Algorithm for islanding detection in distributed generation system

Swarup Ranjan Joshi

710EE2108

Power electronics and drive

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

Under the supervision of

Prof. Sanjeeb Mohanty

CERTIFICATE

This is to certify that the thesis entitled "ALGORITHM FOR ISLANDING DETECTION IN DISTRIBUTED GENERATION SYSTEM" being submitted by SWARUP RANJAN JOSHI(710ee2108) to the National Institute of Technology, Rourkela for the fulfilment of the requirements for the award of degree of M.TECH in ELECTRICAL ENGINEERING, Department of Electrical Engineering under my supervision and guidance
The research reports and the results embodied in this thesis have not been submitted in parts or full to any other University or Institute foraward of any other degree.

Dt: 22/05/2015

Place:Rourkela

Prof. Sanjeeb Mohanty

Department of Electrical Engineering,NIT,Rourkela

ACKNOWLEDGEMENT

I express my gratefulness and sincere thanks to my supervisor **Prof. Sanjeev Mohanty,** Department of Electrical Engineering for his constant motivation and support during the course of my thesis. I truly appreciate and value his esteemed guidance and encouragement from the beginning to the end of this thesis. I wish to extend my sincere thanks to **Prof. A. K. Panda,** Head of our Department, for approving my project work with great interest. I would also like to express my heartfelt gratitude to my friend Sarbajeet Jena who always inspired me and patiently helped me in my work. Last but not the least my sincere thanks to my parents for their encouragement, wishes and support.

Abstract

Power industry has been emphasizing more importance on distributed generation because there are new technology like fuel cell, wind turbine and power electronic use for advancement of power system has been evolved so much which cannot be possible without distributed generation. Hence distributed generation (DG) has become an inseparable part in power system and gained so much importance because of economical and environmental purpose. Islanding is a situation where a part of the distributed generation system containing a distributed generator gets electrically isolated from the remainder of the power system still continues to energise the network where the situation has occurred. Thus it has become important that the portion where islanding has occurred must detect this situation immediately for safety purpose. If tripping doesn't occur in time there can be various and critical problem. Currently in industry practice we disconnect all distributed generators after islanding has occurred. Generally a distributed generator should be disconnected within 0.1s to 0.3s after loss of grid/main supply. To achieve this, each distributed generator must be supplied with an anti-islanding device which detect islanding like vector surge relay and ROCOF relay.

In this thesis we have discussed about,

- current practices and development of power system through distributed generation.
- Islanding and other problems in distributed generation system.
- importance of islanding detection.
- islanding detection techniques which are used in common.
- Wavelet transform and hybrid technology developed in islanding detection.
- New method based on negative sequence component's like voltage and current for islanding detection of wind turbines using the wavelet transform.
- Usage of both active and passive method and how it eliminates most of the non-detective zone.
- The coefficient at d-1 separation through daubechies wavelet transform localizes the corresponding islanding events and the change in energy and standard deviation at d-1 level for one cycle gives the threshold comparing which we conclude about the islanding condition.
- The usage of positive feedback and continuous feedback method and the implementation of DQ model of electrical machine for hybrid detection technology.

- simulation on islanding detection based these two techniques using SIMULINK and MATLAB is done.

Finally a case-study of distributed Generation System containing 9 MW wind farms, 500 kW resistive loads and ,9MVAR filters, are considered for wavelet transform method and results are shown on islanding detection using those data and for hybrid method the same is done using feedback method and dq implementation for active method and checking the parameter through passive method with and without the controller. For islanding and non-islanding condition different conditions are checked so that islanding conditions can be clearly distinguished from the non-islanding condition. Sudden load change, line trip, islanding and normal condition for wavelet transform and detection of islanding with and without controller in hybrid method found to be highly effective in islanding detection. These two methods are then compared according to their stability and importance in different condition of power system.

CONTENTS

LIST OF FIGURES:

TABLE LIST:

Chapter 1
Introduction

1.1 introduction of islanding in DG:

Recently distributed generator installation into low voltage busses near electrical consumers has created some new difficulties for the electrical protection worker that are different from traditional radially based protection methodologies. Therefore, new and general protection configurations must be re-thought such as out-of-step monitoring, impedance relay protection zones, non-detective zone with the detection of sudden and unplanned islanding of distributed generator systems. The condition of islanding, defined as when a section of the nonutility generation system is isolated from the main grid/power system, is considered undesirable because of the potential threat to existing equipment, utility liability concerns, reduction of power quality and other damages.

Islanding detection methods generally monitor over/under voltage and frequency conditions passively and actively(the only two method through which various method has evolved); however, each method has an ideal sensitivity and operating condition and a non-sensitive operating condition with varying degrees of power quality error known as non-detection zone (NDZ). The islanding detection method described in this thesis takes the theoretically accurate concept of negative sequence component measurement and controller method and using the existence of naturally and artificially produced unbalanced conditions for the detection of islanding. Certain applications, where this islanding detection method shows great importance like in wind turbine and inverter based distributed generator are discussed where a generalized solution allows the electrical worker to determine when this method can be used most effectively. With a start this thesis begins with a brief introduction to power systems and the motivation for the extended use of distributed generation. Further chapters then details about the two methods and there use in various application.

1.1.1 electrical energy generation and distribution:

Human progress has been linked to the increase of energy consumed per capita, 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; however, the investment into new bulk electric power sources such as hydro dams and nuclear generation plants has become politically, economically and physically limited. 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 . 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 observed in the Canadian winter demand growth.

Small localized power sources, commonly known as “Distributed Generation” (DG), have become a popular alternative to bulk electric power generation. 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, construction of 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. 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; 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]

The power outage when happens in a country creates a very critical condition to economy and it can be of the order of 146 billion dollar per year in a country like unites states. For a medium sized company it can be 1447 dollar per second also where this one second of power outage can do lot more damage and loss than one hour of power outage so this small time is also considerable in power system. In this case the distributed generators come into action which tighten and increase the stability of power network by providing demand for the nearer load.

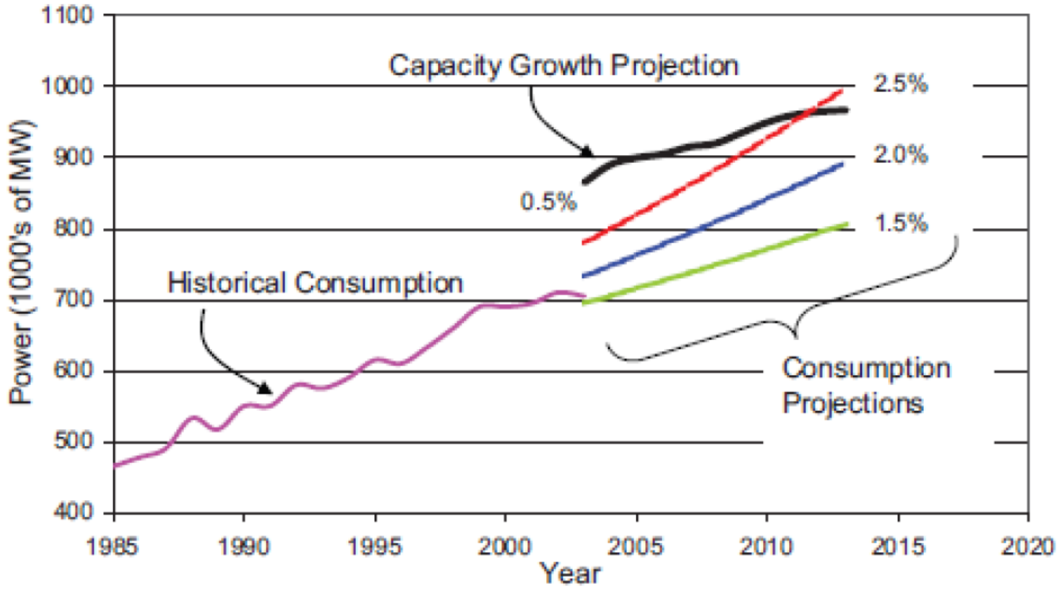


Fig1.1(At the current demand growth, the United States bulk electric power system is estimated to be approximately 5 to 15 years away from the power demand exceeding the generation capacity)[1]

1.1.2 Types of distributed generation and their capacity:

Distributed Generators can be categorized into three basic types: induction, synchronous and asynchronous. Induction generators require excitation externally and start up much like a induction motor(regular). Induction machine are less costly than synchronous machines and are commonly less than 500 KVA. Induction machines are most commonly used in so called wind power applications. synchronous generators are excited through DC field and need to synchronize with the utility grid before connection. Synchronous machines are used commonly with gas turbines, and small hydro dams etc and asynchronous generators are most commonly used with micro turbines, photovoltaic, and fuel cells internal combustion machine. A comparison between some types of distributed generation and their capacity has been described in table 1.1 shown below.

Islanding detection is all about a power system consisting a multiple distributed generators where sometimes one or more distributed generators face the islanding problem. Because of this reason when islanding occurs first thing to do is disconnect all the distributed generators from supplying power and then finding the one where the islanding has actually occurred. The method which we choose for the islanding condition depends on the distributed generator's type so that it will detect islanding condition perfectly without any fault. For example hybrid technology for inverter based distributed generator.

Table 1.1 (some comparison showing capacity of distributed generation and technology used)

Technology used	Capacity	Interference by network
photovoltaic	10VA to 5000VA	inverter
wind	10VA to 500KVA	Inverters,generator(synchronous and induction)
Micro hydro	100VA to some MVA	Both induction and synchronous based generator
geothermal	100VA to some MVA	Synchronous generator
Combustion turbine	1000VA to some MVA	Synchronous generator
Reciprocating engine	1000VA to some MVA	Induction and synchronous generator

1.1.3 Some of the advantages of distributed generations:

Distributed generation system has various advantages and it has started a new era in electrical study and it's application some of which are discussed below.

- DG resources are located at numerous positions within a utility's area. This theory of DG equipment supplies a utility huge flexibility to match the generating resources to needs of system.

- Grid reliability can be improved by it's facility by adding generation capacity closer to the load and thereby minimizing effects from transmission and distribution system noises.
- Multiple units reliability can be increased by dispersing it's capacity across several units and instead of a single large plant.
- The distribution can be done by a local delivery point where also the complexity to understand the system and also security improves.

- Less loading of transmission and distribution equipment- when low-voltage bus of the existing distribution substations places the generating unit, loadings will be reduced on sub-station power transformers in peak hours, therefore, extending the age of equipment.
- Now it is not necessary to build a new transmission and distribution lines or to upgrade any.
- Decreases transmission and distribution losses in the line.
- Voltage profile and power quality of the system improves.

1.1.4 certain technical challenges faced in distributed generation:

we have tabulated in table 1.2 the different technical challenges faced in distributed generation and the last one is discussed broadly in this thesis presentation.

Small signal instability is also a main threat to distribution generator, it will be possible to make the system noise free when the noise is large with possible technique but when signal is small a dynamic model of small signal is needed to eliminate it and also the placing or location of distributed generation is so important to remove the losses, so an optimal location should be chosen.

Table 1.2(technical challenges faced by DG)

- Regulation and loss of voltage.
- Flickering of voltage.
- Injection of harmonic and its control.
- Rising of SC level.
- Transient stability.
- The protection method's sensitivity.
- Co-ordination between generator's when there is more than one.
- Distribution generator's shaft over torque when fault occurs.
- Controlling Islanding of DG.

1.1.5 Introduction to islanding:

Islanding is a situation where a part of the distribution generation system gets electrically isolated from the remainder of the power system still continues to energize the portion where this situation has happened and that particular portion is called as island.

Now a days almost all utilities require that ,the DG should be disconnected from the grid when there is possible case of islanding without taking any chances. IEEE standard requires the disconnection of DG when it is islanded .Islanding can happen intentionally or Non-intentionally. During any repair or maintenance service on utility grid, the off mode of the utility grid may cause islanding of generators. As the loss of main power is already voluntary the islanding is concluded. Non-intentional islanding, caused by accidental or unintentional shut down of the grid is of more importance. When unintentional islanding occurs generally all the DG stops giving energy to the network and it takes a delay of two second to detect islanding.

