MODELLING AND SIMULATION OF CENTRAL CONTROLLER TO CONTROL POWER SHARING IN MICROGRID

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CERTIFICATE

I hereby certify that the work which is being present in the dissertation entitled "**Modelling and Simulation of Central Controller to Control Power Sharing in Microgrid**" in partial fulfillment of the requirements for the award of degree of Master of Engineering in Power Systems submitted in the Electrical and Instrumentation Engineering Department of Thapar University, Patiala is an authentic record of my own work carried out under the guidance of **Dr. Prasenjit Basak**, Assistant Professor, EIED.

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

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ABSTRACT

Presently most of the power generation is contributed by thermal power plants which are coal fired. Fossil fuels, such as coals, are limited in nature and we have to depend on renewable energy resources to sustain the growth of electrical power generation. Small microgrid with inter-connected renewable energy resources is emerging as an alternative means of support to the conventional power generation technique. In this research work, we have designed a model of microgrid using Simulink/Matlab software. The microgrid central controller proposed in this work has several features for distribution of power among several loads as per available generation. In addition, whenever a fault occurs on main grid, it isolates the microgrid from the main grid for protection of microgrid. The central controller works in autonomous mode. Two types of central controllers are designed for the microgrid. One central controller can work based on amount of power demand of load and other can work based on desired level of voltage across the load. The central controller automatically disconnects the non-critical load whenever the capacity of microgrid is reduced in islanded mode. A sample study is also done using Simulink for the wind turbine based microgrid. Satisfactory results are obtained while the wind turbine based microgrid is simulated while feeding the critical and non-critical loads in grid connected and islanded mode. A sample model of microgrid with central controller is proposed based on the electrical layout of Thapar University. The research work presented in this dissertation justifies that the microgrid central controller improves the reliability of the microgrid.

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LIST OF ABBREVIATIONS

RER	Renewable Energy Resources
CHP	Combined Heat Power
DG	Distributed Generators
DER	Distributed Energy Resources
PCC	Point of Common Coupling
MGCC	Microgrid Central Controller
MGVC	Microgrid Voltage Controller
DMS	Distribution Management System
RTS	Real Time Simulator
DSC	Demand and Supply Controller
UPQC	Unified Power Quality Conditioner
VSC	Voltage Source Converter
CGS	Cogeneration System
SOC	State-of-charge
PSO	Particle Swarm Optimization
SAPF	Shunt Active Power Filter
DVR	Dynamic Voltage Restorer
PV	Photo-Voltaic
DFIG	Doubly Fed Induction Generator

CHAPTER-1

INTRODUCTION

1.1 Overview

The electric power system is the most vast and complex system managed by power system community. As the demand is increasing and the conventional energy sources are limited to us, we have alternative option of the renewable energy sources. Fossil fuel based power generation causing several unwanted emissions which are threatening our environment, so our aim is to develop low carbon technologies to meet the power demands. Our purpose is to provide energy efficiently. Global warming and changing climate conditions are the problems which must be tackled, so the microgrid is developed to generate electricity. Also with less pollution the transmission losses are considerably low in microgrid [1].

A microgrid can be defined as a low-voltage distribution system to which small modular generation systems are to be connected. A microgrid consists of small generation systems and electrical loads through a low-voltage distribution network. In microgrid, we find small installation of the renewable energy sources that can fulfill the load demand. The microgrid can be installed for a village or a small town [2].The integration of distributed generators based on renewable energy resources (RER) and micro sources like photovoltaic system, wind turbine, microturbine using CHP system, fuel cell and batteries with storage facilities etc. has initiated more recent concept of microgrid which is considered as a cluster of interconnected distributed generators (DGs), loads and intermediate storage units that co-operate with each other to be collectively treated by the utility grid as a controllable load or generator towards an evolutionary power solution for scarcity of fossil fuel in near future. The integration of microgrid with RER is evolving as an emerging power scenario for electric power generation, transmission & distribution. In this prospective, IEEE-P1547-2003 is a benchmark model for interconnecting DERs with Conventional Electric Power System [3-4]. All these different types of renewable energy sources have one advantage that they produce less pollution and they are in abundance. Among all types of the renewable energy resources, the wind power is the most cost effective technique and the wind power generation is also increasing considerably as compared to photovoltaic cells and bio-gas plants. The advantage of the locally installed renewable sources is that they help to reduce the transmission losses. Microgrid can operated in both grid-connected and islanded-mode. It can be operated manually by switching off the loads when the main grid is disconnected and power generation is less than the demand or in case of external faults. We can improve the function of a microgrid by some computerized modeling at planning stage. As per the requirement of the customer it can be designed to meet his special needs and provide additional benefits, such as improved power quality and reliability, increased efficiency through co-generation and local voltage support [2].

