"Protection of Microgrid using Coordinated Directional Overcurrent Relays"

Major Project Report

Submitted in Partial Fulfillment of the Requirements for Degree of

Master of Technology

In

Electrical Engineering

(Electrical Power Systems)

By

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CERTIFICATE

This is to certify that the Major Project Report entitled **"Protection of Microgrid using Coordinated Directional Overcurrent Relays"** submitted by **Ms. Himani Sharma(14MEEE06)**, towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering)in the field of Electrical Power Systems of Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

As decentralization of generation is gaining popularity nowadays, microgrid finds its application in electrical power system. Microgrid can be termed as smaller version of large power grids. Microgrid is connected with distributed energy resources, along with storage devices and the loads, connected in parallel. Microgrid is capable of operating in grid connected mode or independent i.e. islanded mode. Its purpose is to supply reliable and quality energy in both modes, grid connected and islanded mode. Because of generators at all levels and two mode operation protection of microgrid becomes tricky. Relay coordination ensures that device closest to fault operates first. In the proposed system, PSCAD/EMTDC has been used to simulate a system consisting of microgrid connected to several distributed resources. A protection scheme has been designed which includes directional overcurrent relays. These relays are coordinated in terms of their operating time.

Contents

List of Figures

Chapter 1

Introduction

This report represents a brief study of the major project. Project includes preparing a model of microgrid which comprises of several DG sources, synchronized to grid, and a protection scheme to ensure continuous supply. This protection scheme utilizes the phenomenon of coordination of relays for operation in the desired fashion. Model has been prepared and tested in PSCAD/EMTDC and results are noted down. This particular report includes an introduction to the thesis, literature survey and simulation done till date, along with the output waveforms obtained and future scope of work that can be done in this field.

1.1 Motivation

Decentralization of power, microgrids, renewable power, distributed generators, distributed resources, all these terms make a lot of sense nowadays. Reason being increased demand of reliable power supply and new inventions which makes it easy to tap power with higher efficiency from the microresources. As microgrid comes into picture, so does the protection scheme of distribution system and microgrid. Introduction of microgrid to main grid demands change in existing protection system. Relay coordination ensures that relays operate within the time limit, hence clearing the faults before they cause any major harm to the system. This project tries to model such a protection scheme.

1.2 Definition

Department of energy, USA gave the definition of microgrid as:
"A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid connected or island mode."
Because of some confusion with the definition of microgrid in 2005, IEEE 1547.4 developed the term distributed Resource Island System.And defined it as:
"The term DR island system, sometimes referred to as microgrid is used for electric power system that have DR and load; have the ability to disconnect from and parallel with the area EPS; include the local EPS and may include portions of the area EPS and; are intentionally planned."

1.3 Microgrid

Introduction to decentralization of power system has led to development of concept of microgrid. Microgrid can be defined as a cluster of microsources or distributed resources and loads working as a single system that is responsible for providing both power and heat to the local area[1]. These microresources can be either renewable sources, microturbine or diesel engine. Along with these distributed sources storage devices play a very vital role in maintaining continuous supply.
Three important part of the microgrid for the required characteristics, according to [1] are:

- Local microsource controller.
- System optimizer.
- Distributed protection.

Microgrid is connected to main grid to give the surplus power to the grid. So, a microgrid can work in two modes of operation viz. Grid connected mode and islanded mode of operation. Islanded mode implies that grid is disconnected from

main grid and working in a self-sufficient mode. This mode is used especially in a faulty condition. Disconnecting the grid ensures safety of generators of microresources in microgrid, in case a fault occurred at main grid side and vice versa. For safe operation of the power system a protection scheme is must. When microgrid is connected to the main grid existing protection scheme need to be modified.
This is due to one of the following reasons as given in [4]:

- Modification in fault current level.
- Device discrimination.
- Reduction in reach of impedance relays.
- Reverse power flow.
- Sympathetic tripping.
- Islanding .
- Single phase connection.
- Selectivity.

There are certain standards and protocols defined for microgrid as discussed in [2] at DOE microgrid planning meeting, USA. IEEE 1547 series of standards is given as the standard for interconnecting distributed resources with electric power systems. This includes 1547-2003, 1547.1-2005, 1547.2-2008, 1547.3-2007 etc. standards, these all give guidelines and procedures for relevant performance, operation, testing, safety and maintenance of interconnection.

1.4 Protection

One of the major challenges is to design the protection scheme for microgrid to ensure its proper functioning. And this design has to be in accordance with the relevant national distribution codes. In conventional distribution system, the power flow is assumed to be unidirectional and hence the protection systems are designed accordingly.

So, the microgrid needs to be disconnected in case of any fault. But, microgrid need to be designed to operate in both modes. When it is connected to main grid, the grid sources provide high fault current that can be used to detect faults. However, when considering fault from microgrid side the overcurrent protection is not so promising due to low short circuit current. As given in [10], an ideal protection system for a microgrid should possess following features:

- Must respond to both distribution system and microgrid fault.
- For a fault on main grid, isolate the microgrid as quickly as possible.
- For a fault within microgrid, isolate the smallest possible section of the radial feeder carrying the fault.
- Effective operation of customers' protection.

1.5 Literature Survey

[1] **"R. H. Lasseter in his report titled Microgrid coordinated by CERTS (Consortium for Electric Reliability Technology Solution)**provided an overview of the microgrid paradigm. He discussed the basic architecture, control, protection and energy management of microgrid. Microsource controller make use of local information to keep control on microsources during all events. For system optimisation energy manager is used.[4]
[2] **"Ben Kroposki and Charlie Vartanian at DOE microgrid planning meeting "**discussed the current IEEE 1547 series standards. These include standards for interconnection of DR with EPS, Conformance test procedures, guide for monitoring, information exchange and control of DR. They also discussed the current projects.[3]
[3] **"Y. Zoka et al. in paper titled, an interaction problem of distributed generators installed in a microgrid "**,talked about the interaction problems induced by DR. In this study, the authors developed a microgrid model comprising of DRs, viz. microturbine, fuel cell, diesel engines. Then a problem of interaction is demonstrated using numerical simulation.[10]

[4] **"Jayeshkumar G. Priolkar and Vinayak N. Shet in a review on protection issues in microgrid discussed microgrid "**,its importance and its UK perspective. They also discussed the protection issues that a microgrid faces in both the modes of operation. They described the key issues in protection, viz. Modification in fault current level, Device discrimination, Reduction in reach of impedance relays, Reverse power flow, Sympathetic tripping, Islanding, Single phase connection,Selectivity.[5]

[5] **"Eric Sortomme et al. in paper, Microgrid protection using communication assisted digital relays "**,stated three important aspects that any protection scheme should consider, viz. bidirectional flow in feeders, looped feeders and reduced fault level in islanded operation. A communication assisted system is required for microgrid smooth switching from grid connected mode to islanded mode.[8]

[6] **"Changhee Cho et al. in paper, Active synchronizing control of a microgrid "**,proposed an automatic synchronizing method for a microgrid. This control scheme involves network based control of multiple DGs to adjust voltage and frequency. This paper also proposes an algorithm suitable for each generation source.[1]

[7] **"Standard IEC 61850, "**,this standard is for designing an substation automation. Its features can be stated as: Data Modelling Reporting schemes Fast transfer of events Setting groups Sampled data transfer Commands Data storage.

[8] **"R. John Millar, et al., in, Impact of MV connected microgrid on MV Distribution Planning "**,have discussed Greenfield and Brownfield distribution network planning, considering two cases, one with and another without penetration of microgrid. They places microgrid at different locations and observed the results.[7]

[9] **"R. Lasseter, et al. at CERTS, in paper, Integration of DER,The CERTS microgrid concept "**, gave an initiative to integration of distributed energy sources into main grid. They defined microgrid as a semiautonomous group or cluster of sources along with loads in order to suffice the customers need.

[10] **"XueguangWu, et al. in Protection Guidelines for a Microgrid "**, have discussed the reasons responsible for stability of microgrid. The list includes, the mode of operation, the position of fault, motor load present and the storage capacity. They designed a protection scheme for a random microgrid and tried to test it for

both modes of connections.[9]

[11] **"Alias Khamis, et al. in, Modelling and Simulation of Small Scale Microgrid System "**, gives basic modelling of microgrid in PSCAD. They have also mentioned the parameters they set for different DG sources. They used PV, Wind and storage batteries in microgrid. Major focus is on the parameters and effectiveness of inverter.[2]

[12]**"Faisal Mohamed, in his thesis for the degree of Licentiate of Science and Technology, titled, Microgrid modelling and simulation "**, explains every DG source in detail, he also discussed the modelling of each source and their characteristics.

[13] **"Wencong Su, in his thesis, Microgrid modelling, planning and Operation "**, did a detail analysis of different DGs. He used MATLAB/SIMULINK for modelling. He also performed some case studies to verify the accuracy of components.

1.6 Identification of Problem

This project required simulation of a microgrid, comprising of several microsources, a main grid, to which this microgrid can be connected and synchronised. After these two systems were being simulated, both were then connected and synchronized to ensure stable operation of system. On occurrence of any fault in any part of the system complete system should remain unaffected. If there is some fault in main grid, microgrid should isolate it from main grid and hence prevent itself from any sort of damage.Similarly, in case of any fault in microgrid, also, it should disconnect it from main grid to prevent flow of fault current in the main grid. For such operation a protective scheme is implemented, which works in order to prevent the system from any sort of damage.

1.7 Objective of Project

Project completion required simulation of a power system comprising of a main grid, a microgrid and a protection scheme. The software found suitable for this purpose is

PSCAD/EMTDC, as this has in built Photovoltaic Array and other converter circuits, that simplifies the circuit formation and hence leaves more time for synchronization and calculations. A PV system, a wind system and a battery system is first simulated in PSCAD/EMTDC and run to obtain the desired output, i.e. the current and voltage generated should be free from harmonics, as far as possible. Harmonics free system ensures a stable and quality operation of system. Once these systems were calibrated individually they were then connected together to a load in order to form a Microgrid. This Microgrid is then connected to main grid, that is a WSCC ninebus system, in this case. Both grids were then synchronized for proper functioning of whole system. After synchronization, protective scheme was designed and implemented.

1.8 Scope of Project

- Understanding the concept of microgrid and its protection.
- Literature survey.
- Understanding the software, PSCAD/EMTDC thoroughly, in order to model the system.
- Modelling of Photovoltaic system, wind system and battery system.
- Modelling of WSCC Ninebus system.
- Connection of microresources to form a microgrid.
- Connection and synchronization of grid to microgrid.
- Generation of a protection scheme.
- Implementation of the protection scheme.

