ISLANDING DETECTION IN DISTRIBUTED GENERATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Master of Technology
In
Electrical Engineering

By

TRUPTIMAYEE PUJHARI

Department of Electrical Engineering

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CERTIFICATE

This is to certify that the thesis entitled, "**Islanding Detection in Distributed Generation**" submitted by Mrs. **TRUPTIMAYEE PUJHARI** in partial fulfillment of the requirements for the award of Master of Technology Degree in **Electrical Engineering** with specialization in **"POWER CONTROL AND DRIVES"** at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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Co- Supervisor

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ABSTRACT

The advancement in new technology like fuel cell, wind turbine, photo voltaic and new innovation in power electronics, customer demands for better power quality and reliability are forcing the power industry to shift for distributed generations. Hence distributed generation (DG) has recently gained a lot of momentum in the power industry due to market deregulations and environmental concerns. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system yet continues to be energized by distributed generators. An important requirement to interconnect a DG to power distributed system is the capability of the DG to detect islanding detection. Failure to trip islanded generators can lead to a number of problems to the generators and the connected loads. The current industry practice is to disconnect all distributed generators immediately after the occurrence of islands. Typically, a distributed generator should be disconnected within 100 to 300 ms after loss of main supply. To achieve such a goal, each distributed generator must be equipped with an islanding detection device, which is also called anti islanding devices like vector surge relay and ROCOF relay.

The contributions of this M-tech Thesis are as follows

- Review of the current practices and research work developed on distributed generation
- Problems linked with distributed generations like islanding
- Necessity of islanding detection
- Survey on different islanding detection techniques
- Study of wavelet transform
- Development of new method for islanding detection of wind turbines based on negative sequence component of voltage & current using the wavelet transform. The detailed coefficient at the level-1 (d1) clearly localizes the event and thus detects the islanding condition. Also the change in energy and standard deviations of the detailed coefficients for one cycle current and voltage signals distinguishes islanding conditions from non-islanding ones.

- Development of new method for islanding detection of wind turbines based on negative sequence impedance. The negative sequence impedance is calculated at the target DG location and effectively detects the islanding conditions.
- An extensive simulation studies on islanding detection based on above techniques using MATLAB & SIMULINK

In this work, a case-study of distributed Generation System comprising of two 9 MW wind farms (each connected to a120 kv grid through a 20 km,25kv feeder),two 500 kW resistive loads and two .9MVAR filters, have been considered and studies are made on islanding detection using those above mentioned methods.

The proposed techniques are tested on islanding and possible non-islanding conditions such as normal operation, sudden load change and tripping of other DG etc. and found to be highly effective in islanding detection at different target DG locations in the power distribution network including multiple DGs.

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Chapter-1

Introduction

This thesis deals with a particular problem that occurs at the interface between a distributed generation plant and the rest of the power system. The problem can be described as islanding detection in power systems. The problem has been investigated and discussed extensively in the last few years.

1.1 Islanding Protection for Distributed Generation

This thesis presents a novel method of islanding detection for the protection of distributed generator fed systems that has been tested on power distribution busses of 25 kV and less. Recent interest in distributed generator installation into low voltage busses near electrical consumers has created some new challenges for protection engineers that are different from traditional radially based protection methodologies. Therefore, typical protection configurations need to be re-thought such as re-closures out-of-step monitoring, impedance relay protection zones with the detection of unplanned islanding of distributed generator systems. The condition of islanding, defined as when a section of the non utility generation system is isolated from the main utility system, is often considered undesirable because of the potential damage to existing equipment, utility liability concerns, reduction of power reliability and power quality.

Current islanding detection methods typically monitor over/under voltage and over/under frequency conditions passively and actively; however, each method has an ideal sensitivity operating condition and a non-sensitive operating condition with varying degrees of power quality corruption called the non detection zone (NDZ). The islanding detection method developed in this thesis takes the theoretically accurate concept of impedance measurement and extends it into the symmetrical component impedance domain, using the existence of naturally and artificially produced unbalanced conditions. Specific applications, where this islanding detection method improves beyond existing islanding detection methods, are explored where a generalized solution allows the protection engineer to determine when this method can be used most effectively.

To start, this thesis begins with a brief introduction to power systems in North America and the motivation for the use of distributed generation. Further chapters then detail the background and specifics of this technique.

1.1.1 Electrical Energy Supply and Demand

Human progress has been linked to the increase of energy consumed per capita [1], [2]. In the last 20 years, electrical consumption has been steadily increasing in North America at a rate of 1.1% for Canada, and 2.0% for the United States [3]; however, the investment into new bulk electric power sources such as hydro dams and nuclear generation plants has become politically, economically and physically limited [4]. For example, transmission investment in the year 2000 was $2.5 billion dollars less than the level of investment in 1975, where over this same period, electricity sales nearly doubled [5]. At the current demand growth, the United States bulk electric power system is estimated to be approximately 5 to 15 years away from the power demand exceeding the generation capacity as seen in Figure 1.1. The United States has historically consumed a median of 7.5 times the power of Canada which can be seen in the Canadian winter demand growth in Figure 1.3.

Small localized power sources, commonly known as “Distributed Generation” (DG), have become a popular alternative to bulk electric power generation [6]. There are many reasons for the growing popularity of DG; however, on top of DG tending to be more renewable, DG can serve as a cost effective alternative to major system upgrades for peak shaving or enhancing load capacity margins. Additionally, if the needed generation facilities could be constructed to meet the growing demand, the entire distribution and transmission system would also require upgrading to handle the additional loading. Therefore, constructing additional power sources and upgrading the transmission system will take significant cost and time, both of which may not be achievable. These trends are not only limited to North America, but worldwide; the demand for electricity is expected to double in the next 20 years [7].

The costs of power outages to a country's economy can be staggering. The cost associated with power outages to all business sectors in the United States has been determined to be of the order $164 Billion US per year. More specifically, the average cost of a power outage to a medium sized company is $1477 US for one second and $7000 US for one hour. Though the cost of one second of outage is considerable, the cost of one hour, which is a 3600 times longer duration is only 4.7 times of cost increase [8]; hence, initial quick outages are important to avoid significant cost implications to the economy. Distributed Generators can assist in reducing these occurrences by strengthening networks that are near to their stability limit.

1.1.2 Distributed Generation as a Viable Alternative

Traditionally, electrical power generation and distribution are purely a state owned utility. However, in order to keep up with the growing demand, many states and provinces in North America are deregulating the electrical energy system. This trend is not without its own challenges. For example, how is an independent power producer (IPP) able to enter the market?

Recent innovations in power electronics such as fast switching, high voltage Insulated Gate Bipolar Transistors (IGBT) and developments in power generation technologies have made DG a considerable alternative to either delaying infrastructure upgrades or as additional cogeneration support [9]. Though the cost per KW-hr is still higher than basic power grid distribution costs, ($0.07/Kw-hr for gas turbines and as high as $0.5/KW-hr for PV) [10] [11]. The trend to completely deregulate the North American electric power grid along with the increasing trend in the cost of fossil fuels has resulted in the consideration of DG as a viable opportunity. Currently, BC Hydro, Canada's third largest utility has more than 50 Distributed Generator stations ranging from 0.07 MVA to 34 MVA [12]

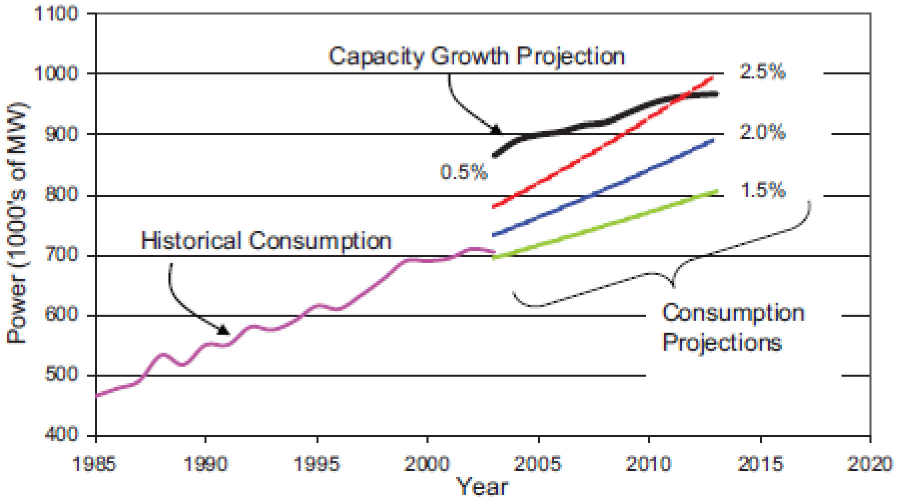

Figure 1.1: 2006 United States Projected Summer Generation and Capacity [13]

1.1.3 Types of Distributed Generation

Distributed Generators can be broken into three basic classes: induction, synchronous and asynchronous. Induction generators require external excitation (VARs) and start up much like a regular induction motor. They are less costly than synchronous machines and are typically less than 500 KVA.

Induction machines are most commonly used in wind power applications. Alternatively, synchronous generators require a DC excitation field and need to synchronize with the utility before connection. Synchronous machines are most commonly used with internal combustion machines, gas turbines, and small hydro dams. Finally, asynchronous generators are transistor switched systems such as inverters. Asynchronous generators are most commonly used with micro turbines, photovoltaic, and fuel cells. A comparison of each type of generation system can be seen in Table 1.1

Table1.1: Types of DG and Typical Capacity

Technology	**Typical capacity**	**Utility interface**
Photovoltaic	10VA to 5000VA	inverter
Wind	10VA to 500KVA	Induction and Synchronous Generators, Inverters
Geothermal	100VA to several MVA	Synchronous Generator
Mycro Hydro	100VA to several MVA	Induction or Synchronous Generator
Reciprocating Engine	1000VA to several MVA	Induction or Synchronous Generator
Combustion Turbine	1000VA to several MVA	Synchronous Generator
Combined Cycle	1000VA to several MVA	Synchronous Generator
Micro Turbines	10 KVA to several MVA	inverter
Fuel Cells	10 KVA to several MVA	inverter

1.1.4 Distribution system with multiple DGs

Distributed or dispersed generation may be defined as generating resources other than central generating stations that is placed close to load being served, usually at customer site. It serves as an alternative to or enhancement of the traditional electric power system. The commonly used distributed resources are wind power, photo voltaic, hydro power. The figure 1.2 shows the single line diagram of the distribution system with multiple DGs.

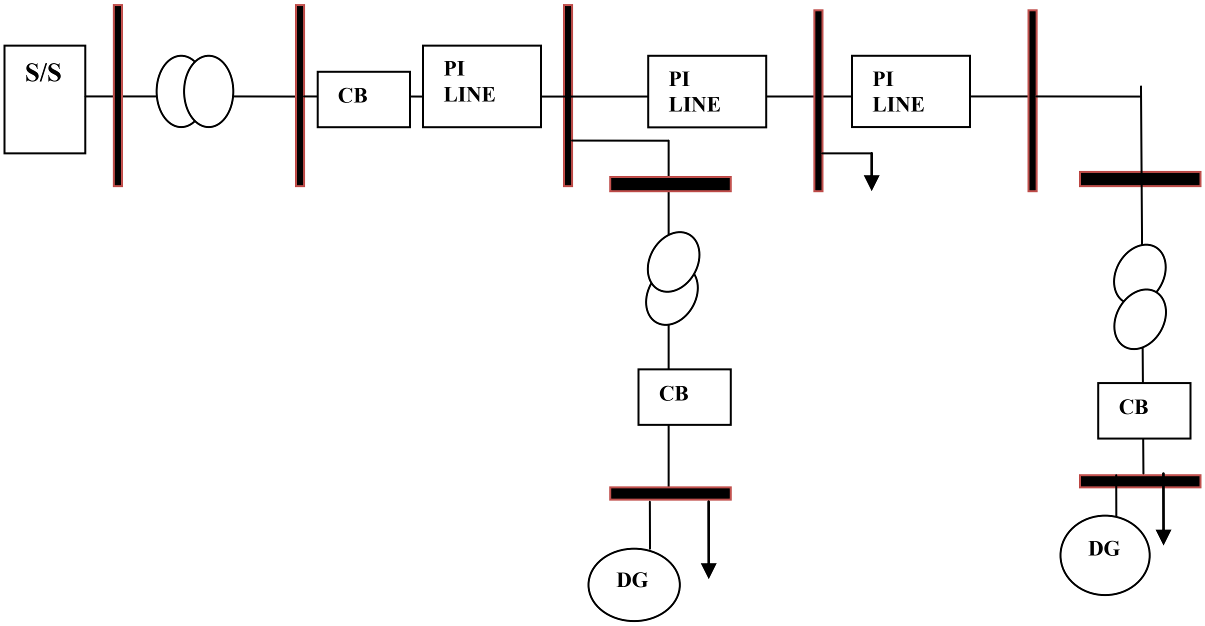

Figure 1.2: single line diagram of Distributed system with multiple DGs

1.1.5 Advantages of distributed generations

- Flexibility - DG resources can be located at numerous locations within a utility's service area. This aspect of DG equipment provides a utility tremendous flexibility to match generation resources to system needs.
- Improved Reliability - DG facilities can improve grid reliability by placing additional generation capacity closer to the load, thereby minimizing impacts from transmission and distribution (T&D) system disturbances, and reducing peak-period congestion on the local grid. Furthermore, multiple units at a site can increase reliability by dispersing the capacity across several units instead of a single large central plant.
- Improved Security - The utility can be served by a local delivery point. This significantly decreases the vulnerability to interrupted service from imported electricity supplies due to natural disasters, supplier deficiencies or interruptio6ns, or acts of terrorism.

- Reduced Loading of T&D Equipment - By locating generating units on the low-voltage bus of existing distribution substations, DG will reduce loadings on substation power transformers during peak hours, thereby extending the useful life of this equipment and deferring planned substation upgrades
- Reduces the necessity to build new transmission and distribution lines or upgrade existing ones.
- Reduce transmission and distribution line losses [14]
- Improve power quality and voltage profile of the system.[14]

In fact, many utilities around the world already have a significant penetration of DG in their system. But there are many issues to be taken into account with the DG and one of the main issues is islanding.

1.1.6 Technical Challenges Facing Distributed Generation

Distributed Generation (DG) is not without problems. DG faces a series of integration challenges, but one of the more significant overall problems is that the electrical distribution and transmission infrastructure has been designed in a configuration where few high power generation stations that are often distant from their consumers, ”push” electrical power onto the many smaller consumers. DG systems are often smaller systems that are that are locally integrated into the low voltage distribution system (see Table1.1)

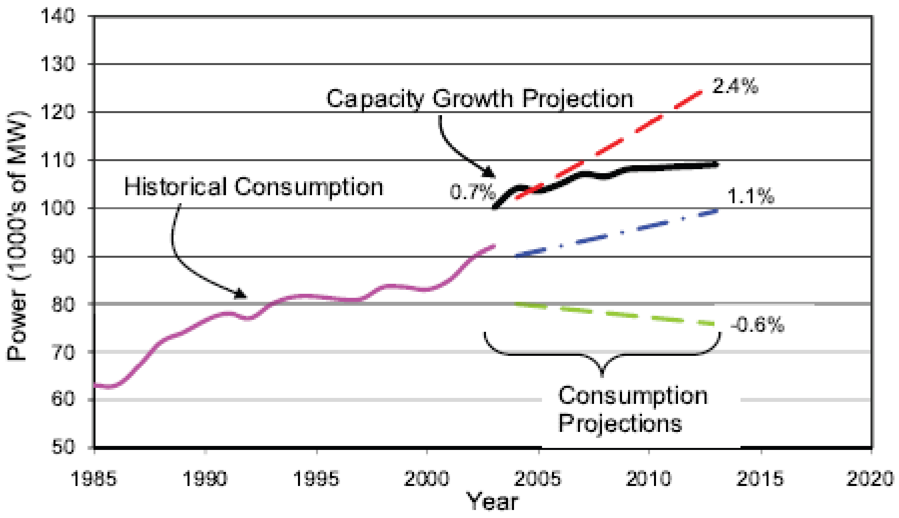

Figure 1.3: 2006 Canadian Projected Winter Generation and Capacity [13]

Which conflicts with the existing power network design paradigm? An example of a similar radial system is with a large city's water distribution where one very large pipe of water slowly becomes narrower and narrower until it reaches the customer's tap at a low flow and low pressure. What would happen if one of the consumers had water well and started pumping water into the system? Adding DG to the existing electric power distribution system can lead to a reduction of protection reliability, system stability and quality of the power to the customers. More specifically, the technical challenges that the installation of distributed generation face have been reviewed in various studies [15] [16] [17][18] [19] [20] [21] [22] where the findings of the various studies are listed in Table 1.2.

Depending on the amount of DG connected and the strength of the utility power system, the issues outlined in Table 1.2 can become substantial problems [23]. Of the challenges with DG listed in Table1.2, the problem of protection against unplanned islanding is a significant one.

