ISLANDING DETECTION AND PROTECTION

A Dissertation
Submitted in partial fulfillment of the requirement for the award of
Degree of

Master of Engineering
In
Power Systems And Electric Drives

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "*Islanding Detection And Protection*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Power System And Electric Drives* submitted in Electrical and Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of *Dr. Amrita Sinha,* Assistant Professor.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.

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

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ABSTRACT

Islanding occurs when a portion of distributed system becomes electrically isolated from the rest of the power system yet continues to be energized by distributed generators. The DG interconnected to power distribution system must be able to detect islanding condition. The current requirement is to disconnect all distributed generators immediately as the island occurs. For this, each distributed generator must be equipped with an islanding detection device. In this thesis, a review of current practices and research work developed on distributed generation has been discussed and main focus is done on DG problem Islanding. 7-Bus system in which one is an Infinite Bus, two are Generator Buses and rest are Load Buses, has been simulated in DIgSILENT. Various parameters like Voltage, Frequency, Active Power and Reactive Power are detected in islanded mode, fault and load switching. If a line is disconnected due to any type of fault, then islanding condition arises. In this thesis, we have considered voltage threshold value of the voltage relay connected at the bus up to 95%. Some cases will be there when generator has to supply more than its capacity. In that case, Load Shedding has been done according to some priority level and that priority level has been followed according to the voltage threshold value of the bus voltage. It has been concluded that when islanding occurs then there is voltage dip and some transients in the bus occurs. The remedies taken to maintain the bus voltage and frequency are like Load Shedding as per priority and Transformer Switching.

LIST OF ABBREVIATIONS

DG	: Distributed Generation
DER	: Distributed Energy Resources
PMU	: Phasor Measurement Unit
SCADA	: Supervisory Control and Data Acquisition
COROCOF	: Comparison of Rate of Change of Frequency
SFS	: Sandia Frequency Shift
SVS	: Sandia Voltage Shift
FJ	: Frequency Jump

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CHAPTER 1

INTRODUCTION

1.1 Distributed Generation

The trend of power engineering has been increasing towards distributed generation. Distributed generation is any small-scale electrical power generation technology that provides electric power at or near the load site; it is either interconnected to the distribution system or directly to the customer's facilities or both. DG technologies include small combustion turbine generators (including micro turbines), internal combustion reciprocating engines and generators, photovoltaic panels, and fuel cells. Other technologies including solar thermal conversion, Stirling engines, and biomass conversion are considered DG. DG has much potential to improve distribution system performance. The use of DG strongly contributes to a clean, reliable and cost effective energy for future. Distributed generation may also be referred to as 'Dispersed generation', 'embedded generation' or 'decentralized generation'. Some of the technical issues are islanding of DG, voltage regulation, protection and stability of the network. Some of the solutions to these problems include designing of standard interface control for individual DG systems by taking care of their diverse characteristics, finding new ways to/or install and control these DG systems and finding new design for distribution system. In combination with demand response and energy storage, it is sometimes referred to as 'Distributed Energy Resources' (DER).

1.1.1 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.

1.1.2 Advantages of Distributed Generation

- **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**-
  DGs can improve grid reliability by placing additional generation capacity closer to the load and in this way transmission and distribution disturbances are minimized.
- Reduces Transmission and Distribution line losses.
- Improves power quality and voltage profile of the system.

1.1.3 Technical challenges faced by distributed generation

DG faces a series of problems. The designing of Electric transmission and distribution is done where few high power generating stations are at a large distance from the consumers and supply electric power to the small consumers. DG systems are smaller systems that are integrated into low voltage distribution 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. Different challenges faced by DG are:-

- Voltage Regulation and losses
- Voltage flicker
- Increased short circuit levels
- Transient stability
- Sensitivity of existing protection schemes
- Islanding control

1.2 Distributed Energy Resources

Most power engineers understand that DER means a power source connected directly to the primary or secondary distribution system. DER is not new. It is as old as power system itself. Earlier it was the natural way to connect power sources to the grid but as a result of development of power system, neighboring systems were interconnected with transmission system. This increased the availability of the system. To increase it further, large power plants were connected to the transmission system.

1.2.1 Energy Sources

Almost all the DER units are considered to be environment friendly. The most common energy sources with their benefits and drawbacks are mentioned below.

- **Wind Power**

The number of wind power units installed in power systems around the world has grown significantly in the last two decades. The trend today is to construct large wind power farms offshore. Many of the installed plants are, however, small farms or individual plants on land connected to the distribution systems. In Europe a few countries, with economic and politic Pre requisites, distinguish themselves from the rest; Spain, Holland, Germany and Denmark. The energy source in wind power plants is the sun and wind power can therefore be claimed to be environmental friendly. It is argued that the environmental impact of wind power is how the towers affect the view of the landscape. If the sun is low on the skyline the turning turbine can also cause optic flicker phenomenon that can be annoying. Tower acoustic noise is another source of irritation.

- **CHP**

Combined heat and power plants (CHP) produce both heat (approximately 60 %) and electricity (some 30 %), which gives them a rather high efficiency. CHP are installed in areas where there is a need for heat. The fuel can be fossil, which gives rise to carbon dioxide. It has therefore been questioned how environmental friendly CHP are. The high efficiency has been used as an argument against this. CHP can also be run on biofuel. The cost of installing hydropower plants is very high. So these are less used.

- **Photovoltaic**

These convert light into electric power. Photovoltaic can produce power from microwatts to megawatts. PV systems have numerous advantages:

i. No moving parts
ii. Operates silently
iii. Requires little maintenance

- **Hydropower**

The number of new installed distributed hydropower plants is not high in the Western Europe systems. The investment costs are very high and the environmental impact is considered to be high. In Sweden a few old dams that have not been used for long times have however been restored and reinvestment programs exist.

- **Landfill Gas**

Landfill gas is produced by decomposing garbage which is collected and either flared off or used to produce electricity. Landfill gas is a mixture of gases including carbon dioxide (CO2) with the largest component being methane gas. This gas can be captured and used to power a turbine generator thus producing electricity.

1.3 Energy Storage

An asset believed to be used more frequently in the future is energy storage. The benefit is the possibility to store energy that can be used during peak hours. By doing so the system can be designed for less than peak power and the influence of bottlenecks can be reduced. There are a few ways to store energy. It is difficult to store AC current. It is comparatively easy to store energy in hydroelectric dams. Norway can store close to 70 TWh, which is more than 50% of the annual consumption of electric energy. In battery storage, the energy is stored chemically in batteries. Kinetic energy can be stored in flywheels and potential energy in pressured air.

1.4 Energy Converters

The generators in the power plants are responsible for the transformation of mechanical energy to electrical energy. There are mainly two kinds of generators connected to the grid: synchronous generators and induction (or asynchronous) generators. Besides these generators there are also power electronic converters, PEC, which can feed electrical energy to the grid.

The kind of generator or PEC installed decides how the DER affects the grid during normal operation and disturbances.

- **Synchronous generators**

Synchronous generators are the kind of generators that are used in large power plants around the world. The reason is that they can control the frequency and voltage level in the grid. If more power from the turbine is fed to the synchronous generator the grid frequency is increased and vice versa. The voltage can be affected by changing the magnetization current in the generator. This affects the reactive output and hence the voltage level. In small power plants synchronous generators are used if they are intended as standalone units operated without connection to the grid. During short-circuits a synchronous generator contributes with large fault currents for a relatively long time. Fault currents four to five times the rated current is normal.

- **Induction generators**

Induction generators have historically been used in small power plants. They are cheap in investment and need relatively little maintenance work. The drawback is that they cannot control voltage level in the grid they are connected to. They also need reactive power from the grid (or from shunt capacitances) to the magnetization. An induction generator only participates with fault current initially. When the terminal voltage drops during a short-circuit, the ability of the machine to maintain magnetization decreases, which reduces the fault current.

- **Power electronic converters**

Power electronic converters can control both active and reactive power. The short-circuit current magnitude from a PEC is not considerably larger than the rated current; a typically value mentioned is 115 %. This is due to the low ability of semiconductors to withstand over currents. The time a PEC continues to energize a fault depends on the algorithms controlling the transistors.

1.5 Power System Impact

The kind of energy converter in a DER-plant determines how the grid is affected during normal operation and disturbances. During normal operation a synchronous generator and a PEC can participate in the voltage regulation. An induction generator cannot contribute to the voltage regulation. On the contrary the reactive consumption of an induction generator can counteract the voltage stability. Depending on the kind of energy converter installed, a DER-plant can affect the fault currents in a system. If a DER-unit with a synchronous generator is installed in a long feeder the fault current from the substation may decrease significantly. This can affect the sensitivity of the over current relay protections negatively, since they have to detect faults both with and without DER-production.

Equation 1.1 gives the current from the feeding substation when the DER plant contributes to the fault current

$$I_{grid} = \frac{U}{X_{grid}+Z_{fault}+X_{grid}\,Z_{fault}} \qquad (1.1)$$

Equation 1.2 gives the fault current without any contribution from the DER plant

$$I_{grid} = \frac{U}{X_{grid}+Z_{fault}} \qquad (1.2)$$

A traditional distribution system is designed for a power flow from the substation to the customers. The distribution transformers connected to the feeder have off load tap changers set to compensate for this drop. With a production source at the end of the feeder the power flow can be reversed during certain situations (low load and high production). Consequently, the customers may experience periods with extreme high voltages.

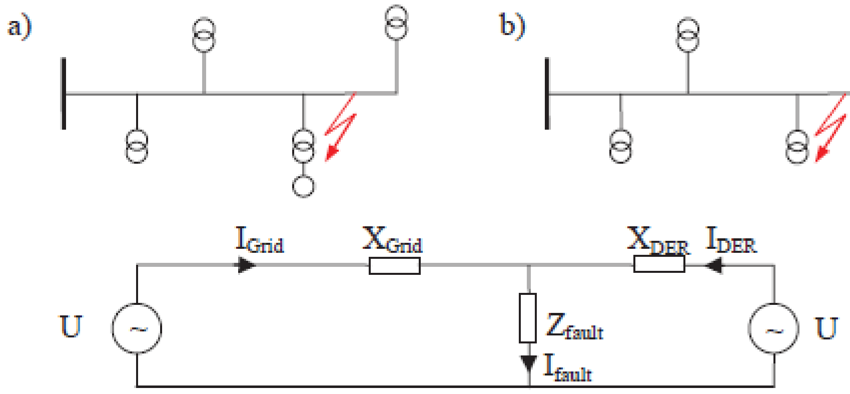


Figure 1.1 Fault current from the feeding substation (I_{grid}) and from the DER plant (I_{DER})

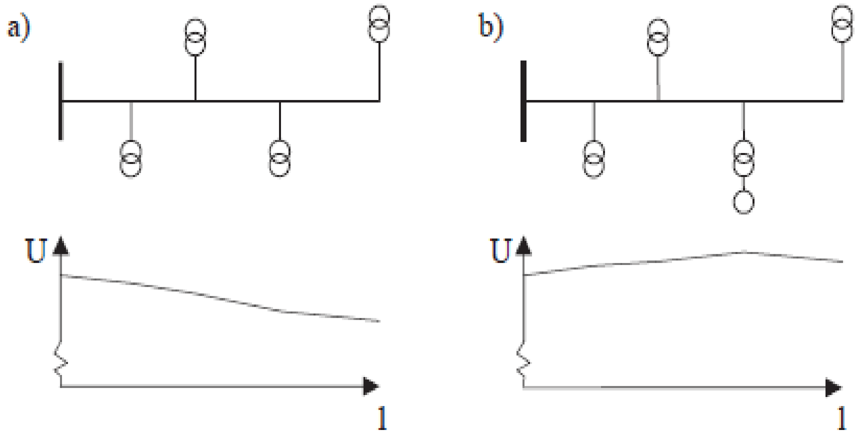


Figure 1.2 Voltage profile over a feeder without (a) and with (b) a DER plant

The most severe impact of DER to the system is properly nuisance tripping of large amounts of DER-plants. The consequences of such an event could propagate throughout the system. Nuisance tripping of DER-plants has relatively recently been considered as a problem to the power system. In the past it was required in many countries to disconnect the DER-plants at an early stage of a disturbance. The reason was to get a less complex system to control.

1.6 Islanding

Islanding phenomena is a condition in which the utility grid is disconnected from the distributed generation which still supplies to any section of local loads. Normally, the distributed generation is required to sense the absence of utility-controlled generation and cease energizing the grid. Otherwise, damages can occur to equipment if the generation in the islanding area, no longer under utility control, operates outside of normal voltage and frequency conditions. Besides, customer and utility equipment can be damaged if the main grid recloses into the island out of synchronization. Energized lines within the island present a shock hazard to unsuspecting utility line workers who think the lines have no electricity.

Islanding can be done intentionally or unintentionally. If Islanding is done intentionally, the system is designed to cope up with the varying parameters. The DER well controls the varying voltage and frequency. In unintentional Islanding, the DER is not suited to control voltage and frequency. The voltage and frequency may get out of range.

1.6.1 Issues with Islanding

- 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. 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 .
- Consequence of voltage& frequency drifts.

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

1.7 Islanding Detection

Islanding detection is an effective tool for distributed generation protection. There are a number of islanding detection schemes currently developed. It can be difficult to directly compare all the islanding detection methods back to back, as each type will operate more effectively than the other depending on the situation. For example, the change of terminal voltage method may be ideal for rotating machine generators due to their often large reactive component, where as the frequency shift methods work well with inverter based generators that supply more real power. A good performing islanding detection scheme has the ability to securely and dependably detect an island state. There are different techniques for islanding detection like remote techniques and local techniques which are further sub divided into active, passive and hybrid techniques. These techniques are described in detail in next third chapter.

1.7.1 Why islanding detection?

The power systems are complex and not always easy to understand. They are highly automated and spread over nations and continents. Contingencies and faults occur regularly and many of these events are cleared automatically without human intervention. The utilities are responsible for the safety of the power system. Electricity can be dangerous to both humans and animals and it can also be harmful to equipment connected to the grid.

If a part of the power system forms an uncontrolled island there is a risk that personnel sent out for maintenance work in the islanded system get in contact with the live parts of the equipment. This can cause severe injuries and death. Hence it is very important to detect and shut down unintended electric islands. Many distribution feeders have protection systems with automatic reclosing equipment. This is common practice when the feeders are constructed with overhead lines where the fault is likely to disappear after a short interruption. Automatic reclosing increases the availability of the power system since the interruption time is minimized. If, however, the automatic reclosing occurs against an energized feeder with a DER-plant it is not unlikely that the grid voltage and the energy converter at the plant are out of phase. This can cause damages to the installed equipment.

Another drawback with automatic reclosing against an energized feeder is that a capacitive switching transient can cause a severe overvoltage. In a lightly damped system, the overvoltage can reach three times the nominal voltage or twice the nominal voltage in a more damped system.