1.9 Organization of Thesis

This thesis is divided into four chapters.

Chapter 1 This chapter is an introduction to the thesis. This gives a basic idea of why this topic is selected and also gives basic understanding of the project. This includes reason for the selection of topic, basic definition of microgrid and Distributed Generation or Distributed Resources, literature survey, identification of problem, objective of problem and scope of project.

Chapter 2 This chapter discusses the simulation platform used in the modelling of system. Also, the simulation models prepared are shown in this chapter, which gives a detailed description of the system used in the project.Models include wind system, photovoltaic system and battery system, as part of microgrid. Also as main grid, a WSCC nine bus system is modeled as per the standards.

Chapter 3 This chapter discusses the importance of protection in power system and its types. It defines almost all the types of protective schemes for power system protection. It also gives details about the overcurrent protection and its types.At the end of this chapter the protection scheme designed and implemented is discussed. The protection scheme makes use of directional overcurrent feature of relays for protection. All these relays are coordinated in order to work together and ensure the continuity of supply.

Chapter 4 This chapter includes the results obtained after simulation of the individual systems and together. The results are graphical representation of the current, voltage and power as seen at the grid end.

Chapter 5 This is the concluding chapter, where an inference is drawn from all the results obtained and hence future scope and improvements required are discussed.

Chapter 2

Modelling of Microgrid

Microgrid modelling involves modelling of the DG sources to be used along with the storage. DG sources are not all AC sources (Photovoltaic) and hence inverter modelling would also be desired. Similarly for wind farm frequency need to be maintained in order to synchronize it to grid.The software used for modelling is PSCAD/EMTDC 4.2 student version.

2.1 Distributed Generation Sources

The IEEE defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system. Though DG range varies from country to country, because of the codes and standards, also varies according to different criteria of different Institutes. DG sources that constitutes the microgrid for the given project are PV and Wind.

2.1.1 Photovoltaic

The model of PV is shown in Figure 2.1.The system includes a PV module, storage capacitance, resistor, breaker, inductor, inverter and a voltage collapse limiter.[6] Input to PV module are solar irradiance and temperature. These inputs can be varied with the help of sliders provided, and accordingly output varies.

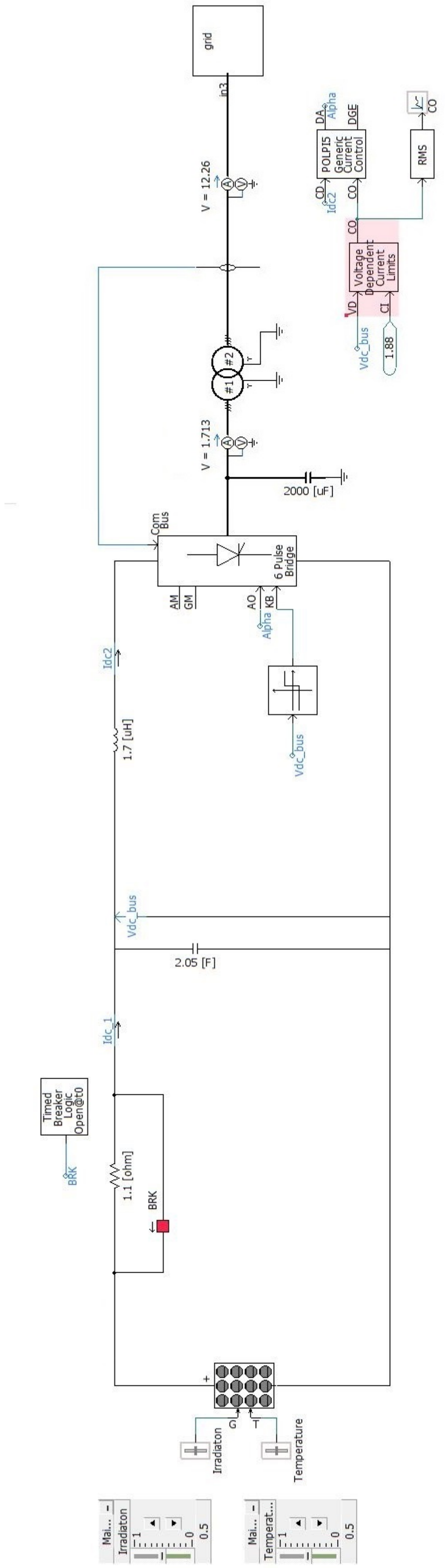

Figure 2.1: PV system in PSCAD

In PSCAD, the PV module has an option to change the number of solar cells, solar cell strings and arrays, in parallel and series both,which helps in changing the output power of the system. PV system gives an output of 375 kW. PV and Wind both models are connected to a grid.

2.1.2 Wind Farm

The Wind farm model shown in figure 2.2 consists of wind source, wind turbine, governor and synchronous generator. This module is then connected to a converter circuit, consisting of, power and frequency converter and other components for voltage regulation.

The combined model is shown in figure 2.3 This model is built according to the PSCAD manual. [6]