The scopes of microgrid seem to be higher dependability of service, better quality of power supply, and better efficiency of energy use by utilizing the available waste heat from power generation systems too. The capacity to make use of renewable energy with modest pollution and potentially less costs is attractive and gains gradually more interests in many countries. Additionally, distributed generation can benefit the electric utility by decreasing overcrowding on the grid, reducing the need for new generation and transmission capacity, and offering supplementary services such as voltage support and demand response [1].

The schematic diagram of a typical microgrid is shown below in Fig. 1.1.

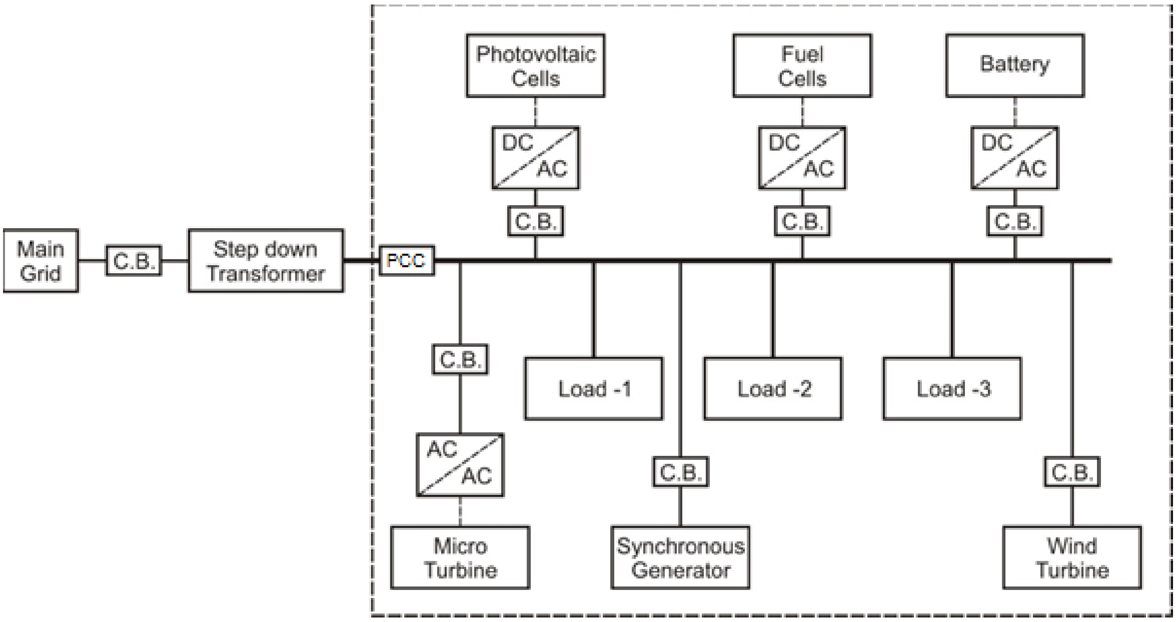

Fig. 1.1 Schematic Diagram of a Typical Microgrid

1.2 Motivation of Dissertation Work

The microgrid concept is becoming popular in the power community and world-wide research is in progress for proper use of some renewable energy systems, such as photovoltaic or wind energy which depend upon natural phenomenon. The motivating factors for work on microgrid are supported by the issues related with integration of distributed energy resources (DERs), operation and control of microgrid and protection issues related with microgrid.

1.2.1 Integration of DERs in Microgrid

The integration of renewable energy resources with microgrid is increasing now a day to reduce carbon dioxide emission and consumption of fossil fuels is also reduced. This results into increased reliability and efficiency. The concept of microgrid is a solution to the problem due to scarcity of the fossil fuel in future [3-4].

1.2.2 Operation and Control of Microgrid

The microgrid is integrated with DERs such as wind, solar, fuel cells, bio gas based resources etc. The microgrid is connected to the main grid/utility grid to fulfill the load demands. There are two modes of microgrid operation i.e. grid-connected and islanded-mode. In grid-connected mode the microgrid either draws or supply power from or to the main grid. The supply from renewable energy resources and main grid are matched up with demand to maintain a proper balance. Whenever a fault occurs on main grid, the microgrid isolates itself from the main grid known as islanded mode. The whole operation of microgrid is controlled and managed by a microgrid central controller [6].

1.2.3 Microgrid Protection

The microgrid should be provided with protection and co-ordination system to protect the microgrid components at the point of common coupling for safety measure of both microgrid and utility grid. Whenever a fault occurs, protection system isolates the microgrid from the main grid [40-41].