Table 1.2: Different Technical challenges for distributed generations:

1. Voltage Regulation and Losses
2. Voltage Flicker
3. DG Shaft Over-Torque During Faults
4. Harmonic Control and Harmonic Injection
5. Increased Short Circuit Levels
6. Grounding and Transformer Interface
7. Transient Stability
8. Sensitivity of Existing Protection Schemes
9. Coordination of Multiple Generators
10. High Penetration Impacts are Unclear
11. Islanding Control

1.1.7 Islanding

Islanding is the situation in which a distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by DG connected to it. As shown in the figure1.4. Traditionally, a distribution system doesn’t have any active power generating source in it and it doesn’t get power in case of a fault in transmission line upstream but with DG, this presumption is no longer valid. Current practice is that almost all utilities require DG to be disconnected from the grid as soon as possible in case of islanding. IEEE 929-1988 standard [24] requires the disconnection of DG once it is islanded .Islanding can be intentional or Non intentional. During maintenance service on the utility grid, the shut down of the utility grid may cause islanding of generators. As the loss of the grid is voluntary the islanding is known. Non-intentional islanding, caused by accidental shut down of the grid is of more interest. As there are various issues with unintentional islanding. IEEE 1547-2003 standard [25] stipulates a maximum delay of 2 seconds for detection of an unintentional island and all DGs ceasing to energize the distribution system,

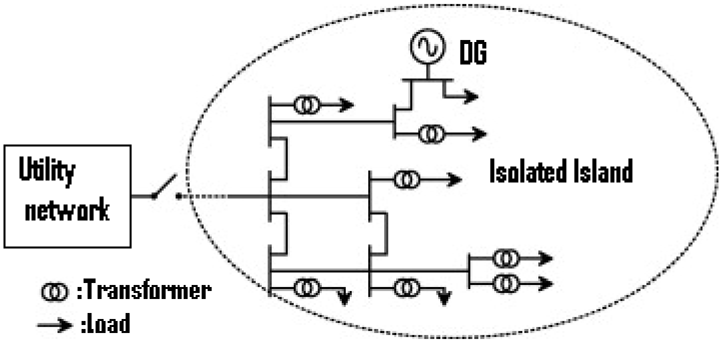

Figure 1.4: Scenario of Islanding operation

1.1.8 Issues with Islanding:

Although there are some benefits of islanding operation there are some drawbacks as well. Some of them are as follows:

- Line worker safety can be threatened by DG sources feeding a system after primary sources have been opened and tagged out.
- The voltage and frequency may not be maintained within a standard permissible level. Islanded system may be inadequately grounded by the DG interconnection.
- Instantaneous reclosing could result in out of phase reclosing of DG. As a result of which large mechanical torques and currents are created that can damage the generators or prime movers [26] Also, transients are created, which are potentially damaging to utility and other customer equipment. Out of phase reclosing, if occurs at a voltage peak, will generate a very severe capacitive switching transient and in a lightly damped system, the crest over-voltage can approach three times rated voltage .[27]
- Various risks resulting from this include the degradation of the electric components as a consequence of voltage& frequency drifts.

Due to these reasons, it is very important to detect the islanding quickly and accurately.

1.1.9 Utility Perspective of Distributed Generator Network Islanding

Utilities have a more pragmatic point of view of distributed generation islanding [28]. Their goal is to improve the distribution level (25 kV and below) customer service reliability especially in regions where the reliability is below customer's needs. It is believed that customer reliability could improve with the addition of DG sources and that the DG may be able to sell electricity back to the utility. However, without complex studies and frequent expensive system upgrades DG islanding is not allowed. Some examples of these studies are: real and reactive power profile and control, planning for islanding, minimum/ maximum feeder loading, islanding load profile, minimum/maximum voltage profile, protection sensitivity and DG inertia. One more specific example is how substation auto-reclosers of circuit breakers and main line reclosers may be disabled and other protection devices may need to be removed to allow proper coordination of utility sources and DG sources.

Maintenance times might also increase as utility workers will not only need to lockout the utility lines but they will need to take additional time to lockout all the installed DG lines. Some of the required installation studies of an Independent power producer must complete to be able to island are: 1. inadvertent islanding and planned islanding study, 2. reliability study, 3. power quality study, 4. utility equipment upgrade assessment, 5. safety and protection reviews, and 6. commercial benefit study. Clearly the costs of designing a DG to be capable of islanding or to simply be installed into the main utility owned network requires extensive and costly engineering and business reviews which may be outside the financial range of smaller DG suppliers.

1.2 Objectives:

The objective of this thesis is to develop an islanding detection technique which works effectively in Power distribution network with multiple DG interface. The proposed research investigates the performance of the negative sequence voltage components for islanding detection. As negative sequence components are the key parameters for detecting unbalanced conditions in the power systems, the same has been considered for islanding detection during the islanding process. The Change in energy and standard deviations of the d1 Wavelet coefficients of the negative sequence voltage and current detects the islanding conditions accurately. Another important parameter such as negative sequence impedance has been measured at the target DG location for islanding detection. Thus this thesis aims to derive a new technique for islanding detection which has edge over the existing conventional techniques.

1.3 Outlines of the thesis:

Chapter 1 starts with the introduction of Distributed generation and islanding operation. Also describes the issues with islanding and necessity of islanding detection.

Chapter 2 gives the overview of conventional islanding detection techniques, their merits and demerits.

Chapter 3 describes the commonly used islanding detection device like vector surge relay and ROCOF relay

Chapter 4 clearly describes the simulation model and all measure parts of the model are described here and also data are presented. Also explains the motivation of research work, indicates the proposed methods for islanding detection and different conditions for islanding non islanding conditions for which simulation works are carried out are mentioned. Also a brief introduction to wavelet transform is described in this chapter.

In **Chapter 5** the model is used in simulations of different islanding formations and contingencies. The results are presented in diagrams and discussed. Also proposed algorithms developed for islanding detection are given.

Conclusions of the study are summarized in **Chapter 6** followed by some ideas on future work.

1.4 Contributions:

- Development of new method for islanding detection of wind turbines based on negative sequence voltage & current using Wavelet transform
- Application of the concept of negative sequence impedance measurements to the problem of islanding detection for distributed generator protection.
- Calculation of standard deviation and energy for different islanding &non islanding conditions
- An extensive simulation studies on islanding detection based on above techniques using MATLAB & SIMULINK

Chapter-2

Review of Islanding Detection Techniques

The main philosophy of detecting an islanding situation is to monitor the DG output parameters and system parameters and/ and decide whether or not an islanding situation has occurred from change in these parameters. Islanding detection techniques can be divided into remote and local techniques and local techniques can further be divided into passive, active and hybrid techniques as shown in Figure 2.1

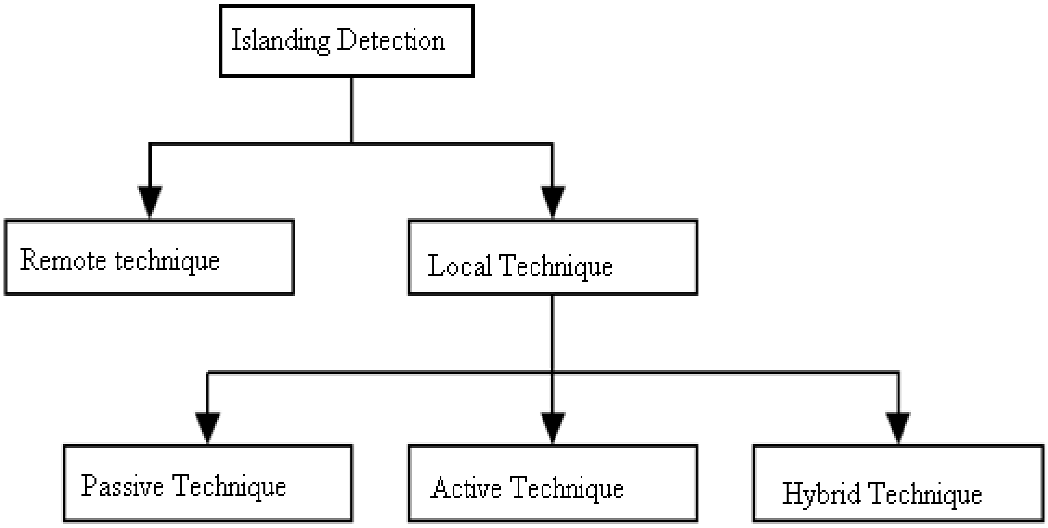

Figure 2.1: Islanding detection techniques

2.1 Remote islanding detection techniques:

Remote islanding detection techniques are based on communication between utilities and DGs. Although these techniques may have better reliability than local techniques, they are expensive to implement and hence uneconomical .Some of the remote islanding detection techniques are as follows:

2.1.1Power line signaling scheme:

These methods use the power line as a carrier of signals to transmit islanded or non-islanded information on the power lines. The apparatus includes a signal generator at the substation (25+ kV) that is coupled into the network where it continually broadcasts a signal as shown in figure (2.2). Due to the low-pass filter nature of a power system, the signals need to be transmitted near or below the fundamental frequency and not interfere with other carrier technologies such as automatic meter reading. Each DG is then equipped with a signal detector to receive this transmitted signal. Under normal operating conditions, the signal is received by the DG and the system remains connected. However, if an island state occurs, the transmitted signal is cut off because of the substation breaker opening and the signal can not be received by the DG, hence indicating an island condition.

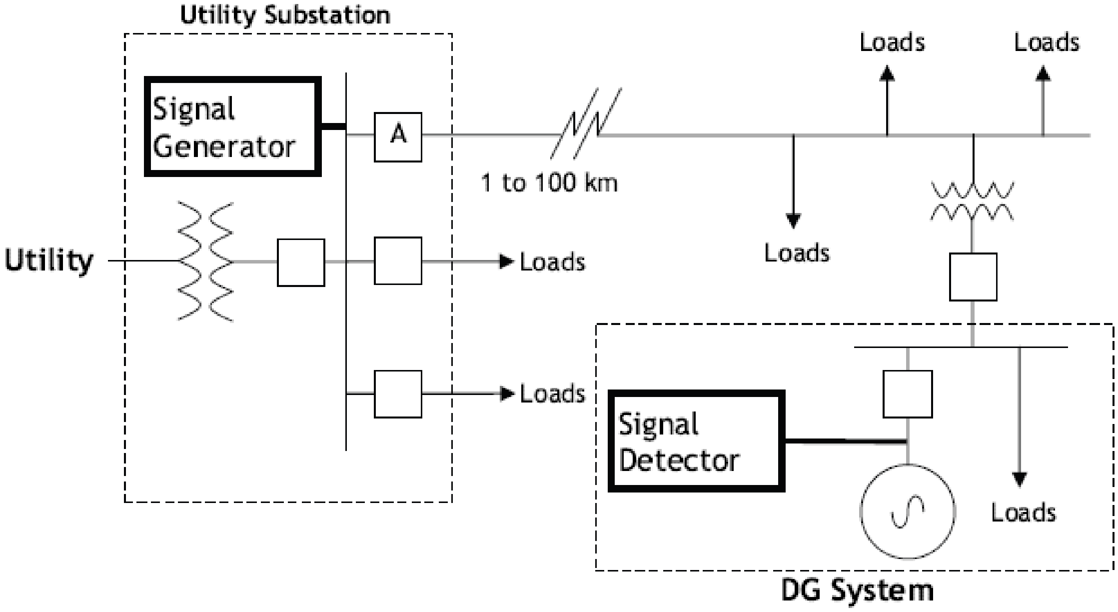

Figure 2.2: Distibuted Generation power line Signaling Islanding Detection

This method has the advantages of its simplicity of control and its reliability. In a radial system there is only one transmitting generator needed that can continuously relay a message to many DGs in the network. The only times the message is not received is if the interconnecting breaker has been opened, or if there is a line fault that corrupts the transmitted signal.

There are also several significant disadvantages to this method, the fist being the practical implementation. To connect the device to a substation, a high voltage to low voltage coupling transformer is required. A transformer of this voltage capacity can have prohibitive cost barriers associated with it that may be especially undesirable for the first DG system installed in the local network. Another disadvantage is if the signaling method is applied in a non radial system, resulting in the use of multiple signal generators. This scenario can be seen in Figure 2.3 where the three feeder busses connect to one island bus. The implementation of this system, opposed to a simple radial system, will be up to three times the cost.

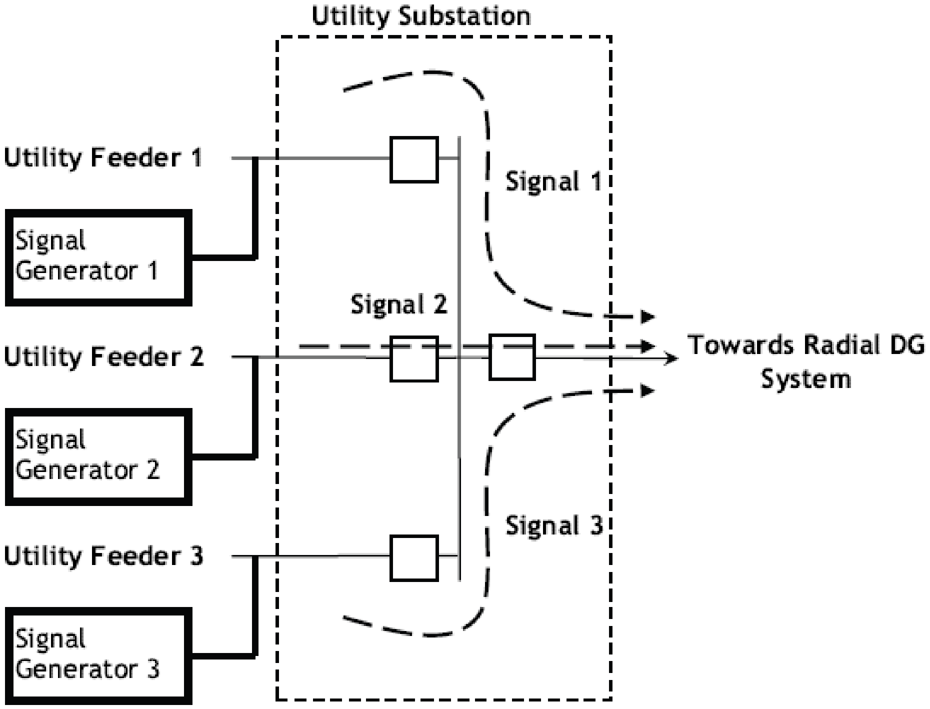

Figure 2.3: Distributed Generation Multi Power Line Signaling Islanding Detection Issue

Another problem for power line communication is the complexity of the network and the affected networks. A perfectly radial network with one connecting breaker is a simple example of island signaling; however, more complex systems with multiple utility feeders may find that differentiation between upstream breakers difficult.

2.1.2 Transfer trip scheme:

The basic idea of transfer trip scheme is to monitor the status of all the circuit breakers and reclosers that could island a distribution system. Supervisory Control and Data Acquisition (SCADA) systems can be used for that. When a disconnection is detected at the substation, the transfer trip system determines which areas are islanded and sends the appropriate signal to the DGs, to either remain in operation, or to discontinue operation. Transfer tip has the distinct advantage similar to Power Line Carrier Signal that it is a very simple concept. With a radial topology that has few DG sources and a limited number of breakers, the system state can be sent to the DG directly from each monitoring point. This is one of the most common schemes used for islanding detection [29].This can be seen in figure 2.4

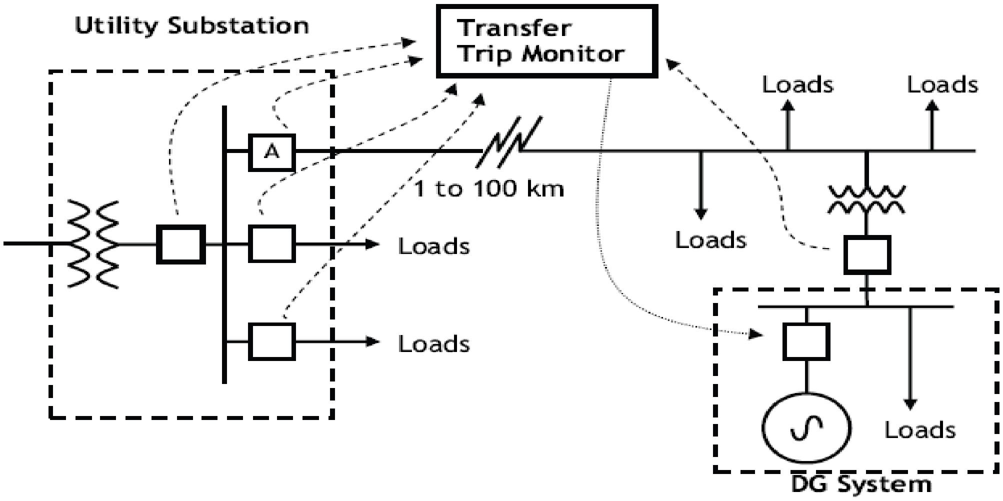

Figure 2.4: Distributed Generation Transfer Trip Islanding Detection

The weaknesses of the transfer trip system are better related to larger system complexity cost and control. As a system grows in complexity, the transfer trip scheme may also become obsolete, and need relocation or updating. Reconfiguration of this device in the planning stages of DG network is necessary in order to consider if the network is expected to grow or if many DG installations are planned. The other weakness of this system is control. As the substation gains control of the DG, the DG may lose control over power producing capability and special agreements may be necessary with the utility. If the transfer trip method is implemented correctly in a simple network, there are no non-detection zones of operation.

