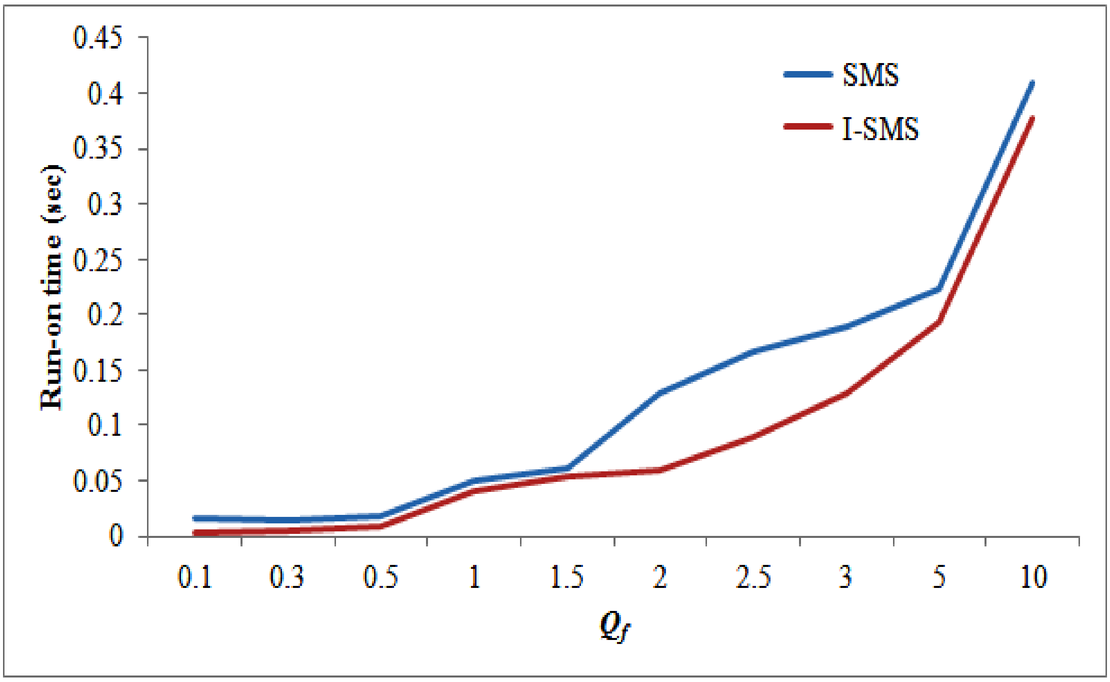

Figure 5.15 Run-on Time v/s Quality Factor for SMS and I-SMS

The following conclusions can be drawn from the graph:

1. It can be clearly seen that as the Quality factor of load is increased, the value of run-on time also gets increased.
2. Run-on time for I-SMS technique is less as compared to SMS technique.

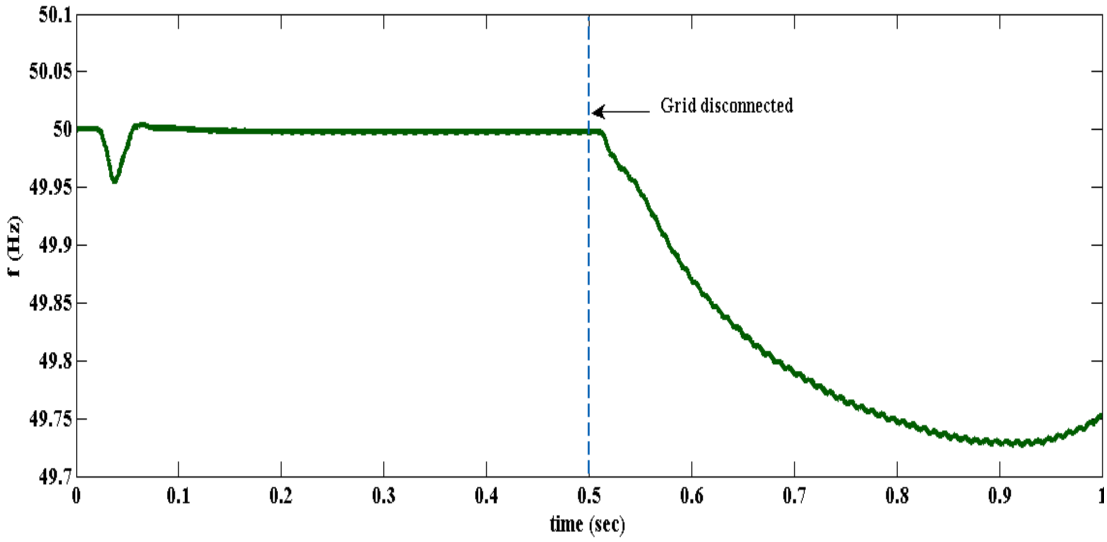

Figure 5.16 Frequency at PCC during Islanding

Fig. 5.16 demonstrates the case of under frequency where the islanding occurs at 0.5s and at 0.51s fall in frequency is sensed by under frequency relay to shut down the inverter.

The effectiveness of islanding detection technique is determined by its area of NDZ. In case of passive techniques this area is large i.e., it cannot identify the condition of islanding for a large range especially when there is small mismatch between local load and generation. However, active methods have an advantage that it can identify islanding even when there is ideal match between generation and load. To validate this, a graph has been plotted using (4.9) between resonant frequency (f_0) and Quality factor (Q_f). This graph defines the area of NDZ for I-SMS method.