1.8 Islanding Protection

The principal objective for an islanding protection technique is to detect the condition where the DG unit is left connected to a portion of the utility's load network, but disconnected from the main source of utility power following a switching operation. When an islanding condition is detected, the protection should trip the inter-tie breaker between the generator's site and the utility. Once this has been done, the presence of the DSG unit will not impede the orderly restoration of the utility supply to the rest of the network. Since the intertie breaker is used to connect two active systems, once the network supply has been established, the DSG unit can be reconnected to the utility.

1.9 Outline of the thesis

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

Chapter 2 describes the literature review of islanding detection and protection.

Chapter 3 starts with the concept and theory of the islanding detection and protection.

Chapter 4 describes the flowchart.

Chapter 5 clearly describes the simulation model and all parts of the model are explained here in detail.

Chapter 6 describes the results obtained from the simulation model and all the discussion about results.

Chapter 7 describes the conclusion and future scope.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of the work of other Researchers

The various issues related with islanding makes it important to detect it and its protection is also required. A significant no. of researchers have contributed in this field. There are different methods of islanding detection. Passive methods use locally available quantities such as voltage or frequency. The quantities are derived from the high voltage level using voltage and current transformer, which feed the detecting device. Active islanding detection methods either try to manipulate the voltage or the frequency at the connection point or the manipulation is a result of measurements used by the method. Hybrid methods employ both active and passive techniques.

Shyh Jier Huang and Fu Sheng Pai [1] describe a new method for islanding detection based on monitoring of magnitude deviation and sign change in $\partial f/\partial P_l$. Even in small power mismatch, this method works effectively. This method was also confirmed to be immune from disturbances such as load change and three phase fault.

Sung-Jang and Kwang-ho kim [2] introduced a new index for islanding detection by introducing a total harmonic distortion of DR terminal and output current. And also a novel logical rule-based detection algorithm, which effectively combines the detection results of four system parameters including newly proposed one: voltage magnitude, phase, frequency, and total harmonic distortion of current was presented. This method was tested for both islanding and non islanding conditions. This method was not affected by variation of DR loading and can be actually implemented in distributed generators and was able to improve the performance of them.

Guo-Kiang Hung, et.al [3] described the most effective method for islanding detection of grid connected PV inverters. But they bear non detection possibilities for parallel RLC loads. To alleviate this problem, automatic phase shift method was introduced. This method was based on phase shift of sinusoidal inverter output current. Unity power factor operation of PV inverters failed for frequency shift methods or automatic phase shift methods.

Kwang-Ho Kim and Sung-Jang [4] proposed new monitoring parameters of islanding detection i.e. THD of the current and voltage unbalance of DG terminal output. This method was proposed for both islanding and non islanding conditions and was not affected by variation of DG loading and proved to be the effective islanding detection technique that could also improve the performance of distributed generators.

Pukar Mahat, et.al [5] proposed a hybrid technique to detect islanding of a distribution system with multiple DG units operating at unity power factor. It combined the real power shift and average rate of voltage change. Real power shift was used only when average rate of voltage change could not discriminate between grid connected and islanding conditions. RPS only changed the real power of DG and it discriminated islanding from other disturbances.

Wencong Wang, et.al [6] proposed anti islanding protection of distributed generators. A power line signaling based anti islanding protection scheme was proposed. This scheme broadcasted a signal from a substation to the DG sites using the distribution feeders as signal paths. The scheme proved to be very economical to satisfy anti islanding protection requirements for synchronous DG interconnections.

Jun Yin, et.al [7] proposed an anti islanding technique based on the proportional power spectral density. The proportional power spectral density (PPSD) was introduced as a normalized measure for islanding detection. The period measured at the PCC was filtered and used to set the command period of the inverter, then a tiny reactive power mismatch in islanding condition resulted in a distinct proportional power spectral density.

H. H. Zeineldin, et.al [8] proposed a method for islanding detection by examining P-V characteristics of DG and load. The P-V characteristics of DG were chosen so that DG maintains stability when grid connected and loses its stability once islanded. The PCC voltage was monitored and Overvoltage protection/under voltage protection was used to disconnect the DG once it was islanded.

Soo-Hyoung Lee and Jung-Wook Park [9] proposed an islanding detection method by the estimation of system impedance based on the high switching frequency of an inverter in the DG system. This method provided zero non detection zone property which avoided the changes like variation of reactive power or harmonics.

S. R. Samantaray, et.al [10] proposed a fuzzy rule based classifier for islanding detection. The classification model was developed using decision tree (DT) algorithm and was then transformed into fuzzy rule base. This method gave 100% islanding detection even on data with and without noise.

Hesan Vahedi, et.al [11] proposed a new method for islanding detection of an inverter based DG unit by using V_{dc}- V_{pc} characteristics. This method was done for inverter based DG under the multiple DG operation modes and did not distort any voltage or current waveform. Islanding was detected within the minimum standard time with this method.

Ankita Samui and S. R. Samantaray [12] proposed a new approach for islanding detection using rate of change of phase angle difference (ROCPAD). ROCPAD works well under active power imbalance when rate of change of frequency (ROCOF) fails. ROCPAD performed well even with active power imbalance of 0% and thus reduced the non detection zone (NDZ) compared to ROCOF relays and gave the secure and safe protection.

Waleed K. A. Najy, et.al [13] proposed an islanding detection technique for grid connected inverter based distributed generation. Passive discrimination method based on the difference in the transient responses of islanding and non islanding events was used and these differences were obtained by Estimation of Signal Parameters via rotational Invariance Techniques (ESPRIT). After applying algorithm on voltage and frequency waveforms at the PCC, these were fed to Bayes classifier. This method proved to be the best for discriminating between islanding and non islanding events for closely matched load DG ratings.

David Díaz Reigosa, et.al [14] presented an active method based on the injection of a high frequency signal for islanding detection of micro grids. Injection of high frequency signal was done by any VSI connected to micro grid. Positive and negative high frequency signals were selected for both islanding detection and communication.

Hua Geng, et.al [15] presented an active islanding detection method based on negative sequence power injection for the DGs with power control interface.Two loops i.e. positive sequence power loop satisfied the conventional power control requirements and negative sequence power/current loop was used for islanding detection. Due to difference between grid impedance and local load impedance, the percentage of voltage imbalance (VI) at the point of common coupling was used to indicate islanding operation.

Ahmad Yafaoui, et.al [16] presented an active islanding detection method that detected islanding with less total harmonic distortion. This method showed 30% reduction of THD in current waveform and detected islanding faster with better with better non detection zone (NDZ).

S.R. Samantaray, et.al [17] presented a new technique for islanding detection in distributed generation (DG) using time-frequency transform such as S-transform. S-transform provided the time frequency contours of voltage and current signals retrieved at the target DG location. The energy index i.e. the ratio of spectral energy content of voltage to current signals was computed to track the islanding condition from non islanding situations such as sudden load change, tripping of other DG etc.

Saeed Jahdi and Loi Lei Lai [18] presented a study on different techniques used in DG operation islanding detection techniques. Combined methods for islanding operation were studied and was recommended to provide a AND gate for DG islanding protection to make sure that islanding is detected and power is not interrupted by false detection by relays.

Jun Zhang, et.al [19] proposed an islanding detection method for grid connected inverter based on Intermittent Bilateral Reactive Power Variation (IBRPV) .The scheme monitored the system frequency and determined the islanding occurrence once the frequency ran out of normal range. The IBRPV islanding detection method eliminated non detection zone (NDZ) and guaranteed that detection time is less than 2s.

Diogo Salles, et.al [20] proposed an index to evaluate the effectiveness of anti-islanding frequency based relays used to protect synchronous distributed generators. This index indicated the time period that the system is unprotected against islanding. A practical method was proposed to calculate this index directly from simple analytical formulas or look up tables.This scheme assisted distributed engineers to set anti islanding protection schemes.

Prakash K. Ray, et.al [21] presented a comparative study between wavelet transform and S-transform based on extracted features for islanding and power quality disturbances in hybrid distributed generation. The analysis of S-transform suggested its capability to detect islanding and power quality disturbance events under both noise and noise free conditions.

Malhar Padhee, et.al [22] presented a fast Gauss-Newton algorithm for islanding detection in DGs when these are disconnected from the main supply systems or there are small load unbalances in the distribution network. A number of test cases considering both islanding and non-islanding, for realistic, hybrid distribution networks has demonstrated the reliability and accuracy of the islanding detection scheme, when a fuzzy expert system (FES) was used in conjunction with the proposed FGNW algorithm.

2.2 Problem Formulation

In this dissertation, it is proposed to detect islanding and then its protection is discussed. Firstly model is drawn in digsilent software then islanding is detected by taking various parameters like voltage, active power, reactive power and current. These parameters change not only in the case of islanding but also in case of fault and load switching. So, these changes are observed and a table is drawn to observe the deviations directly.

CHAPTER 3

CONCEPT AND THEORY OF ISLANDING DETECTION TECHNIQUES

3.1 Introduction

The main philosophy of detecting an islanding condition is to monitor DG output parameters and system parameters and to check whether islanding has occurred due to change in these parameters. Islanding detection techniques can be categorized as remote and local techniques. Local techniques can be subdivided into active, passive and hybrid techniques.

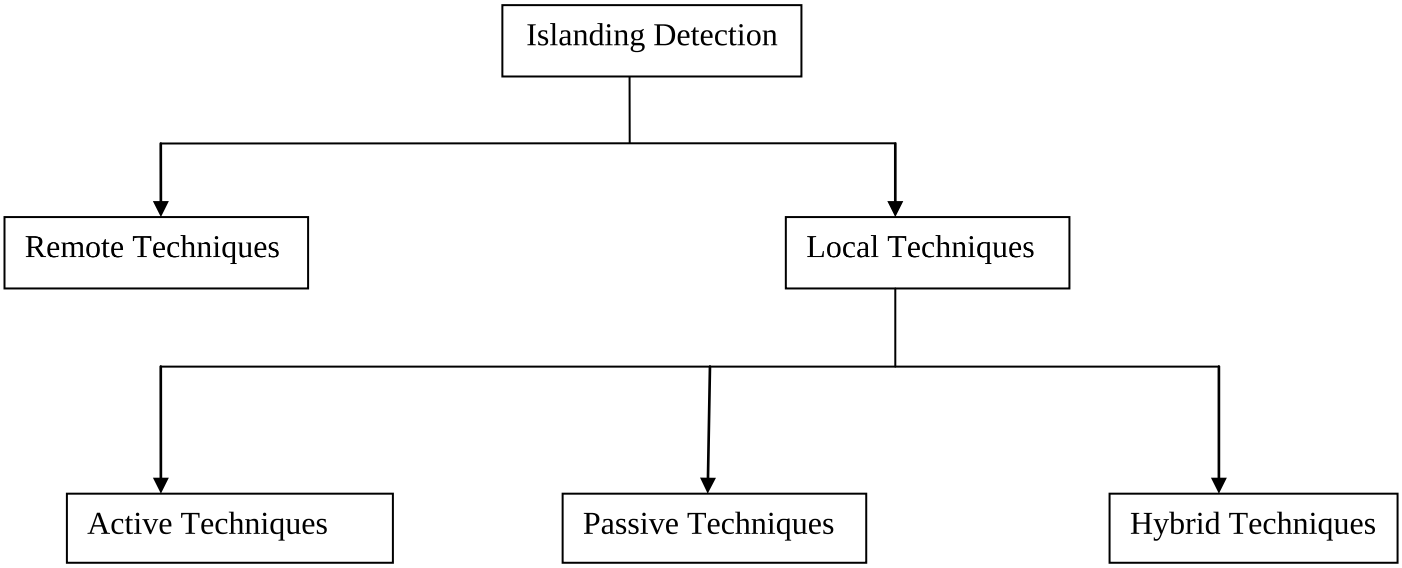


Figure 3.1 Islanding Detection Techniques

3.2 Remote Islanding Detection Techniques

These techniques are based on communication between utility and DGs. But these are very expensive to implement. Traditionally only utility owned wires and channels subscribed from public telephone companies have been considered. Today radio transmitting (FM or AM) and optic fibers can be added to the list.

3.2.1 Phasor Measurement Units

It defines a synchronized Phasor (synchrophasor), frequency and rate of change of frequency (ROCOF). A PMU requires a source for time synchronization. This may be supplied directly from a time broadcast such as GPS or from a local clock using a standard code. The system consists of two units-one at the utility substation and other at the DER plant and time is stamped before sending to the receiver. So, it is very easy to determine that DER plant is synchronized with the grid or not.

3.2.2 Comparison of Rate of Change of Frequency (COROCOF)

It compares frequency changes at two locations in the grid. A COROCOF relay at a generator set (receiving relay) can distinguish between the local disturbance and the disturbance due to the blocking signal sent by COROCOF sending relay.

3.2.3 SCADA

The SCADA system keeps vision on the states of circuit breakers. The information contained in SCADA should be sufficient enough to know that the system is in islanded mode or not. Its drawback is that when the system is subjected to one or more disturbances, it gives a slow response.

3.2.4 Power Line Carrier Communication

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 that is coupled into the network where it continually broadcasts a signal. 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 cannot be received by the DG, hence indicating an island condition.

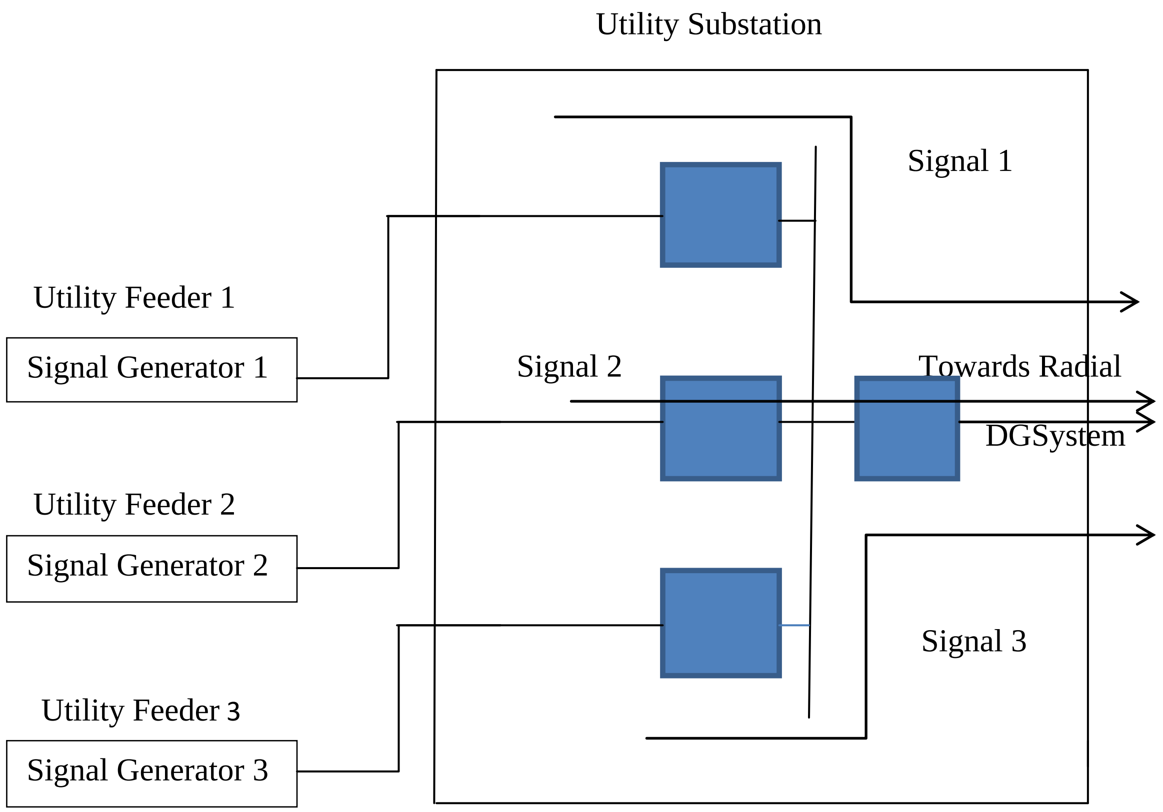


Figure 3.2 Distributed generation multi power line signaling islanding detection

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.