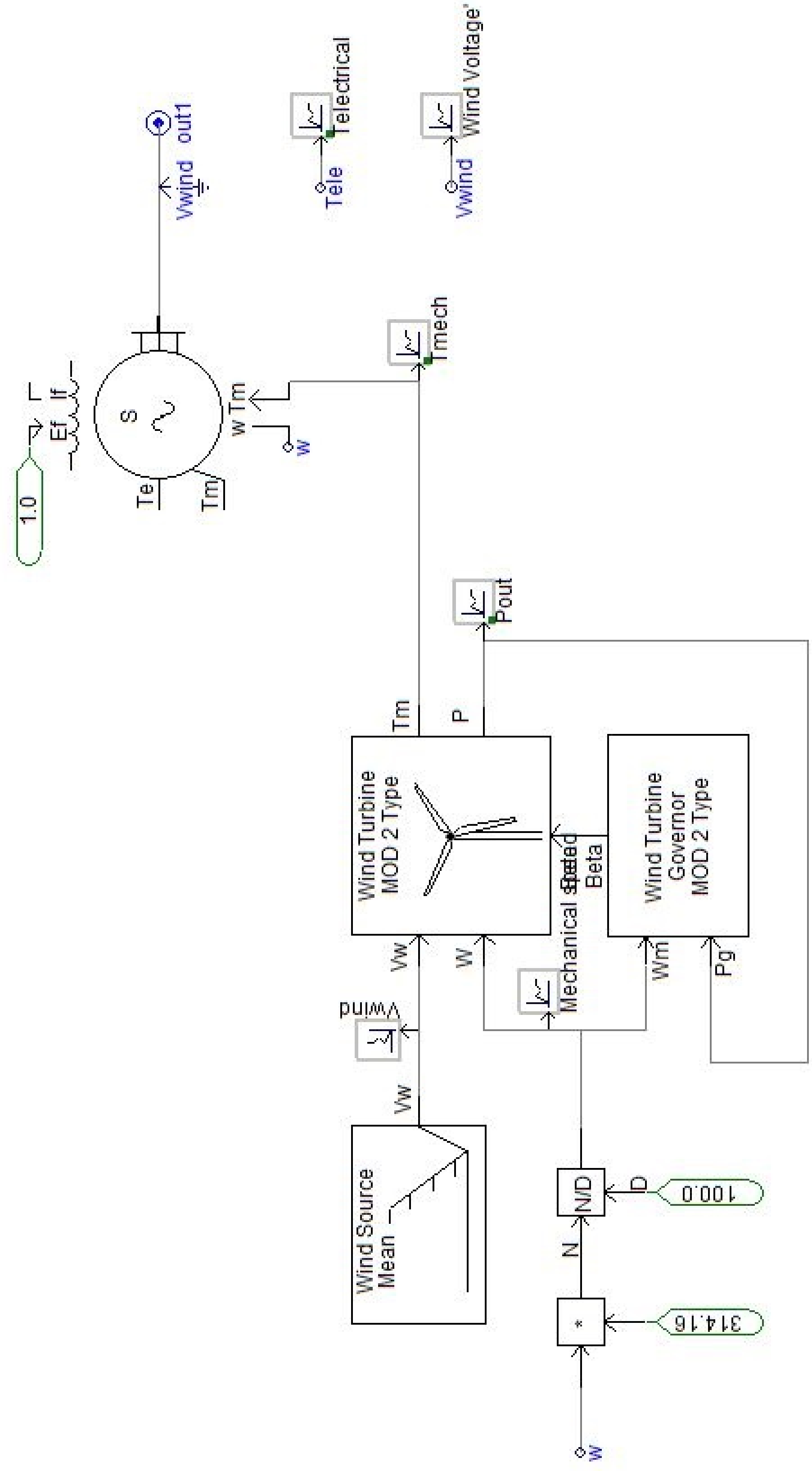

Figure 2.2: Wind System

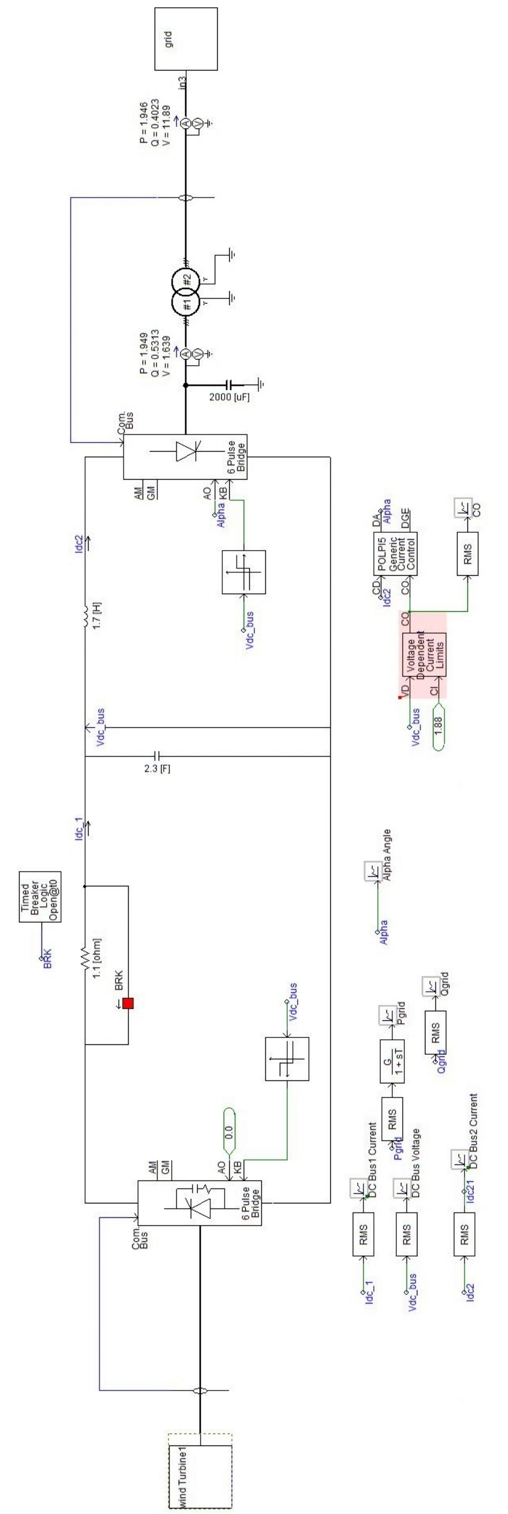

Figure 2.3: Wind with converter circuit

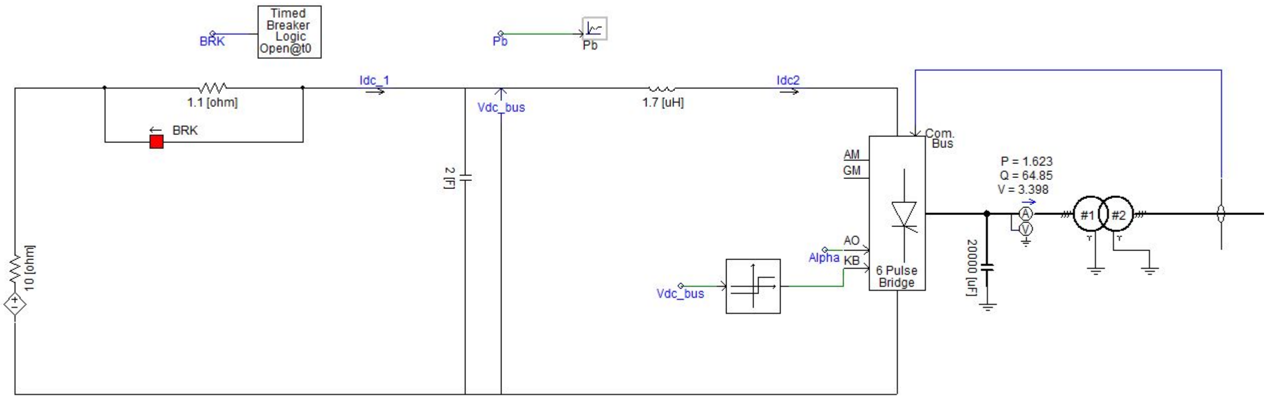

Figure 2.4: Battery system

2.1.3 Battery System

A battery is also required for emergency purposes, because wind and solar are interrupted power sources. So a battery is also designed for the microgrid. It is also a DC source, so inversion circuit is connected to convert DC to AC of desired frequency which is 60 Hz in this case. The figure 2.4 shows the battery system in PSCAD. Though because of synchronization issues battery system designed is not connected in the final system built.

2.1.4 Main Grid

A standard WSCC nine bus system is simulated to form the main grid. This system consists of three generators and these are interconnected through nine busses. Microgrid is to be connected to this main grid.The main grid system is shown in 2.5
The models shown in this chapter were simulated and outputs were obtained in form of waveforms. Those output waveforms are discussed in the next chapter.

2.2 Microgrid

A microgrid is formed by connecting these microsources together to the main grid. The model thus prepared is shown in the figure. The microgrid was synchronized so as to get the desired waveforms of voltage,current and power. Initially, a wind system, a PV system and the battery system simulated were connected together to

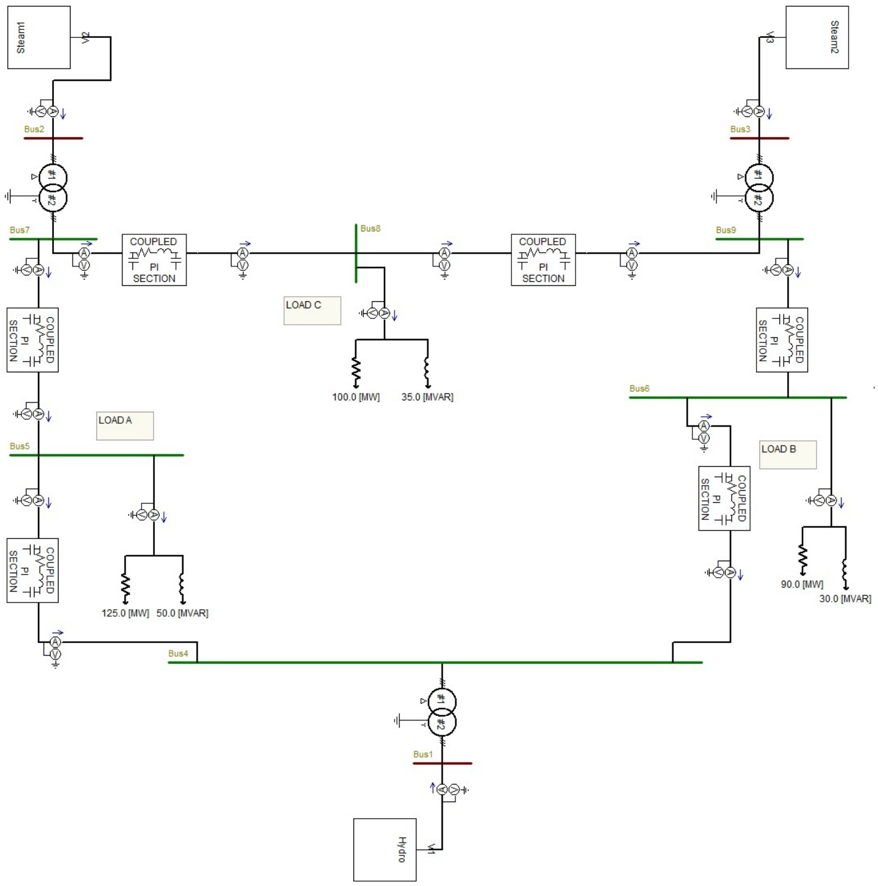

Figure 2.5: Grid

form a microgrid, but, due to synchronization issues, two wind systems and one PV system are connected together to form the desired microgrid system. The waveform thus obtained are shown in chapter 4.

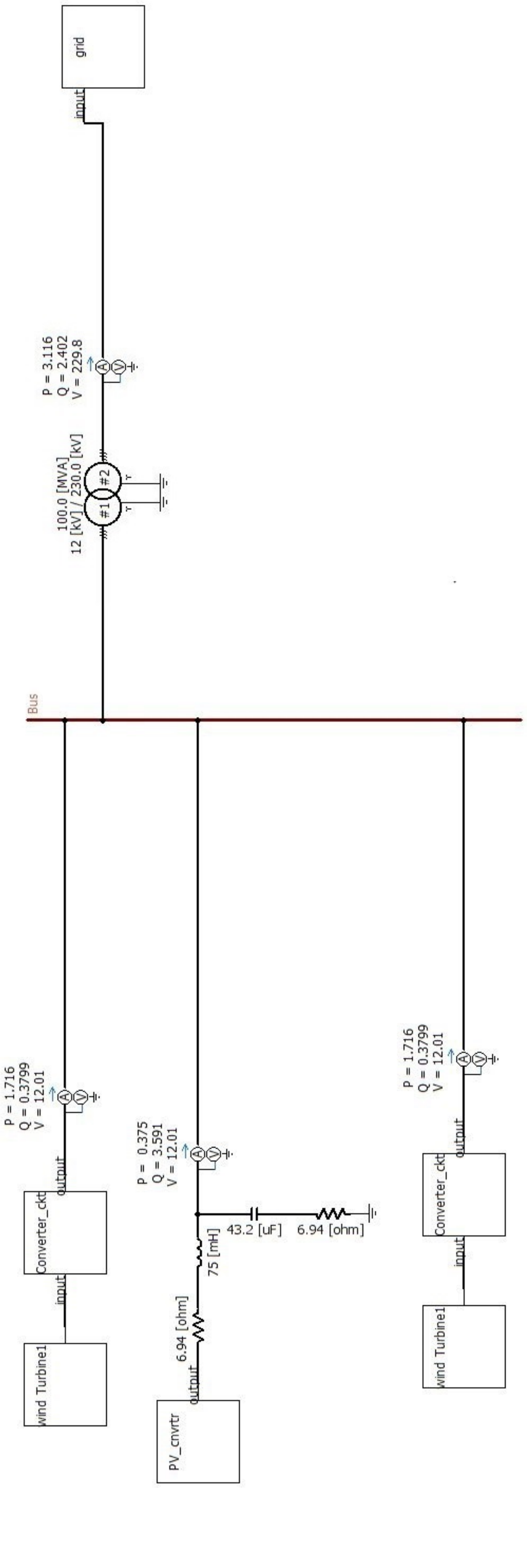

Figure 2.6: Microgrid connected to Main Grid

Chapter 3

Protection

To ensure reliable and uninterrupted power supply, in a Power System, protection is foremost requirement. Protection includes monitoring of the power system; detection of faulty conditions or equipment, if any; operation of relay, in case a fault is seen within the jurisdiction or protective zone; which in turn actuates the circuit breakers to isolate the faulty part, thus, protecting the rest of the system. Protection system devices should have some basic features, viz. reliability, selectivity, speed, cost effectiveness and simplicity.

3.1 Types of Protection Schemes

A protection scheme includes one or more relay, of same or different type, that is responsible for protection of given equipment or section of the line. In modern power system, protection schemes can be classified into four major categories:

Overcurrent Protection A shunt fault leads to abrupt rise in current. This current when goes beyond the permissible limit, damages the equipment and the system. This rise in current can thus be used as a positive sign for presence of fault. When the current feature is used alone, the relays are termed as non-directional overcurrent relays. Sometimes, it is required to know about the position of fault, with respect to breaker position, in such cases the fault current magnitude as well as its phase with respect to the voltage at relay location is taken into account. These are called directional overcurrent relays.

Distance Protection The fault current can be given as a function of the source impedance and the fault type. Both the parameters are variable. So, relays whose reach is independent of the current magnitude should be selected, especially in case of EHV lines. As, no mal operation can be tolerated in EHV lines. Due to limitations of overcurrent protection, i.e. variable reach and variable operating time due to changes in source impedance and fault type, distance protection came into existence. Distance relays reach is dependent on the ration of voltage at relay location and the fault current. Modern distance relays offer high speed fault clearance. These are used for protection of high and extra high voltage transmission and sub transmission line (220kV, 132kV, 66kV, 33kV). Most important distance relays include Impedance relay, Reactance relay and Mho relay.