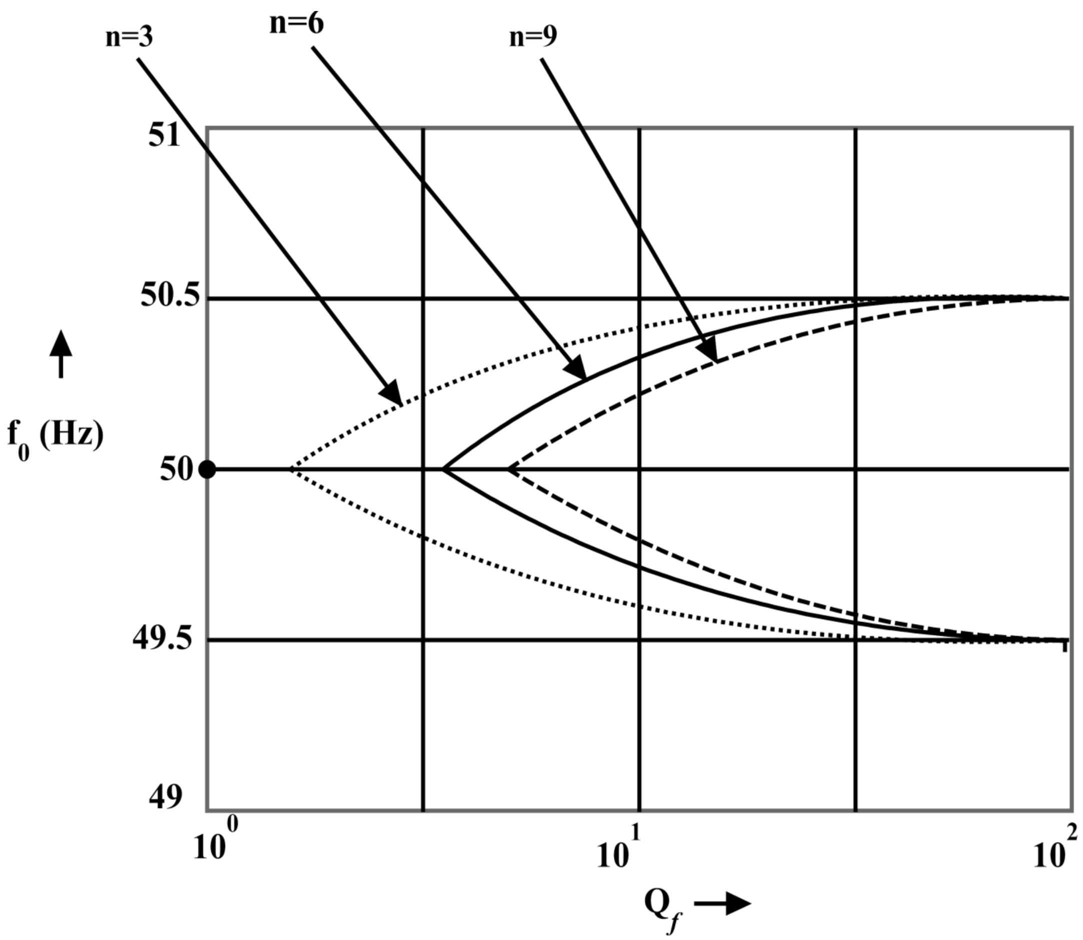

Figure 5.17 NDZ of I-SMS method

From the graph, it can be concluded that on increasing the value of parameter n in (4.3) the area of NDZ also gets reduced for I-SMS method. Therefore, I-SMS method leads to fast detection of islanding and increased reliability as well.

CHAPTER 6

CONCLUSIONS

This thesis presented and analyzed different techniques of islanding detection. These techniques can be classified into two categories depending upon their location in the DG system namely, local techniques and remote techniques. Remote detection technique is located at the main utility side, whereas in case of local techniques, detection algorithm is applied at the inverter side. Further, local methods are classified as passive methods, which depend on parameter estimation such as voltage, current, harmonics etc., and active methods, which introduce disturbance to detect islanding. In this thesis, MATLAB/SIMULINK model of SMS which is one of the active methods was investigated and had been compared with I-SMS which is the improved variant of SMS on the basis of *run-on time* parameter for different load quality factor Q_f. It was observed that due to the additional shift in phase introduced in I-SMS method, the islanding detection effectiveness is guaranteed and it also requires less time to detect islanding as compared to SMS method. This shows the robustness of I-SMS method and its role in reducing the run-on time and increasing the speed of islanding detection. Further, the effectiveness of I-SMS method is analysed using NDZ and it is found that in case of I-SMS method as the value of parameter *n* increases the NDZ is reduced and since, the quality factor of load, $Q_f < 2.5$, the I-SMS technique has least area of NDZ at n=6. Thus, I-SMS technique offers high accuracy, reliability and fast detection.

6.1 Future Scope

More studies need to be carried out to rectify the problems due to nuisance tripping as they can initiate misleading alarm in islanding identification process. As NDZ is a crucial indicator in determining the efficacy of islanding detection, it has to be investigated deeper in order to make its area as small as possible so that islanding can be identified for very small power mismatch.

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