4.2.5 Transfer Tripping Scheme

Transfer trip detection schemes require all circuit breakers which island the DG to be monitored and linked directly to the DG control, or through a central substation SCADA system. 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.

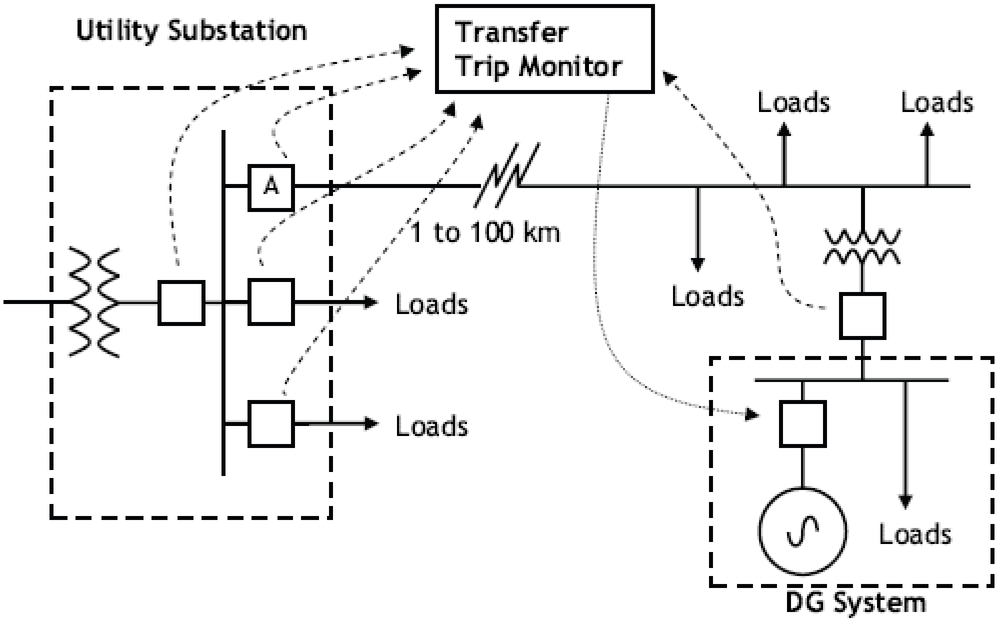


Figure 3.3 Distributed generation transfer trip islanding detection

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.

3.3 Local Islanding detection techniques

These techniques are based on the measurement of system parameters at DG site like voltage, frequency etc. These techniques are further classified as:-

3.3.1 Passive detection techniques

Passive methods work on measuring system parameters such as variation in voltage, frequency, harmonic distortion. The difference between the islanding and grid connected conditions is based on the threshold values set for these parameters. These techniques are fast and don't introduce any disturbance in the system. Some of the passive techniques are:

3.3.1.1 Rate of change of Output Power

The rate of change of power dp/dt at the DG side once it is islanded is much greater than rate of change of output power before islanding for the same rate of load change. This method is more effective for DG with unbalanced load rather than balanced load.

3.3.1.2 Rate of change of frequency

This implies that a relay uses the time derivative of frequency to detect islanding. The rate of change of frequency, df/dt will be very high when DG is islanded.

$$\text{ROCOF, } \frac{df}{dt} = \frac{\Delta P}{2HG} * f \qquad (3.1)$$

Where, $\Delta\text{P} = \text{power mismatch at DG side}$

H = moment of inertia for DG system

G = rated generation capacity of DG

Large systems have large G and H where as small systems have small G and H. ROCOF relay monitors the voltage waveform and operates if ROCOF is higher than setting for certain duration of time. The setting has to be chosen such that relay triggers for island condition but not for load changes. This method is reliable for large mismatch in power but fails to operate if DG's capacity matches with local loads. An advantage of this method along with rate of change of power is that, even these fail to operate when load matches DG's generation, any local load change would lead to islanding being detected as a result of load and generation mismatch in islanded system.

3.3.1.3 Rate of change of frequency over power

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 utilizes this concept to determine islanding condition. For small power mismatch between DG and local load, rate of change of frequency over power is much more sensitive than rate of frequency over time.

3.3.1.4 Voltage Unbalance

After islanding, DG has to take change of loads in the island. If the change in loading is large, then islanding conditions are easily detected by measuring parameters like voltage magnitude, frequency change and phase displacement. These methods may not be effective for small changes. As the distribution networks generally include single phase loads, it is highly possible that islanding will change the load balance of DG. Even though the load changes in DG is small, voltage unbalance will occur due to change in network condition.

3.3.1.5 Over/Under Voltage

Over and under voltage are also used for passive islanding detection, and often as a complementary device coupled with frequency monitoring. This relay operates on the principle that an excess of reactive power mismatch will drive the voltage up and a deficit of reactive power will drive the voltage down. Once the voltage falls out of the preset thresholds, the relay will open the breaker. Hence, by determining the voltage change or its rate of change, it is possible to detect island states that frequency effects alone cannot. Unfortunately, there is limited experience indicating that the reactive power measurement relay will have higher performance than frequency variations. As real power drawn is often much greater than reactive power, a loss of mains is more likely to significantly change the active power than the reactive power.

3.3.1.6 Detection of Voltage and/or Current Harmonics

This method of islanding detection is generally applied in conjunction with inverter based technologies when system harmonics are likely to be present. In this method, the island detector measures the total harmonic distortion (THD), sets a threshold and then shuts down when the harmonic distortion exceeds that level. If an assumption is made that a utility-connected system is more “stiff” than a DG-only system, the THD will be less for a utility connected system than for a DG-only connected system. There are several factors that can increase the level of harmonics in a network. Examples include switching power supplies, motor drives, and non linear components such as overloaded transformers. The level of harmonics produced by inverters will change between full load and no load conditions. A typical requirement for Inverters is to meet the THD specification of less than 5% under full load conditions. These harmonics are often very small due to the low impedance sink provided by the utility system and the measurability and the threshold setting will exhibit significant issues. This method has found setting thresholds and the ability to accurately measure small harmonics to be very difficult to measure and predict.

3.3.2 Active islanding detection techniques

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

3.3.2.1 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 or at the point where the Reed relay is connected. 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. The major drawbacks of this method are it is slow and it cannot be used in the system where DG has to generate power at unity power factor.

3.3.2.2 Slip-mode Frequency Shift

Slip mode frequency shift (SMS) is an inverter based islanding detection scheme that uses a positive feedback control to destabilize the source inverter when an island condition occurs.

$$i_{inverter\cdot} = I_{inverter}\sin{(wt + \emptyset)} \qquad (3.2)$$

As seen in the above equation a current source inverter uses positive feedback of the phase, f, to slip the frequency out-of-phase hence leading to short term frequency change. SMS is implemented by modifying the phase locked loop (PLL) filter to be naturally out of phase at the fundamental. Under normal operating conditions without SMS, the PLL tracks phase and frequency changes of the network. With SMS, the strength of the utility source keeps the inverter in phase. However, if the frequency during an island is pushed upwards, due to the out of phase filter, the PLL will see a negative phase error and try to shift the frequency away from the fundamental. Due to the positive feedback, the phase shift will be in the wrong direction to correct the phase error. The frequency eventually will fall out of acceptable limits and the frequency relay will open the breaker.

SMS also has the advantage of simple implementation as it only requires a modification to existing components in the inverter filter. SMS has been tested to have one of the smallest non-detection zones for islanding detection and is effective in multiple inverter applications

[95]. However, the SMS method will fail if the frequency response of an islanded RLC load is greater than the SMS system. Another non detection zone for SMS is with loads that have high-quality factor, Q, and have resonance frequencies very close to the line frequency.

3.3.2.3 Frequency Bias (Active Frequency Drift)

Frequency Bias, also known as Active Frequency Drift, is also an inverter and computer based islanding detection technique that distorts the frequency output to create a continuous trend to “drift“ the frequency away from the fundamental. The method works by altering the frequency, f, in Equation 3.2 by slightly increasing the frequency of each 1/2 cycle followed by a “dead time“ where the system waits for the fundamental to catch up to the biased frequency, for the fundamental to catch up to the biased frequency.

Similarly to Slip-Mode Frequency Shift, when the inverter is connected to the utility-fed network, the strong utility keeps the system frequency stable. However, when the network becomes islanded, the distorted frequency causes the system to seek the system load’s resonance frequency, resulting in the inverter eventually drifting up or down causing the frequency relays to trip. Frequency bias can work with multiple inverters as long as all inverters drift the frequency in the same direction, otherwise they may not drift the frequency fast enough to meet the detection requirements. The Frequency Bias method clearly requires a small amount of output power distortion where the distortion depends on how big the bias is per 1/2 cycle.

3.3.2.4 Sandia Frequency Shift

Sandia Frequency Shift (SFS) is an enhancement of the Frequency Bias Islanding detection method which uses positive feedback. When this system is connected to the utility, small frequency changes push the inverter out of the range of the line frequency, but the strength of the utility keeps the system stable.

When the utility is disconnected, the errors detected in frequency increase and the dead zone increases. This method has been found to be a significant improvement over normal Frequency Bias, except the transient performance degrades with higher density of sources using this system. This method was found to work well with current control inverters, but was found to be inappropriate for constant power inverters.

3.3.2.5 Sandia Voltage Shift

Similarly to Sandia Frequency Shift, Sandia Voltage Shift (SVS) also uses a form of positive feedback to detect islanding. In this case, the inverter decreases its power output and thus its voltage. When the utility is connected, there is little to no change in the output terminal voltage, however when the utility is not connected, the voltage will drop with the reduction of power. The positive feedback control of the voltage reduction is further accelerated downwards until the under voltage protection relay trips. Since SVS is an inverter based scheme, it is easily implemented in software and can couple well with the Sandia Frequency Shift [95]. The drawback of this method is that it creates a reduction of inverter efficiency, and similarly to other positive feedback techniques, may also suffer from poor performance for transient responses. High Q values have negligible effect on this method.

3.3.2.6 Frequency Jump

Frequency Jump (FJ) is also known as the Zebra Method and is a close relative of the Frequency Bias method. In the FJ method, “dead zones” are added similarly to the frequency bias method, but not in every cycle. The frequency is broken into a predefined algorithm, with dead zones added every second or third cycle. When connected to the utility, the inverter only sees a modified current and an unmodified utility linked voltage. When in island state, the voltage and current change as per the inverter programmed wave shape. Therefore, the inverter can detect an island by the modified frequency, or by matching the voltage pattern to the inverter’s algorithm. This method is believed to lose effectiveness when used in conjunction with many inverters that use the same algorithm.

3.3.2.7 ENS or MSD (A device using multiple methods)

The ENS method is more of a standard than an actual islanding detection technique, but for thoroughness, it is important to describe how it works for this process. The passive component requires that the voltage does not exceed the limits of 80% to 114%, and a frequency of 47.5 Hz to 50.2 Hz (50 Hz is the fundamental frequency in Germany). The DG is to be disconnected within 200 ms (10 cycles) of these limits being exceeded. Along with the instantaneous values, the average voltage measured over ten minutes must also not exceed the limit of 115%. Finally, a resonant LC load is to be switched in parallel with the system to measure the impedance changes on all three phases. Changes outside of the original set range of 5% results in a relay trip within 5 seconds of the occurrence.

3.3.2.8 Current Unbalance

Karimi used negative sequence current injections for islanding detection in simulation. A voltage source inverter controller made the injections. The negative-sequence current injection in the range of 2% to 3% allowed for fast islanding detection. The time of detection was less than 60 ms (3.5 cycles).

3.3.3 Hybrid detection techniques

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:

3.3.3.1 Technique based on positive feedback and voltage unbalance

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 . 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.

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

Where, V_{+sq} =positive sequence Voltage

and V_{-sq} =negative sequence Voltage

3.3.3.2 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 active islanding detection technique.