Carrier Protection This scheme finds its application in protection of EHV and UHV power lines. Distance protection has some drawbacks that leads to implementation of this type of protection scheme. The major drawback is that distance protection is not able to provide instantaneous and simultaneous tripping of circuit breakers at both the ends of the line. It provides high speed accurate protection to only 60% of the entire line. Any unit protection scheme like carrier protection scheme does not face any such problem. So it is able to provide high speed and accurate protection to whole line. In carrier current protection scheme, the carrier current can either initiate or prevent the relay to trip, depending on the scheme chosen. So, it is called carrier inter tripping scheme in first case and carrier blocking scheme in later one.

Differential Protection In normal condition the current entering and leaving an equipment is same. But in presence of some fault, the current leaving differs from the entering current. This property is utilized by Differential protection scheme. It measures current at the two terminals of the equipment to be protected and compares them. When this difference is higher than the set value it generates a trip signal to bring the breakers in operation. These find application in protection of electrical equipment viz. transformer, generator, large size motors, bus, reactors and capacitors. They do not find any application in protection of transmission line as the length becomes a problem.

3.2 Overcurrent Protection

The project focusses on directional over current protection. As stated before, overcurrent component utilizes the fact that fault leads to abrupt rise in current level. Both electromechanical and numerical relays find application in overcurrent protection scheme. The relays operate on time and current setting, also known as plug setting. Time setting decides the time taken to operate and plug setting determines the current required for the relay to operate.Relays can be classified according to the different time-current characteristics. There are major six types.

a. **Definite-time Overcurrent Relay** As the current exceeds the set pick up value, the relay operates only after an already fixed time. This time is constant irrespective of the value of fault current. This time can be set using intentional time delay mechanism.

b. **Instantaneous Overcurrent Relay** Instantaneous implies that there is no intentional time delay in the relay, although some time is still taken by relay to operate. The time of operation is in terms of few milliseconds. Such relay has only pick up setting and no time setting.

c. **Inverse time Overcurrent Relay** This operates as the current exceeds the pick-up value, the time of operation depends on the magnitude of fault current. Higher the fault current lesser is the operating time. This is helpful, because higher the fault current faster is the relay operation.

d. **Inverse Definite Minimum Time Overcurrent Relay** IDMT relay incorporates features of both inverse time relay and definite time relay. Initially for plug setting less than 10, the relay behaves like inverse time overcurrent relay. For plug setting more than 10, it tends to act as definite minimum time overcurrent relay. These find application in protection of distribution lines.

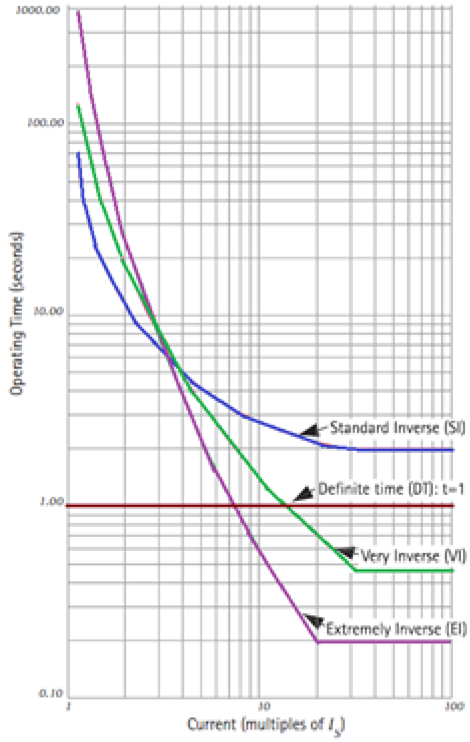

Figure 3.1: Time-Current Characteristics

e. **Very Inverse Time overcurrent Relay** The time-current characteristics are more inverse than the normal inverse relay or IDMT relay. Its characteristics lie somewhere between IDMT and extremely inverse characteristics. This has better selectivity than IDMT. The operating time of this relay can be given by:

$$T_{op} = \frac{13.5(TMS)}{PSM - 1} \tag{3.1}$$

f. **Extremely Inverse Time Overcurrent Relay** The time-current characteristics are even more inverse than very inverse and IDMT relays. These are used where both IDMT and very inverse relays fail in selectivity. The operating time is given by :

$$T_{op} = \frac{80(TMS)}{PSM^2 - 1} \tag{3.2}$$

All above discussed relay time-current characteristics can be represented by the figure 3.1

3.3 Directional Overcurrent Relay

In case of a radial feeder fed from both the ends or in case of parallel feeder, to maintain uninterrupted supply to all the loads, overcurrent feature alone is not sufficient. In such cases, along with overcurrent a directional feature is also to be employed. Directional feature ensures operation only for the direction they are destined to operate. Directional feature is added by comparing the direction of flow of current and the bus voltage. Basically it measures the phase angle between voltage and current vectors. In the project voltage and current phasers are generated using FFT block and then these are compared to get the phase difference.

3.4 Coordination

The protective devices that together form the protection scheme need to work in coordination. Coordination can be done by adjusting the time of operation of each device after the fault is seen. Dividing the power system into zones also helps in coordination scheme. In the model prepared directional overcurrent relays are used. All these relays are coordinated in terms of their operating time.

3.5 Protection Scheme in PSCAD

The microgrid designed and simulated needs to operate without any interruption. For smooth, uninterrupted supply of power a reliable protection scheme should be employed. The protection scheme designed in this project is using directional overcurrent relays. As explained earlier, Directional Overcurrent relays trip when the current goes beyond the pickup value and also the direction of fault current is as per the relay setting. To implement overcurrent feature an overcurrent relay block available in PSCAD/EMTDC is used. This block helps in setting a pick up value, above which it gives a logic one, otherwise zero. A logic circuit is prepared to incorporate both directional and overcurrent features together. This circuit makes use of AND and OR logic gates. Bidirectional relays use only two parameters, time setting and

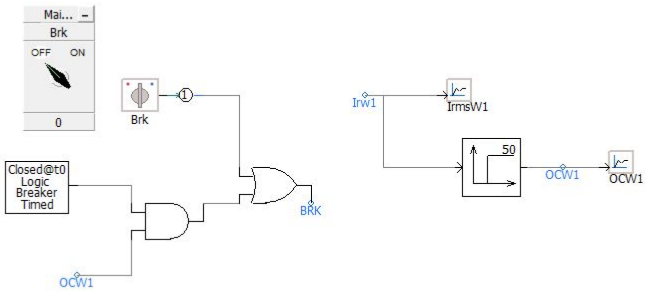

Figure 3.2: Logic circuit for Bi-directional Relay

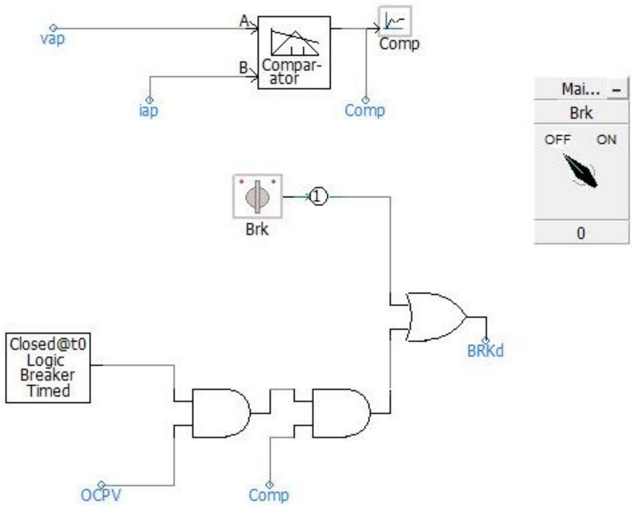

Figure 3.3: Logic circuit for Directional Relay

pick up value. So, at the given time as the current value increases beyond pickup value, the relay sends a trip signal to the respective circuit breaker. The logic circuit is shown in figure 3.2.

To add directional feature to this logic, one more AND gate is required. It is also taken care that circuit breaker is initially closed. The new logic circuit is as shown in figure 3.3.

It is of utmost importance that relays trip only when they are supposed to, i.e. no relay should false trigger in case of overloading. So, the pickup value is such set that it takes care of the overloading current. The current flowing in normal condition and in overloading condition(10%) was measured and noted down. The pick up value set was kept higher than this overloading current value. The overall protection scheme installed in the microgrid is shown in the figure 3.4.

It is clear from the figure that the relays are both directional and bidirectional. The reason behind is that, relays near source does not need to be directional. Whereas, the ones near the bus need to prevent the reverse flow of current in case of fault. So, directional component is to be added to them. If a fault occurs at line 1, i.e. the line with Wind source 1, the breaker BRKw1 opens first, follwed by opening of BRKw1d. The bidirectional one is connected to the relay logic which works only on time setting and current setting, so as soon as the current goes beyond pickup value at the desired time the relay send logic one to breaker BRKw1 to operate. BRKw1d prevents the current feeding from other sources to the fault current. Similar is the case for other two lines connecting PV and Wind source 2. For the line connecting microgrid to main grid one breaker near bus is bidirectional and other near grid uses directional logic. The logic used is already explained before.

As the project discusses protection scheme using only directional overcurrent relays, this scheme was proposed. Although, there are lot of other protective schemes that can be added to the existing scheme for improving the reliability of the system. The results obtained are given in next chapter.