2.2 Local detection techniques

It is based on the measurement of system parameters at the DG site, like voltage, frequency, etc. It is further classified as:

2.2.1 Passive detection techniques

Passive methods work on measuring system parameters such as variations in voltage, frequency, harmonic distortion, etc. These parameters vary greatly when the system is islanded. Differentiation between an islanding and grid connected condition is based upon the thresholds set for these parameters. Special care should be taken while setting the threshold value so as to differentiate islanding from other disturbances in the system. Passive techniques are fast and they don't introduce disturbance in the system but they have a large non detectable zone (NDZ) where they fail to detect the islanding condition.

There are various passive islanding detection techniques and some of them are as follows:

(a) **Rate of change of output power:** The rate of change of output power, $\frac{dp}{dt}$, at the DG side, once it is islanded, will be much greater than that of the rate of change of output power before the DG is islanded for the same rate of load change[30]. It has been found that this method is much more effective when the distribution system with DG has unbalanced load rather than balanced load. [31]

(b) Rate of change of frequency: The rate of change of frequency, $\frac{df}{dt}$, will be very high when the DG is islanded. The rate of change of frequency (ROCOF) can be given by [32]

$$\text{ROCOF, } \frac{df}{dt} = \frac{\Delta p}{2HG} \times f$$

Where, ΔP is power mismatch at the DG side

H is the moment of inertia for DG/system

G is the rated generation capacity of the DG/system

Large systems have large H and G where as small systems have small H and G giving larger value for $\frac{df}{dt}$ ROCOF relay monitors the voltage waveform and will operate if ROCOF is higher than setting for certain duration of time. The setting has to be chosen in such a way that the relay will trigger for island condition but not for load changes. This method is highly reliable when there is large mismatch in power but it fails to operate if DG's capacity matches with its local loads. However, an advantage of this method along with he rate of change of power algorithm is that, even they fail to operate when load matches DG's generation, any subsequent local load change would generally lead to islanding being detected as a result of load and generation mismatch in the islanded system.

(c) Rate of change of frequency over power:

$\frac{df}{dp}$ in a small generation system is larger than that of the power system with larger capacity. Rate of change of frequency over power utilize this concept to determine islanding condition .Further more, test results have shown that for a small power mismatch between the DG and local loads, rate of change of frequency over power is much more sensitive than rate of frequency over time.[33]

(d) Voltage unbalance:

Once the islanding occurs, DG has to take change of the loads in the island. If the change in loading is large, then islanding conditions are easily detected by monitoring several parameters: voltage magnitude, phase displacement, and frequency change. However, these methods may not be effective if the changes are small. As the distribution networks generally include single-phase loads, it is highly possible that the islanding will change the load balance of DG. Furthermore, even though the change in DG loads is small, voltage unbalance will occur due to the change in network condition. [34-35]

(e) Harmonic distortion:

Change in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has inverter based DGs. One approach to detect islanding is to monitor the change of total harmonic distortion (THD) of the terminal voltage at the DG before and after the island is formed. **[36].**The change in the third harmonic of the DG’s voltage also gives a good picture of when the DG is islanded.

2.2.2. Active detection techniques

With active methods, islanding can be detected even under the perfect match of generation and load, which is not possible in case of the passive detection schemes. Active methods directly interact with the power system operation by introducing perturbations. The idea of an active detection method is that this small perturbation will result in a significant change in system parameters when the DG is islanded, whereas the change will be negligible when the DG is connected to the grid.

(a) Reactive power export error detection:

In this scheme, DG generates a level of reactive power flow at the point of common coupling (PCC) between the DG site and grid [37] or at the point where the Reed relay is connected [38]. This power flow can only be maintained when the grid is connected. Islanding can be detected if the level of reactive power flow is not maintained at the set value. For the synchronous generator based DG, islanding can be detected by increasing the internal induced voltage of DG by a small amount from time to time and monitoring the change in voltage and reactive power at the terminal where DG is connected to the distribution system. A large change in the terminal voltage, with the reactive power remaining almost unchanged, indicates islanding. [39]The major drawbacks of this method are it is slow and it can not be used in the system where DG has to generate power at unity power factor.

(b) Phase (or frequency) shift methods:

Measurement of the relative phase shift can give a good idea of when the inverter based DG is islanded. A small perturbation is introduced in form of phase shift. When the DG is grid connected, the frequency will be stabilized. When the system is islanded, the perturbation will result in significant change in frequency. The Slip-Mode Frequency Shift Algorithm (SMS) [40] uses positive feedback which changes phase angle of the current of the inverter with respect to the deviation of frequency at the PCC.

A SMS curve is given by the equation:

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

Where θ_m is the maximum phase shift that occurs at frequency f_m . f_n is the nominal frequency and $f^{(k-1)}$ is the frequency at previous cycle. A SMS curve is designed in such a way that its slope is greater than that of the phase of the load in the unstable region. A SMS curve, with θ_m =10° and f_m = 53 Hz, is shown in Figure

2.5. When the utility is disconnected, operation will move through the unstable region towards a stable operating point (denoted by black dots in Figure 2.5). Islanding is detected when the inverter frequency exceeds the setting.

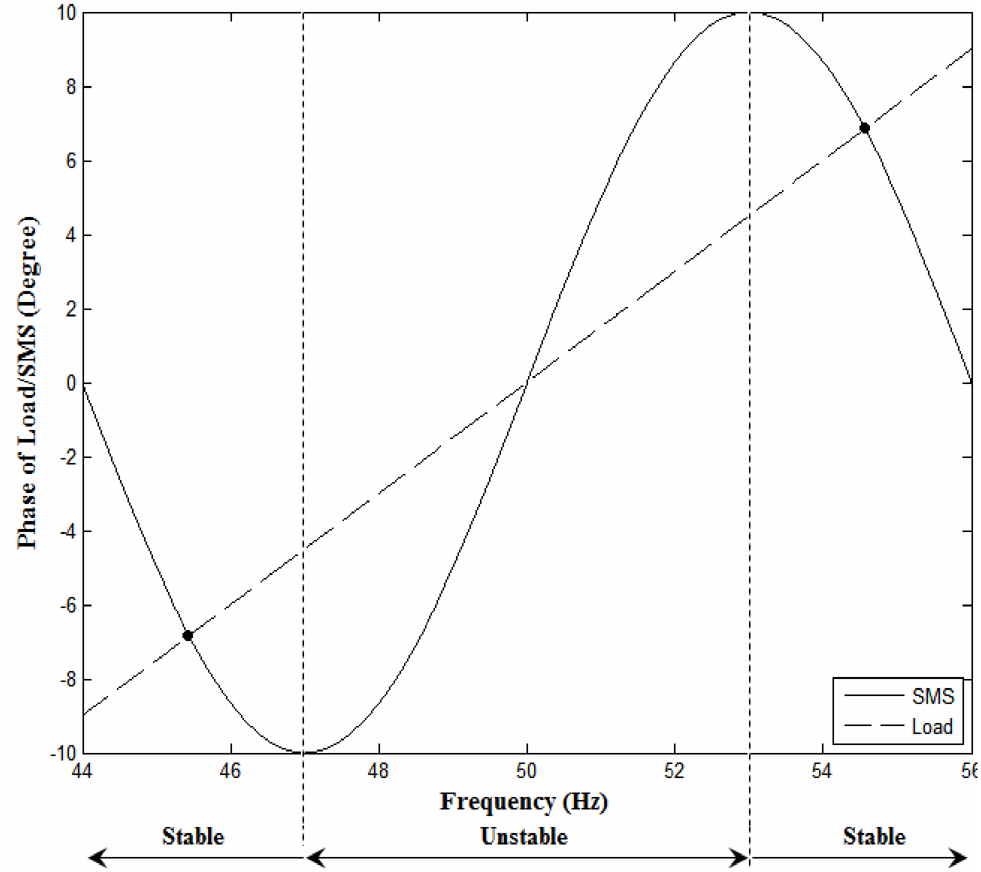

Figure 2.5 Phase response of DG and local load

This detection scheme can be used in a system with more than one inverter based DG. The drawback of this method is that the islanding can go undetected if the slope of the phase of the load is higher than that of the SMS line, as there can be stable operating points within the unstable zone [41].

2.2.3 Hybrid detection schemes

Hybrid methods employ both the active and passive detection techniques. The active technique is implemented only when the islanding is suspected by the passive technique. Some of the hybrid techniques are discussed as follows:

(a) Technique based on positive feedback (PF) and voltage imbalance (VU):

This islanding detection technique uses the PF (active technique) and VU (passive technique). The main idea is to monitor the three-phase voltages continuously to determinate VU [42] which is given as

$$\text{VU}= \frac{V + sq}{V - sq}$$

V_{+Sq} and V_{-Sq} are the positive and negative sequence voltages, respectively. Voltage spikes will be observed for load change, islanding, switching action, etc. Whenever a VU spike is above the set value, frequency set point of the DG is changed. The system frequency will change if the system is islanded.

(b) Technique based on voltage and reactive power shift:

In this technique voltage variation over a time is measured to get a covariance value (passive) which is used to initiate an active islanding detection technique, adaptive reactive power shift (ARPS) algorithm [43].

$$\text{Co-variance}\,(T_{av'}, T_v) = E \;\; T_{av'}^{(n)} - U_{av} \quad T_v^{(n)} - U_v$$

$T_{av'}$ is the average of the previous four voltage periods.

U_{av} is the mean of $T_{av'}$

Tv is the voltage periods

U_V is the mean of T_V

The ARPS uses the same mechanism as ALPS, except it uses the d-axis current shift instead of current phase shift. The d-axis current shift, $\mathbf{i_d^k}$ or reactive power shift is given as

$$i_d^k = k_d \left(\frac{T_{av'} - T_v^{(k)}}{T_v^{(k)}} \right)$$

k_d is chosen such that the d-axis current variation is less than 1 percent of q-axis current in inverter's normal operation. The additional d-axis current, after the suspicion of island, would accelerates the phase shift action, which leads to a fast frequency shift when the DG is islanded. There is no single islanding detection technique which will work satisfactorily for all systems under all situations. The choice of the islanding detection technique will largely depend on the type of the DG and system characteristics. Recently, hybrid detection techniques have been proposed and it seems that the hybrid detection technique is the way to go with passive technique detecting the islanding when change in system parameter is large and initiating the active technique when the change in system parameter is not so large for the passive technique to have an absolute discrimination.

Table 2.1 summarizes the islanding detection techniques, their advantage and disadvantage, and examples.[44]

Table 2.1: Comparisons of islanding detection techniques

Islanding Detection Techniques	Advantages	Disadvantages	Examples
1 Remote Techniques	• Highly reliable	• Expensive to implement especially for small systems.	• Transfer trip scheme • Power line signaling scheme
2 Local Techniques			
a. Passive Techniques	• Short detection time • Do not perturb the system • Accurate when there is a large mismatch in generation and demand in the islanded system.	• Difficult to detect islanding when the load and generation in the islanded system closely match • Special care has to be taken while setting the thresholds • If the setting is too aggressive then it could result in nuisance tripping	• Rate of change of output power scheme • Rate of change of frequency scheme • Rate of change of frequency over power scheme • Change of impedance scheme • Voltage unbalance scheme • Harmonic distortion scheme
b. Active techniques	• Can detect islanding even in a perfect match between generation and demand in the islanded system (Small NDZ	• Introduce perturbation in the system • Detection time is slow as a result of extra time needed to see the system response for perturbation • Perturbation often degrades the power quantity and if significant enough, it may degrade the system stability even when connected to the grid	• Reactive power export error detection scheme • Impedance measurement scheme • Phase (or frequency) shift schemes (like SMS, AFD, AFDPF and ALPS
c .Hybrid Techniques	• Have small NDZ. • Perturbation is introduced only when islanding is suspected	• Islanding detection time is prolonged as both passive and active technique is implemented	• Technique based on positive feedback and voltage imbalance • Technique based on voltage and reactive power shift

Chapter- 3

Existing Voltage Surge and ROCOF relay for Islanding Detection

3.1 ROCOF Relay

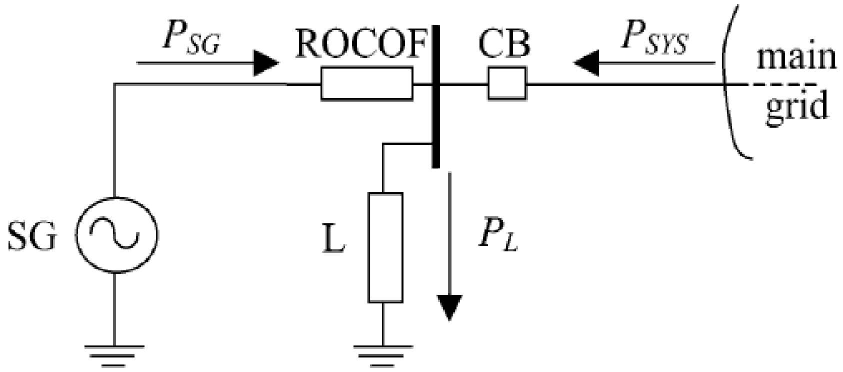

Figure 3.1 Equivalent Circuit of Synchronous Generator equipped with ROCOF Relay operating parallel with Utility [46]

Fig. 3.1 presents an equivalent circuit of a synchronous generator equipped with a ROCOF relay operating in parallel with a distribution network. In this figure, a synchronous generator (SG) feeds a load (L). The difference between the electrical powers P_{SG} supplied by the generator and P_L consumed by the load is provided (or consumed) by the main grid. Therefore, the system frequency remains constant. If the circuit breaker (CB) opens, due to a fault for example, the system composed by the generator and the load becomes islanded.

In this case, there is an electrical power imbalance due to the lost grid power P_{SYS} This power imbalance causes transients in the islanded system and the system frequency starts to vary dynamically. Such system behavior can be used to detect an islanding condition. However, if the power imbalance in the islanded system is small, then the frequency will change slowly. Thus, the rate of change of frequency $\frac{df}{dt}$ can be used to accelerate the islanding detection for this situation. [45] The rate of change of frequency is calculated considering a measure window over a few cycles, usually between 2 and50 cycles.

This signal is processed by filters and then the resulting signal is used to detect islanding. If the value of the rate of change of frequency is higher than a threshold value, a trip signal is immediately sent to the generator CB. Typical ROCOF settings installed in 60-Hz systems are between 0.10and 1.20 Hz/s. Another important characteristic available in these relays is a block function by minimum terminal voltage. If the terminal voltage drops below an adjustable level V_{min} , the trip signal from the ROCOF relay is blocked. This is to avoid, for example, the actuation of the ROCOF relay during generators start-up or short circuits.

3.2 Vector Surge Relay

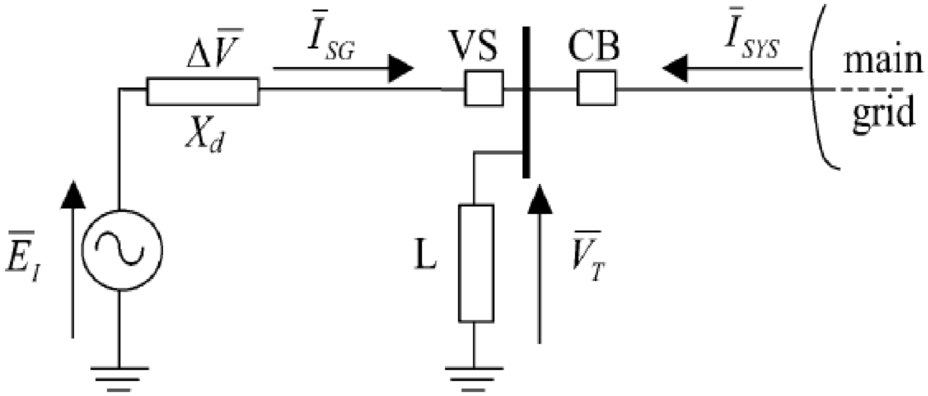

Figure 3.2: Equivalent circuit of Synchronous Generator equipped with Vector Surge Relay operating parallel with Utility [46]

A synchronous generator equipped with a VS relay operating in parallel with a distribution network is depicted in Fig. 3.2. There is a voltage drop V between the terminal voltage VT and the generator internal voltage EI due to the generator current ISG passing through the generator reactance Xd . Consequently, there is a displacement angle between the terminal voltage and the generator internal voltage, whose phasor diagram is presented in Fig. 3.3(a). In Fig. 3.2, if the CB opens due to a fault, for example, the system composed by the generator and the load L becomes islanded. At this instant, the synchronous machine begins to feed a larger load (or smaller) because the current ISYS provided (or consumed) by the power grid is abruptly interrupted. Thus, the generator begins to decelerate (or accelerate).