CHAPTER 4

FLOWCHART OF ISLANDING DETECTION

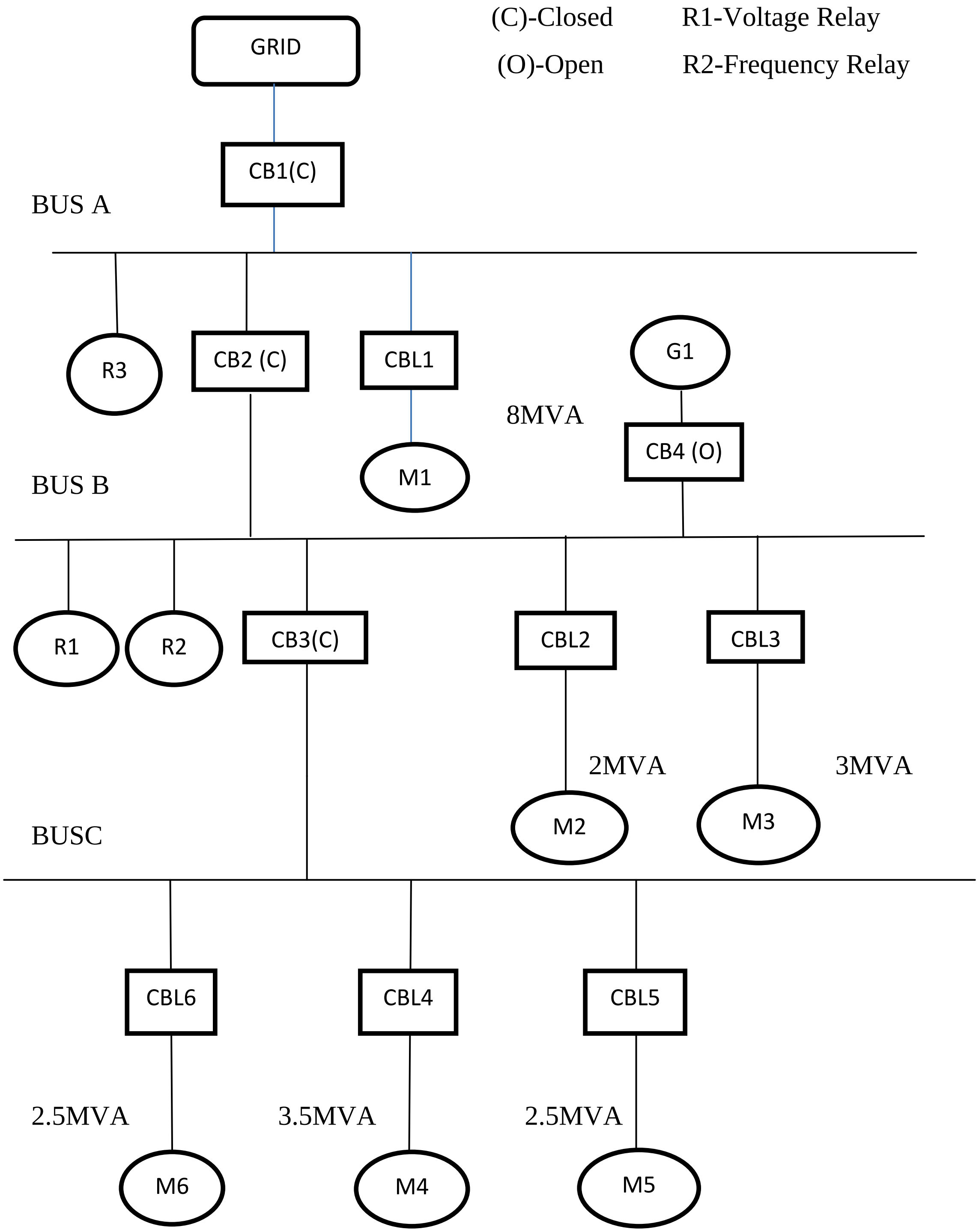
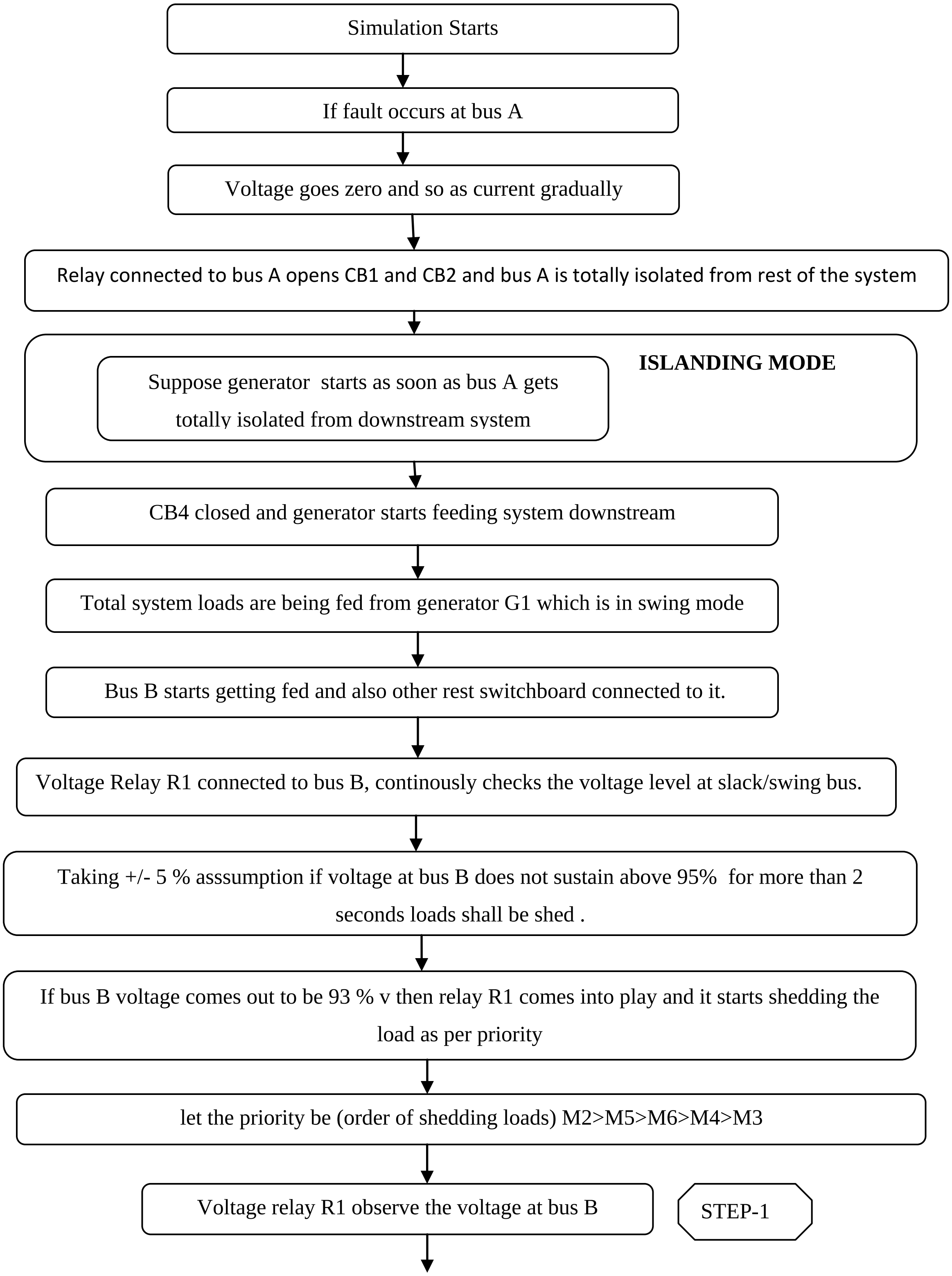


Figure 4.1 showing Islanding Detection and Load Shedding

FLOWCHART



Simulation Starts

If fault occurs at bus A

Voltage goes zero and so as current gradually

Relay connected to bus A opens CB1 and CB2 and bus A is totally isolated from rest of the system

Suppose generator starts as soon as bus A gets totally isolated from downstream system

CB4 closed and generator starts feeding system downstream

Total system loads are being fed from generator G1 which is in swing mode

Bus B starts getting fed and also other rest switchboard connected to it.

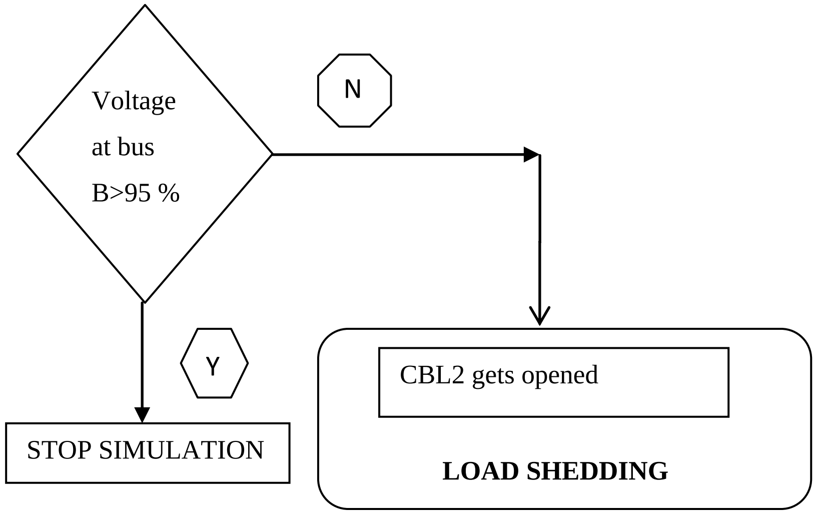
Voltage Relay R1 connected to bus B, continously checks the voltage level at slack/swing bus.

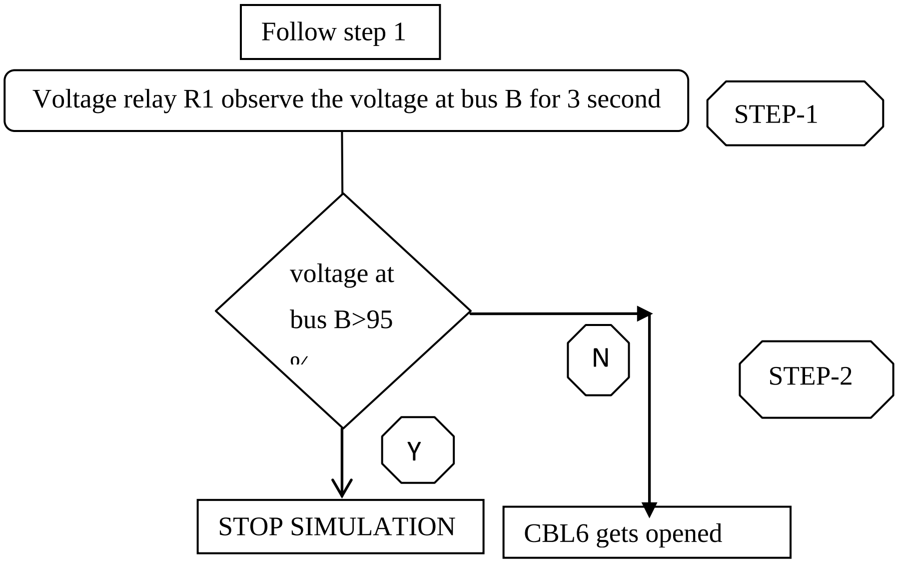
Taking +/- 5 % asssumption if voltage at bus B does not sustain above 95% for more than 2 seconds loads shall be shed .

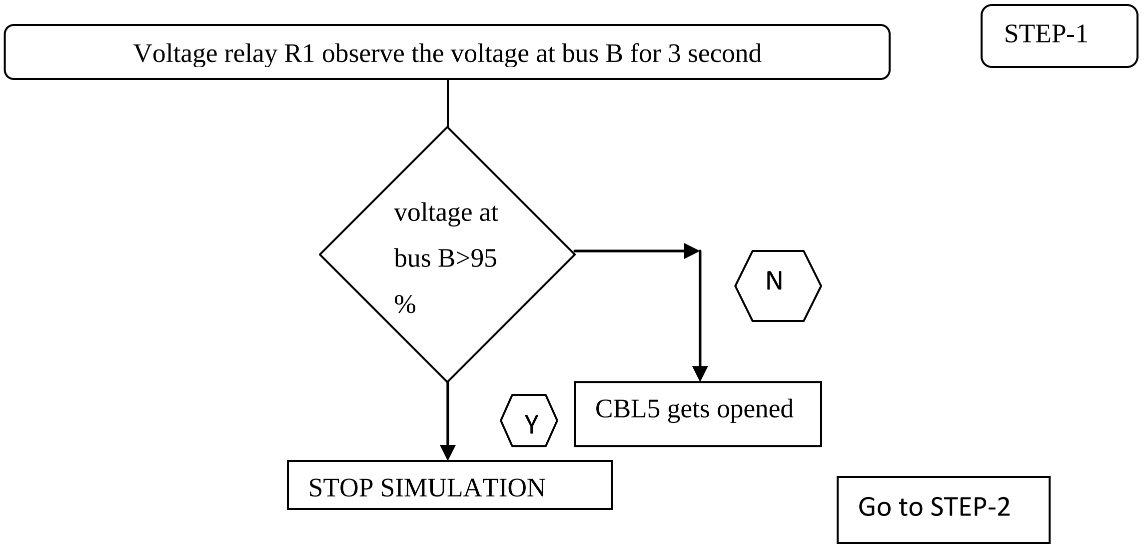
If bus B voltage comes out to be 93 % v then relay R1 comes into play and it starts shedding the load as per priority

let the priority be (order of shedding loads) M2>M5>M6>M4>M3

Voltage relay R1 observe the voltage at bus B


Voltage at bus B>95 %
N
Y
STOP SIMULATION
CBL2 gets opened
LOAD SHEDDING


Follow step 1
Voltage relay R1 observe the voltage at bus B for 3 second
STEP-1
voltage at bus B>95
N
STEP-2
Y
STOP SIMULATION
CBL6 gets opened


Voltage relay R1 observe the voltage at bus B for 3 second
STEP-1
voltage at bus B>95 %
N
Y
CBL5 gets opened
STOP SIMULATION
Go to STEP-2

CHAPTER 5

ISLANDING DETECTION AND PROTECTION

A simulation model is designed in DIgSILENT software. DigSILENT has set standards and trends in power system modeling, analysis and simulation. It is the most economical solution for distributed power generation modeling.

5.1 DIgSILENT Introduction

DIgSILENT is a computer aided engineering tool for the analysis of transmission, distribution, and industrial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimisation. The name DIgSILENT stands for "DIgital SImuLation and Electrical NeTwork calculation program". DIgSILENT Version 7 was the world's first power system analysis software with an integrated graphical single-line diagram interface. That interactive single-line diagram included drawing functions, editing capabilities and all relevant static and dynamic calculation features. The PowerFactory package was designed and developed by qualified engineers and programmers with many years of experience in both electrical power system analysis and programming fields. The accuracy and validity of the results obtained with this package has been confirmed in a large number of implementations, by organisations involved in planning and operation of power systems.

In order to meet today's power system analysis requirements, the DIgSILENT PowerFactory power system calculation package was designed as an integrated engineering tool which provides a complete 'walk-around' technique through all available functions, rather than a collection of different software modules. The following key-features are provided by the program:

- PowerFactory core functions: definition, modification and organisation of cases; core numerical routines; output and documentation functions
- Integrated interactive single line graphic and data case handling

- Power system element and base case database
- Integrated calculation functions (e.g. line and machine parameter calculation based on geometrical or nameplate information)
- Power system network configuration with interactive or on-line access to the SCADA system
- Generic interface for computer-based mapping systems

By using just a single database, containing all the required data for all equipment within a power system (e.g. line data, generator data, protection data, harmonic data, controller data), PowerFactory can easily execute any or all available functions, all within the same program environment. Some of these functions are load-flow, short-circuit calculation, harmonic analysis, protection coordination, stability calculation and modal analysis.

5.2 System

The model is set having two distributed generators SG1 and SG2 of capacities 10 MW and 10 MW respectively. The model is well suited for observing variation in parameters over short periods of time.

5.3 External Grid

A grid is an interconnected network for delivering electricity from suppliers to consumers. The voltage is 120 KV.