1.3 Objective of the Dissertation

The main objective of the dissertation work is to design a central controller for microgrid operation and control under both the grid-connected and islanded-mode. The central controller senses the fault or outage at the point of common coupling of microgrid with main-grid and control the critical and non-critical load according to its own power generation capacity. This work is divided into following steps:-

1. To perform a comprehensive literature survey on microgrid central controller to realize the present status of its development.

2. To design central controller for a microgrid using Simulink/Matlab

3. To investigate the operation of microgrid central controller in the wind- turbine based microgrid through modeling and simulation using simulink/Matlab software.

4. To propose a microgrid model as per present electrical layout of the Thapar University.

5. To propose a microgrid central controller for the microgrid model of Thapar University for satisfactory distribution of power among the critical and non-critical loads.

1.4 Organization of the Dissertation Work

The dissertation is organized in six chapters.

The overview of microgrid operation and control technology, motivation of the present work, objectives of the present work as presented in the dissertation including organization of the dissertation are presented in the current **Chapter 1**. A comprehensive literature survey on the evolution of microgrid central controller (MGCC) is presented in **Chapter 2**. The **Chapter 3** proposes a central controller which controls the operation of a single phase sample ac microgrid system based on the power generation and demand. **Chapter 4** presents a voltage based MGCC which is proposed and simulated for a wind turbine based microgrid delivering or serving critical and non-critical loads. In **Chapter 5**, an automated microgrid model is proposed for the electrical network of Thapar University in which function of a voltage based proposed MGCC is investigated. **Chapter 6** presents the conclusion and scopes of future research work.

CHAPTER-2

LITERATURE REVIEW ON
MICROGRID CENTRAL CONTROLLER

2.1 Introduction of Microgrid Central Controller

This chapter presents the literature survey on MGCC, its need, implementation and technological developments in the field of microgrid. Literature survey is divided into following sections:-

2.1.1 Concept of Microgrid Central Controller

A microgrid central controller controls the load in the microgrid by proper managing the energy balance in the system. MGCC compares the total generation with the load demand in microgrid and some non-critical loads is shaded if load demand becomes higher than the generation. MGCC regulates the voltage and frequency to maintain system stability [5].

2.1.2 Need of MGCC

To supply various loads in microgrid, the different energy resources are integrated with the main grid, which makes the system complex. So for proper co-ordination of the energy sources there is a need of controller in microgrid for satisfactory operation. Microgrid central controller monitors the power generated by DGs and match up with the demand to maintain balance in the system. Microgrid central controller is needed to detect the power quality at PCC and so that it can decide whether to disconnect grid i.e. to initiate islanding mode. Resynchronization is done by central controller once the grid is restored by properly matching the voltage and frequency with that on the grid side. So there is need for microgrid central controller for resynchronization purposes and islanding decisions reported in [5]. Microgrid central controller reduces the operational cost of microgrid for customers. As microgrid central controller fulfill the demand of the microgrid by using its own energy resources, so that it reduces the network congestion at time of peak demand when energy prices are high in open market shown in [6].

2.1.3 Implementation of MGCC

[5] suggests a laboratory test setup for operation and control of DGs and implementation of microgrid central controller is suggested. To properly co-ordinate the operation and

control of different DGs in microgrid, MGCC is used to manage the system in both grid connected and islanded mode. The total generation from DGs and grid is supplied to the loads in grid-connected mode, whereas in island-mode, droop control approach is used to control the generating units. During island mode, microgrid central controller detects the real and reactive power which flows through different DGs.

2.2 The Evolution and Advancement of Microgrid Central Controller Technology

At the very initial stage of development the operation of microgrid central controller was suggested in the following manner:

In [7], automated load management technique is used for energy balance. In which microgrid central controller isolates the loads during peak-load hours to reduce demand on the system. The proposed technique reduces the maintenance cost of microgrid and thus increases the reliability of the system. In [8] the network based control of multiple DGs is adopted by an active synchronizing control scheme. This technique provides the reliable connection of main/utility grid with the microgrid. A reliable synchronization is achieved by using microgrid pilot-plant.

In [9], to improve the voltage profile of microgrid, Microgrid Voltage Controller (MGVC) is implemented. The grid-connected and island-mode, both the condition are considered. The improved results are shown with the addition of MGVC. In [5] A MGCC is implemented to work in various modes of operation in grid-connected, islanded and transition from grid connected to island and vice-versa. A MGCC monitors the loads to ensure stability of the system. In [10] A Central controller is designed for stable operation of microgrid. To adjust the voltage and frequency a droop control scheme is provided by connecting inverters in parallel.