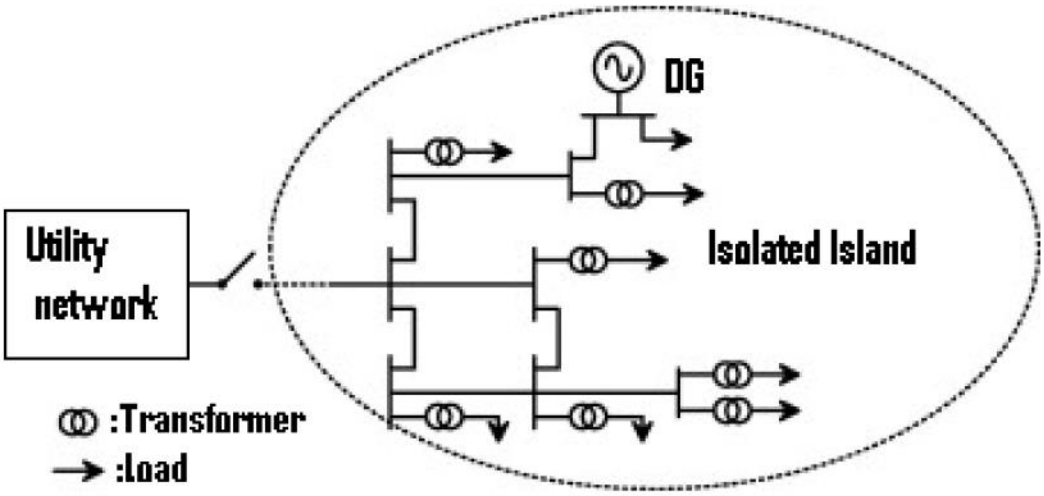


Fig 1.2(depicting an islanding condition)

As shown in fig 1.2, when islanding occurs the utility network gets disconnected from the generator where islanding is going to occur.

1.1.6 Drawbacks of Islanding:

As islanding has its advantages it also have so demerits which we should know. Few of them are as follows:

- Line worker safety are threatened by the sources distributed generator feeding the system after main sources have been removed.

- Sometime voltage and frequency are not maintained within a permissible level standard. Islanded portion may be improperly grounded by the interconnection of DG.

- Instantaneous reclosing may result in out of phase reclosing of Distributed generator. As a result mechanical torques and currents are increased by huge amount which can damage the generators and sometime prime movers.

- Transients are created, which can potentially damage the utility and other equipment. Out of phase reclosing which if occurs at a voltage peak will generate critical capacitive switching transient. In a light damped system, the peak over-voltage may approach 3 times rated voltage.

- Other risks results from islanding are degradation of the components associated with the power sytem as a consequence of frequency and voltage variation.

And due to various reason islanding has gained so much importance to be detected fast and accurately.

1.2 Objectives:

The main objective of our project thesis is to design an islanding detection method which can works properly in Power system network with multiple distributed generator interface. This p research analyses the performance of the -ve sequence voltage and current component in wavelet transform and usage of active and passive method for hybrid technique for islanding detection. As -ve sequence components are the main parameters for detecting any unbalanced conditions in power systems, that's why this has been utilised for islanding detection during islanding. The standard deviations and change in energy of the d1 coefficients of wavelet transform of the negative sequence current and voltage conclude about the islanding accurately and in hybrid technology the active part is done through positive and continuous feedback signal injection through dq implementation. Thus here our aim is to compare these two technique under different condition and finally concluding the suitable method for different particular purposes. The simulation and result are to be studied to know which method give the best under different circumstances. Mainly these two methods of our study as compared to other techniques were able to detect islanding under different load condition most accurately. Thus in this project work we gave attention on the results and compared them under islanding and non-islanding condition.

1.3 Thesis outline:

In chapter 1 there is introduction about distributed generator it's advantages, disadvantages, introduction to islanding detection, it's positive and negative impact on power system.

chapter 2 we have described about conventional islanding detection technique(eg: active and passive method and other methods)

chapter 3 describes commonly used anti-islanding device like ROCOF and vector surge relay

chapter 4 explains about motivation of this work and analyses about the two proposed methods for detecting islanding and non-islanding conditions under various circumstances for which simulations are carried out. Also wavelet transform and use of controller are described in this chapter.

In chapter 5 simulations are shown for both islanding and non-islanding conditions for the conditions we have considered and results are discussed for the two methods and compared to get a clear view about how the method chosen effects the islanding detection ability.

Chapter 6 concludes this thesis and also gives some idea on future work

Almost all the works has already been done on this project, we just have to find the suitable method for suitable condition to detect islanding fast and accurately about which we can get a broad idea at the end of this thesis.

This thesis has discussed about the development of new technology of islanding detection for wind turbines using negative sequence components and for inverter based distributed generator using feedback controller.

Calculation of standard deviation and change in energy of d1 coefficient of wavelet transform for islanding and non-islanding detection and also calculating threshold for our proposed two methods.

Extensive simulation work on the above techniques and their comparison using MATLAB AND SIMULINK.

CHAPTER 2

OVERVIEW OF ISLANDING DETECTION TECHNIQUE

The base or the philosophy of islanding detection is to monitor and observe the output parameters of distributed generator then comparing it with the predetermined threshold beyond which islanding occurs. Islanding detection technique can be devided into two parts, local and remote techniques. Local techniques can be splitted in to active, passive and hybrid technique.

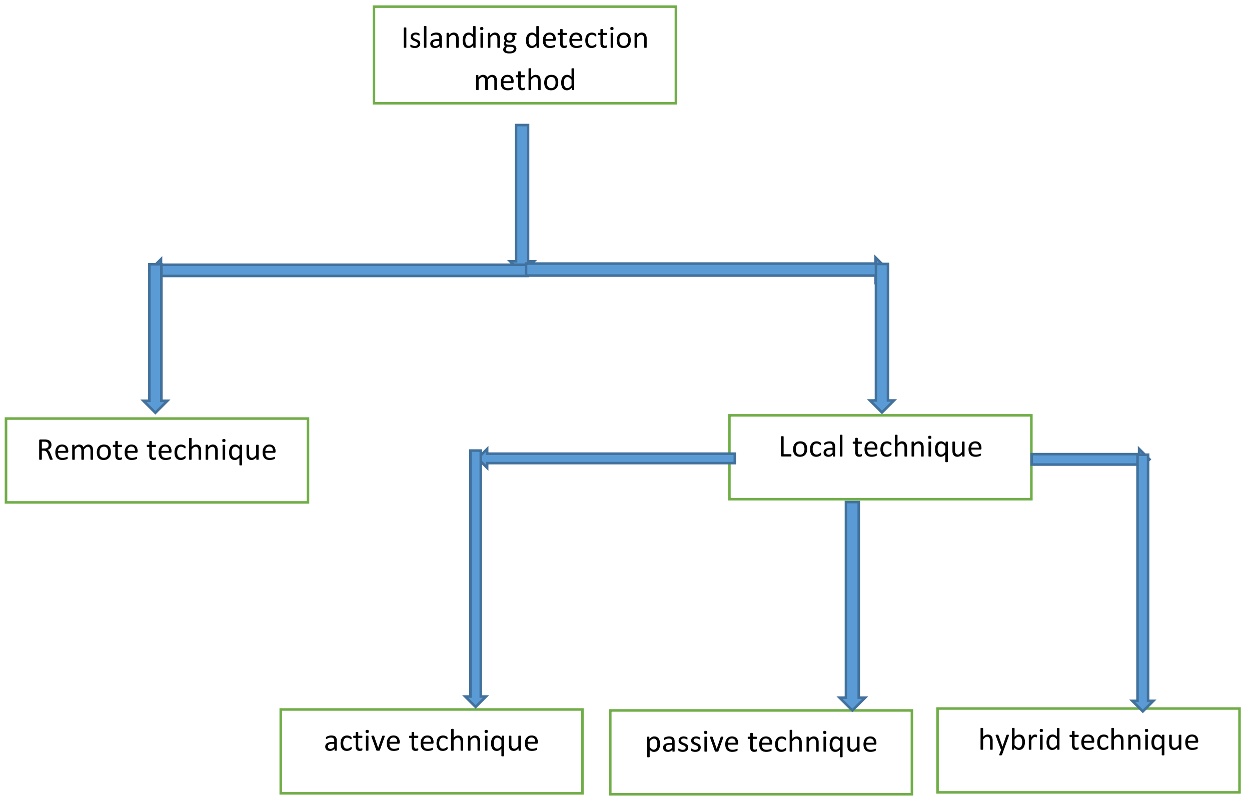


Fig. 2.1(categorization of islanding detection technique)

Here we have represented the categorization of islanding detection and description of these are as follows.

2.1 Remote technique:

It is based on the communication between distributed generators and the utility. Remote techniques are more reliable than local techniques but they are most expensive which is uneconomical. Hence these are not used in most of the practical cases. Some of the techniques which uses remote technique are power line signalling scheme and transfer trip scheme. The first one transmit islanding and non-islanding signal through the power line considering the transmission line as the medium and the main idea of transfer trip scheme is to determine the status of all the reclosers and CB and that could be the result of islanding of distributed generator. Due to remote technique's uneconomical property these are not described and studied thoroughly and directly shifted towards local detection technique.

2.2 local technique:

Local detection technique is based on the parameters of DG output such as voltage, frequency, total harmonic distortion and other parameters and are classified as active, passive and hybrid technique.

2.2.1 Active detection technique:

Islanding detection can happen even if there is close mismatch of generation and load**.** it produces perturbation at the distributed generator's output parameters trying to destabilize it. When distributed generator is connected to grid these parameters does not change much and remains inside the boundaries whereas the threshold is breached when islanding has occurred. Active detection techniques are further discussed in brief as follows.

a) Reactive power export error detection:

Reactive power flows occurs from distributed generator site to grid at PCC(point of common coupling) and this reactive power flow can b maintained only when DG is connected to the grid. Islanding is detected when reactive power flow extends beyond the pre-set threshold value. In case of synchronous generator based distributed generator detection of islanding is done by changing internal induced voltage of distributed generator with certain interval and continuously checking reactive power and change in voltage where distributed generator is connected to the system. When reactive power almost remain unchanged and there is a large change in terminal voltage we conclude that islanding has occurred. When DG has to maintain power at UPF(unity power factor) this can't be used and it's demerit is that it's slow.

b) Frequency/phase shift method:

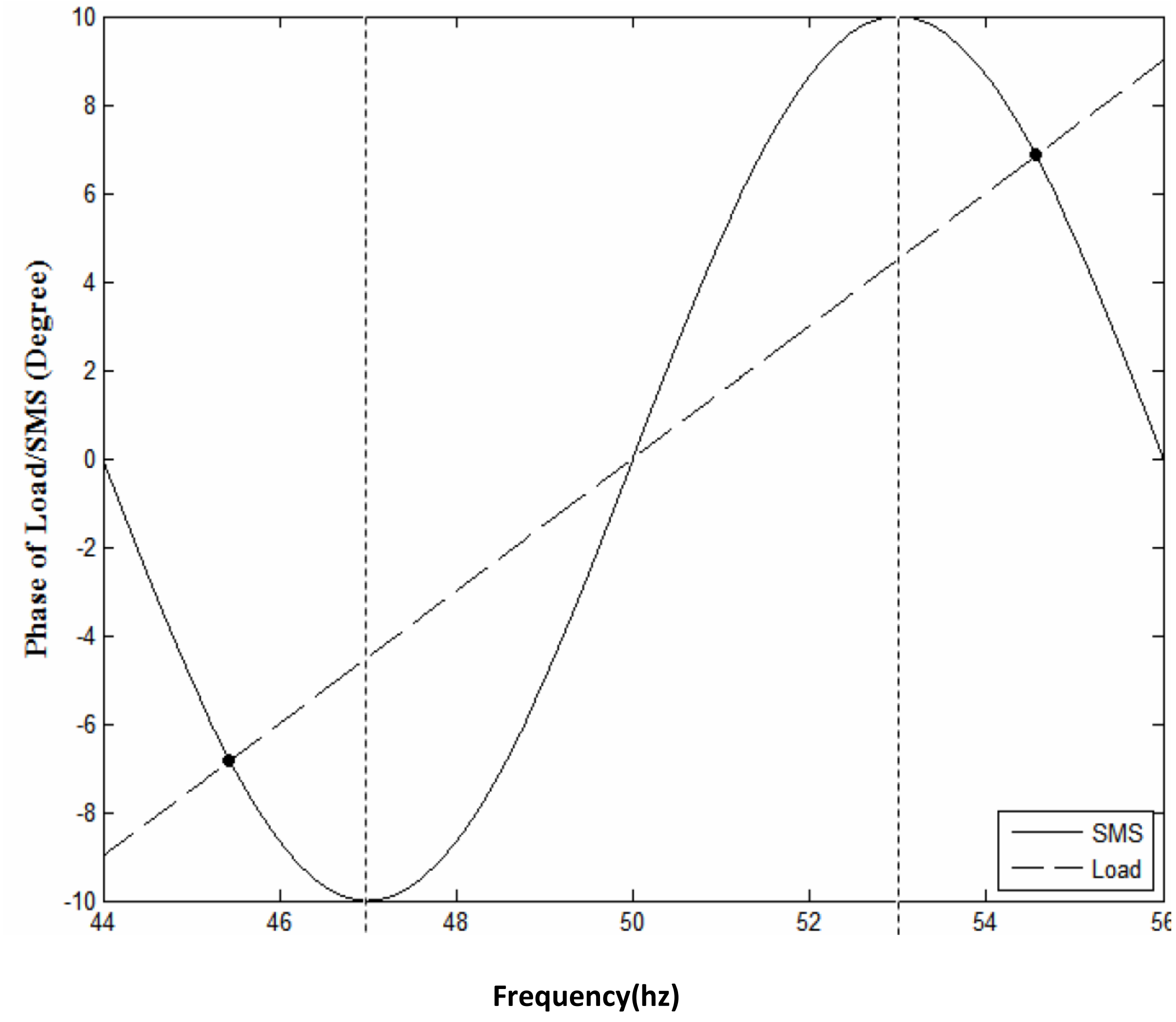
A small disturbance is given in phase shift which can be a good method to distinguish islanding from noon-islanding one. When grid is connected to DG frequency will not vary much otherwise there will be significant change in frequency when islanding is detected. SMS(slip mode frequency shift algorithm) changes phase angle of inverter current using positive feedback w.r.t change of frequency at the point of common coupling(PCC).

$$\Theta = \Theta m \sin\left(\frac{\Pi}{2}\frac{f(k-1)-fn}{fm-fn}\right) \quad (2.1)$$

It's the equation of SMS curve where

f_n is the nominal frequency and f^{k-1} is the frequency at the previous cycle.

SMS curve slope is more than phase of load in unstable regions. When the main utility is disconnected operation will go through unstable region to a stable operating point. When the setting is exceeded by inverter frequency islanding is detected.



Stable region stable region

Fig 2.2(stable region with the SMS curve)

Even if there are more distributed generator(inverter based) this scheme can detect islanding. If slope of the phase of load is more than SMS curve islanding can't be detected which is a major drawback of this technique. Because there can be stable point of operation in unstable zone also.

Active method has so many application except that it produces perturbation in the system which reduces the power quality and interfere with the stability of the distributed generation system.

2.2.2 passive detection technique:

In this technique we measures the output parameters like voltage, frequency total harmonic distortion and other parameters and depending on the threshold value we conclude about the islanding condition. So we must take special care and consideration on the threshold value and the output parameters measurement. Passive techniques don't introduce disturbance in the system and they are faster but it's demerit is that it has a large non-detective zone where it can't detect islanding even if the grid is disconnected.

Some of the passive technique are described below.

a) Rate of change of output power:

This rate of change of output power dp/dt will increase by a considerable amount once the DG is islanded or when disconnected from the grid from when it was running normal without any islanding for the same load change rate. When the distributed generator has unbalanced load this method is very effective rather than when it has balanced load.

b) Rate of change of frequency(ROCOF):

Rate of change of frequency will increase beyond threshold when the distributed generator is islanded. The ROCOF can be shown I equation as,

$$\frac{df}{dt}=\frac{\Delta p}{2HG} \tag{2.2}$$

where Δp=power mismatch at DG site

H=moment of inertia of the distributed generation system

G=rated distributed generator’s power capacity

H and G will be small for smaller system where it gives large value for df/dt ROCOF relay which monitors the waveform for voltage and this ROCOF if higher than the setting for certain interval of time then it operates and the relay will trigger when islanding has occurred but not when the load changes. When there is large mismatch of power this method is reliable. When generation output is close to load demand it fails to operate which is a demerit for this method to be used for particular purposes. Any subsequent change of local load will be the reason for islanding being detected when there is mismatch between generation and load in the islanded system.

c) Rate of change of frequency over power:

The power system with large capacity to produce power will have small df/dt and rate of change of frequency over power use this basics concept to acknowledge the islanded condition. Rate of change of frequency over power will be highly sensitive than rate of change of frequency over time when there is small mismatch of power.

d) Voltage unbalance:

When islanding occurs the distributed generator will receive the load change in the island formed. When change is considerably large by monitoring parameters islanding condition is detected where the parameters are phase displacement, voltage magnitude, change of frequency and the changes should be large for this to happen. The load balance of distributed generator when islanding occurs as the distributed generation include single phased load sometimes. Voltage unbalance may happen because of the change in network condition.

e) Harmonic distortion:

Various harmonic currents may occur due to change in configuration or size of the load mainly when distributed generator is inverter based. By monitoring the total harmonic distortion of terminal voltage islanding distinguished from non-islanded one. Change in third harmonic is mainly considered to get a good idea about islanding condition of the DG.

Hybrid detection technique which is the combination of these two techniques are studied briefly in this thesis afterward.

Table 2.1(islanding methods and their positive and negative points)

methods	advantages	disadvantages
Active method	Introduces perturbation in the output parameters and monitoring it it concludes about islanding even if there is perfect matches between DG generation and load. Also it has small NDZ.	Due to perturbation DG system faces problem in terms of stability and power quality of the system reduces. Also takes more time to detect it. small non detective zone
Passive method	Detects the output parameters like voltage, frequency, THD etc and doesn't perturb the system. Also it's a fast method of islanding detection which is Very desirable for islanding detection.	When there is a close mismatch between distributed generator's generation and load demand it fails to distinguish between islanding from non-islanded system. It has more NDZ then active method.

Chapter 3

Voltage surge relay and ROCOF relay to detect islanding condition

3.1 ROCOF relay:

Equivalent circuit diagram of synchronous generator which is equipped with this relay is shown in fig 3.1 where it operates parallel to distribution network.

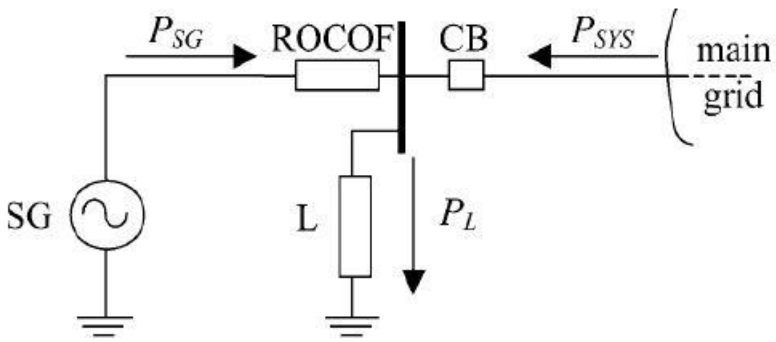


Fig 3.1(equivalent circuit diagram of ROCOF relay equipped into ROCOF relay operating parallel to utility)

As shown a synchronous generator fills the demand of load, p_{sg} is supplied by generator and $p_{L,which}$ is consumed by load and the difference is the power p_{sys} is consumed by utility grid hence there is no change of frequency. If the circuit breaker opens somehow then islanding situation will occur.

When grid power p_{sys} is lost power variation cause the same in islanded system and frequency starts to vary dynamically from which islanding can be detected sometimes. If power imbalance is less, then there will be small rate of change in frequency. So df/dt is a major parameter to acknowledge the islanding situation. A measure window is taken in some cycle interval which is between 2 to 50 and then we calculate the rate of change of frequency.

After the calculation of rate of change of frequency a signal is sent by filtering and the signal resulting from this is used to detect islanding. When threshold value of rate of change of frequency is breached a trip signal to the generator circuit breaker is sent immediately to shutdown it. The installed ROCOF of 60-hz network or machine has setting between 0.1 and 1.20 hz/s. a block function is also associated with it. if terminal voltage reduces under a adjustable limit the signal coming from ROCOF relay is blocked where it can't detect islanding anymore.

3.2 Vector surge relay:

Vector surge relay equipped into a synchronous generator(SG) shown in fig 3.2 where it is parallel to distribution network.

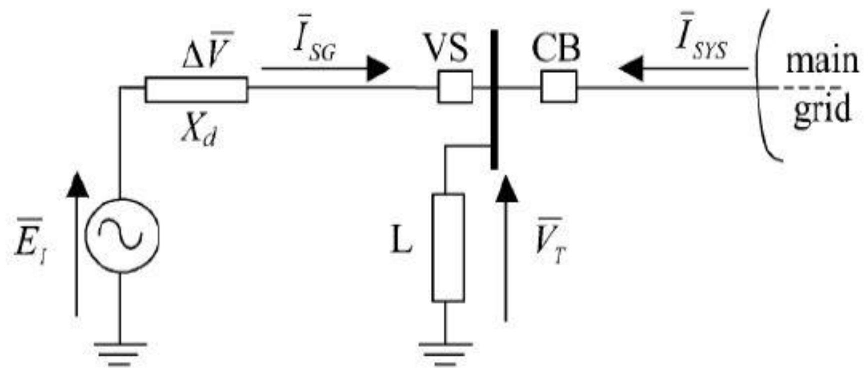


Fig 3.2(equivalent diagram of vecor surge relay parallel to distribution network equipped into a synchronous generator)

The voltage drop V between generator voltage and terminal voltage which is caused by generator current due to X_d is shown. The displacement angle caused by the terminal and generator voltage is depicted in figure 3.3 . We know when circuit breaker opens there will be loss of grid and islanding occur and the generator starts to provide the demand for the change of load because I_{sys} is continuously interrupted. Suddenly the angular difference between generator and terminal voltage changes and V_T phasor's direction is changed. Considering these change and comparing it to threshold value islanding is detected.

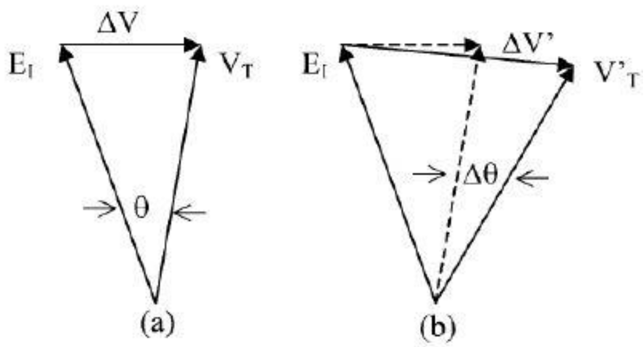


Fig 3.3(displacement angle caused by generator and terminal voltage (a) before islanding and (b) after islanding)

After these basic ideas about islanding detection our study shifts toward the project work based on two proposed method.

Chapter 4

Literature Review

As cited above in table 1.3 both active and passive method has some demerits which are not allowable in islanding detection. As islanding detection is a very critical issue which can create severe capacitive switching transient and degradation of electrical equipment due to voltage and frequency drift and can be the reason of shutdown of whole power system. So it leads us to find an accurate and fast method to detect islanding.