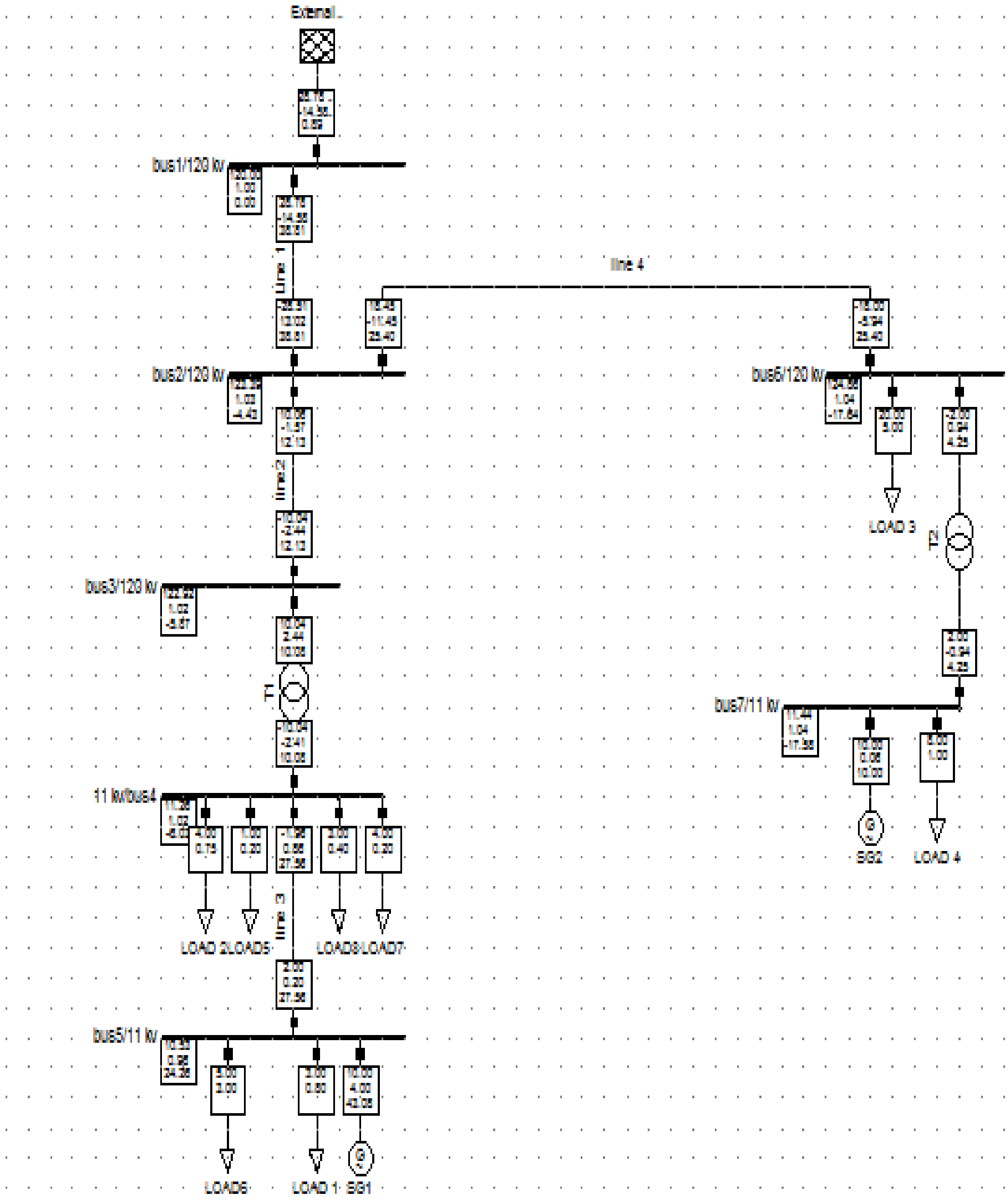


Fig.5.1 Model for Islanding Detection

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5.4 Transformer

The transformer data is presented in table 5.1

Transformer	Rated Power	Rated Frequency	HV side	LV side
T1	100MVA	50 Hz	120 KV	11 KV
T2	50 MVA	50 Hz	120 KV	0.415KV

5.5 Lines

There are 4 transmission lines used in the model.

Lines	Rated Voltage(KV)	Rated Current(KA)	Frequency (Hz)	Resistance (ohm/km)	Reactance (ohm/km)	Length (km)
Line 1	120	0.4	50	4.4965	38.81	1
Line 2	120	0.4	50	0.01	0.02	1
Line 3	11	0.4	50	4.49	38.08	1
Line 4	120	0.4	50	4.49	38.08	15

5.5 Loads

The loads are represented by delta connected parallel resistances and inductances. Active and Reactive power shall decrease first and then rise and become constant to a level. If that happens that means generator is able to cater the required supply of system but if KW and KVAR keeps on decreasing that means generator power is not enough.

5.6 Description of the model

The model is having two generators with four transmission lines and islanding is shown in various cases and then various cases are compared. All the transmission lines are disconnected one by one and then various cases are compared. Parameters like voltage, current, active power, reactive power and reactance are compared. First, generator 1 is shown in islanded mode and then generator 2 in being islanded. At last both the generators are islanded and also various curves due to load switching and fault are drawn. These are then compared and islanding is being detected.

CHAPTER 6

RESULTS AND DISCUSSION

Case1: When Line1 is disconnected. Generator SG1 will be in islanded mode & Generator SG2 will be in islanded mode. There will be transients in the system. To remove the transients, we will switch of Transformer T1 and to improve the voltage, we will switch of some load.

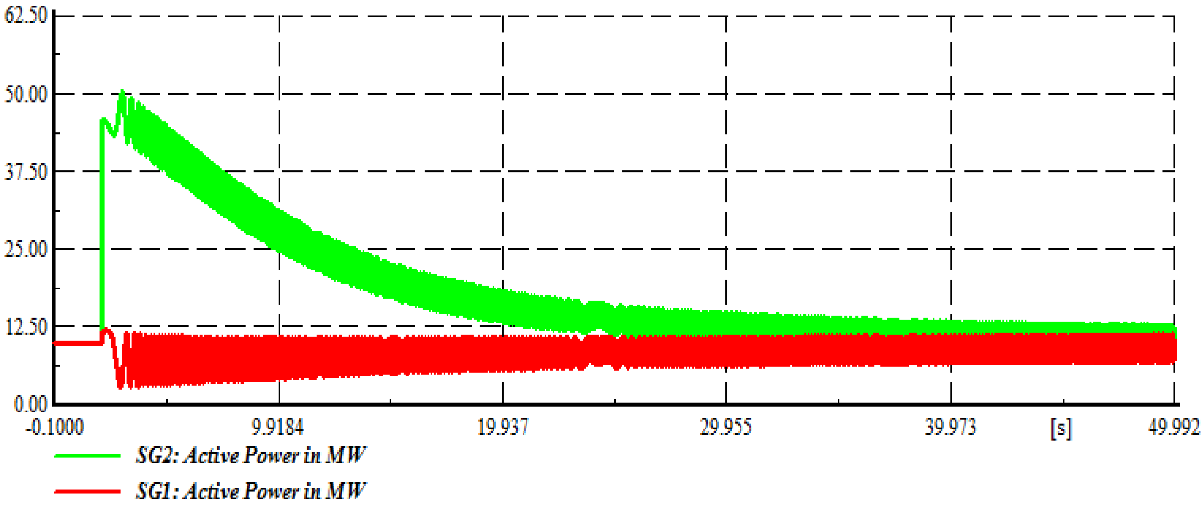

Fig. 6.1 Active Power curves of SG1 and SG2

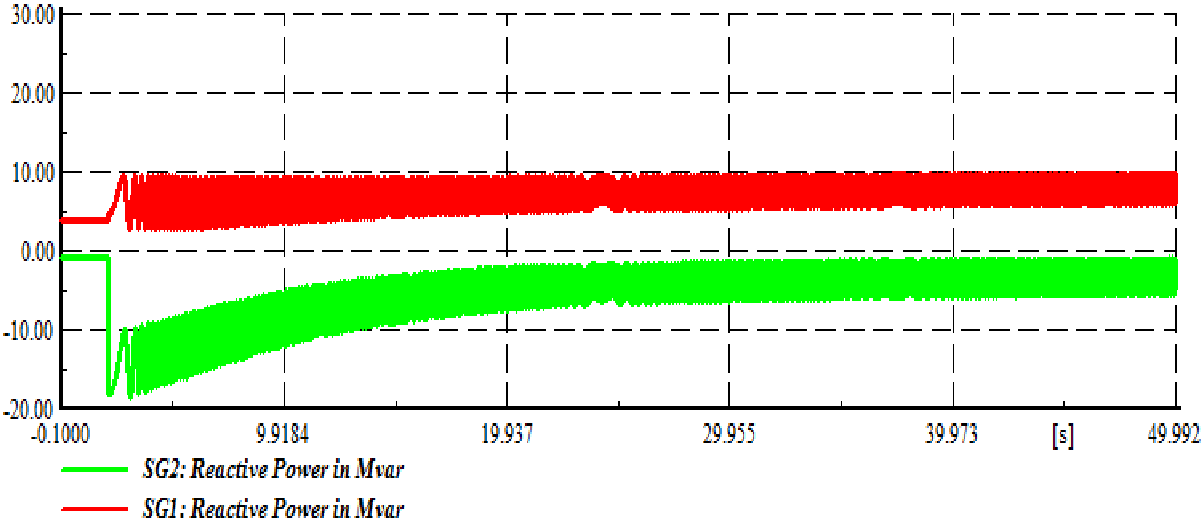

Fig.6.2 Reactive Power curves of SG1 and SG2

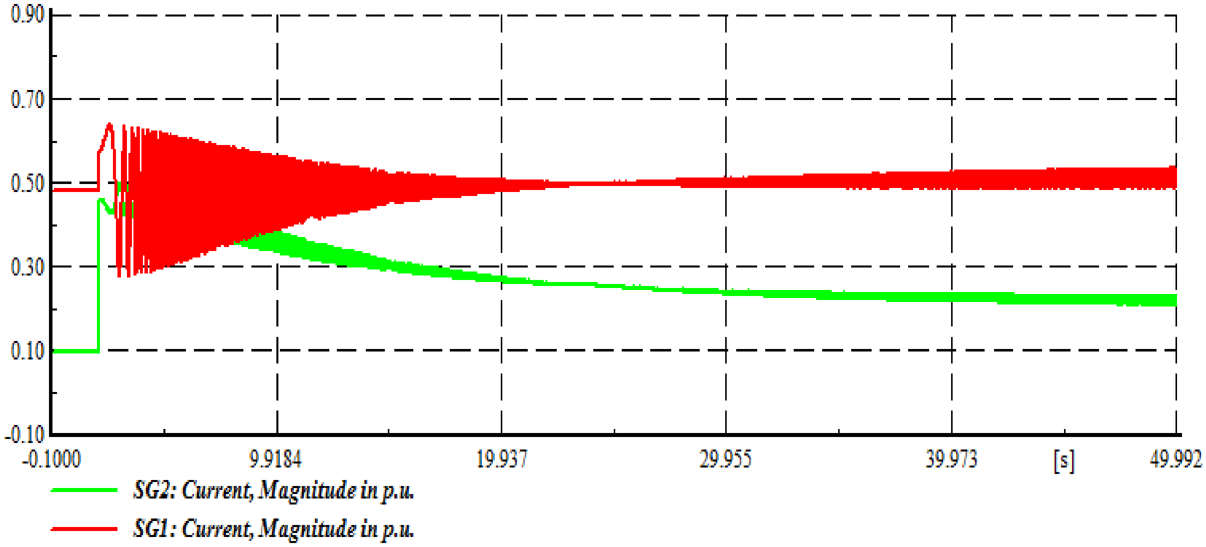

Fig. 6.3 Current waveforms of SG1 and SG2 (in p.u.)

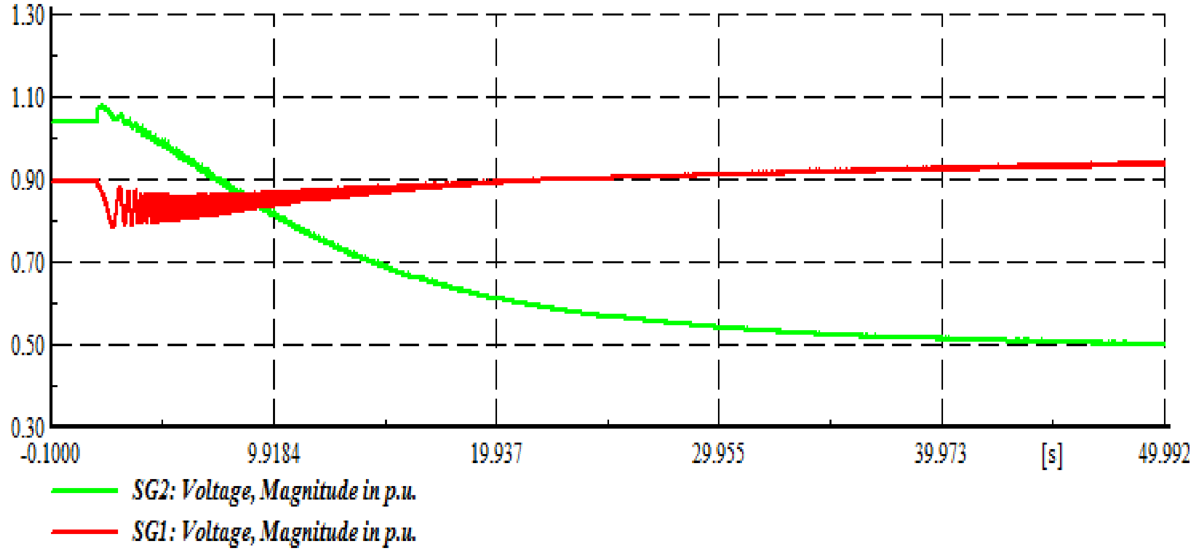

Fig. 6.4 Voltage waveforms of SG1 and SG2 (in p.u.)

Remedies: Transformer T1 is disconnected along with Line 1 switching. Generator SG1 will be in the islanding mode and Generator SG2 will be in the islanded mode. As we can see from the waveform, transients have been removed. After switching Load 3 & Load 6, voltage can be improved.