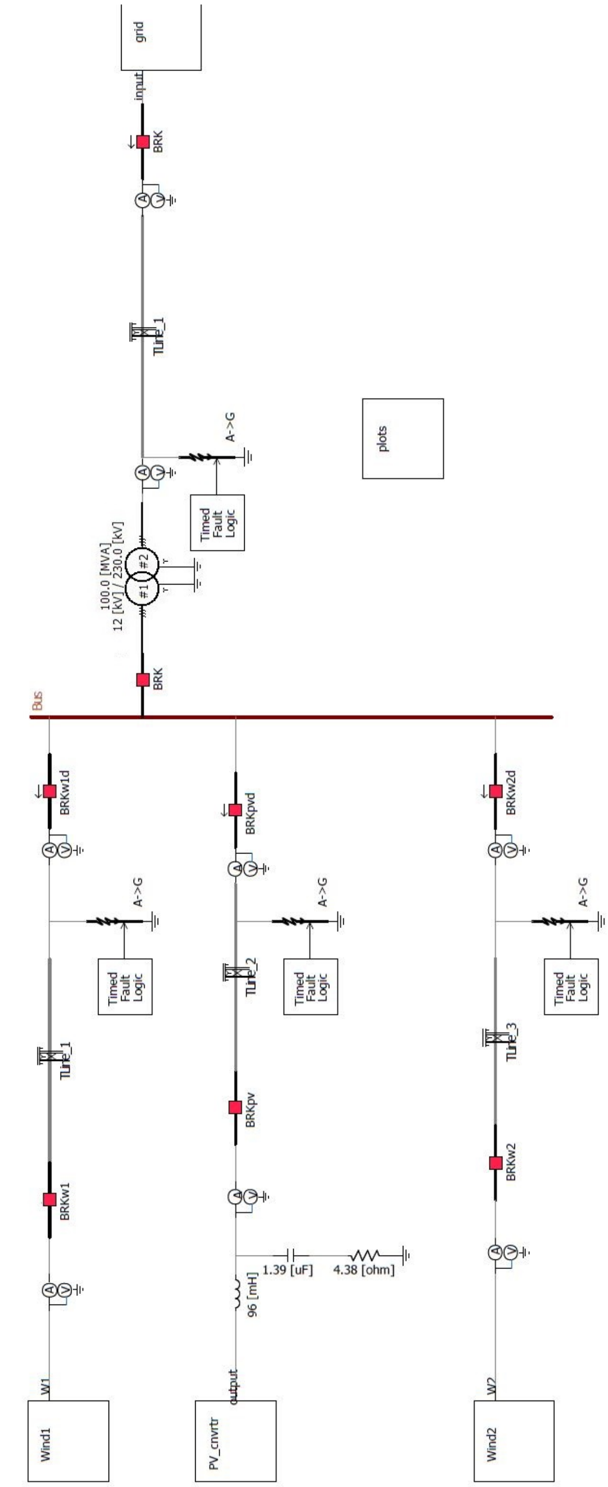

Figure 3.4: Complete Protection Scheme for gird connected Microgrid

Chapter 4

Results and Discussions

The simulation model prepared were run individually in grid connected mode and corresponding waveforms were obtained. Here are explained those waveforms.

4.1 Photovoltaic system

Photovoltaic module is responsible for generating DC, which is converted in AC with the help of converter circuit. The voltage waveform obtained is as shown in fig4.1. It is having amplitude of 1.7 kV which is then stepped up using a transformer before connecting to grid. Next figure represents the current waveform at the inverter end.The current waveform is not smooth, the reason being the harmonics introduced due to converter circuit. Power output also witness some harmonics that can be clearly seen in the waveform obtained.

4.2 Wind Farm

Similar to PV system, wind farm is also connected to grid via a converter circuitry. This circuit is responsible for frequency conversion and AC to DC and then back to AC conversion. In between voltage regulation is also done in order to avoid any voltage limit violation. The figure4.4 shows the waveforms before converter circuit. This includes waveform of voltage, torque, both electrical and mechanical, output power and mechanical speed.