4.1 Gauss Newton Algorithm:

A fast gauss newton algorithm for islanding detection in distributed generation minimizes the forgetting factor weighed error cost by this well-known gauss newton algorithm and ignoring the off-diagonal terms the resulting hessian matrix is approximated to get the new FGNW method to estimate all the voltage and current signals accurately in a decoupled and recursive manner even if there is significant noise in power system. In this method a passive islanding detection technique with a data-mining approach is used. The measured voltage and current signal at the targeted distributed generator is taken as input to our method. Forgetting factor(lambda) controls the performance of gauss newton method in tracking, stability and convergence rate. suitable value of forgetting factor is choosen to improve noise rejection capacity. This method is good while there's a considerable mismatch between generation and load.

In THD The observed power, voltage and current signal consist of a dc decaying current, fundamental and harmonics of order N and are represented as

$$\sum_{r=1}^{N} Ar(k)\sin(wr(k)k + \Phi r\ (k)) + Adc(k) + v(k) \qquad (4.1)$$

Where y(k) = current/voltage signal which is varying at sampling k.

V(k)(random noise) = used to calculate/estimate current/voltage signal parameters

Ar, Adc, ϕr = voltage/current signal parameter.

A priori error signal estimation is obtained from signal y(k) as measured and finally approximated hessian matrix is drawn.

The simplified equations for estimating fundamental, sub-harmonic and harmonic and dc decaying component is calculated are

$$Adc(k) = A'dc(k-1)+\frac{0.5er(k)}{c(k)} \quad (4.2)$$

And $$C(k) = \lambda_k C(k-1) +\frac{1}{2} \quad (4.3)$$

Advantage of which is power signal determination problem has minimized and real time application can be done. λ controls the performance for this method in stability, tracking and convergence. This method is passive and can be suitable sometimes in certain application of islanding.

4.2 ROCOF and Vector Surge relay:

Among the various techniques for islanding detection working principles of ROCOF and vector shift relays is the most important one about which a paper was published by **x.Ding, P.A. Crossley and D. J. Morrow**. A simulator was used to investigate about stability of both relays and the loss of bulk generation or the tripping of a transmission feeder in ROCOF relay. Regarding the reliability of Loss of Mains protection, a new islanding detection technique which is based on a GPS phasor measurement system was proposed. A detailed description of this technique is described with figures above in chapter 3.

4.3 Voltage Unbalance and Harmonic Distortion:

When there is small changes in loading the method of voltage unbalance and harmonic distortion can't work properly as it can't detect islanding in this case. It faces difficulty to detect islanding in this case. So we combine a new method with the conventional method as we can't use only passive method to detect islanding when loading change is small. When there is different loading there will be various harmonic curents.

Voltage unbalance can be shown as,

$$VUt = \frac{NSt}{PSt} \times 100 \quad (4.4)$$

$$\Delta VUavg,t = \frac{1}{N}\sum_0^{N-1} VU(t-1) \quad (4.5)$$

$$\Delta VUt = \frac{VUavg,s - VUavg,t}{VUavg,s} \times 100 \quad (4.6)$$

If ΔVUtremains from -100 to +50 percentage VUavg,s replaced by VUavg,t sothat it will be adapted to normal loading condition and avoid false in short transient. Sometimes there are abrupt changesof above 0.5% in VUavg,t in ¼ cycle duration where it goes to next time step after ¼ cycle.

VUt=VUavg,t-VUavg,t-p

The total harmonic distortion after this is

$$\text{THDt} = \frac{\sqrt{\sum_{2}^{H}(Ih\times Ih)}}{I1}\times 100 \tag{4.7}$$

Ih = rms harmonic component

I1=fundamental rams component

Avererage THDt,

$$\text{THDavg,t}=\frac{1}{N}\sum_{i=0}^{N-1}THD(t-i) \tag{4.8}$$

ΔTHDt should be in between -100 to +75 percentage in one cycle for the update of THDavg,s to THDavg,t and for abrupt change of THDavg,t higher than 0.1 percentagein ¼ cycle it will shift to next step.

THDt = THDavg,t-THDavg,t-p (4.9)

Finally the islanding condition can be shown for little load change is,

{(ΔTHDt > +75%) or (ΔTHDt < -100%)} (4.10)

{(ΔVUt > +50%) or (ΔVUt < -100%)} (4.11)

Which are the conditions for islanding detection in this method.

4.4 Negative sequence impedance method:

Negative sequence impedance method also provides some basics about islanding detection which has a small non detective zone and a threshold window(large). Injecting negative sequence component highten the accuracy of this impedance calculation facing some challenges like cost of installation, power quality reduction, complexity of integration and injection of high power. Methods like signal injection and variation in frequency and voltage also uses this. Single and without harmonic frequency is an powerful method for impedance measurement but has costly interfacing and integration complexity. It uses small signal injection which are unbalance to calculate fundamental impedance. Impedance for islanded condition is so much higher then no-islanded system. A case study with MATLAB SIMULINK laboratory of power system will validate an islanding state. By introducing three phase impedance unbalance averaging technique accuracy of measurement is increased.

The negative sequence impedance is calculated as Zn = $\frac{Vn}{In}$

Vn=negative sequence voltage and

In=negative sequence current

Non-islanded condition can be shown in a live system. Adding to this method a negative sequence injection of current by varying load from phase to phase connected leaving another phase open can lessen the impedance change than steady state and this is not adequate for detection of islanding.

4.5 Hybrid Detection Technology:

Another method which is based on both active and passive method hence minimizing the non detective zone was proposed. Thus this method is known as hybrid anti-islanding detection technique. This paper proposes a robust hybrid anti-islanding method for the inverter based distributed generators. Active anti-islanding detection creates disturbances at the output of the distributed generator by continuous feedback signal and positive feedback signal injection through DQ model of conversion where as passive method detect the voltage frequency, active and reactive power and harmonic distortion. This method of control eliminates the demerits shown by both the method individually. Hence it is able to detect islanding in different load condition and also fast in response.

4.6 Negative Sequence Current And Voltage :

A suitable method which uses passive method for islanding detection of wind turbines is the wavelet-transform method of DGs which uses negative sequence current and voltage of the targeted DG as its input to the wavelet transform method. The time frequency information derived at level one decomposition localizes the islanding. The standard deviation and change of energy at the d1 level coefficient for one cycle provide the threshold to detect islanding. The details of last two are as follows.

Chapter 5

Proposed Method And Study Of The Method Used

5.1 Motivation:

When there is loss of power from the main grid the DG getting power from the main grid get islanded but still continues to supply power to the load and the change of load connected to it and that part of the power system is an island. When islanding occurs there must be a trip signal which will be sent to the distributed generator. For this all distributed generator are equipped with voltage surge and ROCOF relay where signal will be sent through transmission line or normally to trip it but if this signal sending is failed the DG can't be tripped which can cause several problems like power quality will be reduced, stability problem, capacitive switching transient when voltage peak will occur because of instantaneous reclosing and there may be degradation of electrical equipment when voltage and drifts of frequency occur where safety of the electrical worker has to be compromised. So all the distributed generators are disconnected when an island is formed in industrial plants.

Negative sequence current and voltage are used in our proposed daubechies Wavelet transform method and as we know the negative sequence components are the main parameter to have a knowledge about unbalanced condition and stability of system and islanding is all about knowing the system's stability. Because of this reason our attention shifts toward this method because of the vital information it provides about instability. The advantage of this method is that, time and frequency information is known simultaneously and we can know the exact time where islanding has occurred and also when number of distributed generator increases this method can be used as an alternative to the already existing methods which is easy to program. Considering these advantages this method has been a great interest for being studied where as the hybrid detection technology which is the combination of both active and passive technology is also a better alternative for inverter based distributed generator. Here we use positive and continuous feedback injection of current through the inverter with DQ implementation. First active method finds out about islanding with the disturbances and pushing the limits of the passive parameters outside the threshold and then through passive method islanding is detected.

Our research project about islanding detection in distributed generation is to develop a better and effective method for islanding detection which can work properly even under circumstances where the electrical network goes through various changes which may not be necessarily an islanding situation but a closed one. The last two methods of literature review has overcome many problems and better at distinguishing an islanding condition from the non-islanding ones cited as robust hybrid method and wavelet transform method of islanding detection which were found to have a very small non-detective zone. Other methods like active and passive method do have their negative impact on power quality, stability and also have their respective non-detective zone which motivated to have a improved technique to overcome nearly all this problem. Thus our interests shift towards these two method which seems to have the best technique as compared to others while it comes to islanding detection.

5.2 <u>project in brief:</u>

5.2.1 Islanding detection based on wavelet transform:

Negative sequence of voltage or current after extracting from the output of the distributed generator are then passed through daubechies wavelet transform after which the time and frequency information are found at level-1 decomposition and this method finds out the islanding condition in space. But these found values and observation require a threshold value to compare to know about the islanding condition and for this the standard deviation and change I energy after the d1 level decomposition is computed for one cycle and this d1 level coefficient gives the whole idea about our islanding event.

This technique is based on the usage of negative sequence current and voltage which are extracted from the derived voltage and current signal and then processed through wavelet transform. The time frequency information derived at level one decomposition localizes the corresponding islanding event. To provide threshold for detecting islanding the standard deviation and change in energy of the d1 level co-efficient (daubechies wavelet transform used) for one cycle is computed.

The possible condition for islanding and non-islanding which we can face are

- tripping of main circuit breaker for islanding condition.

- tripping of any circuit breaker between power system and distributed generator.
- Loss of power on pcc bus.
- sudden load change at targeted DG location.
- tripping of other DGS apart from targeted one.

Wavelet transform is a mathematical tool(a time-scale representation of signal) that is nearly similar to fourier transform of signal. It also gives time sv=cale representation of signal without any reduction in resolution unlike short time fourier transform where window size is fixed. Where any attempt to increase the window size to increase frequency resolution leads to loss of time information. Change in energy s found out by deducting energy content of d coefficient for one cycle signal before islanding inception from after islanding inception.

The processed signal in daubechies wavelet transform is devided into two parts, high frequency and low frequency component. Low frequency again devided into low and high frequency components.

The dwt in discrete in terms of scaling and shifting, defined as,

$$C(J,K)=\sum_{n\in z}\sum_{n\in z} s(n)g\,(n) \quad (5.1)$$

G is defined as a time function with finite energy and fast decay called mother wavelet.

$$g_{J,k}(n)=a^{-1/2}g(a^{-j}n-kb) \quad (5.2)$$

a and b depends on the family of scaled and shifted mother wavelet.

S(n) can be represented as,

$$S(n)=\sum_{n\in z}\sum_{k\in z} d(j,k)g(n) \quad (5.3)$$

Coefficient $d_{j,k}$ generated by daubechies wavelet transform and it is called as resemblance index in between wavelet and signal. The mutuality will be strong if index is more.

The flow chart diagram of this is given below in figure below.