Consequently, the angular difference between VT and EI is suddenly increased (or decreased) and the terminal voltage phasor changes its direction, as shown in Fig. 3.3(b). Analyzing such phenomenon in the time domain, the instantaneous value of the terminal voltage jumps to another value and the phase changes the phase position changes as depicted in Fig. 3.4, where the point A indicates the islanding instant. Additionally, the frequency of the terminal voltage also changes. This behavior of the terminal voltage is called vector surge. VS relays are based on such phenomena. VS relays available in the market measure the duration time of an electrical cycle and start a new measurement at each zero rising crossing of the terminal voltage. The current cycle duration (measured waveform) is compared with the last one (reference cycle). In an islanding situation, the cycle duration is either shorter or longer, depending on if there is an excess or a deficit of active power in the islanded system, as shown in Fig. 3.4. This variation of the cycle duration results in a proportional variation of the terminal voltage angle, which is the input parameter of VS relays. If the variation of the terminal voltage angle exceeds a predetermined threshold, a trip signal is immediately sent to the CB. Usually, VS relays allow this angle threshold to be adjusted in the range from 2 to 20. The relay is also disabled if the magnitude of the terminal voltage drops below a threshold value to avoid false operation.

To avoid false operation, ROCOF and VS relays are disabled if the terminal voltage decreases below a determined voltage threshold. Showed that ROCOF relays require a smaller active power imbalance level than VS relays for successful islanding detection. On the other hand, ROCOF relays are much more susceptible to false operation than VS relays.

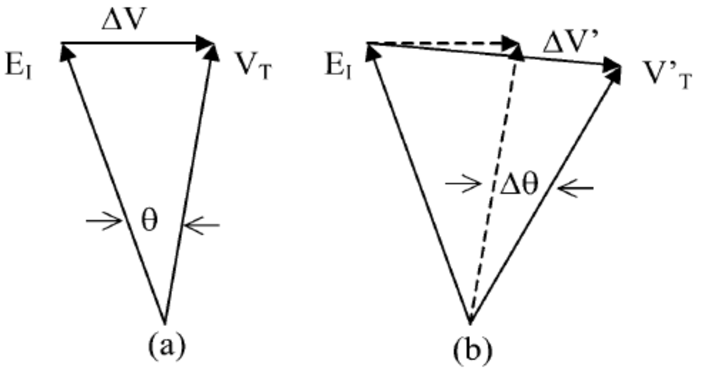

Figure 3.3: Internal and terminal voltage phasors (a) before opening with CB (b) after opening with CB

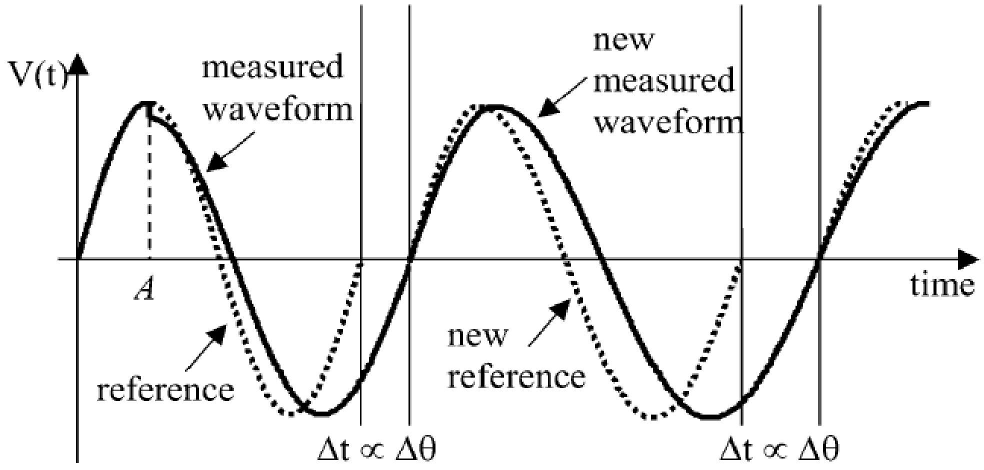

Figure 3.4: Voltage Vector Surge

Chapter-4

Proposed Techniques and System Studied

4.1 Motivation for the research work

Integrations of Distributed Generations (DGs) in the distribution network is expected to play an increasingly important role in the electric power system infrastructure and market. As more DG systems become part of the power grid, there is an increased safety hazard for personnel and an increased risk of damage to the power system. Despite the favorable aspects grid-connected DGs can provide to the distribution system, a critical demanding concern is islanding detection and prevention.

Islanding operation is a condition that occurs when a part of a network is disconnected from the remainder of power system but remains energized by DG units interconnected to the distribution system, which normally comprises multiple DGs with diverse technologies. Failure to trip islanded DG can lead to a number of problems for these resources and the connected loads, which includes power quality, safety and operation problems. Therefore, the current industry practice is to disconnect all DR's immediately after the occurrence of islands. The disconnection is normally performed by a special protection scheme called islanding detection relays which can be implemented using different techniques.

Islanding detection techniques may be classified as passive or active. Passive techniques use information available at the DG side to determine whether the DG system is isolated from the grid. The advantage of passive techniques is that the implementation does not have an impact on the normal operation of the DG system. Active techniques introduce an external perturbation at the output of the inverter. These tend to have a faster response and a smaller non-detection zone compared to passive approaches. However, the power quality (PQ) of the inverter can be degraded by the perturbation.

Recently pattern recognition technique based on Wavelet Transform [47-49] has been found to be an effective tool in monitoring and analyzing power system disturbances including power quality assessment and system protection against faults. This paper investigates the time-localization property of Wavelet transform for islanding detection by processing negative sequence Components of voltage and current signals retrieved at the target DG location. As negative sequence components provide vital information in case of unbalanced conditions in power system, thus same has been considered for the proposed islanding detection technique which is subjected to disturbance during islanding process such as deviations in frequency, voltage and active power etc.

The negative sequence component of the voltage and current signals are extracted from the derived voltage and current signal at the target DG locations. The one cycle negative sequence voltage and current signal are processed through Wavelet transform (db4). The time-frequency information derived at the level-1 decompositions (d1) localizes the corresponding islanding events. Further to provide a threshold for detecting islanding conditions from non-islanding ones, the standard deviations (std) and change in energy (ce) of the d1 level coefficients for one cycle are computed.

Further to know the impact of negative sequence impedance in the islanding detection, the same is found out at the target DG location. It is observed that time variation of the negative sequence impedance provides effective islanding detection compared to non-islanding situations. Further, the standard deviation of the negative sequence impedance for one cycle data, detects the islanding conditions accurately over non-sanding ones. Thus the above two techniques based on negative sequence components provide effective islanding detection techniques, which has edge over some earlier techniques.

4.2 Simulation model

In order to investigate the performance of the different Techniques during various contingencies a simulation model was implemented. It is important that the model reflects a real system in all vital parts. The behavior of the simulated system must be similar to what happens in a real situation. How this has been achieved is described in the following.

In this thesis the emphasis has been put on wind power turbines and induction generators. The reason for this is the ongoing extension of wind power. In the preliminary study we have considered a system as shown in the fig-4.1

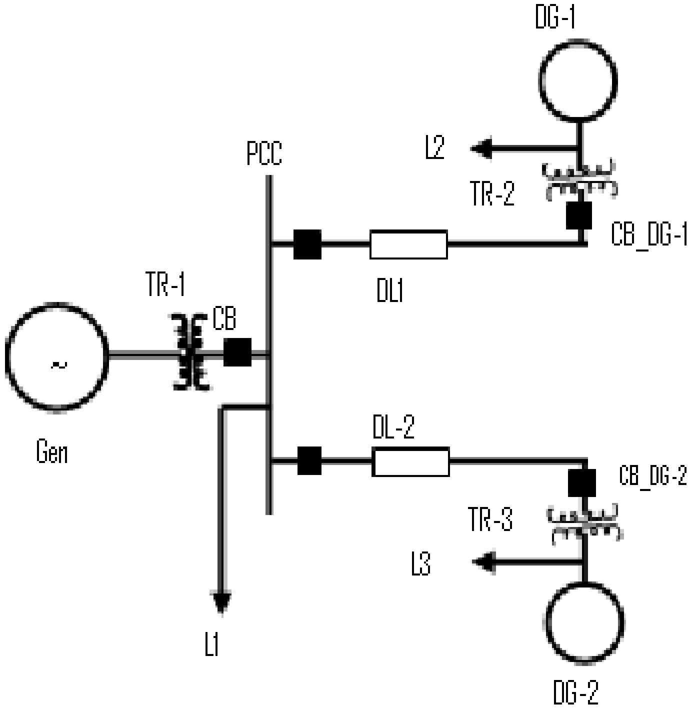

Figure 4.1: The studied Power Distribution network with multiple DGs

4.3 Description of the model

This model is set having 2 9MW wind farms using detailed model of a doubly-Fed Induction generators (DFIG) driven by a wind turbine. The model is well suited for observing harmonics and control system dynamic performance over relatively short periods of time. Each 9MW wind farm consists of six 1.5 MW wind turbines connected to a 120 KV grid through a 30 KM,25 KV feeder .A 500 KW resistive load and .9 MVAR filter are connected at the 575 generation bus. Wind turbines using a double fed induction generator (DFIG) and an AC/DC/AC IGBT based PWM converter.

The switching frequency is 1620 Hz. The stator winding is connected directly to the 60 Hz grid while the rotor fed at variable frequency through AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing the mechanical stress on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. The wind speed is maintained constant at 10m/s.

The control System uses a torque controller in order to maintain the speed at 1.09 pu. The reactive power produced by the wind turbine is regulated at 0 MVAR. Sample time used to discretise the model is 5 micro seconds and the sample time used by the control system is 10 microseconds. For a wind speed of 10m/s, the maximum turbine output is .55 pu of its rated power .55*9MW=4.95MW. at a speed of 1.09 pu of generator synchronous.

The details of the generator, DGs, transformers, distribution lines and loads are mentioned as below

- Generator: rated short-circuit MVA=1000, f=50 Hz, rated kV =120, V_{base} = 120 kV.
- Distributed Generations (DGs): Wind farm (9 MW) consisting of six 1.5-MW wind turbines (Doubly Fed Induction Generator) is connected to a 25-kV distribution system exports power to a 120-kV grid through a 30-km 25-kV feeder.
- Transformer T1: rated MVA = 25, f = 50 Hz, rated kV = 120/25, V_{base} = 25 kV, R_1 = 0.00375 pu, X_1= 0.1 pu, R_m= 500 pu, X_m= 500 pu.

- Transformer T2, T3, T4 and T5: rated MVA = 10, f = 50 Hz, rated kV = 575 V/ 25 kV, V_{base} = 25 kV, R_1 = 0.00375 pu, X_1= 0.1 pu, R_m= 500 pu, X_m= 500 pu
- Distribution lines (DL): DL-1, DL-2, DL-3 and DL-4: PI-Section, 30 km each, Rated kV = 25, rated MVA = 20, V_{base} = 25 kV, R_0 = 0.1153 ohms/km, R_1 = 0.413 ohms/km, L_0 = 1.05e-3 H/km, L_1 = 3.32e-3 H/km, C_0 = 11.33e-009 F/km, X_1 = 5.01e-009 F/km,
- Normal Loading data: L1 = 15 MW, 5 MVAR. L2, L-3, L4, L5=8.0MW, 3 MVAR.

The voltage and current signals are retrieved at the target DG location for islanding conditions and non-islanding conditions (other disturbances). The relays for each DG units are placed at the DG end. For example, the relay for CB_DG-1 is placed at DG-1 to collect the voltage and current information for both islanding and non-islanding conditions. The possible situations of islanding and non-islanding conditions studied are given as follows

- Tripping of main circuit breaker (CB) for islanding conditions.
- Opening of any breakers between the power system and DG.
- Loss of power on the PCC bus.
- Sudden load change at the target DG location.
- Tripping of other DGs apart from the target one.

The above conditions are simulated under possible variations in operating loading at normal, minimum and maximum loading conditions. The loads are varied at the DG end as well as at the PCC. The model is simulated at 1.6 kHz (32 samples on 50 Hz base frequency). The voltage and current signals are retrieved at the target DG location (DG-1, DG-4). The islanding starts at 0.3 sec as shown in the Fig.4.2. The complete simulation is carried out using MATLAB-SIMULINK software package.

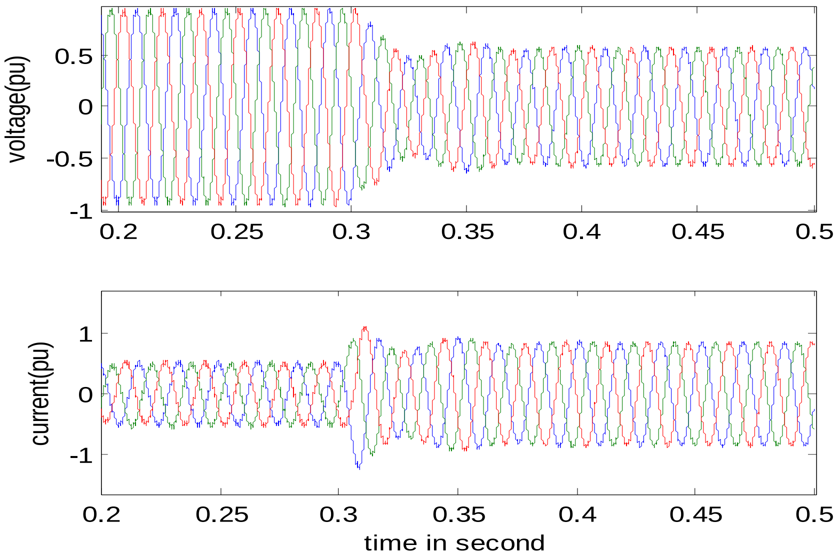

Figure 4.2: Three-Phase Voltage and Current Signals under Islanding Condition retrieved at the target DG location (starts at 0.3 sec)

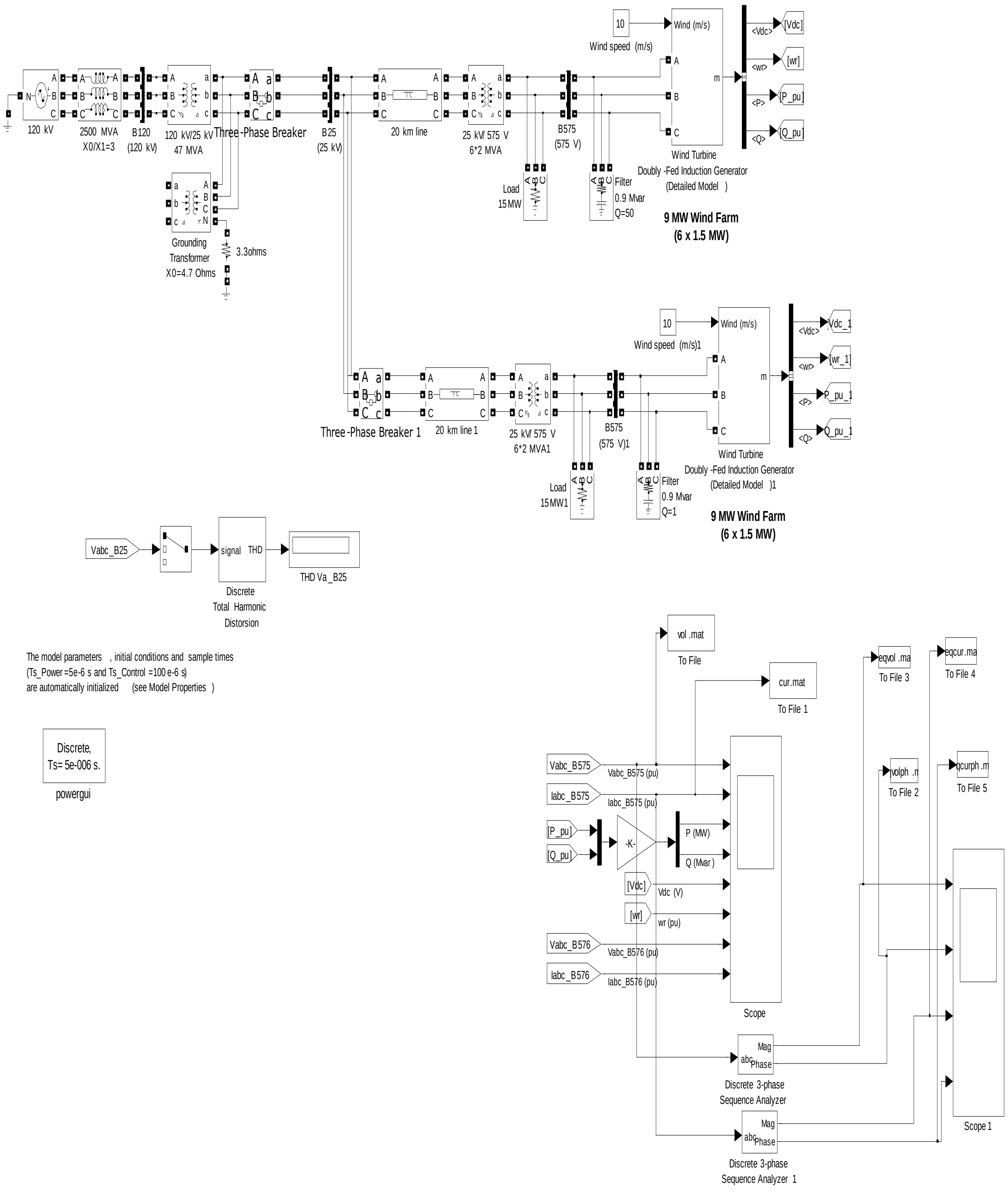

Figure 4.3: MATLAB/SIMULINK MODEL

4.4 Conditions for islanding & non islanding

Condition-1:

Both the three phase circuit breaker& three phase circuit breaker1 are in closed conditions. That is the normal condition .So the voltage& current waveforms found at any DG end is purely sinusoidal.