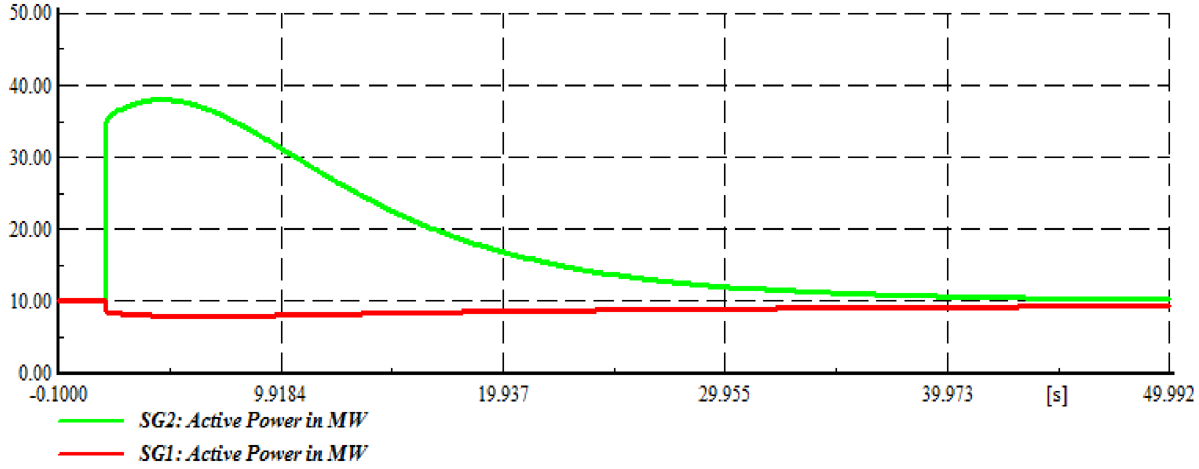

Fig. 6.5 Active Power curves of SG1 and SG

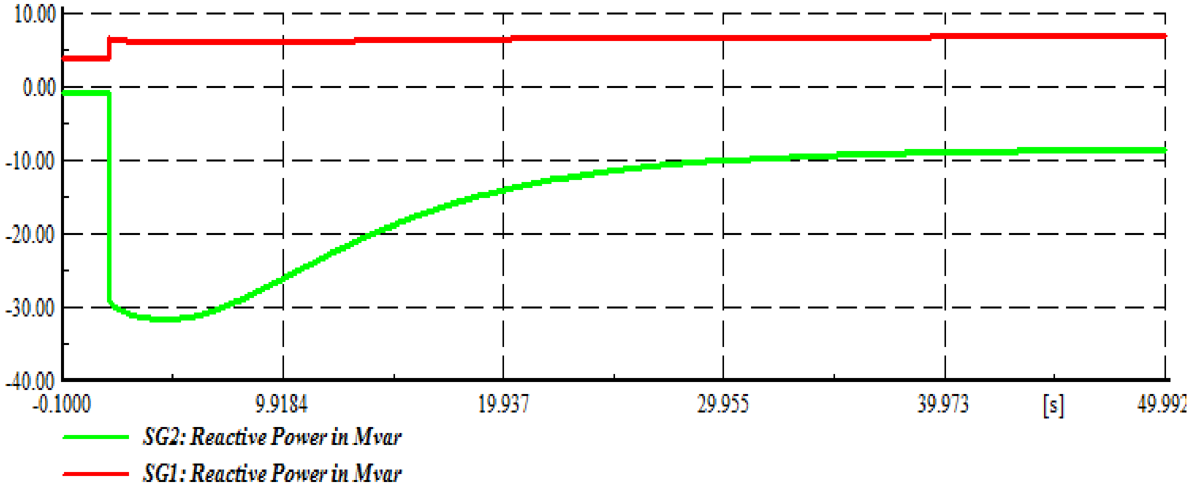

Fig.6.6 Reactive Power curves of SG1 and SG2

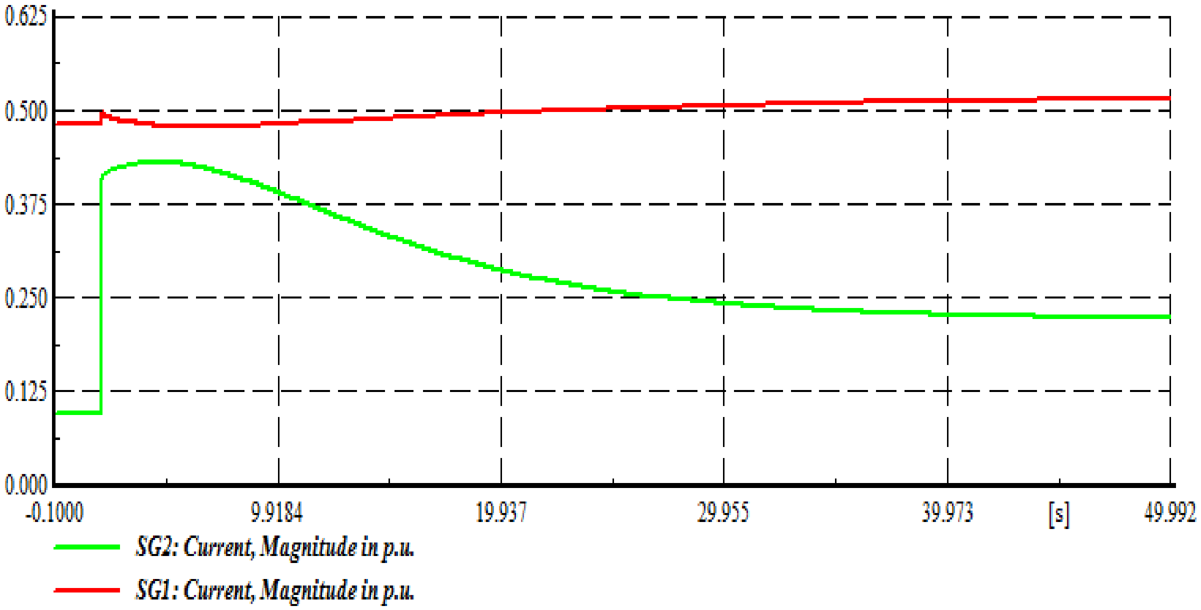

Fig. 6.7 Current waveforms of SG1 and SG2 (in p.u.)

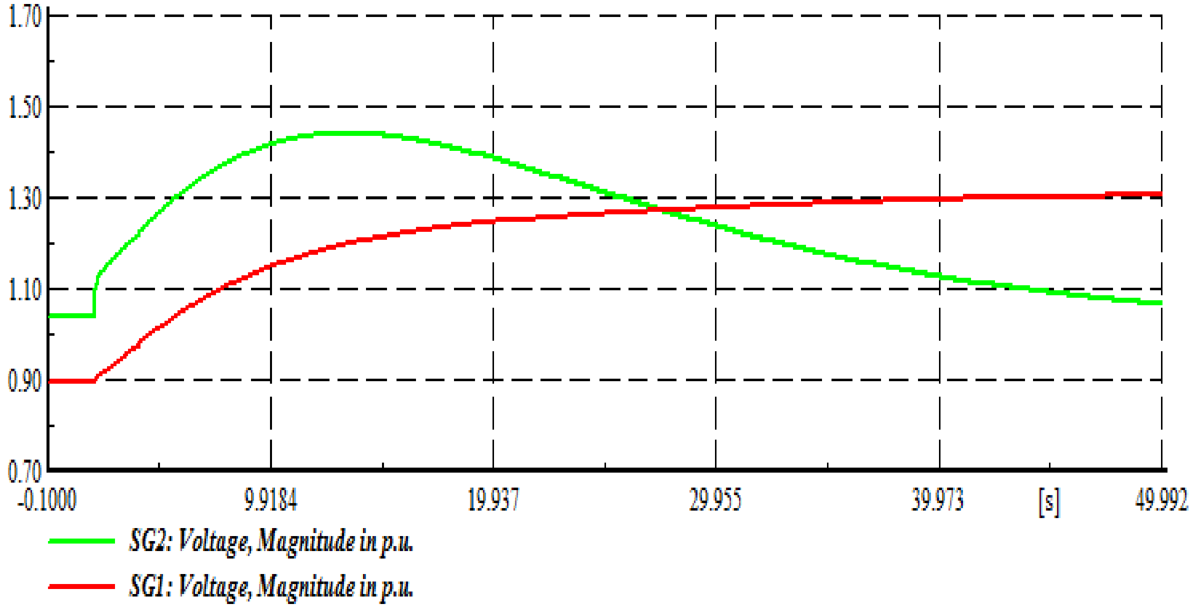

Fig. 6.8 Voltage waveforms of SG1 and SG2 (in p.u.)

Case2: When Line2 is disconnected. Generator SG1 will be in the islanding condition and Generator SG2 will be in non-islanding condition. Generator SG1 has to fetch the Load 1, Load 2, Load 5, Load 6, Load 7, Load 8. Generator SG1 is of 10MW but it will have to fetch the Bus 4 and Bus 5 loads which is of total 20MW. Generator SG1 will be overloaded. To overcome this, load shedding will be provided according to some critical and non-critical loads.

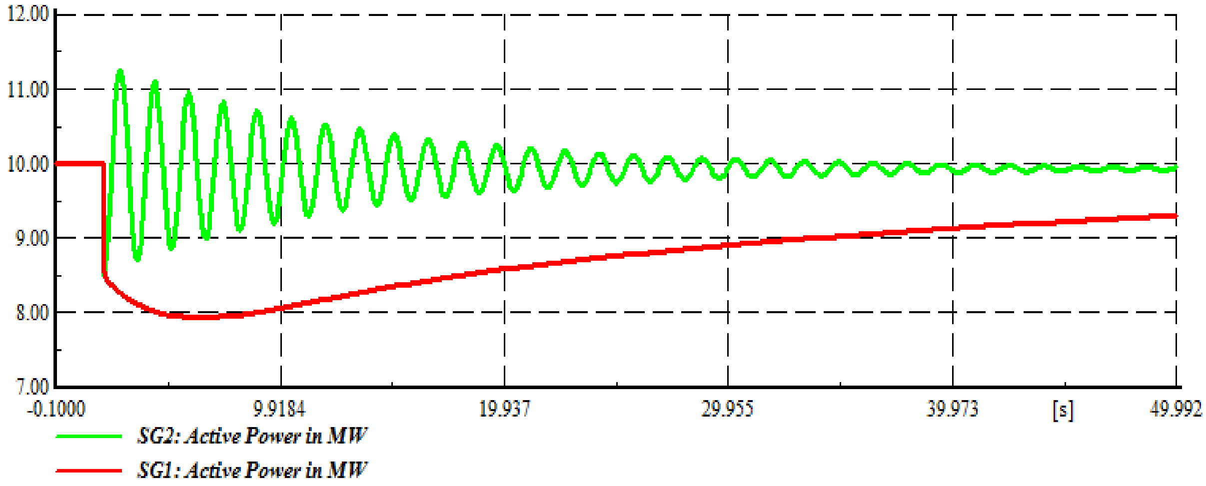

Fig. 6.9 Active Power curves of SG1 and SG

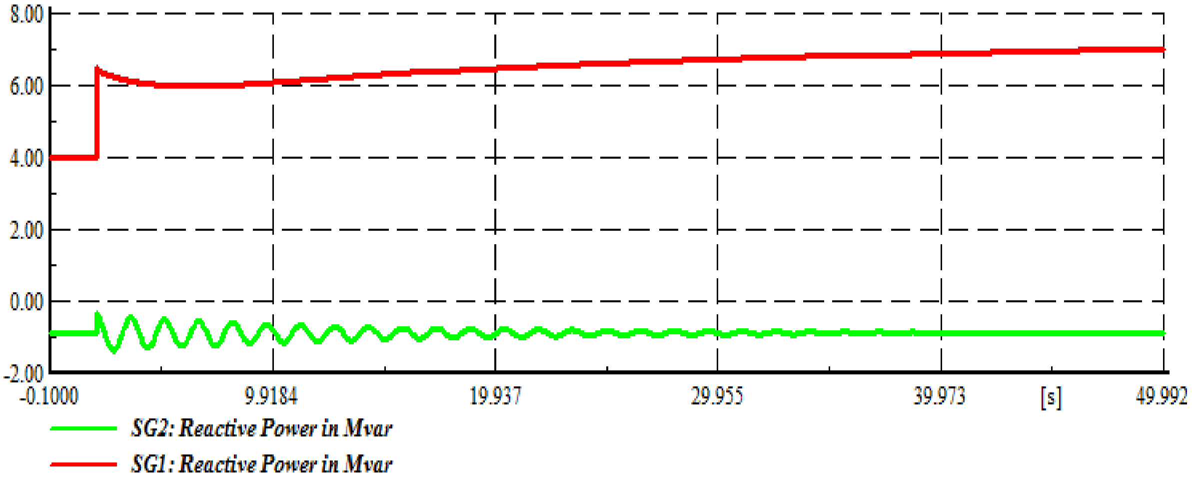

Fig.6.10 Reactive Power curves of SG1 and SG2

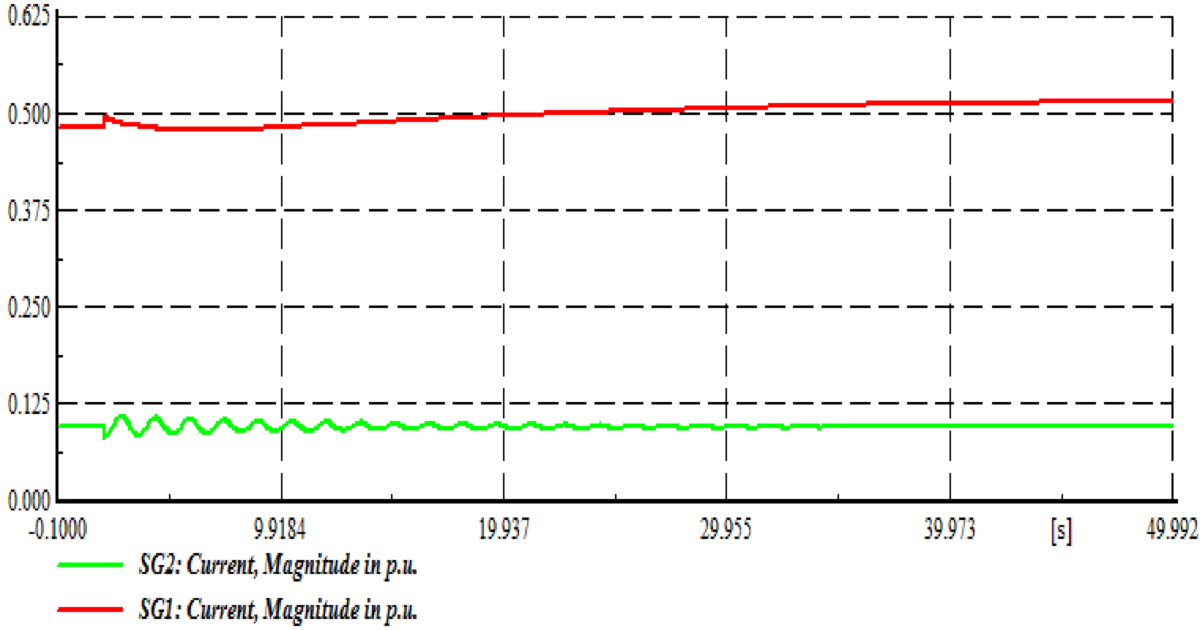

Fig. 6.11 Current waveforms of SG1 and SG2 (in p.u.)

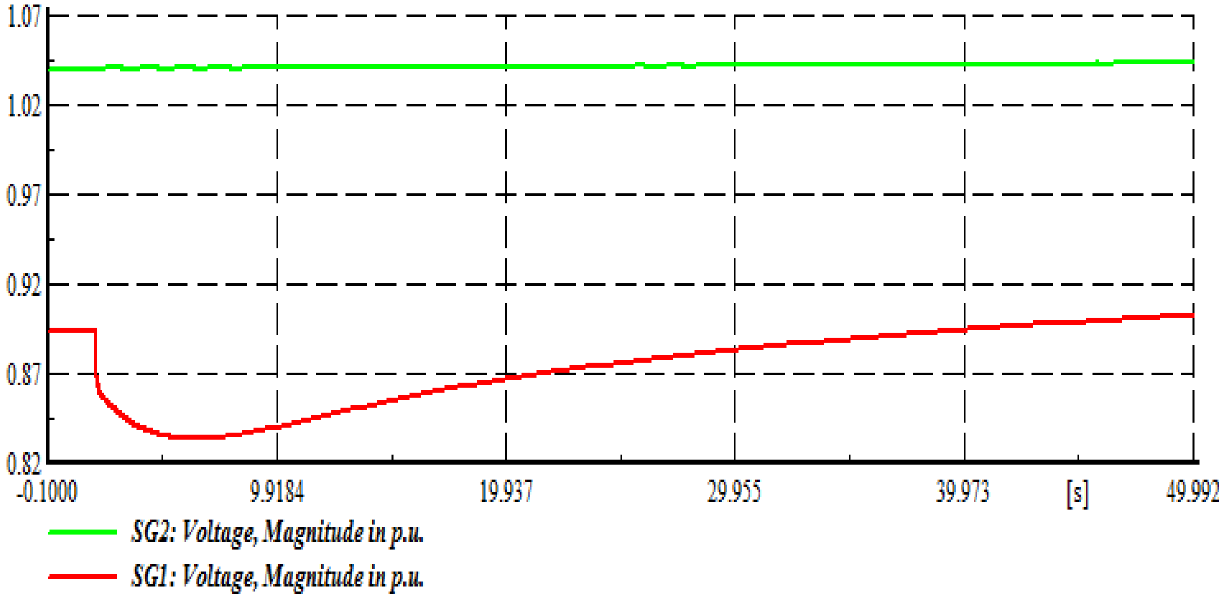

Fig. 6.12 Voltage waveforms of SG1 and SG2 (in p.u.)