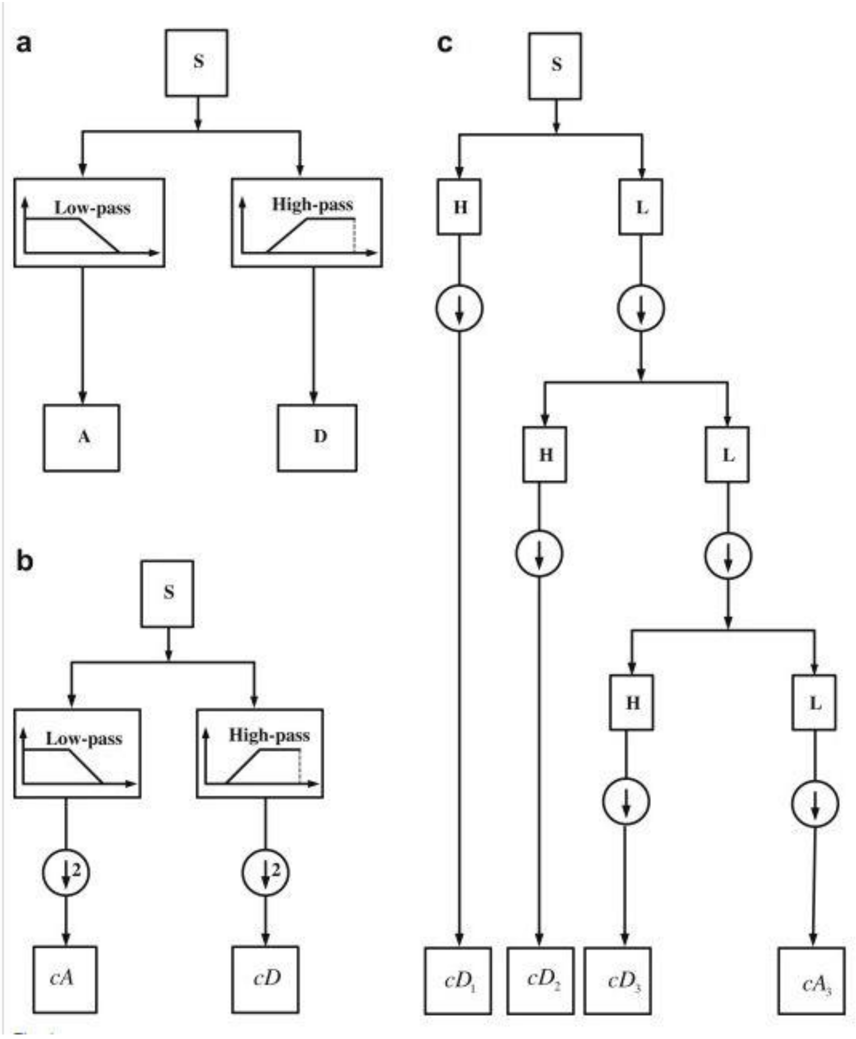


Fig 5.1(the process of decomposing a signal and deriving time and frequency information in wavelet transform)

Where s is the signal and H and L are the high and low pass filter respectively. After the signal has gone through wavelet transform the results are shown through simulation for the 4 conditions given above to conclude about the islanding condition and distinguish it from the non islanding one's. The signal passing through wavelet component were filtered out through high pass and low pass filter.

The important most basis of this transform which is a mathematical tool just like fourier transform while analysing a signal where through this method is individual wavelet functions can be placed in space and can be described in a good way with the help of filter bank theory as explained taking into consideration the low pass and high pass filter. We always choose an inverse relation between frequency and its resolution in wavelet transform not only the time and frequency knowledge it also take care of the resolution where as in short time fourier transform window size can't be changed. If we try anyhow to larger the window size for the sake of frequency resolution, there will be loss of time information. Standard deviation and change in energy is found out by deducting signal before from after islanding detection.

5.2.2 Hybrid islanding detection technique:

This method is a combination of active and passive detection technique. Active method produce disturbance at the output of the distributed generator through continuous and positive feedback loop through dq model implementation followed by passive detection technique. We already know if the targeted generator is connected to the grid then the output parameter doesn't change much which shows a non-islanding condition in active method and threshold value will be compared for both active and passive method through which we detect a islanding condition. This method uses inductive, capacitive and also resistive load in parallel with the RLC load and gives out the result with and without controller. Different islanding conditions are shown through MATLAB SIMULATION and verified with analysis.

Active technique is implemented after there is a suspection of islanding by passive detection technique. Along with the conventional islanding detection technique voltage magnitude is also considered for inspection. Monitoring the changes in various parameter and diagnosing the operation of the distributed generation in different loading condition such as resistive, capacitive and inductive load in parallel we conclude the final result. For example let's take a RLC load whose load demand is fulfilled by supply power grid and the generator connected to it. if the grid is now disconnected then it's an islanding condition and the voltage(v), frequency(f) and other magnitudes will change at the point of common coupling to (v') and (f') because of angular relationship between the phase angle monitoring which we find out about islanding. If the DG'S generation matches the load then these parameters won't fluctuate more from there boundaries. In the mean time the active method push these limits outside there boundaries which will now indicate an islanding condition. The active anti-islanding controller injects current and produce fluctuation and continuous feedback signal during islanding and passive controller gives the result about islanding. Both the controller are part of hybrid anti-islanding controller whose simulation is done using MATLAB. During islanding condition voltage and/or frequency are destabilized during islanding using positive and continuous feedback signal injection through dq implementation. The RLC load(as used in feedback control) used as local load and d-axis voltage feedback scheme is used and when d-axis voltage increases inverter senses it and command the feedback controller's d-axis current reference to increase which will lead to increase in active power. Due to load characteristics the voltage and frequency will pass there limit. Now the passive technique check there limit at the output .when islanding detected a signal will be sent to shut down the targeted DG. There's an BPF shown which is used to eliminate noise injection.

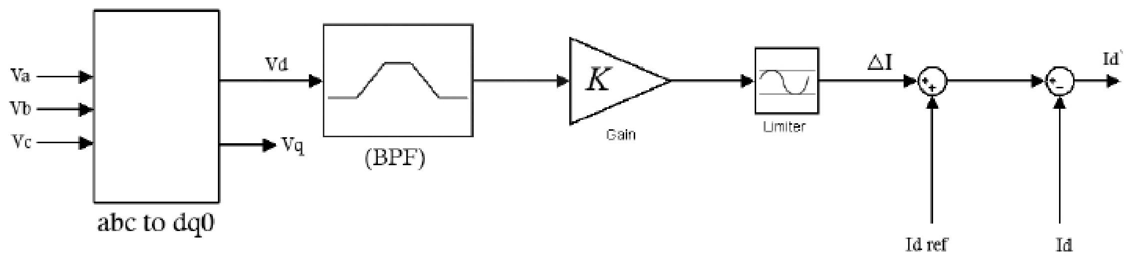


Fig 5.2.(showing the operation of the feedback loop)

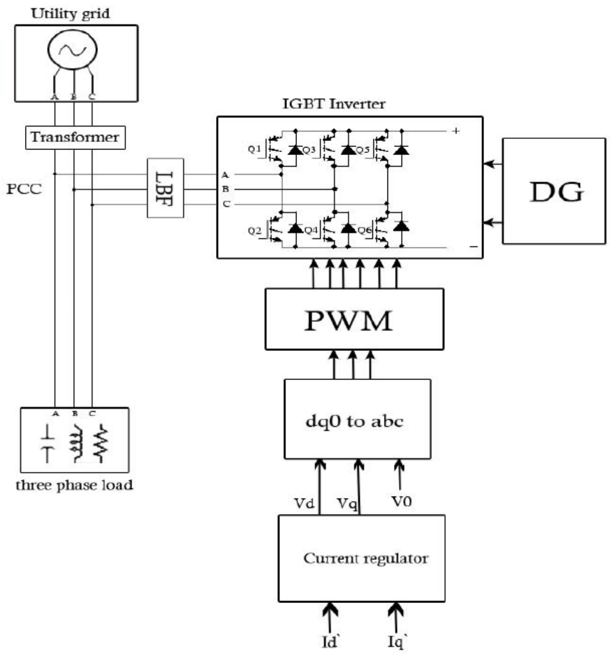


Fig 5.3.(active anti-islanding controller with current regulator)

Presence of noise may effect the power quality. Gain is small in grid connected mode for stability purpose and at the time of islanding the gain should be high to make the parameters unstable. Limiter is used to limit the maximum current that can be injected. Inverter over current capability and allowable power factor determines limiter's limit.

After destabilizing the components passive technique measures the output parameters and conclude about the islanding condition. After this simulations of the measured parameters are done showing the threshold value and various islanding condition.

Chapter 6

Result and discussion with the comparison between two proposed methods

The model description of islanding detection through wavelet transform are as follows.

Doubly fed induction generator based wind turbines are used here, each of 9 MW and they are attached to a 120KV grid and it has been possible through a 25 KV feeder of 25 km length. A 0.9 MVAR filter and 500 kw resistive load attached to 575v bus. PWM converter is AC/DC/AC IGBT based where switching frequency choosen as 1620 hz. DFIG is used for extraction of maximum possible energy when wind speed is less and wind speed is fixed at 10 m/s say. Sample time used for the model to discretize it is 5µs and that of control system is taken as 10 µs.

The details of the equipment like transformer, generator, inductor, resistor are described here.

- For generator, V_{base} = 120kv, V_{rated} = 120kv and short circuit rated power= 1000MVA.

- In case of transformer T1,rate power=25MVA, frequency(f)=50hz, 120/25kv stepdown, X1=0.1 pu, R1=0.00375 pu and R_m and X_m both 500pu.

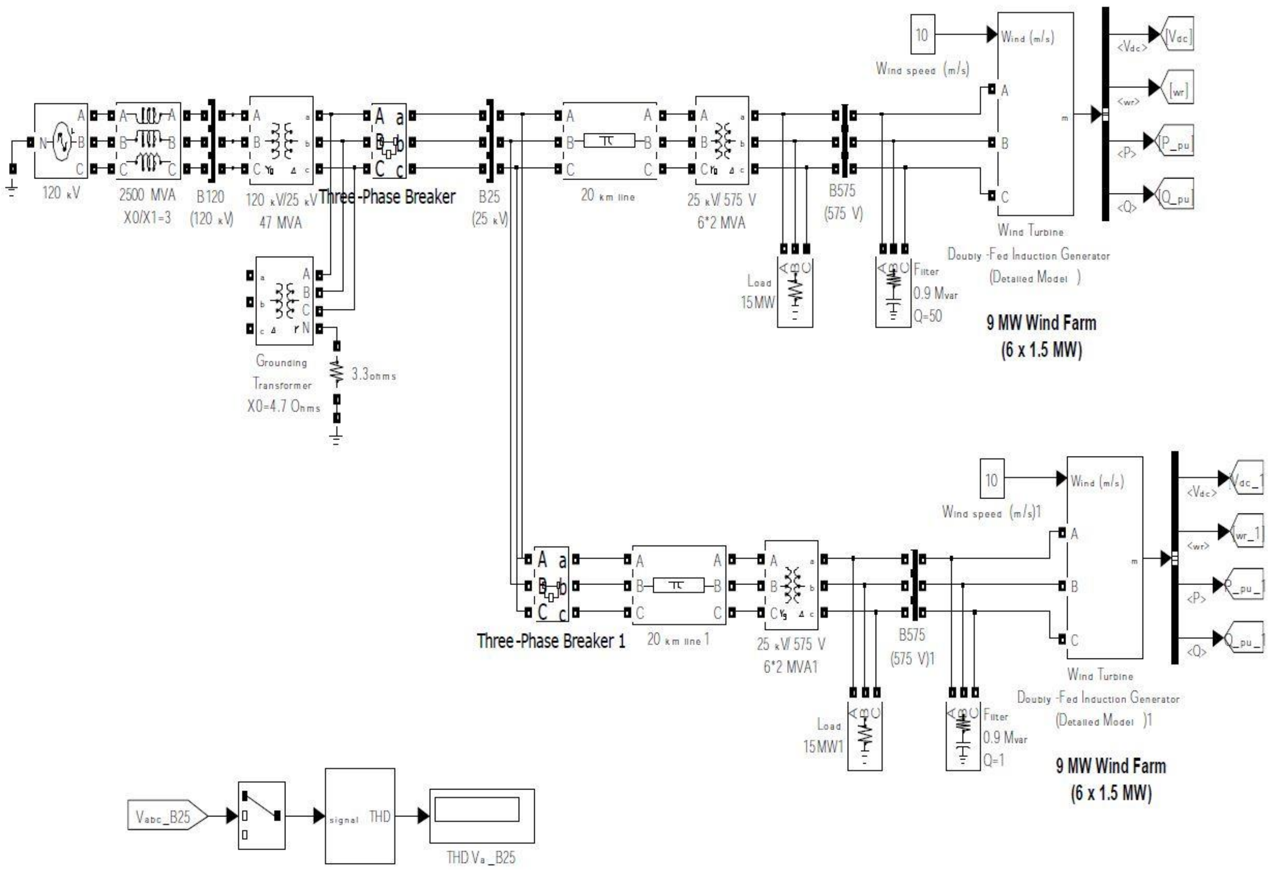
- For other transformer, rated power 10 MVA, frequency=50hz, 575v/25kv step-up, base voltage=25kv, X1=0.1 and R1=0.00375 in pu, R_m and X_m same as before.