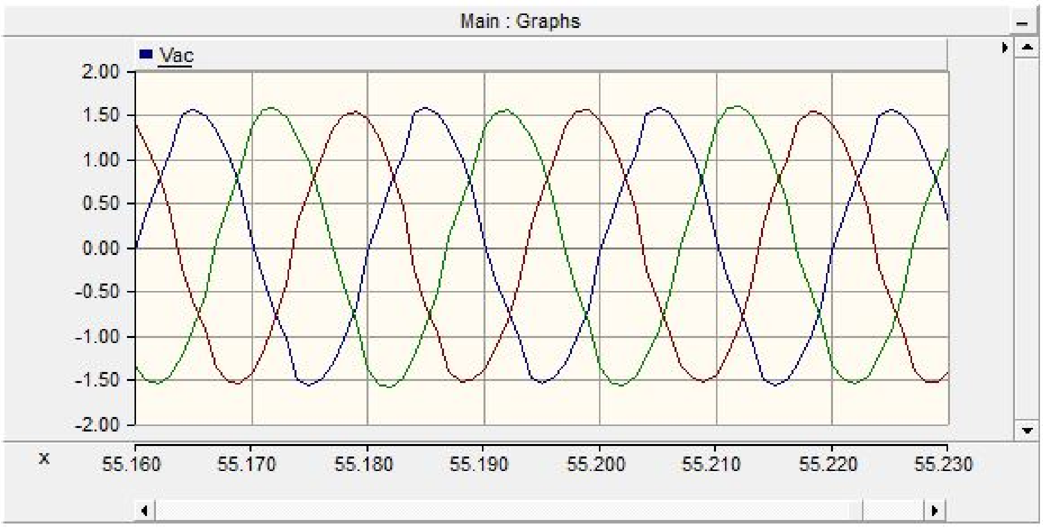

Figure 4.1: Voltage output at inverter end of PV system

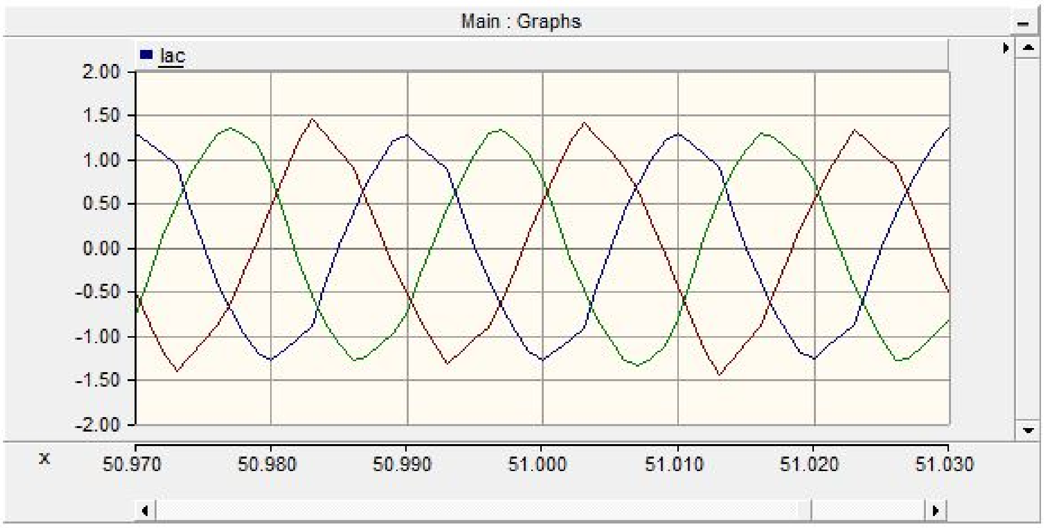

Figure 4.2: Current output at inverter end of PV system

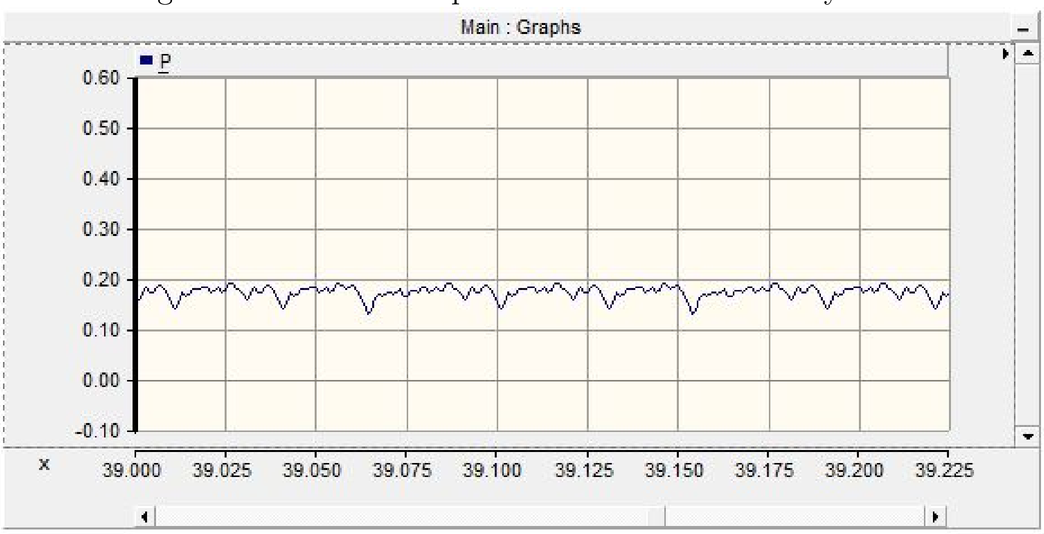

Figure 4.3: Power output at inverter end of PV system

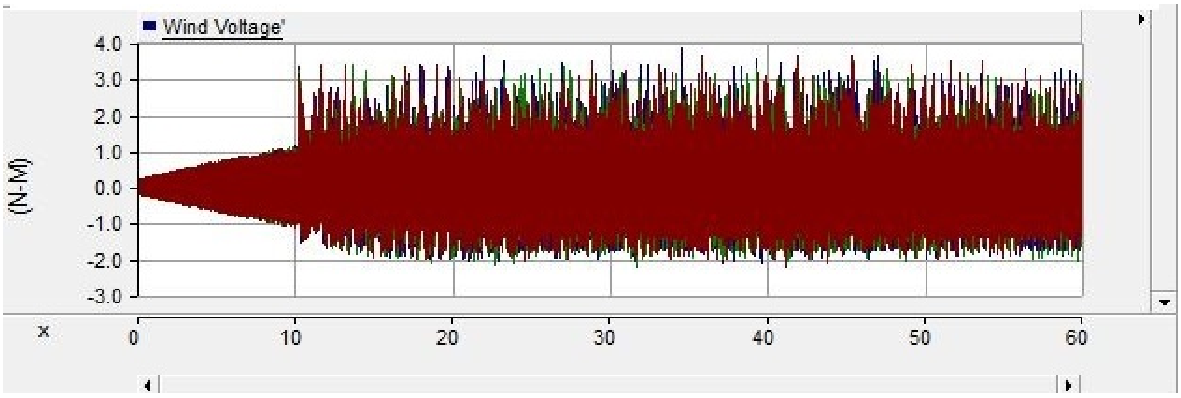

Figure 4.4: Voltage before conversion

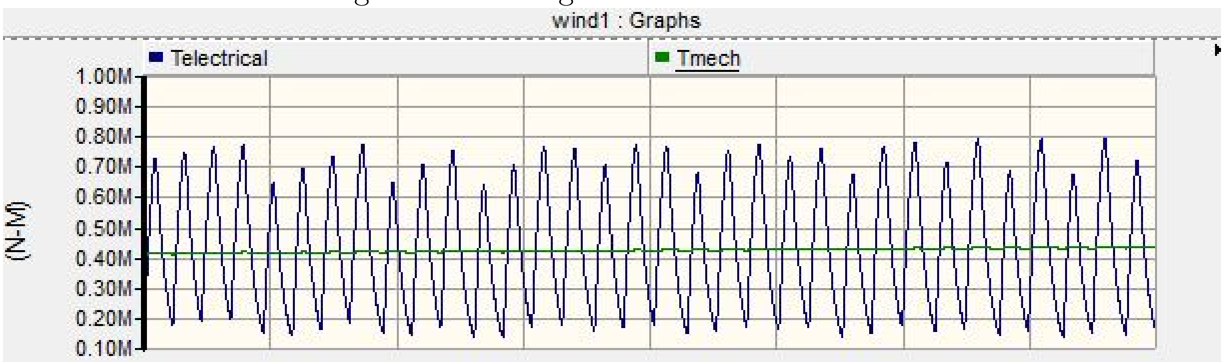

Figure 4.5: Electrical and Mechanical torque

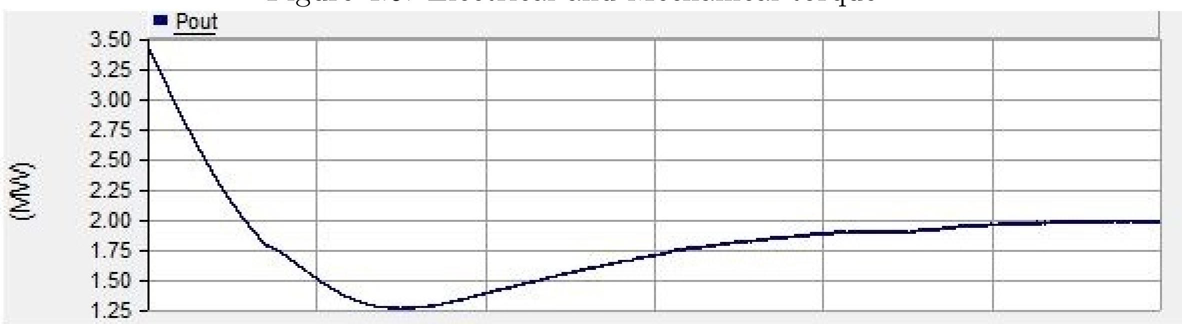

Figure 4.6: Electrical power output

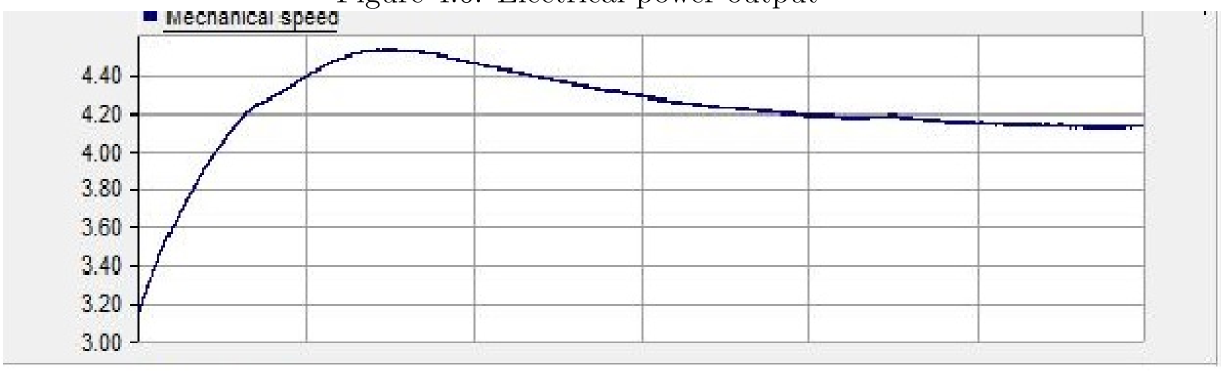

Figure 4.7: Mechanical speed

4.3 Battery system

The battery output, DC is converted to get 60Hz AC power. The output power, voltage and current waveforms are as shown in the figure below. The inverter triggers at alpha angle that is calculated by comparing the grid voltage and system voltage.

4.4 Nine Bus System

WSCC nine bus model shown in previous chapter was simulated to get the obtained output. The figure shows power waveform, current waveforms and voltage waveform. Frequency of operation is 60 Hz. Their are different waveforms for different generators. One of the generators is hydro and remaining two are steam turbine generators. Figure 4.11 is for generator active power, reactive power and rms voltage. Another figure shows the load end waveforms at bus 6. These waveforms are again active power, reactive power and voltage waveforms.

4.5 Microgrid connected to Main Grid

The microgrid thus formed by connecting different microsources together is then connected to main grid, nine bus system, and synchronized. After synchronization of microgrid output waveforms were obtained for voltage, power and current. The waveforms thus obtained are placed in this chapter.

4.6 Protection Scheme for grid connected Microgrid

The microgrid thus synchronized need to have a protection scheme. A protection scheme using directional overcurrent relay logic was designed and implemented. The results obtained include the fault condition and current waveform after fault clearance. These also include the comparator output which turns one in presence of fault in the desired direction. Figure4.19shows the presence of fault in the system, which leads to