Condition-2:

Three phase circuit breaker is initially closed and is opened with transition time.3 to .5 . Three phase circuit breaker 1 is permanently closed. As after switching off the three phase breaker whole part of the distribution system is isolated from the remainder part of the power system. So this is the islanding condition.

Condition-3:

Three phase circuit breaker is permanently closed. Three phase breaker1 is initially closed and is opened with transition time .3 to .5. As another DG is there in the line where three phase breaker1 is connected. This is the DG line trip condition.

Condition-4:

This is the sudden load change condition. Where suddenly load is changed up to 50%.

For the above four events experimental study is observed and islanding is detected by developing some algorithm.

4.5 Proposed Islanding Detection Methods

There are some new techniques we have developed for islanding detection.

A Negative sequence component and d1 coefficients for islanding detection

B Negative Sequence impedance for islanding detection

1 phase Voltage and current waveforms observed at the DG-1 location during islanding:

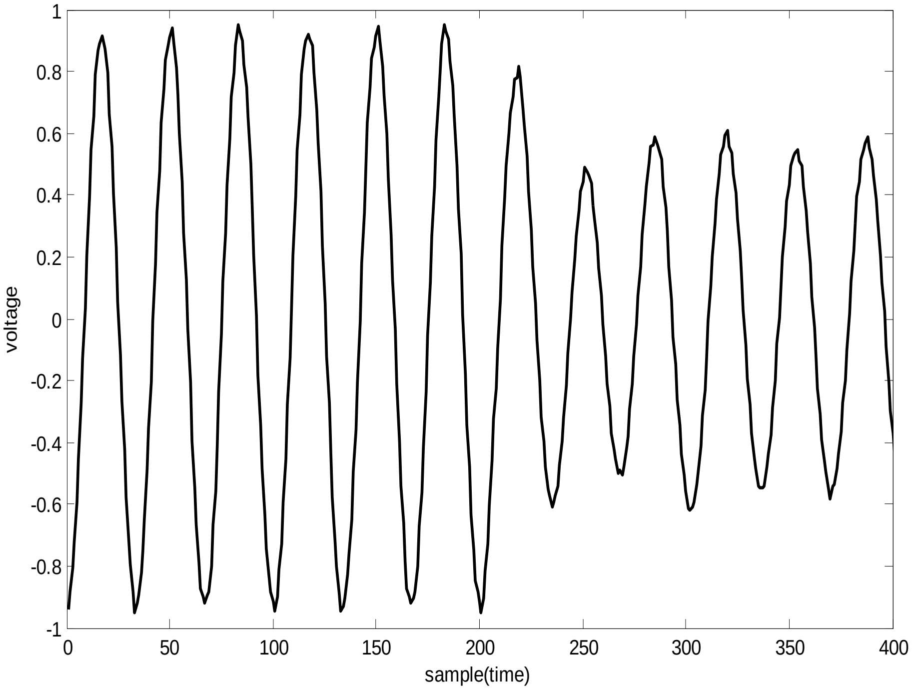

Figure:4.4 1 phaseVoltage waveform at DG-1 during Islanding

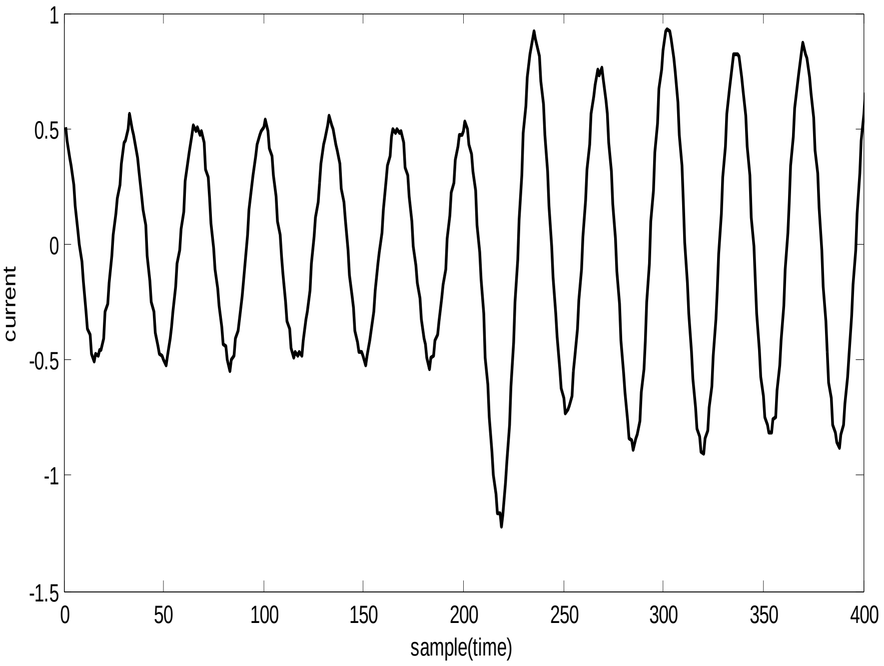

Figure: 4.5 1 phase Current waveform at the DG-1 during Islanding

In the Figure 4.4 the voltage waveform at the DG location after switching off the three phase breaker is shown. It is observed that suddenly voltage decreases. Similarly Figure 4.5 the current waveform at the DG location after switching off the three phase breaker is shown. It is observed that suddenly current increases.

4.6 Islanding-detection using wavelet Transform

In this Thesis, a wavelet transform-based approach is proposed to detect the occurrence of islanding events in distributed generation systems. Thanks to time–frequency localization capabilities exhibited by wavelet transform, the approach embedded with this transform technique has grasped the appearance of the islanding event in a highly effective manner. Moreover, for those regions which are in need of a better visualization, the proposed approach would serve as an efficient aid such that the mains power disconnection can be better distinguished. To validate the feasibility of this approach, the method has been validated through several scenarios. Test results supported the effectiveness of the method for the application considered.

In this Thesis, a wavelet transform-based approach is proposed to monitor the parameter variations of interests, where Daubechies wavelet serves as basis. Enhanced by such an approach, it is anticipated that any abrupt change occurred in the acquired signal would be effectively caught, hence increasing the reliability of islanding-detection. Some useful features of this new method are listed below:[50]

(1) It helps improve the islanding-detection capability of protective relays. The safety of utility engineers is, meanwhile, better ensured.
(2) Because the time and frequency information can be simultaneously observed, the robustness of the method can be better realized for the application considered.
(3) With the increased number of installed distributed generators, the proposed method would serve as a potential alternative in addition to existent approaches.
(4) The method is easy to program, facilitating the firmware realization of integrated circuit design for the portable detector applications.

The basis functions in wavelet analysis are localized in frequency making mathematical tools such as power spectra (power in a frequency interval) useful at picking out frequencies and calculating power distributions. The most important feature of this transforms is that individual wavelet functions are localized in space .This localization feature, along with wavelets localization of frequency, makes many functions and operators using wavelets “sparse”, when transformed into the wavelet domain. This sparseness, in turn results in a number of useful applications along with islanding detection.

Wavelet Transform

Given a function f(t), its continuous Wavelet Transform (CWT) can be calculated as follows:

$$\mathrm{CWT}(f, x, y) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)\psi^{*}\left(\frac{t-y}{x}\right)dt \qquad (4.1)$$

Where x and y are scaling (dilation) and translation (time shift) constants, respectively, and ψ is the wavelet function. Wavelet Transform of sampled waveforms can be obtained by implementing the discrete Wavelet Transform, which is given by

$$\mathrm{DWT}(f,x,y) = \frac{1}{\sqrt{x_0^m}} \sum_k f(k)\psi^*\left(\frac{n - kx_0^m}{x_0^m}\right) \qquad (4.2)$$

Where the parameters x and y in (5.1) are replaced by x_0^m and kx_0^m **,** k and m being integer variables. In a standard DWT, the coefficients are sampled from the CWT on a dyadic **grid.**

Associated with the wavelet is a scaling function $\varphi(t)$**.** The scaling function along with the wavelet function creates a multi-resolution analysis (MRA) of the signal. The scaling function of one level can be represented as a sum of a scaling function of the next finer level.

$$\varphi(t) = \sum_{n=-\infty}^{\infty} h(n)\sqrt{2}\varphi(2t - n) \qquad (4.3)$$

The wavelet function is also related to the scaling function by

$$\psi(t) = \sum_{n=-\infty}^{\infty} h_1(n)\sqrt{2}\varphi(2t - n) \qquad \mathbf{(4.4)}$$

Where h(k) and h_1(k) represent the scaling and wavelet functions, respectively, and are related as

$$h_1(k) = (-1)^k h(1-k) \qquad \mathbf{(4.5)}$$

We can make use of the scaling function to represent the signal as

$$y(t) = \sum_{k=-\infty}^{\infty} c_{jo}(k) 2^{jo/2} \varphi(2^{jo}t - k) + \sum_{k=-\infty}^{\infty} \sum_{j=jo}^{\infty} d_j(k) 2^{j/2} \psi(2^j t - k) \qquad \mathbf{(4.6)}$$

Where jo represents the coarsest scale spanned by the scaling function.

The scaling and wavelet coefficients of the signal $y(t)$ can be evaluated by using a filter bank of quadrature mirror filters (QMF).

$$c_j(k) = \sum_{m=-\infty}^{\infty} c_{j+1}(m)h(m-2k) \tag{4.7}$$

$$d_j(k) = \sum_{m=-\infty}^{\infty} c_{j+1}(m)h_1(m-2k) \tag{4.8}$$

Equations (4.7) and (4.8) show that the coefficients at a coarser level can be attained by passing the coefficients at the finer level to their respective filters followed by a decimation of two. This will result in the number of samples in the coarser level to be approximately half of the number of samples at the finer level.

For a signal that is sampled at a frequency higher than the Nyquist frequency, the samples are used as $c_{j+1}(m)$. The filter bandwidth and center frequency for a dyadic wavelet filter at scale k is given as

$$B_k = \frac{f_s}{2^{k+1}} \tag{4.9}$$

$$f_k = \frac{3f_s}{2^{k+2}} \tag{4.10}$$

The three level wavelet decomposition structure is given in Fig. 4.6

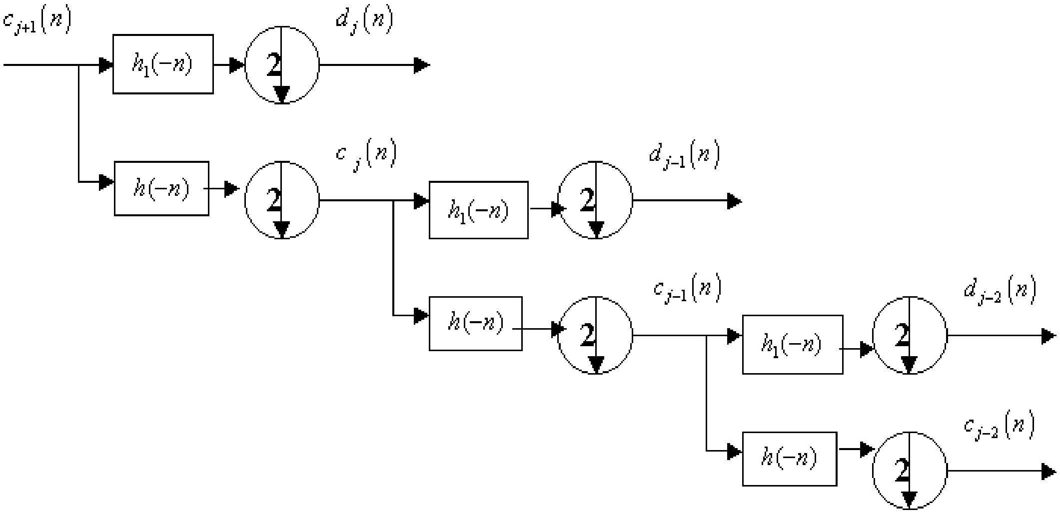

Figure 4.6: Three level wavelet decomposition

of high pass and low pass filters at each scaling stage of Wavelet Transform. This can be thought of as successive approximations of the same function, each approximation providing the incremental information related to a particular scale (frequency range), the first scale covering a broad frequency range at the high frequency end of the frequency spectrum, however, with progressively shorter bandwidths. Conversely, the first scale will have the highest time resolution; higher scales will cover increasingly longer time intervals. While in principle any admissible wavelet can be used in the Wavelet analysis, Daubechies Wavelet (DB4) is used in this work for both the purposes of fault section identification and phase selection for a transmission line.

If the used scaling function and the Wavelet function form an orthogonal basis, then Parseval’s theorem relates the energy of the distorted signal to the energy in each expansion coefficients and their Wavelet coefficients. This means that the norm of energy of the signal can be partitioned in terms of expansion coefficients .This feature is utilized here to differentiate different faults. The energy of the distorted signal will be partitioned at different resolution levels in different ways depending on the signals to be analyzed. The Energy of the signal is given by

$$E_{signal} = \int \left|y(t)\right|^2 dt = \sum_{k=-\infty}^{\infty} \left|c(k)\right|^2 + \sum_{j=jo}^{\infty} \sum_{k=-\infty}^{\infty} \left|d_j(k)\right|^2 \qquad \textbf{(4.11)}$$

The change in energy is found out by deducting the energy content of the d1 coefficients for one cycle signal before islanding inception from the energy content of the d1 coefficients for one cycle signal after islanding inception. Similarly the standard deviation of the d1 coefficients for one cycle signal is computed for detecting islanding events from non-islanding ones .Standard deviation can be considered as a measure of the energy for a distorted signal with zero mean and is utilized in this work as a feature to detect the islanding from non islanding one, in power distribution network with multiple DG interface.

Chapter 5

Simulation Results & Discussion

The test system is simulated with sampling rate 1.6 KHz. Sampling period is 5e-006.Samples/cycle is 32.The four events described above are simulated. Here the steady state operation of the DFIG and its dynamic response for a remote fault on the 120-KV system is observed. The voltage and current wave forms are observed at DG terminals by closing and opening of the two circuit breakers.

5.1 Negative Sequence Component and d-1 coefficients for islanding detection

Negative-sequence is one of three quantities used in the symmetrical component analysis of three-phase power systems. Symmetrical components are used to calculate unbalanced conditions on a three-phase system using only a single-phase calculation. This greatly simplifies the process of calculating fault quantities for phase-to-phase, phase-to-ground, and phase-to phase- to-ground faults on power systems. Symmetrical components consist of positive-, negative-, and zero-sequence quantities. Basically, positive-sequence quantities are those present during balanced, three-phase conditions.

Positive sequence quantities makeup the normal voltages and currents observed on power systems during typical, steady-state conditions. Negative-sequence quantities are a measure of the amount of unbalance existing on a power system. Zero-sequence quantities are most commonly associated with ground being involved in an unbalanced condition. Negative- and zero-sequence quantities are usually only present in substantial levels during unbalanced, faulted conditions on a power system. Since negative- and zero-sequence quantities are only present in relatively large values for faulted conditions, they are often used to determine that a faulted condition exists on a power system. Negative-sequence can be used to detect phase-to-phase, phase-to-ground, and phase-to phase- to-ground faults. Zero-sequence can be used to detect phase-to-ground and phase-to phase- to-ground faults.

The equations to calculate negative-sequence are given as:

$$V_n = \frac{1}{3}(V_a + a^2 V_b + aV_c)$$

$$I_n = \frac{1}{3}(I_a + a^2 I_b + aI_c)$$

where V_a, V_b, V_c are three phase voltages, and I_a, I_b, I_c are three phase currents retrieved at the taget DG location, and $a = 1\angle 120^\circ$, is the complex operator. The negative sequence components are found out using sequence analyser block of Simulink.

The negative sequence voltage and currents are processed through Wavlet Tranfrom (db4) for time localization of the islanding event. The negative sequence voltage and corresponding d1 coefficints for different islanding and nonislanding conditions are shown in Fig. 5.1,5.2,5.3,5.4. The negative sequence current and corresponding d1 coefficients for different islanding and nonislanding conditions are shown in Fig. 5.5,5.6,5.7,5.8. The d1 coefficients clearly localizes the islanding event and thus helps in detecting the same.