- Distributed generator: In this case doubly-fed induction generator of 9 MW in used attached to 25 kv power export through a 25 kv feeder of length 30 km to 120 kv grid.

- Distribution lines, in simulation diagram(indicated as L) are of 30 km, 25 kv, and 20 MVA, base voltage being 25kv and load magnitudes are as given,
  R1=0.413 Ώ, L1=3.32e-3 H, L_0=1.05e-3 H, C_0=11.33e-009 F and X1=5.01e-009 F and all these parameters are measured per km.

- Finally the normal loading information is, line 1 of 15 MW and 5 MVAR and for other line it is 8MW and 3 MVAR.

According to this proposed method the voltage and current signal are extracted from the output of the generator on which we are experimenting about islanding and only the negative sequence components are passed through wavelet transform. DG-1 is considered here for and the situation about which islanding and non-islanding condition are described below. Using these data and various loading conditions as minimum, normal and maximum loads. Simulation is done at 1.6khz and signals are extracted from both the generator where islanding occurs at 0.3s at the lower one after the the loss of mains power. Now the simulation part is done using MATLAB SIMULINK and results are shown after which we shift to the next one.



Discrete THD

Fig 6.1(the circuit model of our simulation as described above)

- Condition 1: Normal condition where circuit breaker and circuit breaker 1 both are in closed condition, normal 3-phase power flow occurs and sinusoidal curve for both voltage and current are shown in figure.

- Condition 2: Now the three phase circuit breaker is opened, there will be loss of mains power and load changes occurs keeping the circuit breaker1 closed. The distributed generator continues to supply power to the connected loads and this one is an islanding condition where sudden trip signal is need to be sent to disconnect the DG to avoid further fault conditions.

- Condition 3: in DG generator line trip condition the main circuit breaker is closed and circuit breaker-1 opens for which the simulation result will be shown.

- Condition 4: there will be load change up to 50 percentage suddenly which may not be a islanding condition.

For above four conditions simulation programme is run at period of sampling 5e-006 and 32 samples/cycle.

After islanding voltage may increase or decrease depending upon load change.

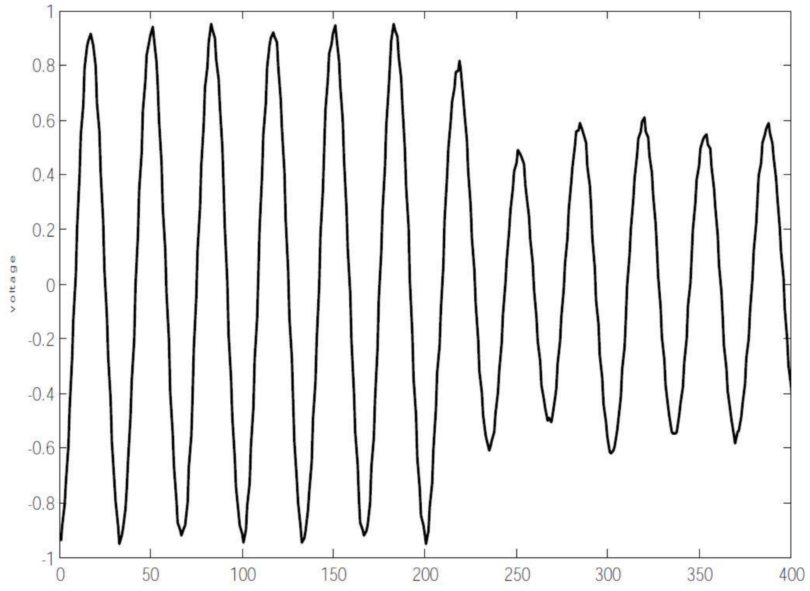


Fig 6.2(change in voltage after islanding)

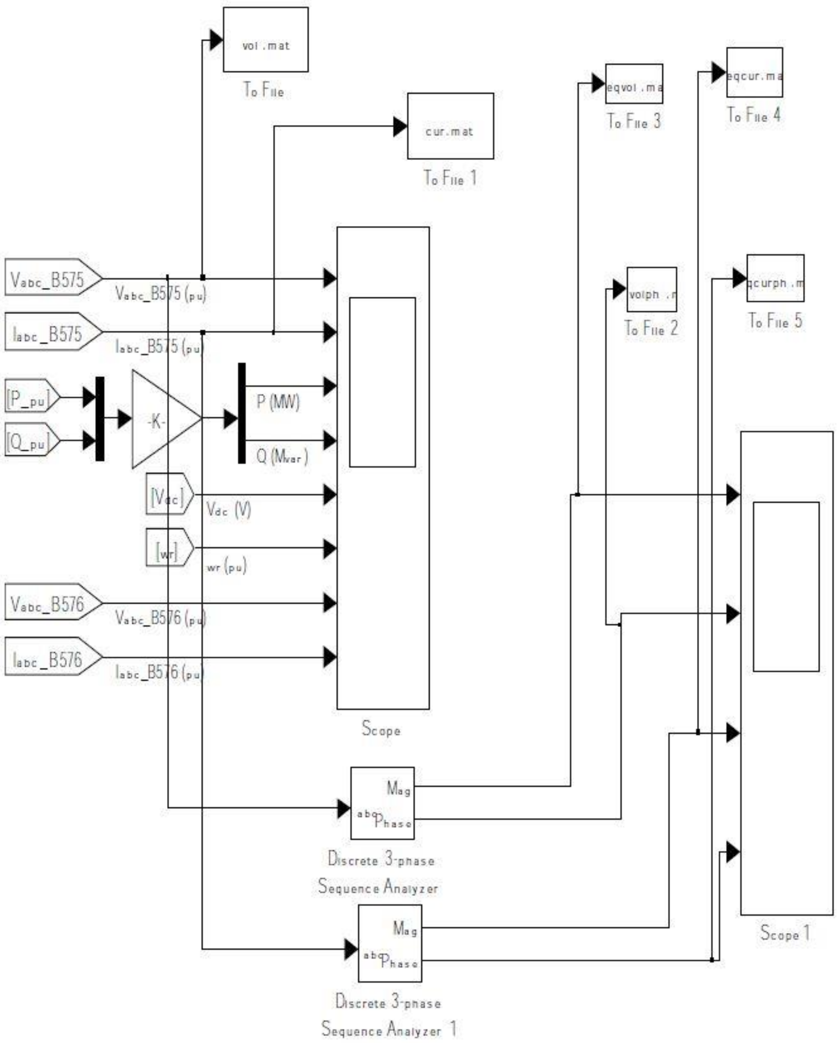


Fig 6.3(after extraction of negative sequence component its wavelet transform is done where we get the d1 coefficient)

Where negative sequence components are found by formulas,

$v_n = \frac{1}{3}(v_a + a^2 v_b + a v_c)$ and similarly for current where v_a,, v_b and v_c the voltages of the three phases respectively and v_n the negative sequence voltage .

a = 1∟120 degree

the d1 coefficient localizes the corresponding islanding event.

a) Normal condition:

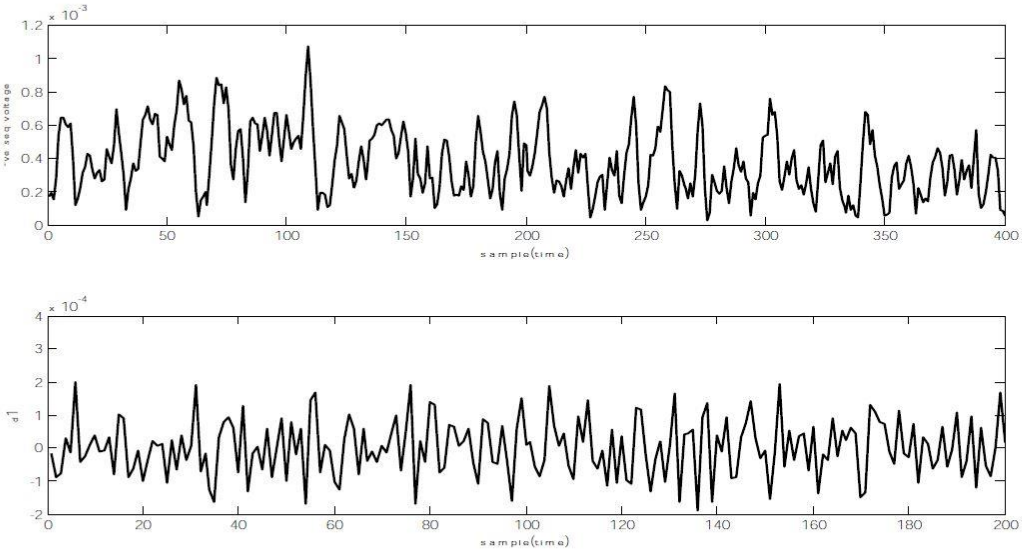


Fig 6.4(showing the output negative sequence voltage and d-1 coefficient of this) Sample(time) is shown and voltage as pu.

b) Islanding condition:

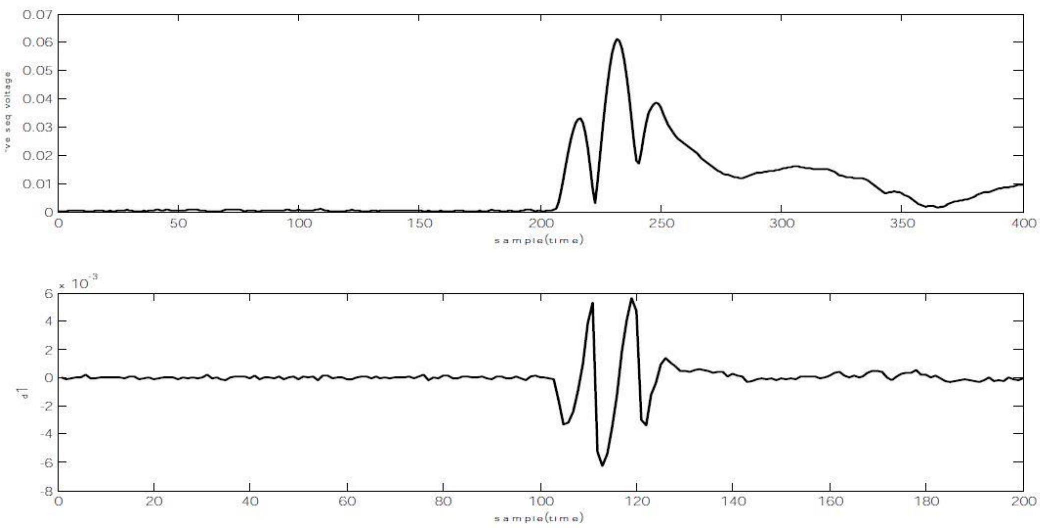


Fig 6.5(-ve sequence voltage and corresponding d-1 coefficient when islanding occurs)

c) Line trip condition:

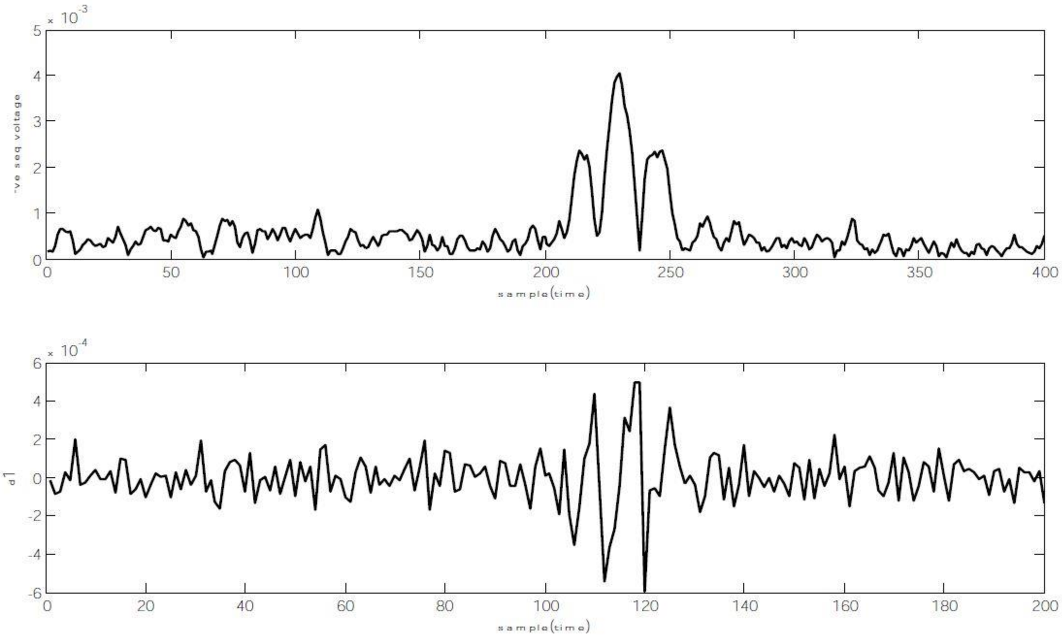


Fig 6.6(negative sequence voltage and respective d-1 coefficient after line trip)

d) Sudden load change:

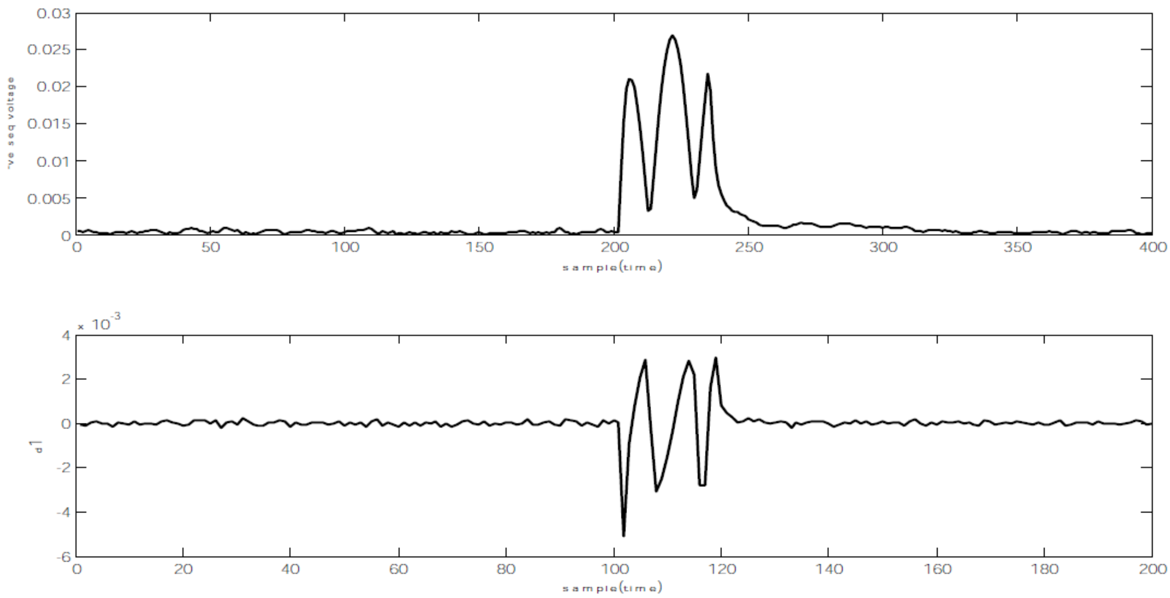


Fig 6.7(negative sequence voltage and corresponding d-1 coefficient when sudden load change is done)

Another useful method described in this thesis is the hybrid technology, where we test the method first in active methodology and then measuring the parameter through passive technology and concluding about the islanding condition. This method is best for inverter based distributed generator. As external disturbances can be given through the inverter to the distributed generator easily.

Figure below represents simulation diagram of the whole scheme of detecting islanding through passive method.

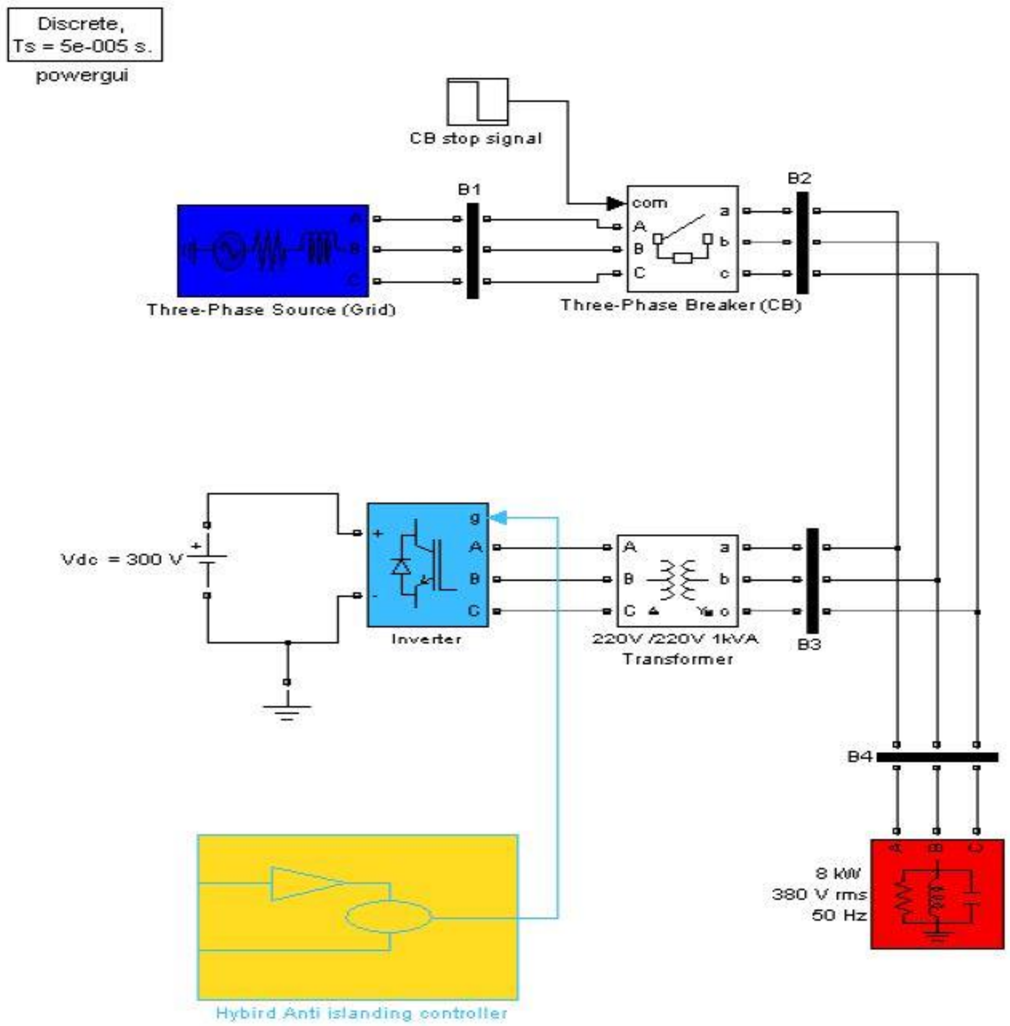


Fig 6.8(hybrid anti-islanding controller based grid inverter connection)

The data we have used for this simulation are as follows.

- Grid: voltage=220v, frequency=50hz.
- Distributed generator: Rated power=8 KVA, Rated voltage=220V and DC link voltage=300V and with load rated power 8kw.

The simulation diagram of the full cotroller(both active and passive is shown below.

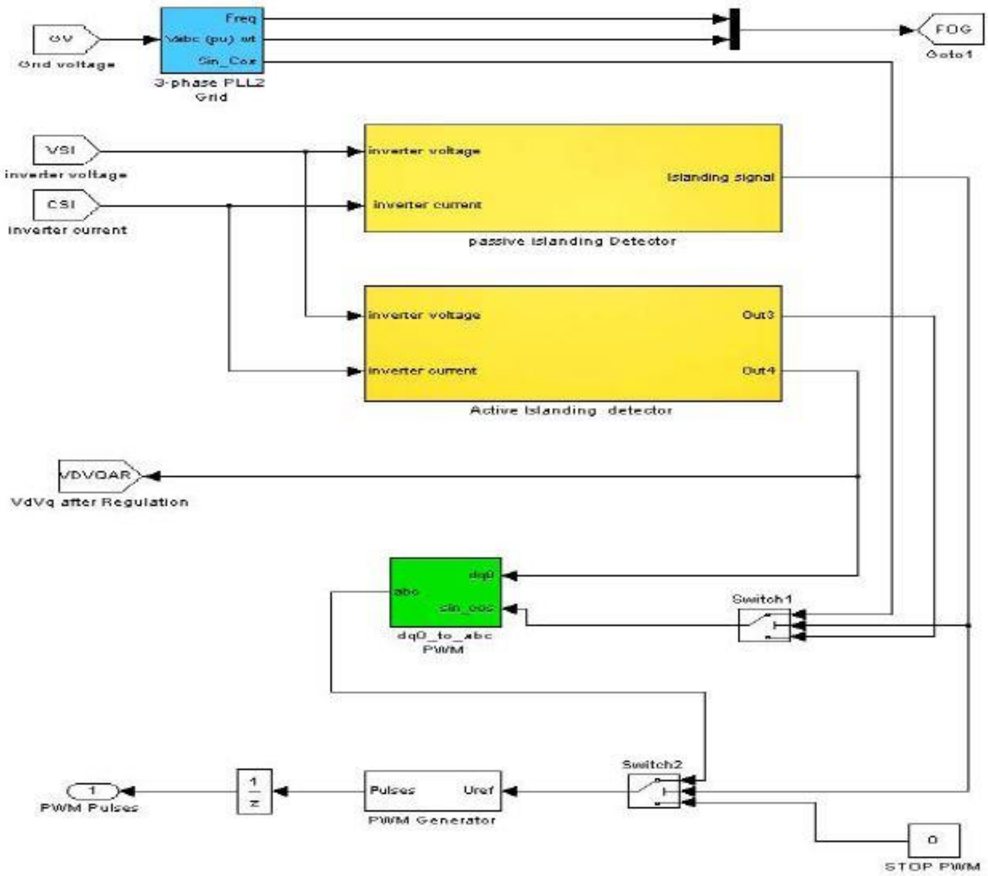


Fig 6.9(full controller diagram of hybrid technology)

The simulations are plotted and the results are obtained to compare with the wavelet transform method which is the basis of this thesis.

Anti-islanding technology after the MATLAB SIMULATION previously done.