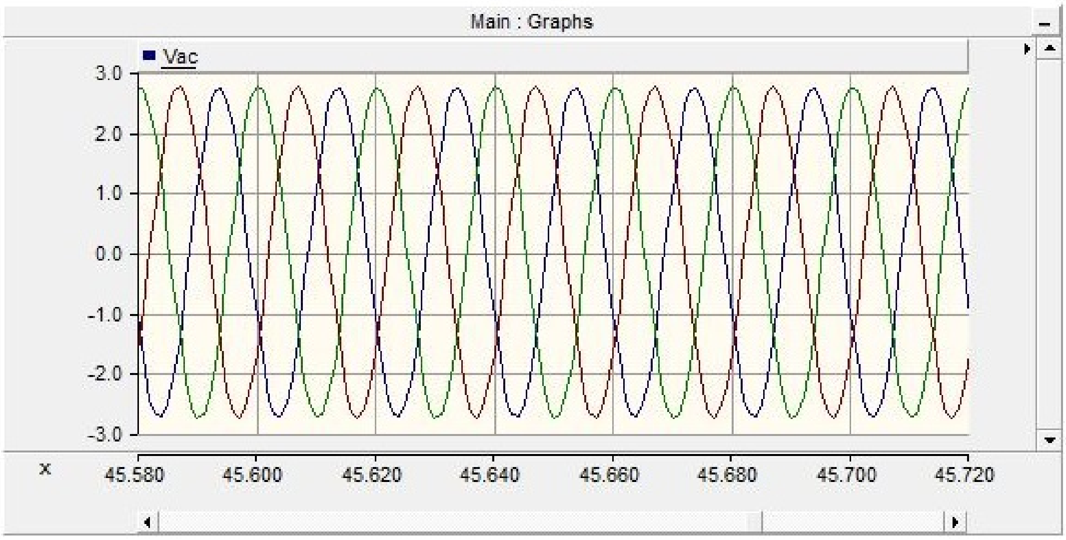

Figure 4.8: Voltage of battery after conversion

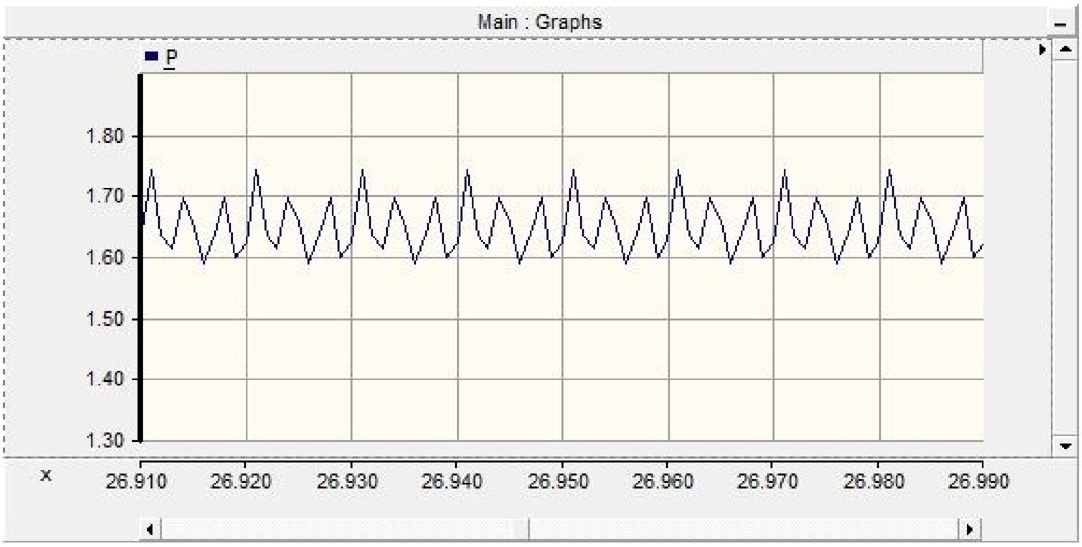

Figure 4.9: Electrical Power Output of battery

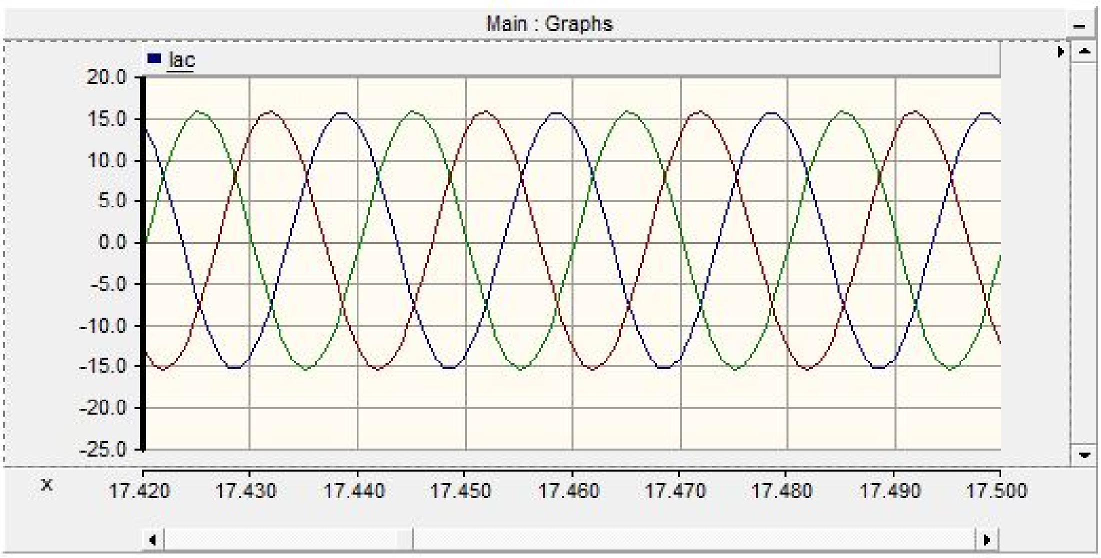

Figure 4.10: Current output of battery

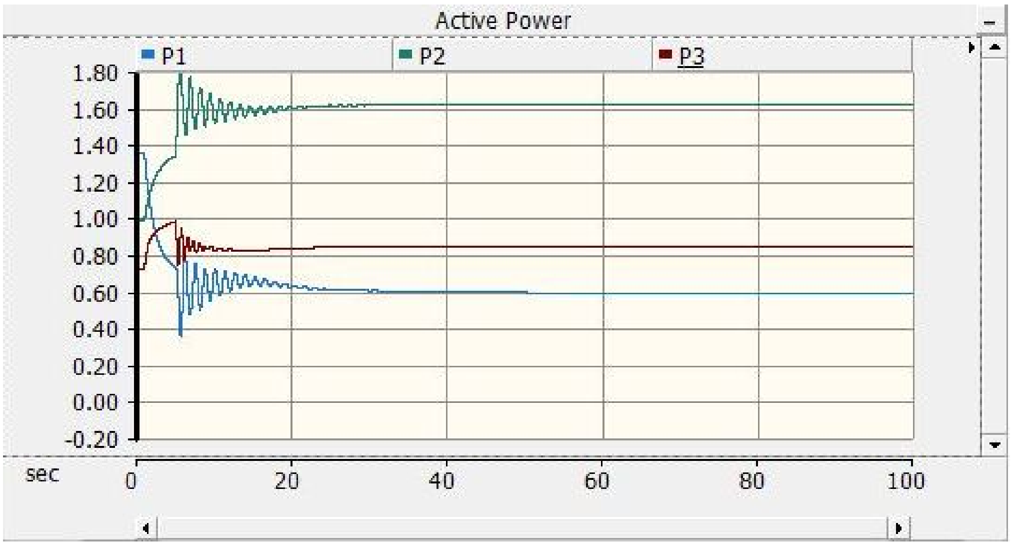

Figure 4.11: Active power of generators

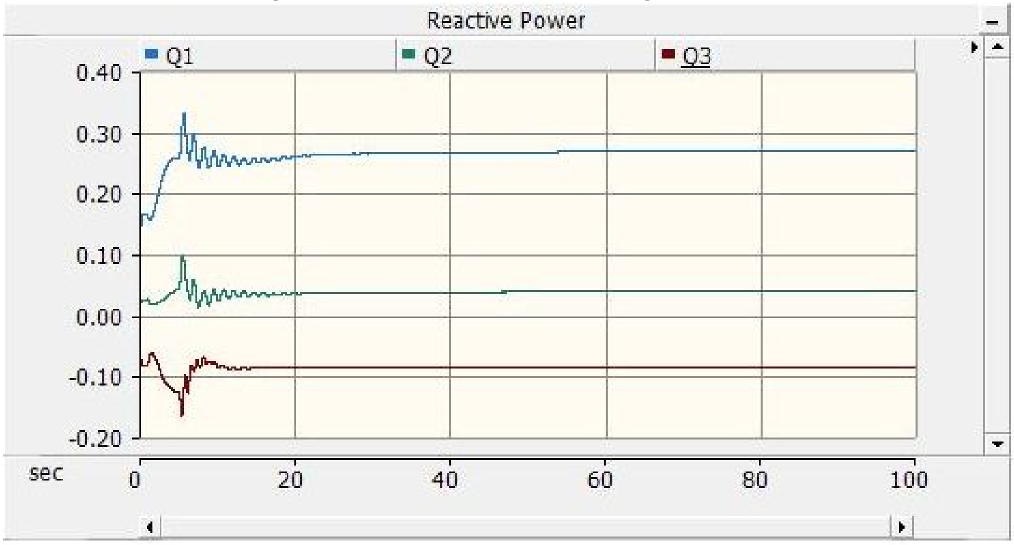

Figure 4.12: Reactive power of generators

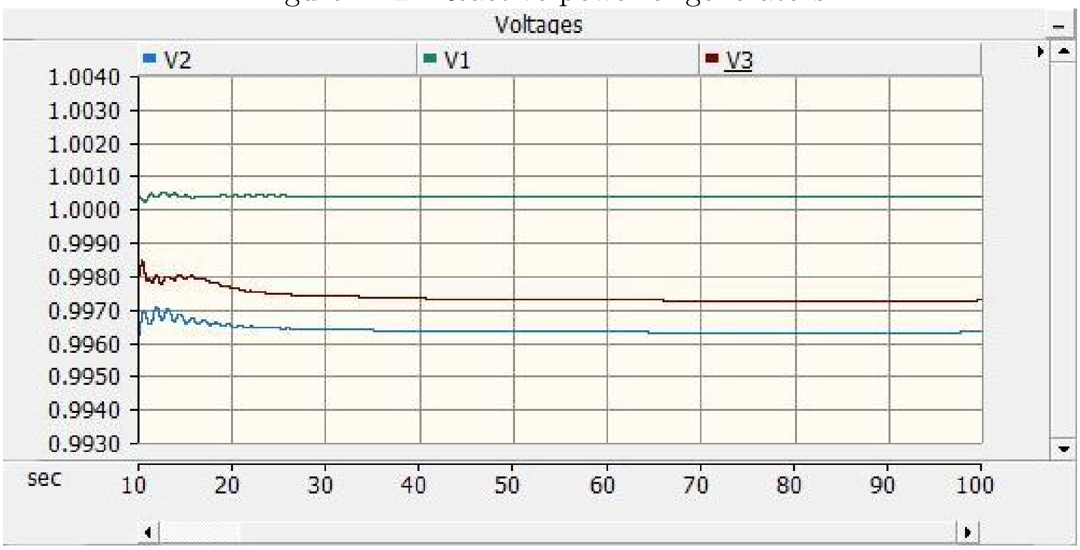

Figure 4.13: Voltage output of generators

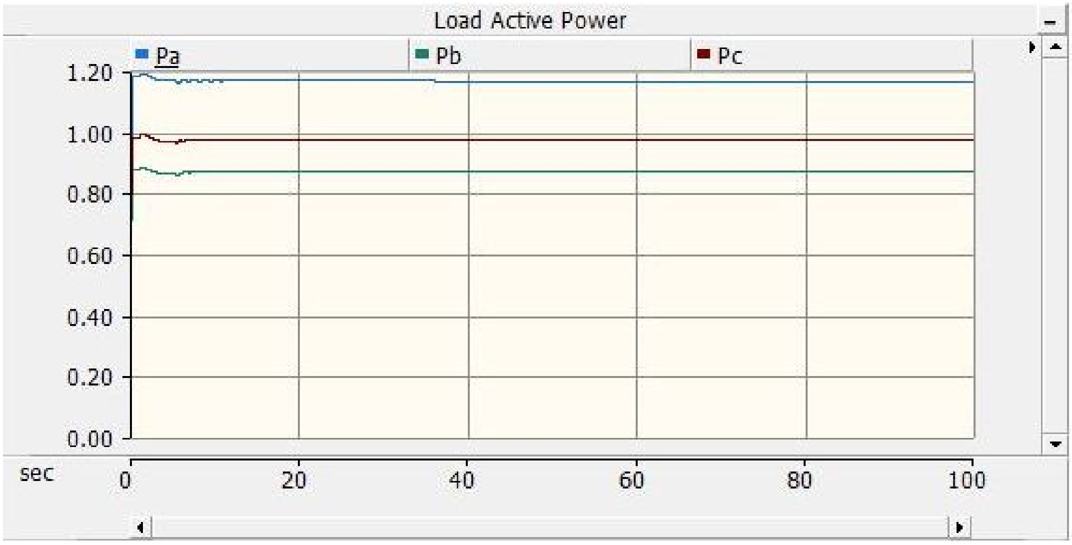

Figure 4.14: Active power at Load

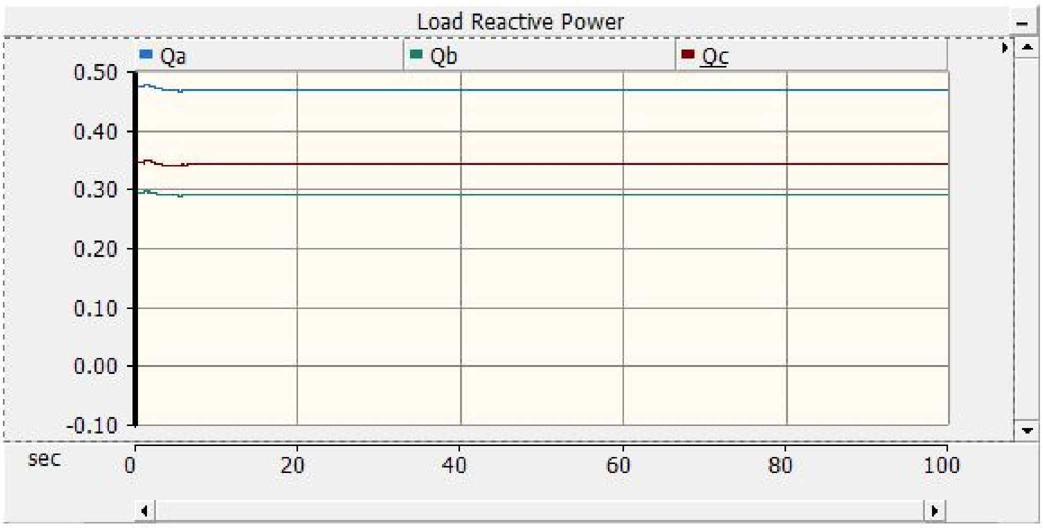

Figure 4.15: Reactive power at Load

Figure 4.16: Active power of Distributed Generators

Figure 4.17: Active power of Main Grid

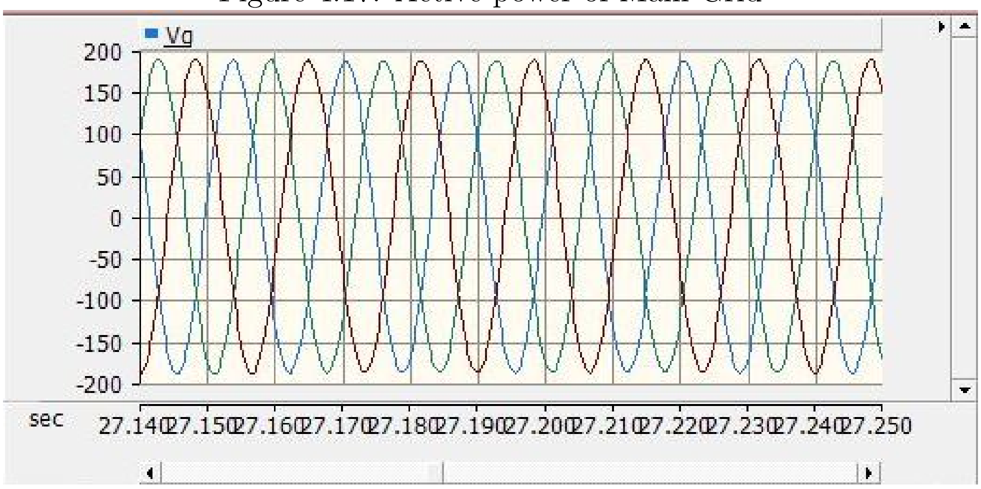

Figure 4.18: Voltage output of grid

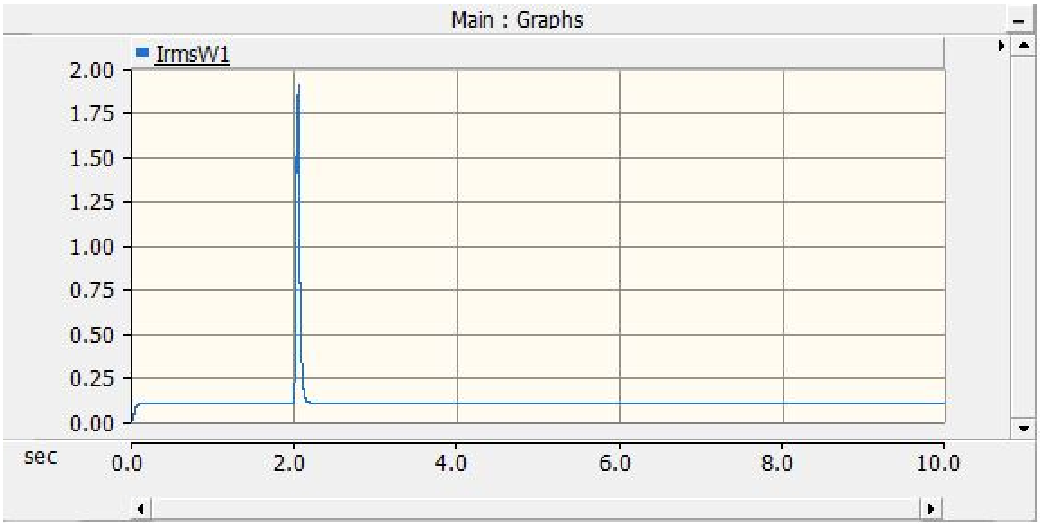

Figure 4.19: Fault current in RMS

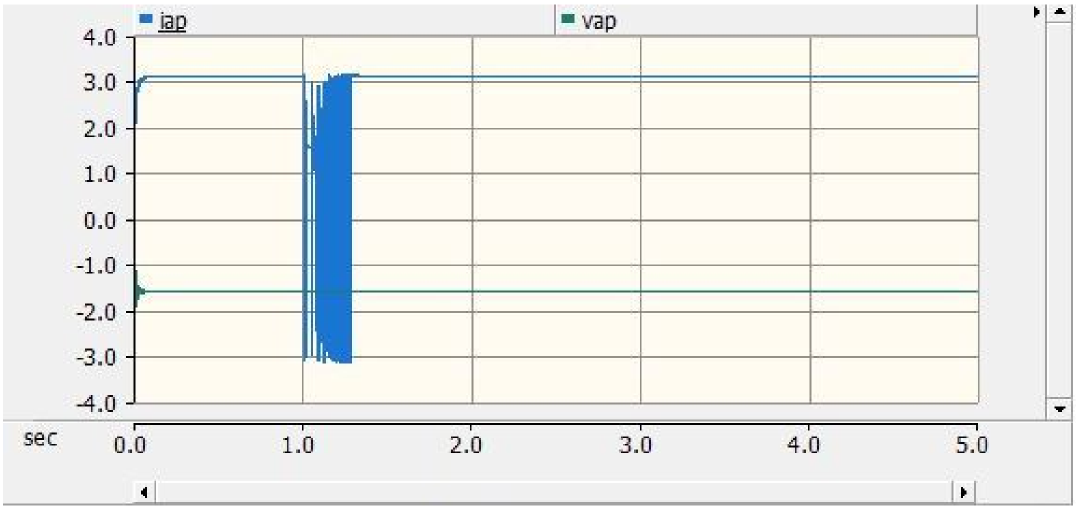

Figure 4.20: Comparison of Voltage and current phase

sudden rise in RMS current in the system. Once, the fault is detected, the relay starts to function. If it is overcurrent bidirectional relay it sends a trip signal immediately, and the current can be seen as in figure 4.22. In case of directional overcurrent relays, one additional feature is implemented, where both voltage and current phasers are compared to detect the direction of fault current. When the direction is against the desired one, the comparator gives a logic one as output, which is sent to the logic of relay. And hence the relay sends a trip signal for breaker to operate.

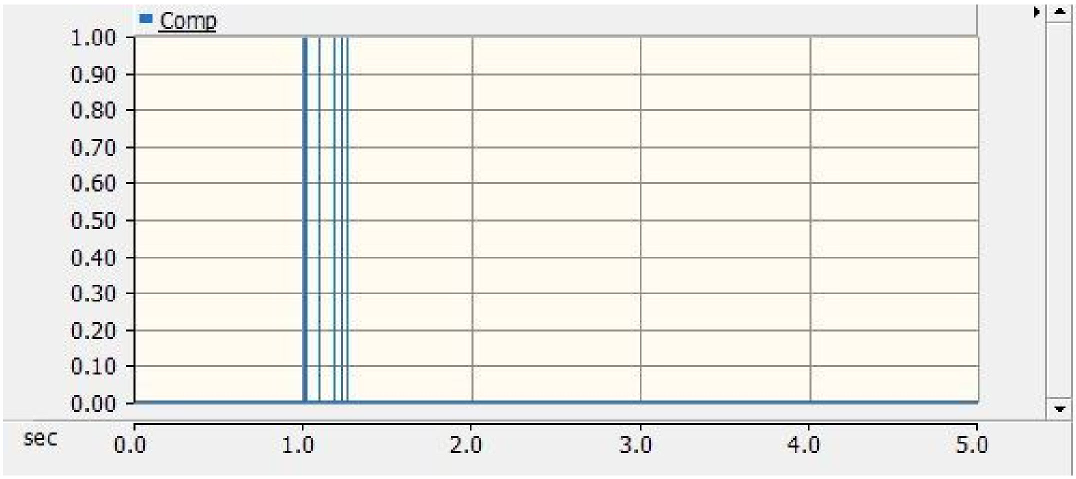

Figure 4.21: Comparator Output

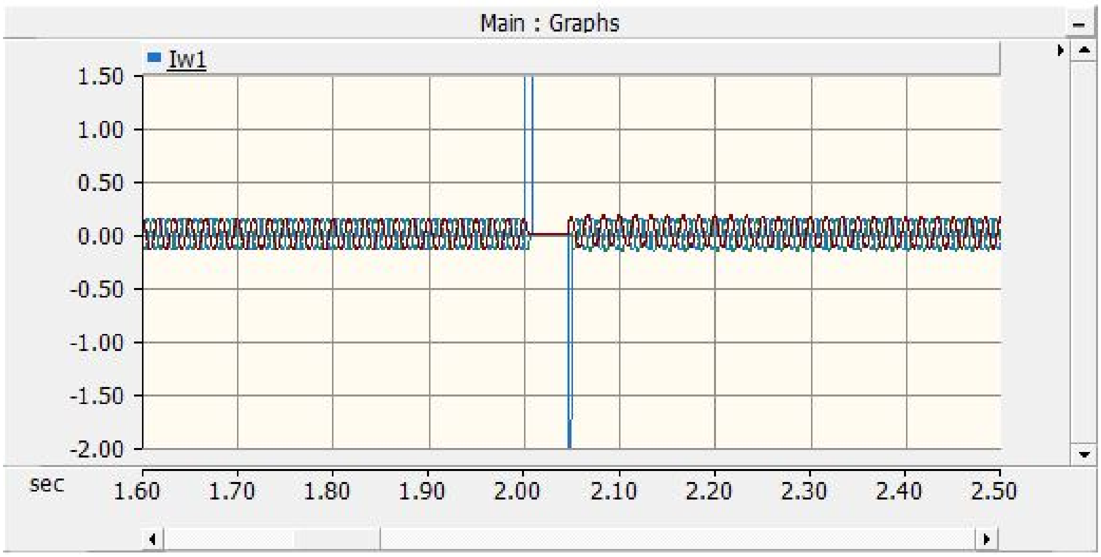

Figure 4.22: Current after breaker operation

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

A model of microgrid has been prepared using PSCAD/EMTDC which consists of photovoltaic and wind source. The model simulated in PSCAD is shown and discussed in the above chapters. Also the waveforms obtained are given in chapter 4. After synchronization of microgrid to main grid, a protection scheme was designed. The scheme utilized coordinated directional overcurrent relays. the scheme comprised of both bidirectional and directional overcurrent relays as per the requirement. A logic was developed and implemented using logic gates to carry out the desired overcurrent and directional features int he scheme. So far, the problems faced includes, removing harmonics and getting the required power and voltage magnitude. In case of PV, the output power is 375 kW and in case of wind farm the power obtained is 1.9 MW. Quiet difficulty was observed when microgrid was to be synchronized with main grid. Also protection scheme is developed according to the requirements. The microgrid modelled has been now connected and synchronized to the nine bus system. After synchronization is done, a faulty situation was created and system was observed.

5.2 Future Scope

A grid connected microgrid has been developed and synchronized to grid. Later a protection scheme was developed using logic for directional overcurrent relays. The relays are in coordination with each other. The designed protection scheme ensures reliable and continuous power supply. The project includes protection scheme using only directional overcurrent relays, so, further protection scheme can be added using other types of protection schemes for better system operation.

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