5.1.1 Islanding Detection based upon Negative Sequence Component of Voltage and its Wavelet Transform

Condition-1 (Normal Condition)

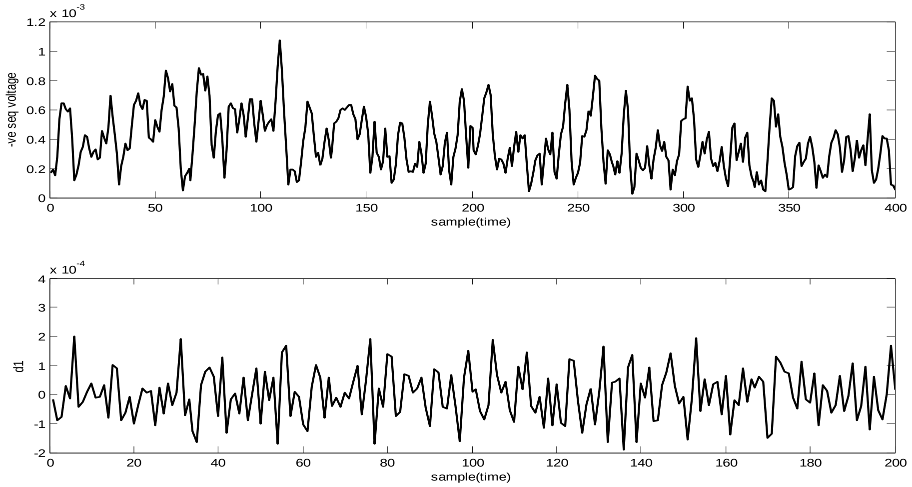

Figure 5.1: The negative sequence component of voltage and d-1 coefficient for Normal condition

Condition-2 (Islanding Condition)

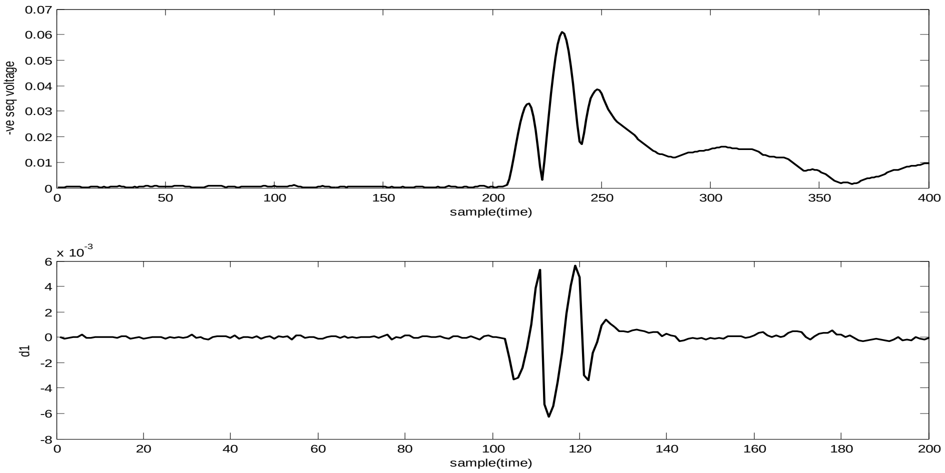

Figure 5.2: The negative sequence component of voltage and d-1 coefficient for Islanding condition

Condition-3 (DG line trip Condition)

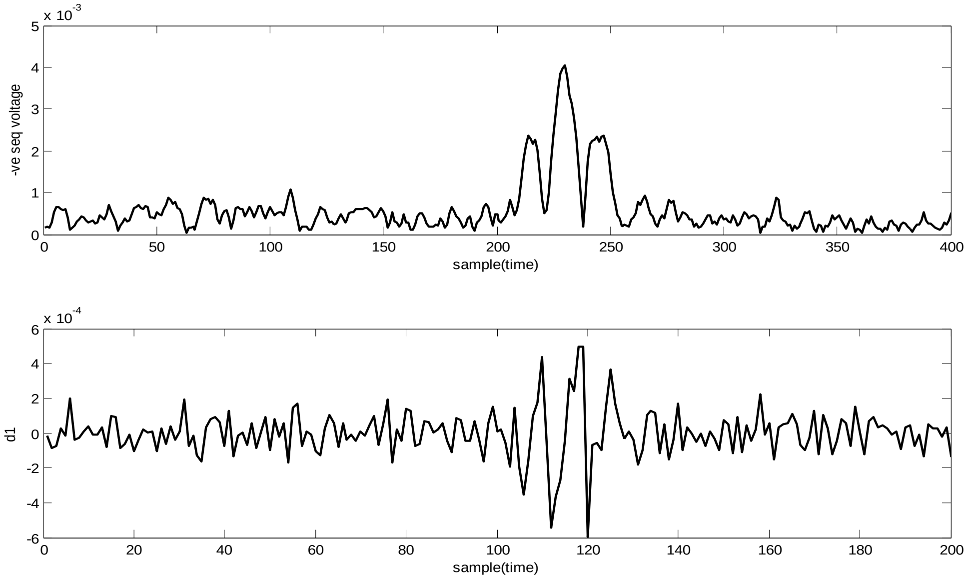

Figure 5.3: The negative sequence component of voltage and d-1 coefficient for DG line trip condition

Condition-4 (Sudden load change)

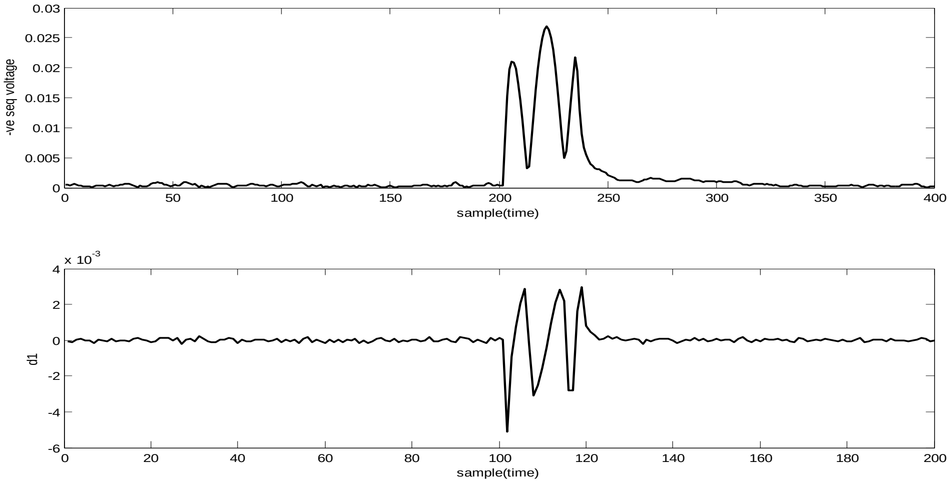

Figure 5.4: The negative sequence component of voltage and d-1 coefficient for sudden load change condition

5.1.2 Islanding Detection based upon Negative Sequence Component Current and its Wavelet transform

Normal Condition

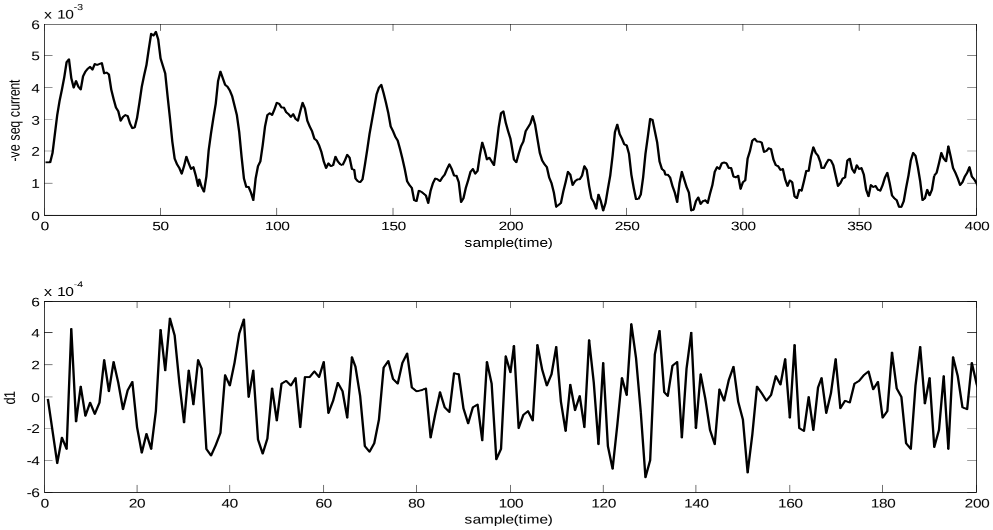

Figure 5.5: The negative sequence component of current and d-1 coefficient for normal condition

Islanding Condition

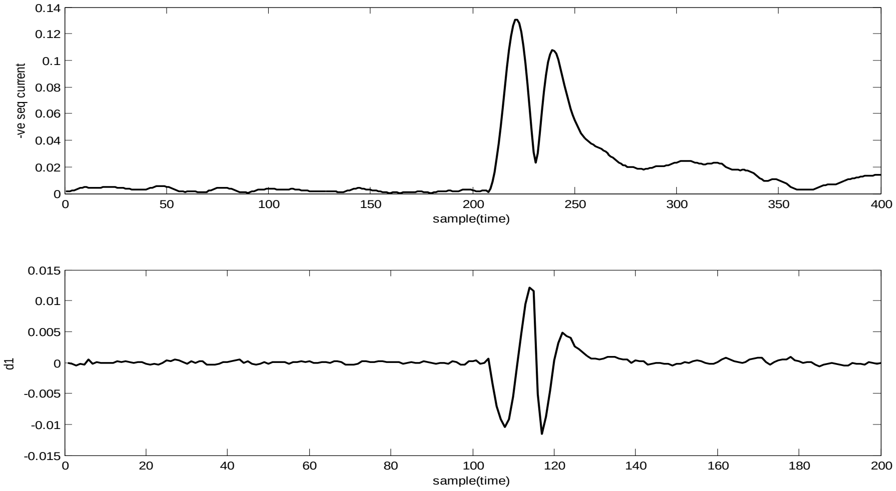

Figure 5.6: The negative sequence component of current and d-1 coefficient for Islanding condition

DG line Trip Condition

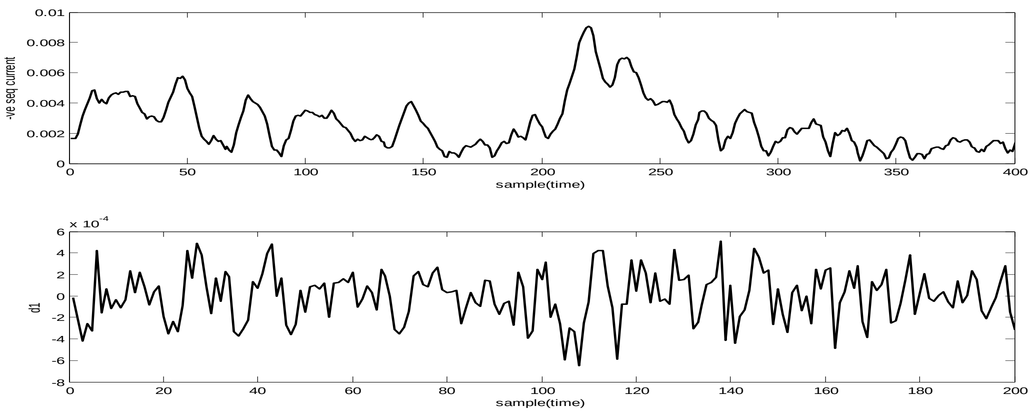

Figure 5.7: The negative sequence component of current and d-1 coefficient for DG line trip condition

Sudden Load change Condition

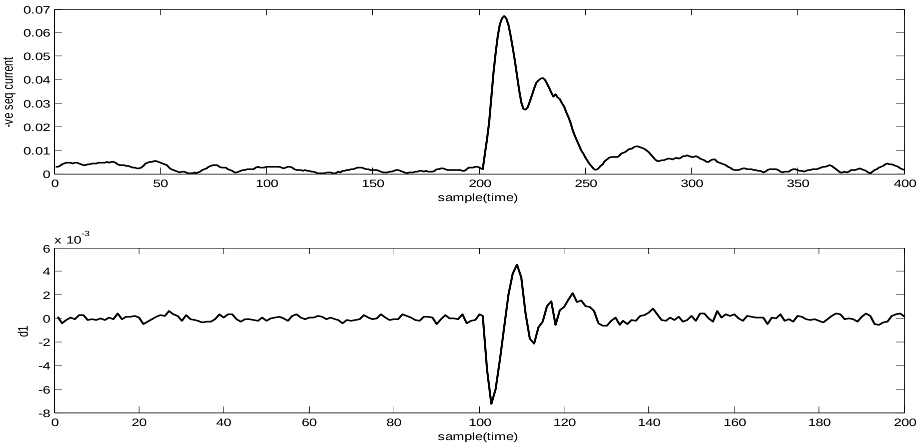

Figure 5.8: The negative sequence component of current and d-1 coefficient for sudden load change condition

5.1.3 Comparative Study of Islanding & non Islanding Situation

The comparision between islanding and non-islanidng conditions (normal operation) based upen d1 coefficient of negative sequence voltage is given in Fig. 5.9. Similar comaprision between islanidng and non-islanding conditions such as sudden load change and DG line cut-off are shown in Fig. 5.10and 5.11 respectively. It is observed that the d1 coefficients are highly pronounced in case of islanding compared to non-islaning situations. In case of 50 % load change (non-islanding) , even the d1 coefficients are highly pronounced compared to other non-islanding situations, but still a threshold will work to distinguish between islanding and non-islanding conditon.

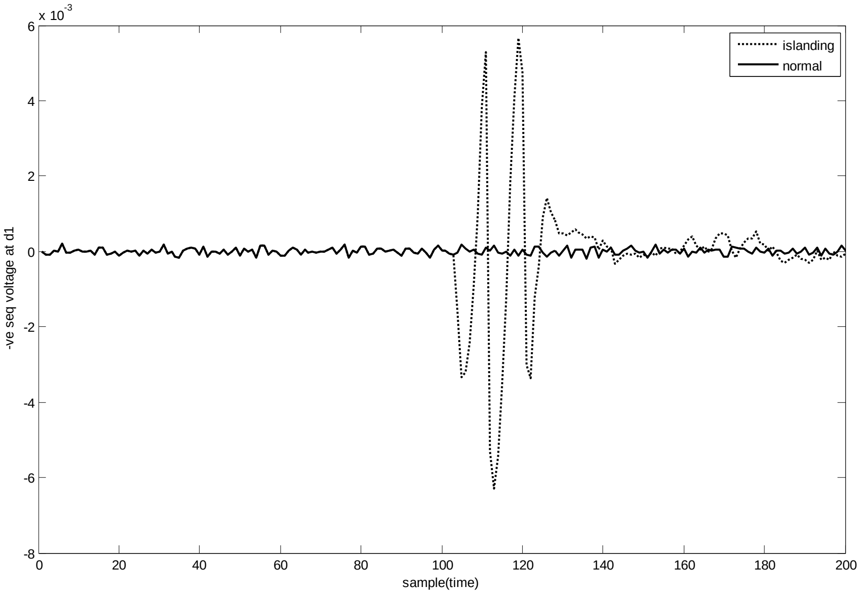

Figure 5.9: Comparison between d-1 coefficient of negative sequence voltage for islanding and normal condition

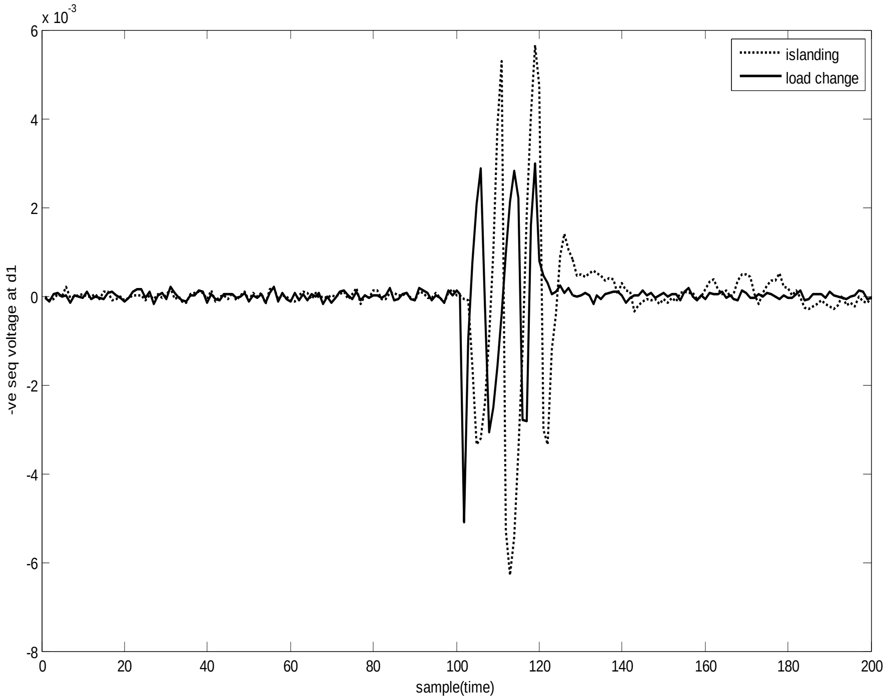

Figure 5.10: Comparison between d-1 coefficient of negative sequence voltage for islanding and load change (up to 50%) condition