Case3: When Line 3 is disconnected. Generator SG1 will be in islanded mode & Generator SG2 will be in non-islanded mode. Generator SG1 is of 10MW but it will have to fetch the Bus 4 and Bus 5 loads which is of total 20MW. Generator SG1 will be overloaded. To overcome this, load shedding will be provided according to some critical and non-critical loads.

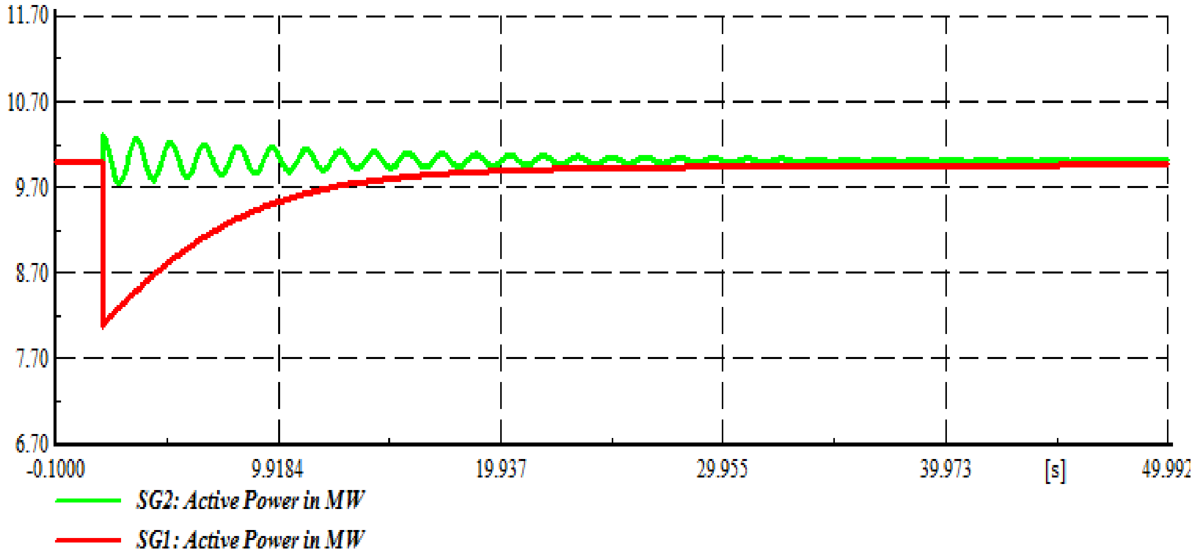

Fig. 6.13 Active Power curves of SG1 and SG

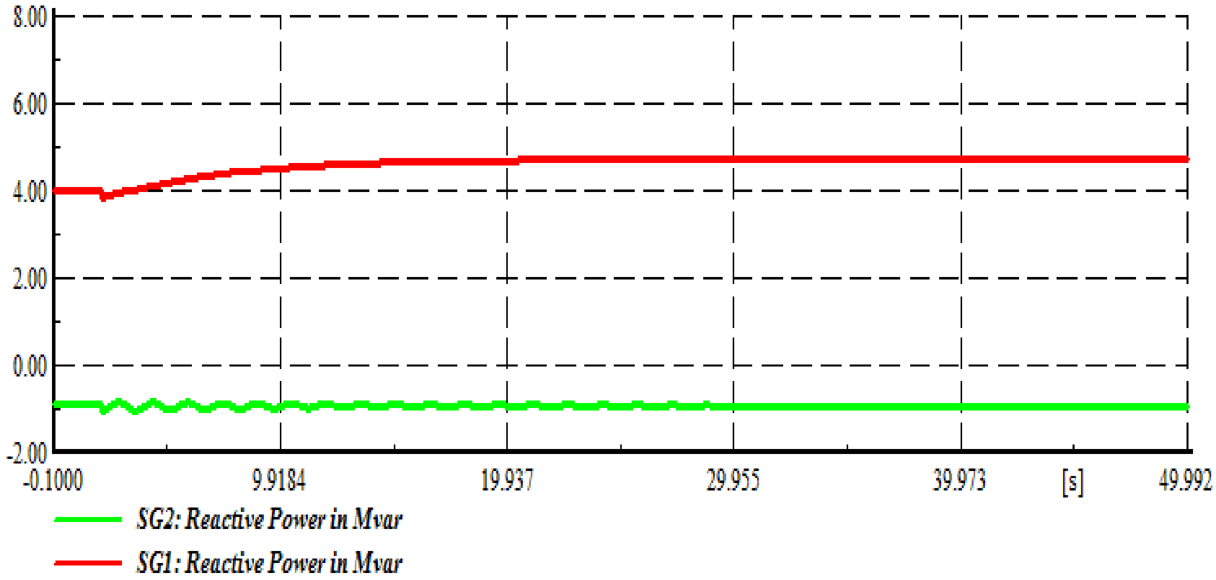

Fig.6.14 Reactive Power curves of SG1 and SG2

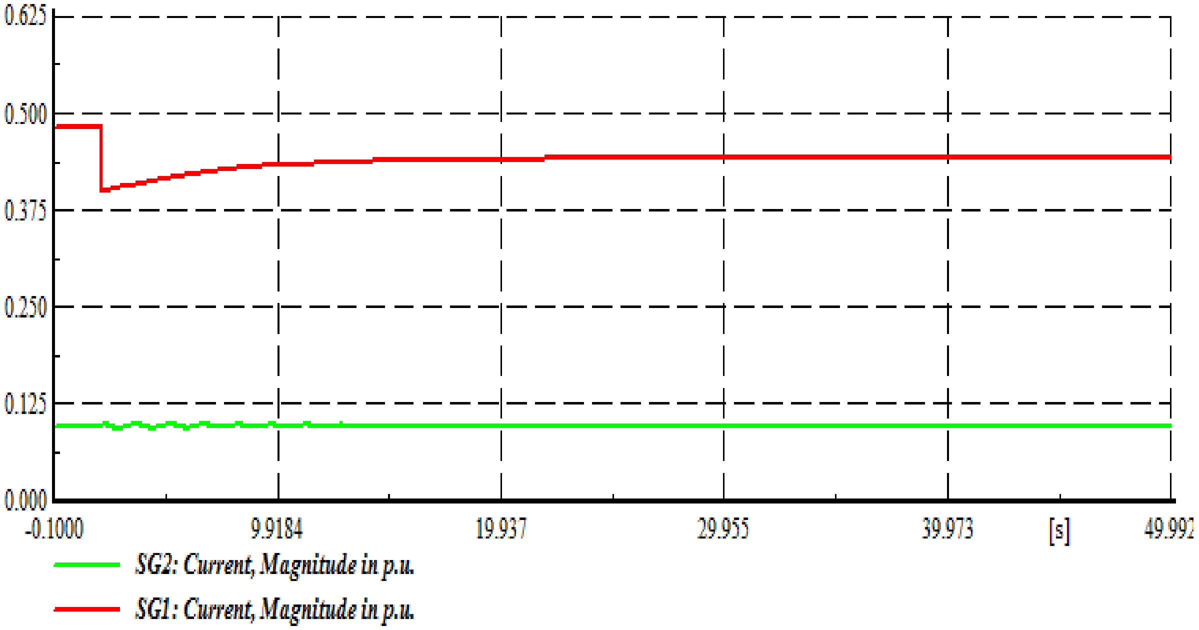

Fig. 6.15 Current waveforms of SG1 and SG2 (in p.u.)

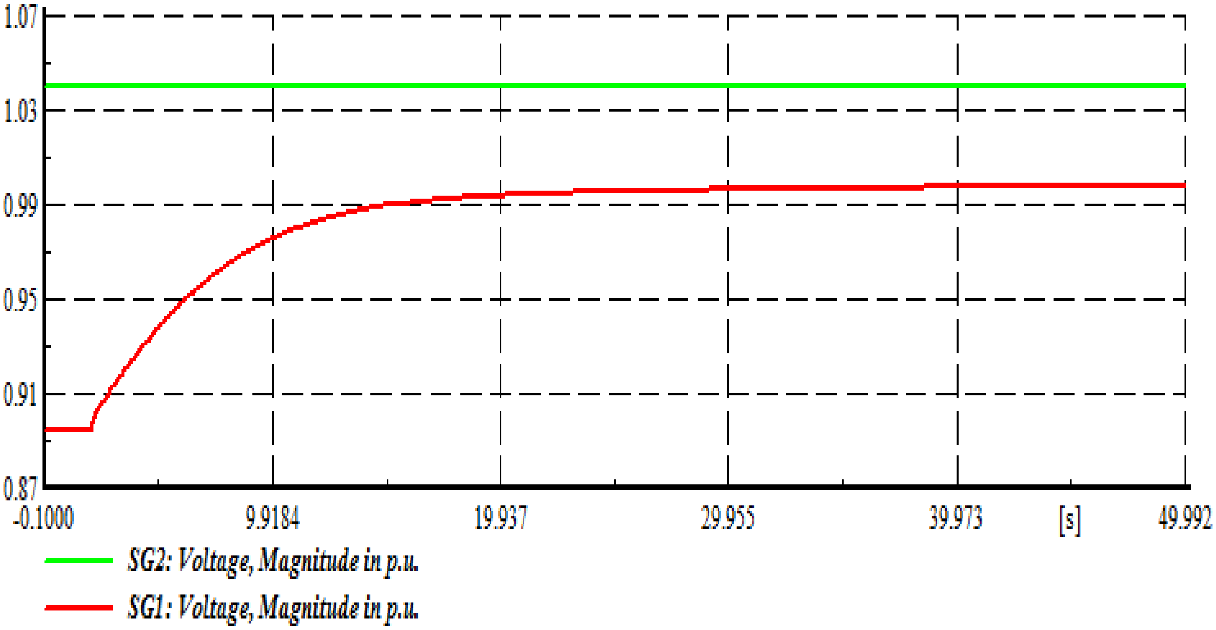

Fig. 6.16 Voltage waveforms of SG1 and SG2 (in p.u.)

Case4: When Line 4 is disconnected, Generator SG1 will be in non-islanded mode & Generator SG2 will be in islanded mode. Generator SG2 is of 10MW but it will have to fetch the Bus 6 and Bus 7 loads which is of total 20MW. Generator SG2 will be overloaded. To overcome this, load shedding will be provided according to some critical and non-critical loads. To improve the voltage level, disconnect Load 3 along with Line 4 switching.