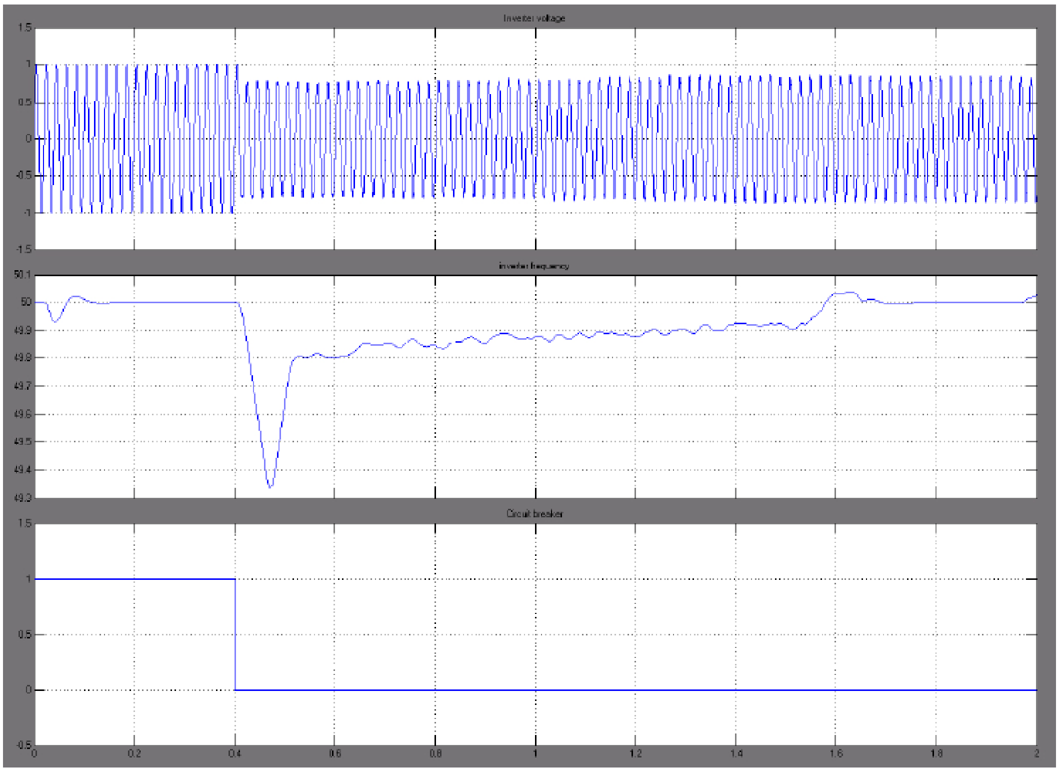


Fig.6.10(inverter voltage, inverter frequency and the circuit breaker signal)

This result is an output for inverter voltage, inverter frequency and circuit breaker signal before the islanding has occurred.

But in the absence of grid current which is a case for islanding condition both the grid current and inverter current will change. In our obtained result in fig.6 load current has decreased from 6 amp to 4.4 amp where as the inverter current has changed from 2.8 amp to 4.4 amp. Inverter current will increase after the islanding. In the mean time load current increases. Results of this islanding condition shown in fig 6. In all this simulation the non detective zone(NDZ) can be shown where the voltage and frequency at the connection point are located between 0.8pu<Vpcc<1.1pu and frequency between 49.3hz<fpcc<50.5hz .

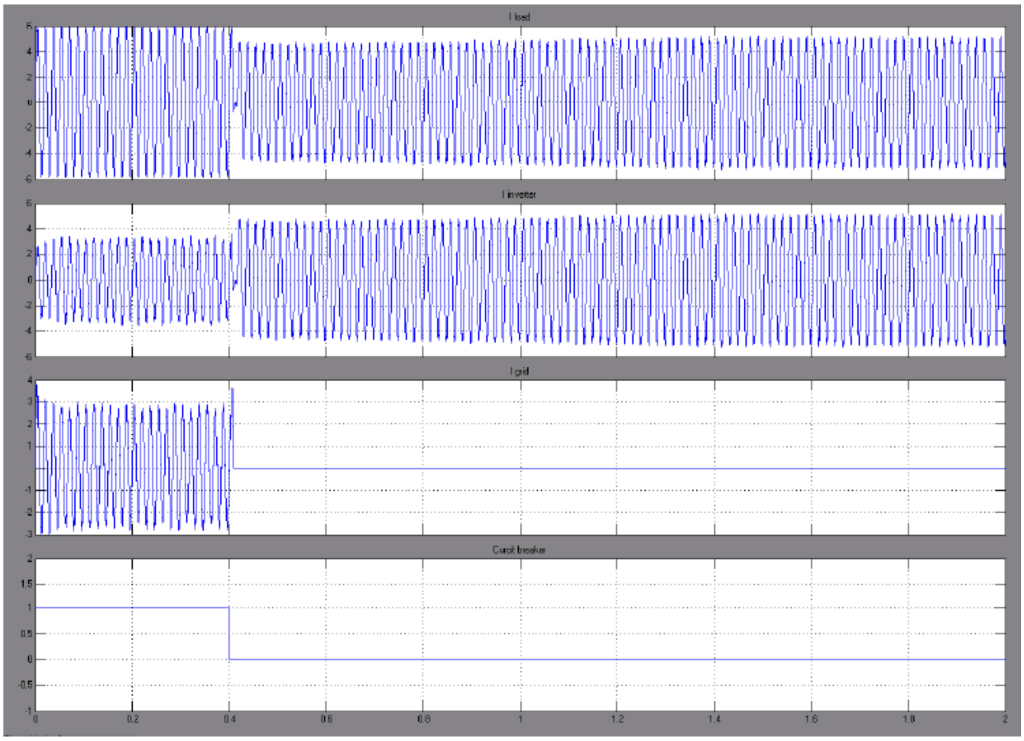


Fig.6.11(load current, inverter current, grid current and circuit breaker signal after islanding)

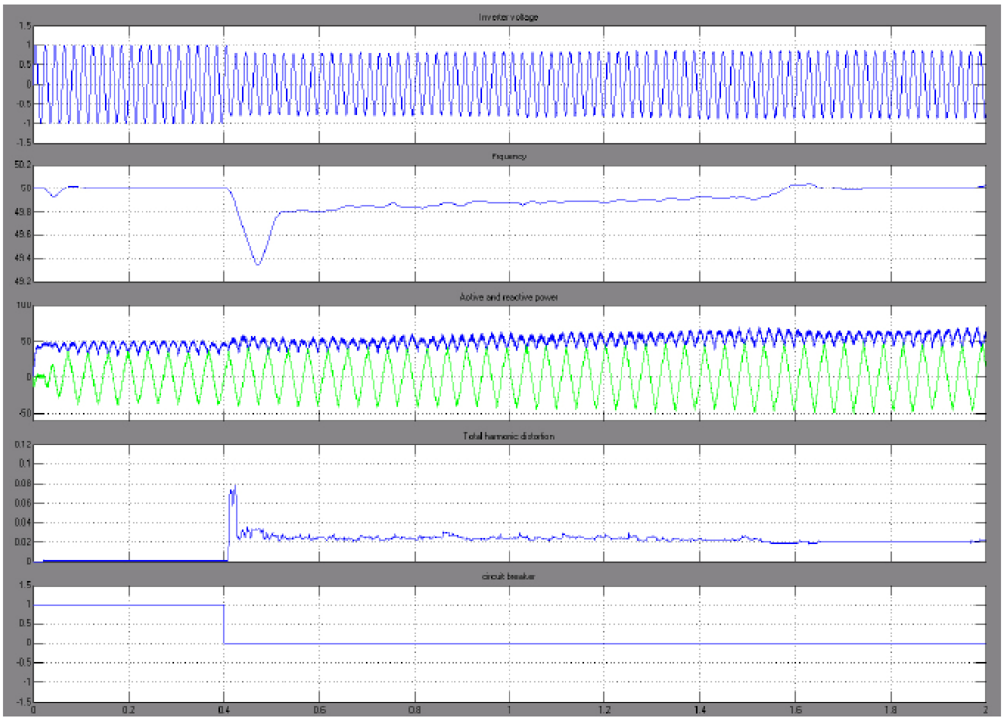


Fig.6.112(passive monitoring parameter(v, f ,active power, reactive power ,THD, circuit breaker signal with controller). It has not varied much with or without controller in our simulation)

The result is an output for inverter voltage, inverter frequency and circuit breaker signal before the islanding has occurred.

But in the absence of grid current which is a case for islanding condition both the grid current and inverter current will change. In our obtained result in fig.6 load current has decreased from 6 amp to 4.4 amp where as the inverter current has changed from 2.8 amp to 4.4 amp. Inverter current will increase after the islanding. In the mean time load current increases. Results of this islanding condition shown in fig 6. In all this simulation the non detective zone(NDZ) can be shown where the voltage and frequency at the connection point are located between 0.8pu<Vpcc<1.1pu and frequency between 49.3hz<Fpcc<50.5hz .

For wavelet transform method we have obtained our simulation for 4 condition as shown below.

For each condition we have obtained the negative sequence component of voltage and corresponding d-1 coefficient and the same is done for negative sequence current and plotted through simulation.

We have obtained our result both for negative sequence component based islanding detection and hybrid detection and observed that both the method serves as good basis for islanding detection where one is for wind turbine generator and another is best for inverter based islanding detection. We can say wavelet method is a passive method where as other one is combination of two and both method has a very small non-detective zone.

Conclusion:

We have verified the results of our work through MATLAB SIMULATION and also shown that the proposed method is suitable for islanding state determination although it has a very small non detective zone. Hybrid method while using both active and passive method is able to detect islanding when the voltage and frequency doesn’t lie in the region between 0.8pu<Vpcc<1.1pu and 49.3hz<Fpcc<50.5hz respectively and wavelet transform method is able to detect islanding universally except in certain cases when there is sudden load change(approximately 50 percentage or above). Hybrid technology is the best for islanding detection when distributed generator is inverter based as it becomes easier to inject external disturbance to the output of the generator to destabilize the parameter and push the parameter outside the limit so that islanding can be detected even if there is a close mismatch between generation and load. Also in case of wavelet transform we can do time space representation of signal and localize the corresponding islanding event where the result shows considerable fluctuation outside the threshold to denote the islanding condition.

References:

[1] A. M. Massoud , K. H. Ahmed , S. J. Finney and B. W. Williams "Harmonic distortion-based island detection technique for inverter-based distributed generation", *IET Renew. Power Generation*, vol. 3, no. 4, pp.493 -507 2009

[2] Jenkings, N.; Allan, R.; Crossley, P.; Kirschen, D.;and Strbac, G., " Embedded Generation " IEE Power and Energy Series 31, IEE 2000.

[3] M. N. Abdul Kadir, S. Mekhilef, and H. W. Ping "Dual Vector Control Strategy for a Three-Stage Hybrid Cascaded Multilevel Inverter" Journal of Power Electronics, vol. 10, no. 2, pp.155-164, 2010

[4] M. E. Ropp, M. Begovic, A. Rohatgi, "Determining the Relative Effectiveness of Islanding Prevention Techniques Using Phase Criteria and Non-detection Zones", IEEE Transactions on Energy Conversion Vol. 15 no. 3, p. 290-296, September 2000.

[5] R. A. Walling, and N. W. Miller, "Distributed generation islanding implications on power system dynamic performance," IEEE Power Engineering Society Summer Meeting, vol.1, pp. 92-96, 2002.

[6] S. Jang, and K. Ho Kim, "An Islanding Detection Method for Distributed Generations Using Voltage Unbalance and Total Harmonic Distortion of Current" IEEE Transactions on Power Delivery, Vol. 19, No. 2, April 2004.

[7]M. A. Kashem and Gerard Ledwich. Multiple distributed generators for distribution feeder voltage support. IEEE Transactions On Energy Conversion, 20:676–684, 2005.

[8] P. L. Villenueve. Concerns generated by islanding [electric power generation]. Power and Energy Magazine, IEEE, 2(3):49– 53, 2004.

[9] Manisa Pipattanasomporn, Michael Willingham, and Saifur Rahma. Implications of on-site distributed generation for commercial/industrial facilities. IEEE Transactions of Power Systems, 20(4):206–212, 2005.

[10] T. Ackermann, G. Andersson, and L. Soder, "Electricity Market Regulations and their Impact on Distributed Generatiron," IEEE, 0–7803–5902-X/00, 2000.

[11] A. Safari and S. Mekhilef " Simulation and Hardware Implementation of Incremental conductance MPPT with Direct control method using Cuk converter" IEEE Transactions on industrial electronic, DOI: 10.1109/TIE.2010.2048834, in press.

[12] M. N. A. Kadir, S. Mekhilef, and H. W. Ping "Voltage Vector Control of a Hybrid Three-Stage Eighteen-Level Inverter by Vector decomposition" IET Transaction on Power Electronics, Vol. 3, Issue 4, pp.601- 611, 2010.