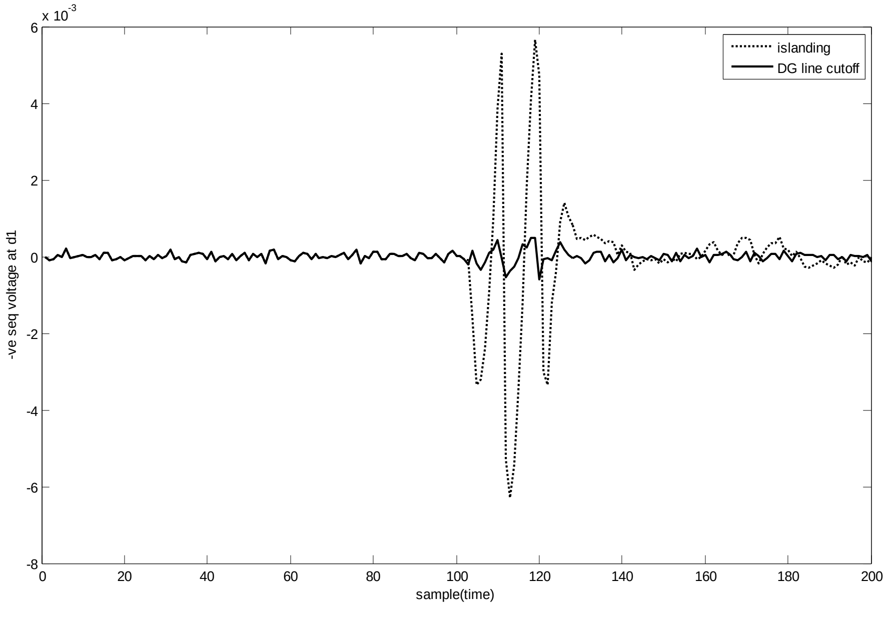

Figure 5.11: Comparison between d-1 coefficient of negative sequence voltage for islanding and DG line cutoff condition

Similar studies are made for different islanding and non islanding condition based upon the d1 coefficients of negative sequence currents. The results are described in fig. 5.12, 5.13, 5.14. Similar conclusions are drawn.

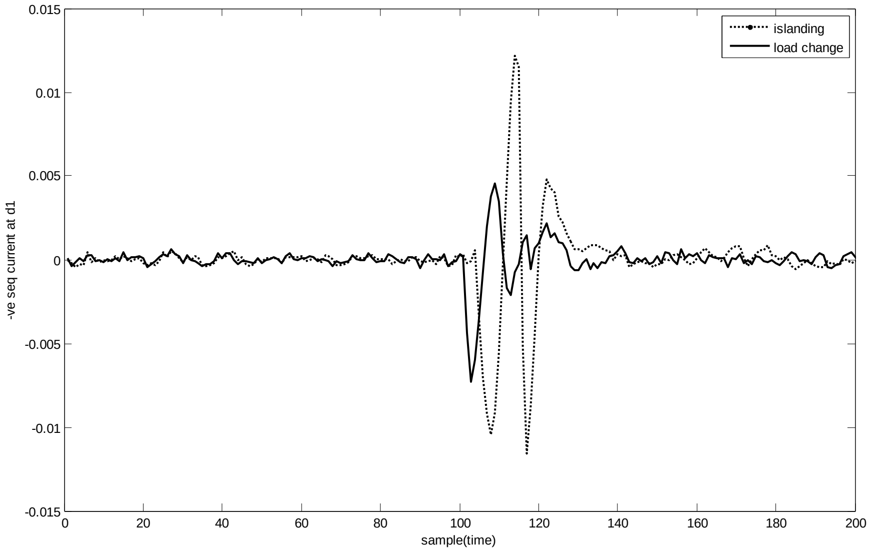

Figure 5.12: Comparison between d-1 coefficient of negative sequence current for islanding and Load change condition

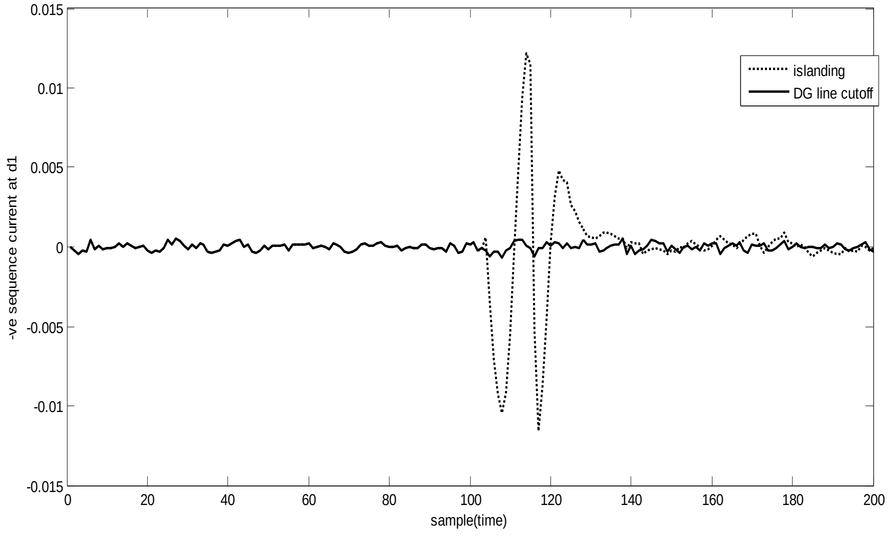

Figure 5.13: Comparison between d-1 coefficient of negative sequence current for islanding and DG line cutoff condition

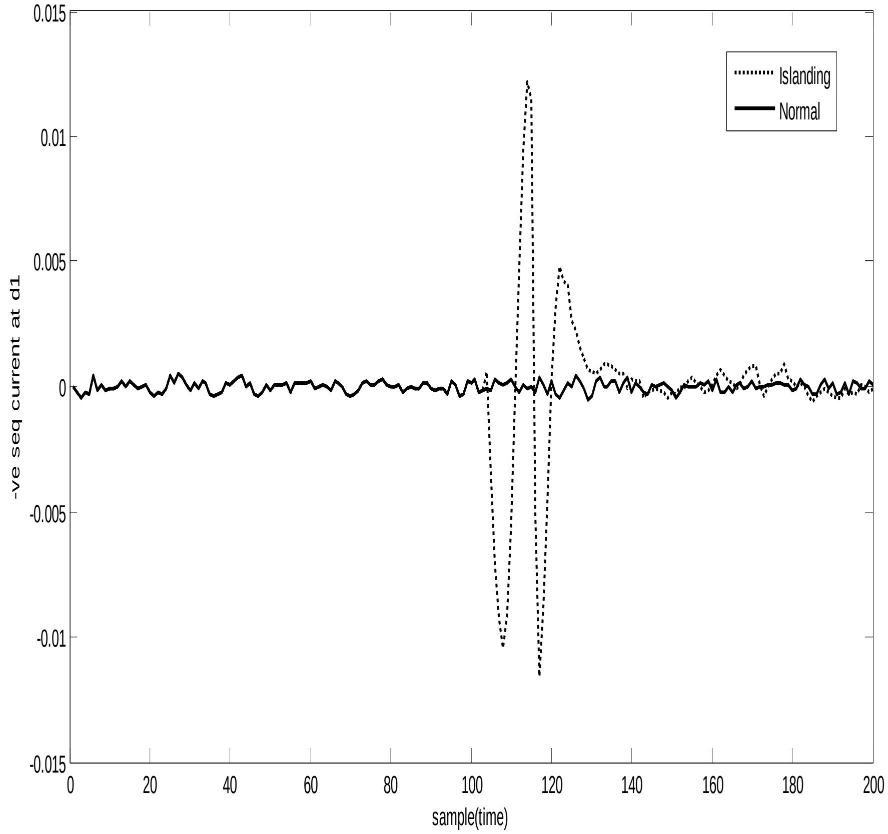

Figure 5.14: Comparison between d-1 coefficient of negative sequence current for islanding and normal condition

5.1.4 Proposed Algorithm for Islanding Detection using the negative sequence voltage and current

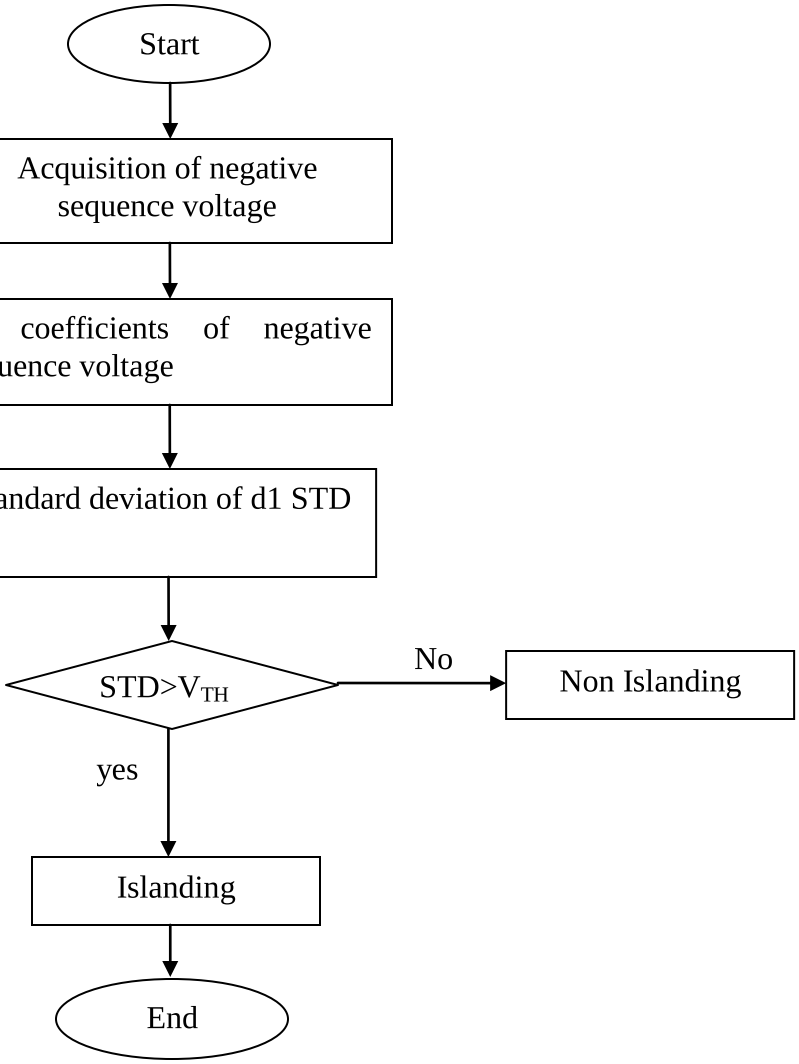

Figure 5.15: Proposed algorithm for negative sequence of voltage relay

Same case happens for negative sequence current. So algorithm can be developed accordingly. The complete statistics of the derived standard devitaions and change in energy of the d1 coefficients are depicetd in Table-5.1 . It is found from the Table-5.1 that the change in energy is 0.1225 for islanidng conditon compared to 0.0041, 5.4797e-004 and 0.00675 for non-islanding cases. Similar observations are made for standard deviation for islanding conditions. The above results are for negative sequence voltage retrieved at target DG location DG-1.

Similar observations are made for negative sequence currents retrieved at same target DG location DG-1 as depicted in Table-5.2. Thus the change in energy and standard deviations are high valued compared to non-islanding cases and thus effective in distinguishing them.

To verify the effect of changing target DG locations, the change in energy and standard deviations are found out for islanding and non-islanding situations at target DG location DG-2. It is observed from the Table-5.3 and 5.4 that the change in energy and standard deviations for islanding case are substantially high compared to non-islanding cases. Thus a threshold V_{TH} can easily be selected for detecting islanding events from non-islanding ones.

Table- 5.1: Standard Deviations at D1-Coefficients (Negative Sequence Voltage) for Islanding and
Non Islanding situations at DG-1

Events	**Change in energy (ΔE)**	**Change in standard deviation(std)**
1-Islanding condition	**.1225**	**.0234**
2-Normal condition	**.0041**	**6.9840e-004**
3-DG line cutoff condition	**5.4797e-004**	**8.5193e-005**
4-sudden load change	**.00675**	**.00121**

Table- 5.2: Standard Deviations at D1-Coefficients (Negative Sequence Current) for Islanding and non Islanding situations at DG-1

Events	**Change in energy((ΔE)**	**Change in standard deviation(Δstd)**
1-Islanding condition	**.1153**	**0.0264**
2-Normal condition	**0.0065**	**0.0019**
3-DG line cutoff condition	**0.0013**	**0.0029**
4-sudden load change	**0.0032**	**0.0085**

Table -5.3: Standard Deviations at D1-Coefficients (Negative Sequence Voltage) for Islanding and Non Islanding situations at DG-2

Events	**Change in energy((ΔE)**	**Change in standard deviation(Δstd)**
1-Islanding condition	**0.1315**	**.0127**
2-Normal condition	**0.0021**	**5.24550e-004**
3-DG line cutoff condition	**6.3167e-004**	**7.8934e-005**
4-sudden load change	**0.00524**	**0.00142**

Table-5.4: Standard Deviations at D1-Coefficients (Neagtive Sequence Current) for Islanding and Non-Islanidng Situations at DG-2

Events	**Change in energy((ΔE)**	**Change in standard deviation(Δstd)**
1-Islanding condition	**0.1256**	**0.0189**
2-Normal condition	**0.0087**	**0.0021**
3-DG line cutoff condition	**0.0013**	**0.0018**
4-sudden load change	**0.0032**	**0.0098**

5.2 Negative Sequence Impedance for Islanding Detection

As negative seqence components of the volatage and current signals at the traget DG loaction are highly pronounced in case of islanding situations compatred to non-islanding situations, thus the negative sequience impedance seen at the traget DG location has been computed to detect the islanding conditions. The negative seuqece impedance has been one of the key indicator in distrubance conditions such as fault process. Thus, during the islanding process, the negative sequence impedance provides vital information which can be effecetvely used for islanding detection. The negative sequence impedance can be found as

$$Z_n = \frac{V_n}{I_n}$$

where V_n is the negative sequence voltage and I_n is the negative sequence current derived at taget DG location.

5.2.1 Negative sequence impedance for different Islanding and Non Islanding Situations

The negative sequence imepdance for different islanding and nonislanding conditions such as nomal,islanding, DG line trip and sudden load change conditions are shown in Fig. 5.16,5.17,5.18,5.19 respectively. Similarly, negative sequence impedance comparision between islanding and non-islanding conditions such as normal operation, sudden load change (non-islanding) and DG line cut-off are shown in Fig. 5.20, Fig. 5.21and 5.22 respectively. It is found that the negative sequence impedance becomes steady after islanding compared to non-islanding situations.

To further provide a thershold for islanding detection, the standard deviations of the negative sequence imepdance for one cycle is found out and given in Table- 5.5 and 5.6. It is found that the standard deviation is 0.0152 compraed to 0.3551,0.2977,0.1336 for non-islanding cases at target DG location DG-1. To furhter know the efect of changing DG locations, the similar observations are made for standard devtaions for negative equence impadance at target DG location DG-2.

It is seen that the standard deviation is very low for islanding condition compared to non-islanding ones, and thus providing a threshold effectively distinguishes the islanding events from non-islanindg conditions. It is observed that the negative sequence impedance is marginally affected when the target DG location is changed. Thus the negative sequence impedance is a potential measure for detecting islanding conditions in distributed generations.