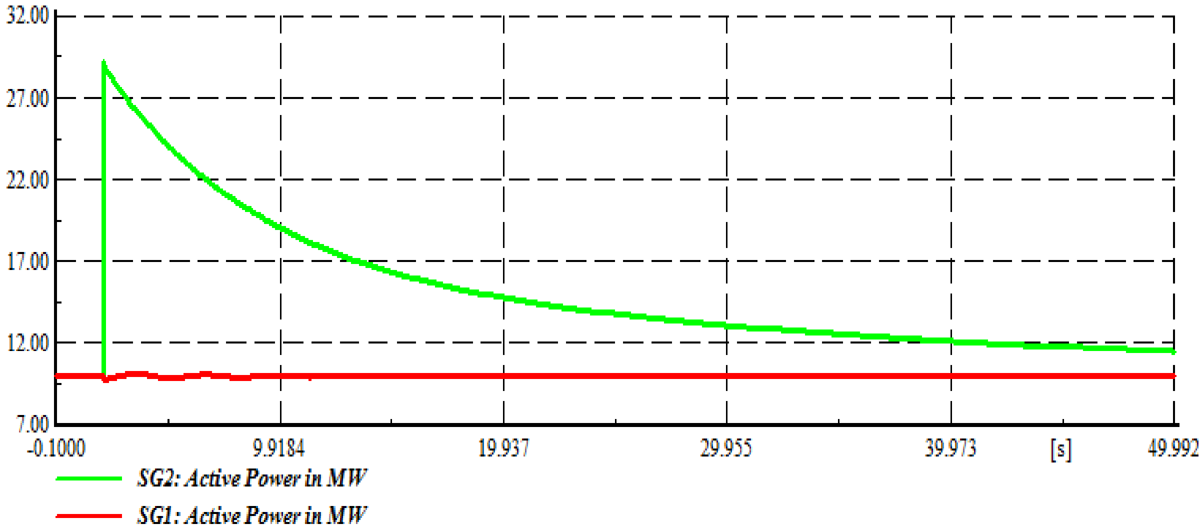

Fig. 6.17 Active Power curves of SG1 and SG

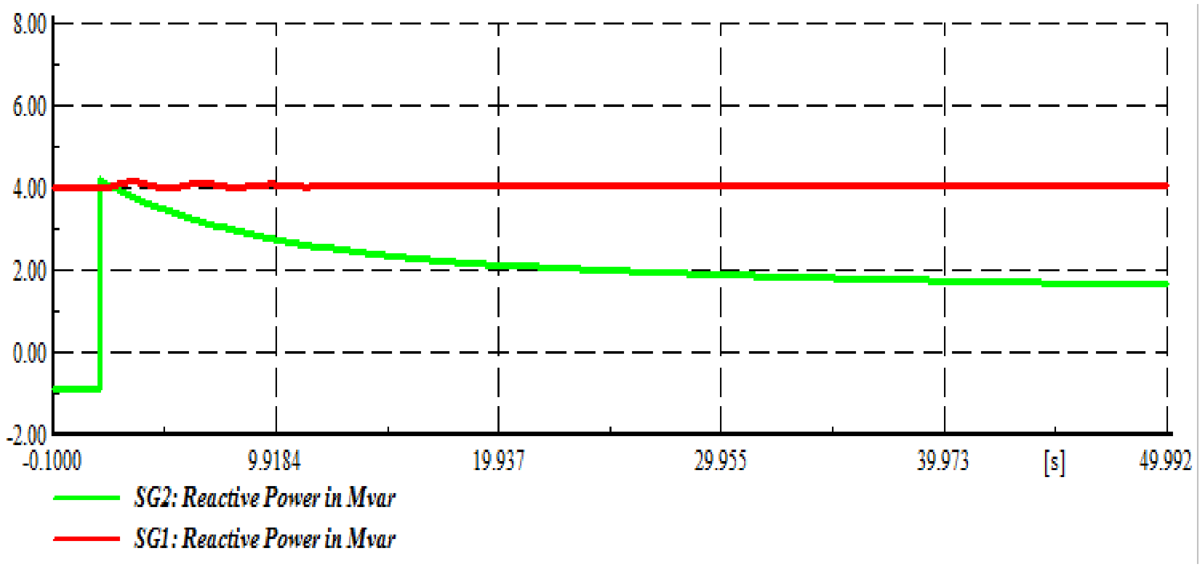

Fig.6.18 Reactive Power curves of SG1 and SG2

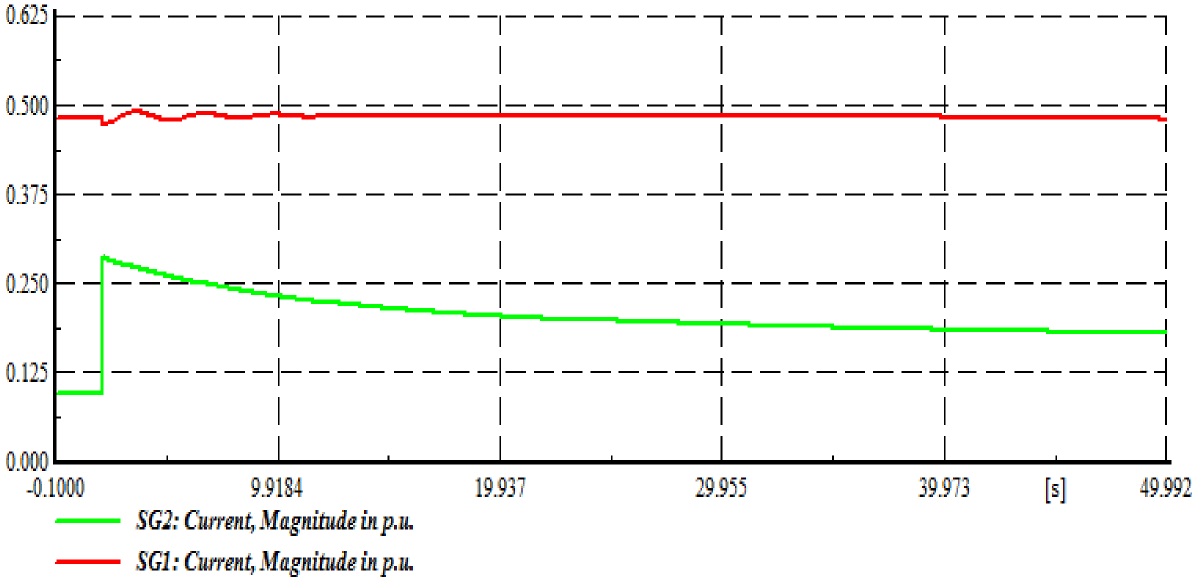

Fig. 6.19 Current waveforms of SG1 and SG2 (in p.u.)

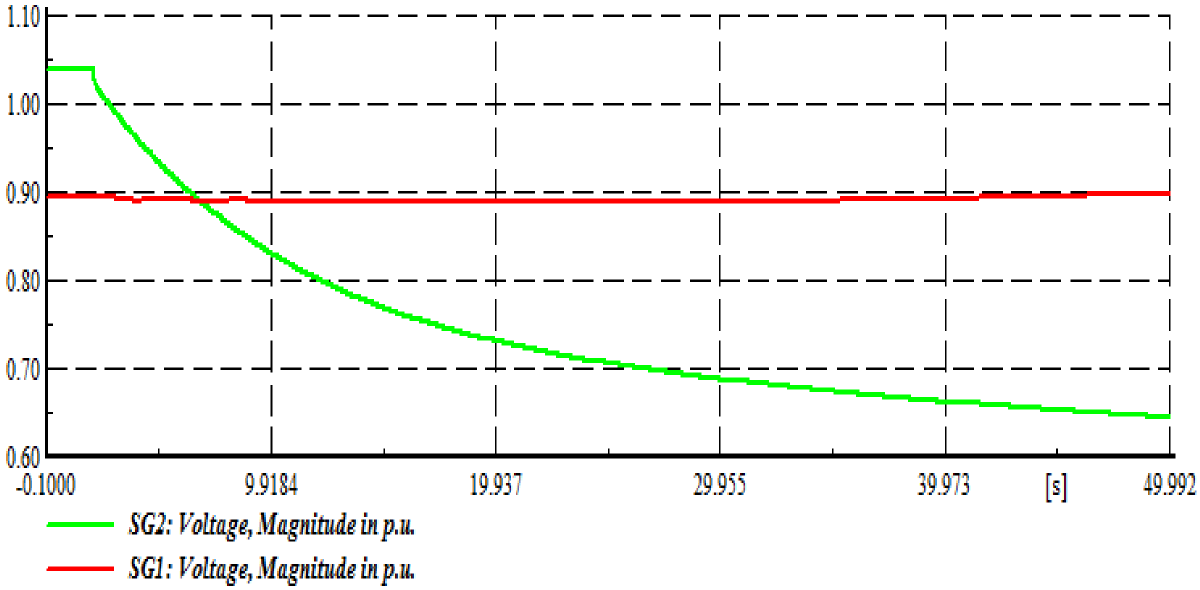

Fig. 6.20 Voltage waveforms of SG1 and SG2 (in p.u.)

Remedies: To improve the voltage, disconnect Load 3 along with Line 4.

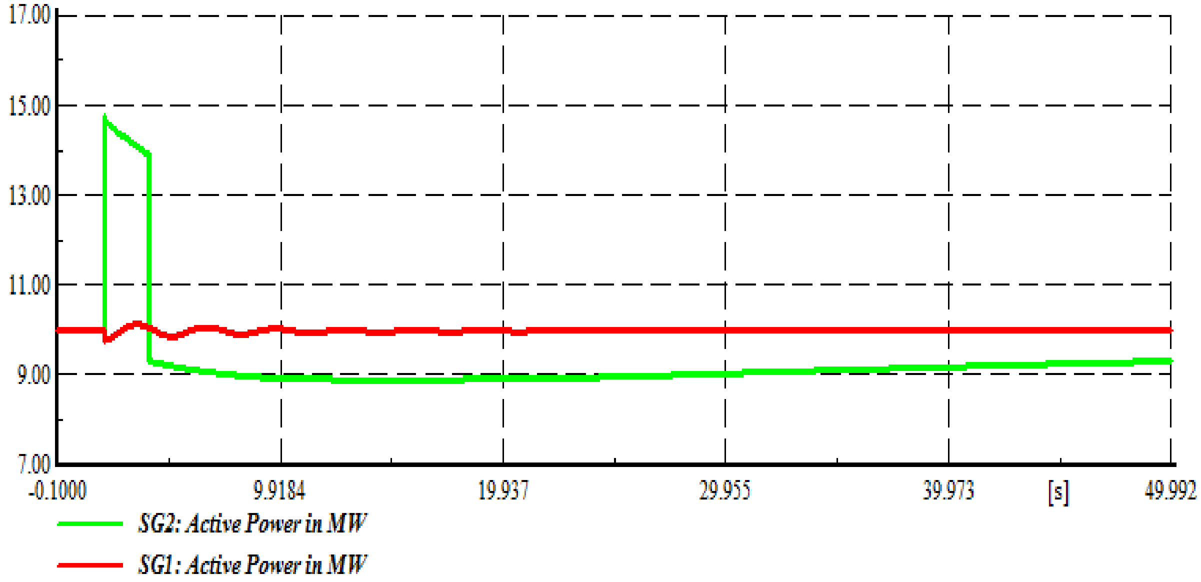

Fig. 6.21 Active Power curves of SG1 and SG

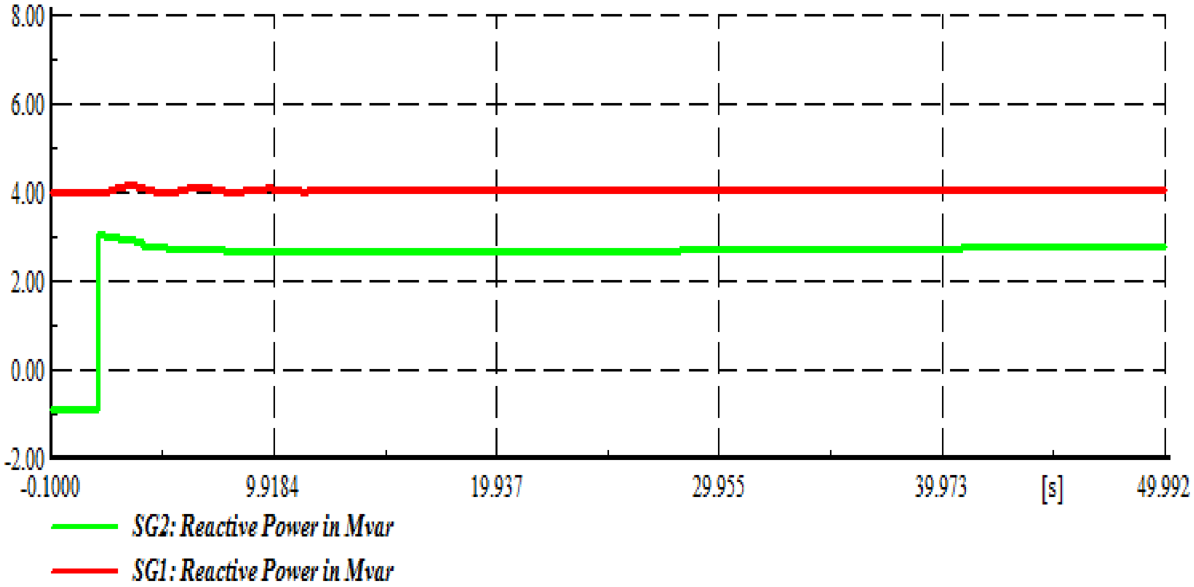

Fig.6.22 Reactive Power curves of SG1 and SG2

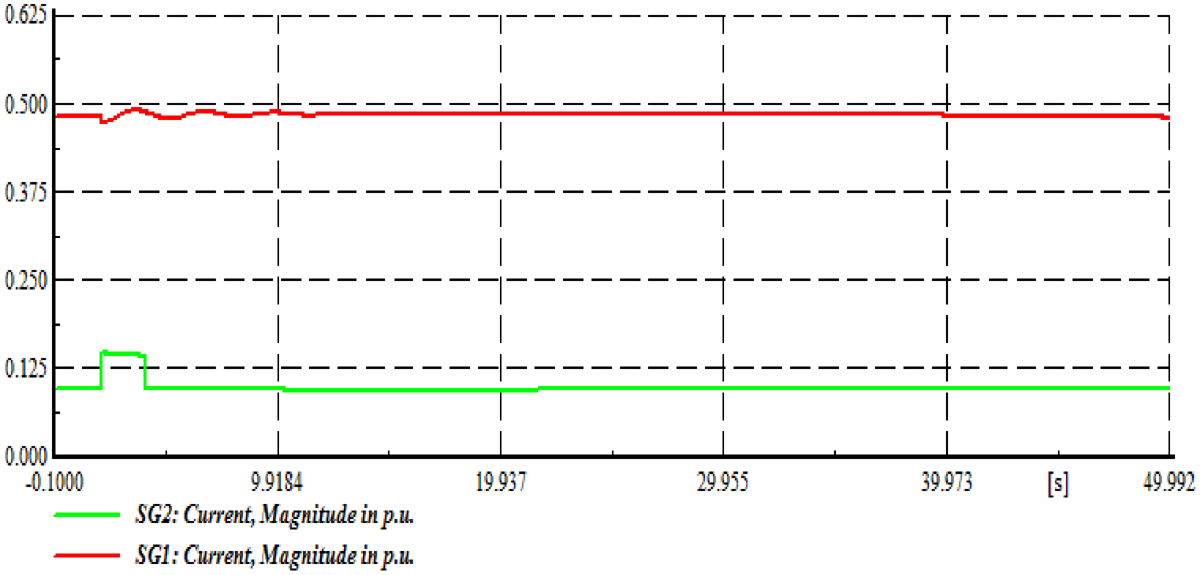

Fig. 6.23 Current waveforms of SG1 and SG2 (in p.u.)

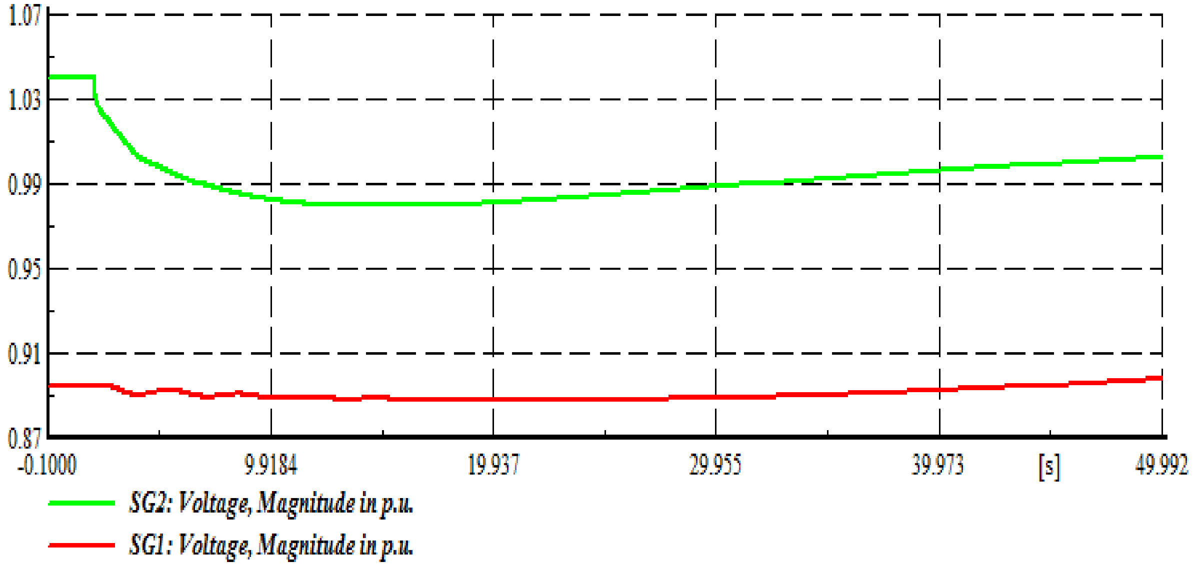

Fig. 6.24 Voltage waveforms of SG1 and SG2 (in p.u.)

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

Islanding is being detected as a result of change in parameters like voltage, current, active power and reactive power. These parameters change also in case of fault, load switching. These are also detected. Variations show how the islanding operation affects the DG.

7.2 Future Scope

More studies are required to meet the problems caused due to islanding and the Islanding can also be detected by taking other parameters like frequency and negative sequence impedance.

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