Table-5.5: Standard Deviations of the Negative Sequence Impedance seen at DG-1

Conditions	Change in standard deviation((std)
Islanding condition	0.0152
Normal condition	0.3521
DG line cutoff	0.2977
Sudden load change	0.1336

Table-5.6: Standard Deviations of the Negative Sequence Impedance seen at DG-2

Conditions	Change in standard deviation((std)
Islanding condition	0.0172
Normal condition	0.4123
DG line cutoff	0.3178
Sudden load change	0.1542

Condition-1

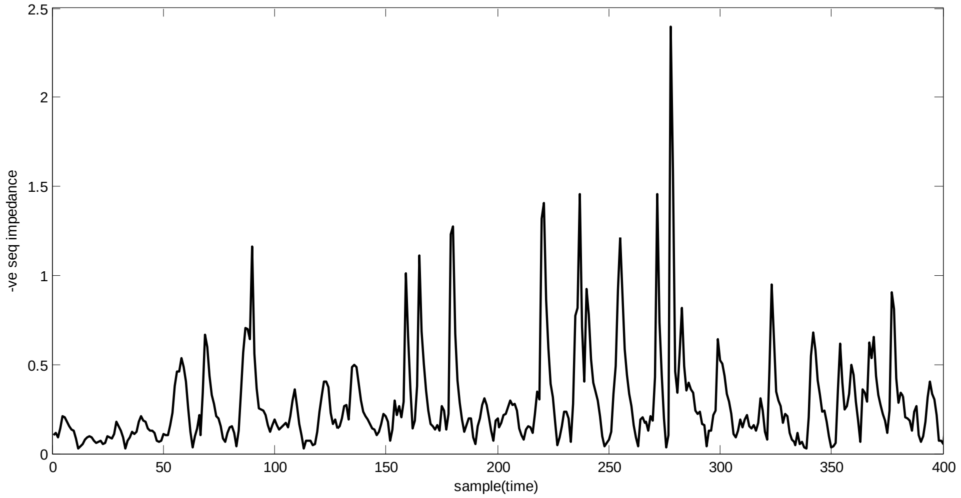

Figure 5.16: The negative sequence Impedance for normal condition

Condition-2

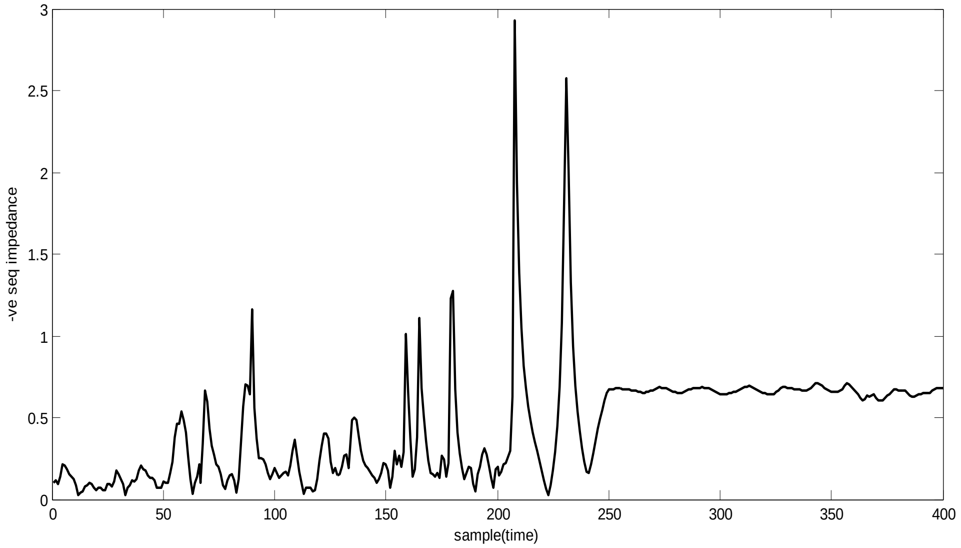

Figure 5.17: The negative sequence Impedance for Islanding condition

Condition-3

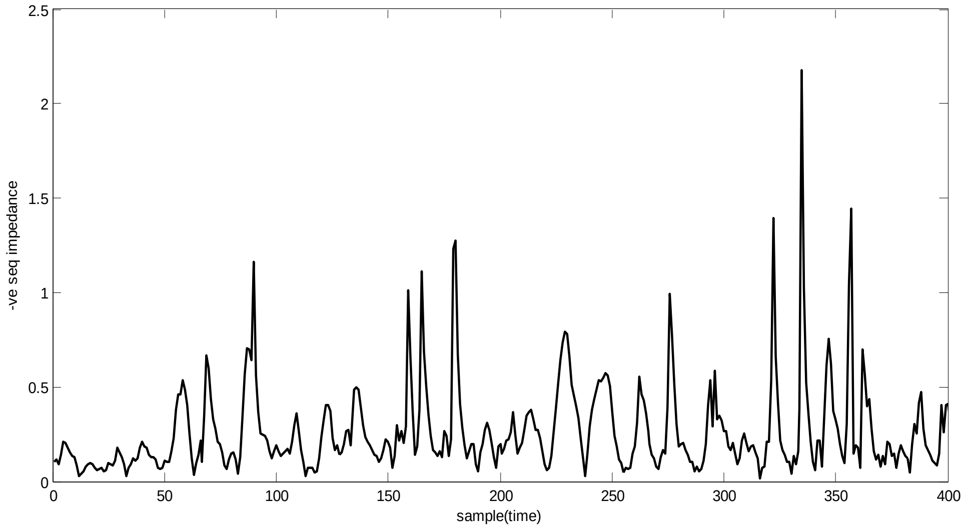

Figure 5.18: The negative sequence Impedance for DG line trip Condition

Condition-4

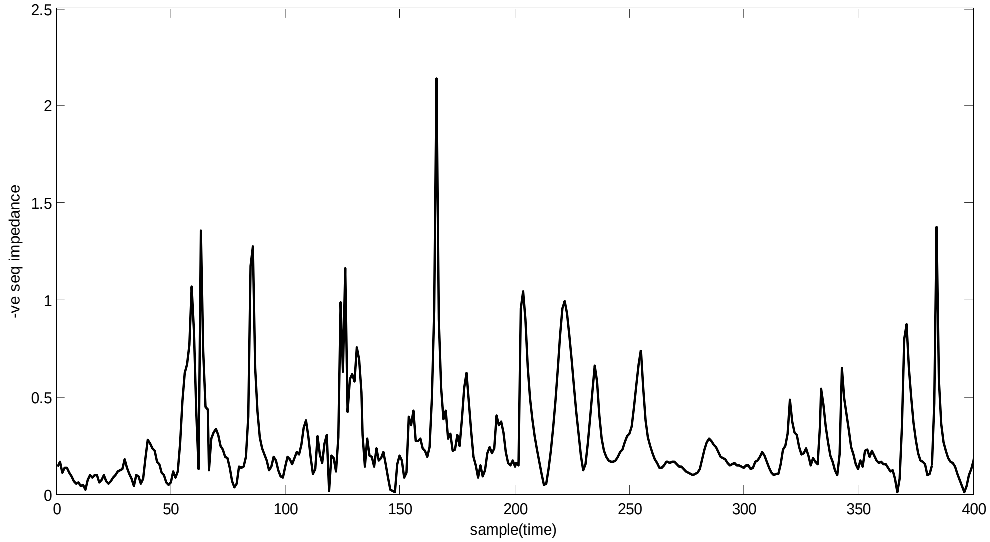

Figure 5.19: The negative sequence Impedance for sudden load change Condition

5.2.2 Comparative Study of Islanding & non Islanding Situation

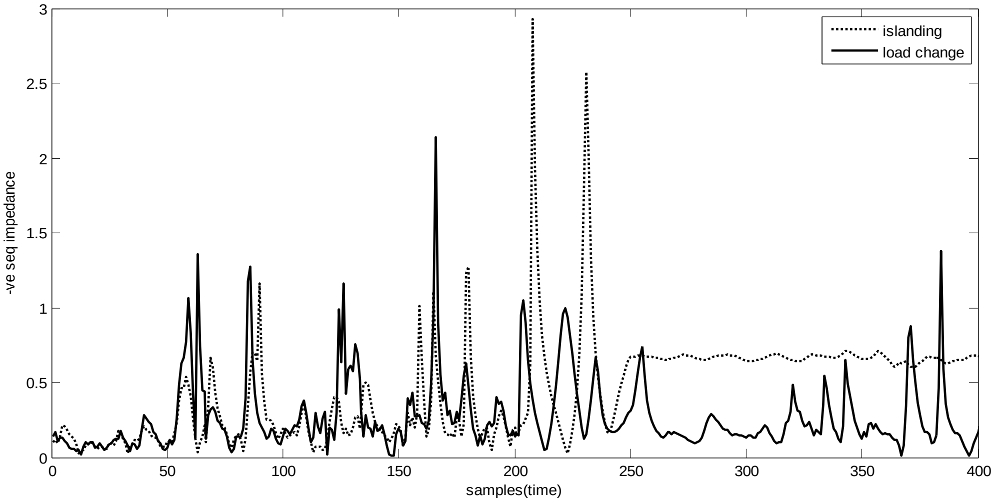

Figure 5.20: The negative sequence impedance comparison between islanding vs load change by 50% (non-islanding)

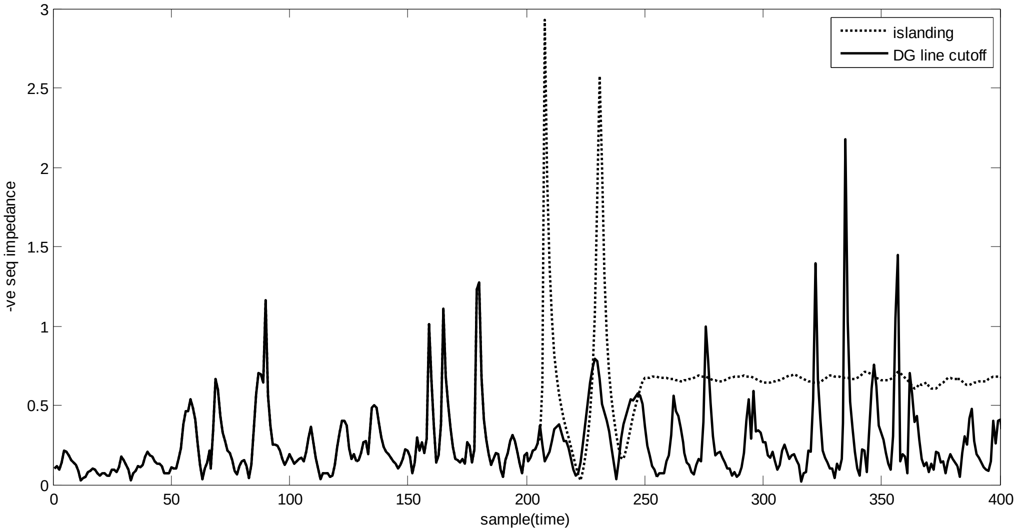

Figure 5.21: The negative sequence impedance comparison between islanding vs DG line cut-off

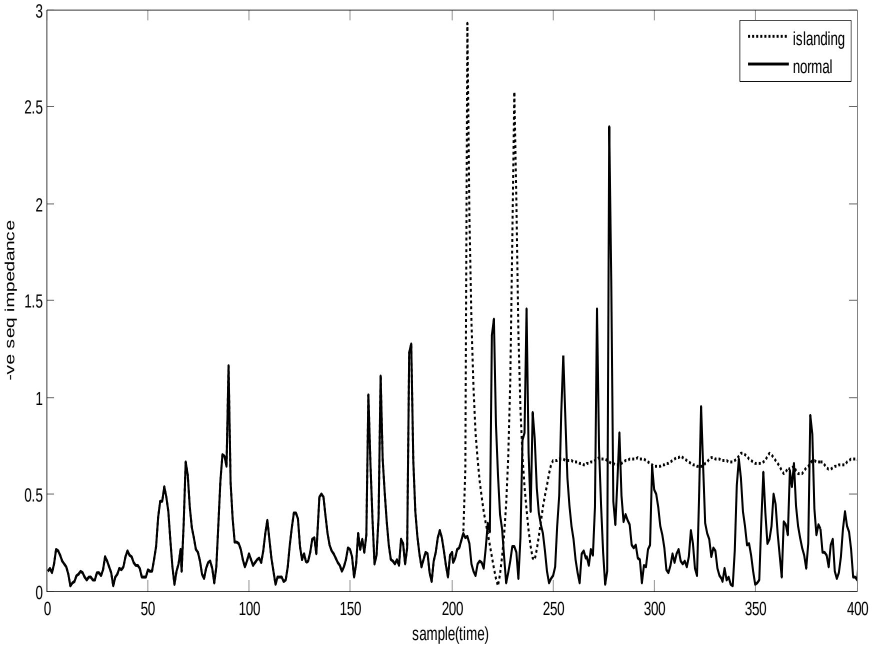

Figure 5.22: The negative sequence impedance comparison between islanding and non islanding condition (normal condition)

5.2.3 Proposed Algorithm for islanding detection based upon Negative Sequence Impedance

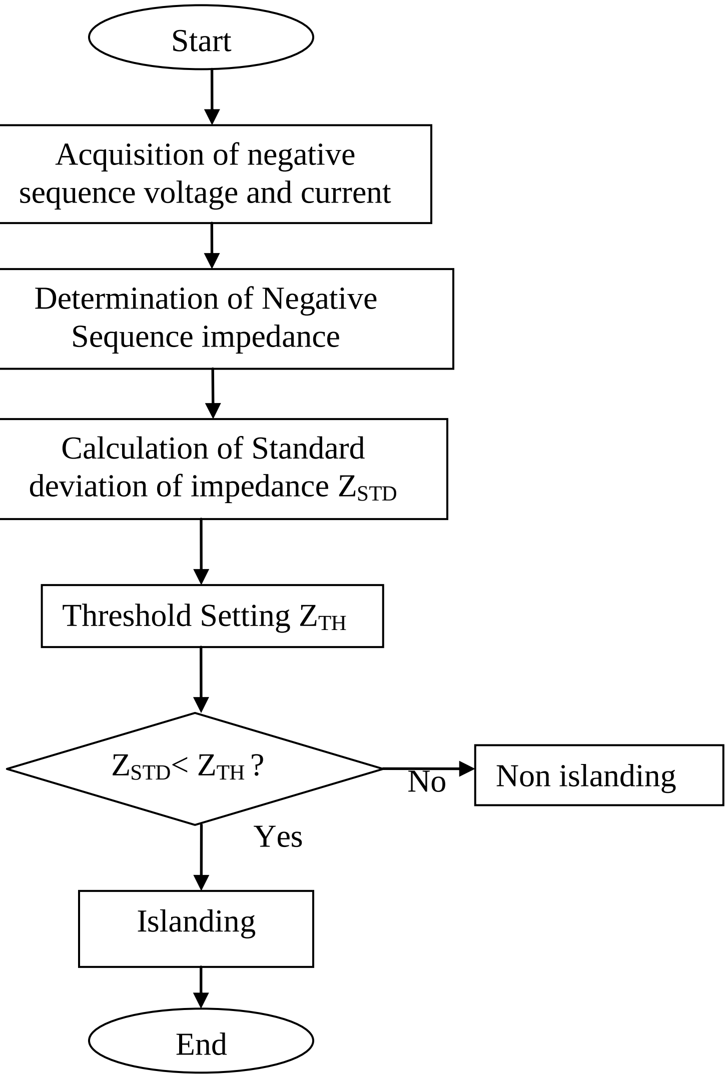

Figure 5.23: Negative sequence impedance based relay for islanding detection

Chapter-6

Discussions & Conclusions

6.1 Discussions

The proposed research investigates the potential of negative sequence components of voltage, current and impedance for islanding detection in distributed generation in power distribution network. It is observed that the d1 coefficients of the negative sequence current and voltage is highly pronounced in case of islanding events compared to non-islanding ones. But in case of 50% load change (considered as non-islanding condition), the d1 coefficients are more close to islanding condition compared to other non-islanding conditions and still a threshold can separate them. But 50% load change is one of the extreme non-islanding conditions, where ROCOF fails to detect islanding. Thus improved results are obtained with the proposed approach.

The second approach uses negative sequence impedance for islanding detection. Generally, the negative sequence impedance is one of the potential parameter for detecting unbalanced conditions in the power systems. Thus the potential of negative sequence impedance has been investigated for islanding detection. It is observed that the negative sequence impedance for islanding and non-islanding cases is clearly separable and thus able to detect islanding events accurately.

6.2 Conclusions

This thesis describes and compares different islanding detection techniques. Fast and accurate detection of islanding is one of the major challenges in today’s power system with many distribution systems already having significant penetration of DG as there are few issues yet to be resolved with islanding. Islanding detection is also important as islanding operation of distributed system is seen a viable option in the future to improve the reliability and quality of the supply .The proposed technique investigates the negative sequence component of voltage, current and impedance for islanding detection in distributed generations.

Wavelet transform is used to process the negative sequence voltage and current signals and the d1 coefficients clearly detect the islanding events from non-islanding ones. Further, the change in energy and standard deviation of d1 coefficients for one cycle signal data is found out which clearly detects the islanding conditions. Also the negative sequence impedance is found out for both islanding and non-islanding events, and it is observed that the standard deviation of the negative sequence impedance of islanding event is very low compared to non-islanding condition, thus able to detect the islanding events effectively. Thus the proposed methods are highly effective for islanding.

Future Scope:

- More studies are required to meet the problems caused due to sudden load change which may create false alarm in the islanding detection process.
- The problem due to Non-Detection Zone (NDZ) has to be studied further. As NDZ is the key performance index for any islanding process.
- The performance of the proposed schemes is to be studied on IEEE standard power distribution (Initially 7 Bus system) network with multiple DG interface.

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