Automated load management is employed to minimize the energy imbalance issue.[7] presented a self-configuring for demand side in which microgrid central controller controls the load and isolate them to reduce load demand on the system for maintaining energy balance. The system is fully automated with minimum costs and maintenance. Wireless sensor network approach is used to maintain communication between microgrid central controllers and loads. Self-organization, low power consumption and low cost are the main features. This approach provides stability to microgrid. [6] proposed a microgrid central controller which uses optimization technique for the operation of microgrid. The controller optimized the total generation of DGs and exchange of power with the main/utility grid.

Demand-side bidding options are considered for controllable loads which lead to reduced energy prices for customers.

[8] proposes an active synchronizing control system which uses the DG to adjust the voltage and frequency of microgrid. A reliable synchronization can be achieved with this method under the condition of the fluctuating output and rapid load change. The author setup the microgrid pilot plant to verify and test the behaviour of microgrid. [11] Discussed a microgrid operation control which work on local-level distributed generation and system-level distributed generation control for stable work. In local-level DG control in microgrid, inverter based DG-units are used due to faster dynamics and it can quickly switch between grid-connected and islanded mode. In system-level operation control, Distribution Management System (DMS) is used. MGCC as the main interface between DMS and microgrid detect the blackouts and decide when to start the blackout procedure. [9] Proposes a control controller for the improvement of voltage profile in microgrid and avoid any voltage tripping. The grid-connected and islanded-mode are considered for simulation. To evaluate the performance of controller, a 22-bus microgrid test system is used, which include different types of DGs.

[12] describes the functions of microgrid central controller for the participation of the microgrid in future real-markets. To reduce operational cost the economic scheduling, forecasting function is developed for co-ordinated management of the microgrid micro-sources. [13] proposed a distributed secondary control approach to share reactive power between DGs by removing frequency and voltage errors. Also the failure of single unit will not lead to fail down of the whole system. To show the feasibility of distributed control, experimental results are presented. [10] employed a control strategy to switch the microgrid between grid-connected and islanded-mode. A droop control scheme is used to adjust the voltage and frequency by connecting inverters in parallel. In island mode voltage deviations control controller are eliminated by secondary loop to enhance the power quality of microgrid.

[14] Presents a several control techniques in island-mode of operation. The active and reactive powers are controlled for stable operation of microgrid in islanded mode. The results are simulated which shows the transition of microgrid from grid-connected mode to islanded-mode. [15] Proposed a real time simulator (RTS) to verify performance of demand and supply control in microgrid. The problem is simulated under both grid-

connected and islanded-mode. RTS is used verify a performance of Demand & Supply Controller (DSC).

2.3 Classification of MGCC

As per the literature survey on MGCC, it can be broadly classified in two types such as (i) A.C Microgrid Central Controller and (ii) D.C Microgrid Central Controller

2.3.1 AC MGCC (Alternating Current Microgrid Central Controller)

In AC grid, AC power sources and load are connected. To enable the connection of renewable based power generating sources with the present AC system, AC microgrid have been developed in [16]. By connecting microgrid directly to the AC grid investment cost lowers and structure is simple but with less reliability and lack of flexibility, therefore an interface is needed reported in [17].

AC microgrid using different techniques

The simulation work is carried out for harmonics study within an AC microgrid to mitigate the harmonics, Simulink model is well developed in [17].For more flexibility and reliability, a possible method is proposed in AC microgrid by using a back-to-back converter interface. The interface has strong voltage and current decoupling capability between the microgrid and the distribution grid in terms of various system disturbances shown in [18-19].For maximum utilization of integration of RER in a distributed generation system, a high frequency AC-based microgrid is presented. The successful implementation is done by using UPQC (Unified Power Quality Conditioner). The UPQC ensures the harmonic-free voltage. It also compensate for the harmonic-current and reactive power. The controller is based on P-Q theory used in [20]. The power flow between the main grid and microgrid cannot be controlled in grid-connected mode. If any fault occurs, cannot be isolated and power supply cannot be ensured and transmission of harmonics occur. So a new scheme is developed to connect microgrid to the AC grid by a flexible interface device comprises of back-to-back VSC converter. It also controls the active power flowing between main grid and microgrid. Also it is helpful in reactive power compensation and keeping the microgrid voltage stable illustrated in [21].

To improve the power quality and reliability of the system, a flexible AC Distribution system is employed. In microgrid, for tracking of frequency and to extract the harmonic spectra of the grid voltage and the load currents, extended Kalman filter are employed in

[21]. A droop control scheme is proposed to adjust the voltage and frequency by connecting inverters in parallel but this method has several drawbacks. Due to mismatch of line impedances, circulations will be generated between the inverters in islanded mode, when load or generation inside the microgrid changes. In grid-connected mode, the active output power of inverter is not regulated reported in [10].

A two cost-prioritized droop scheme is proposed for DGs in islanded microgrid having lower generation cost shown in [22].A high-frequency generators having large-signal transient stability are introduced in [23].

2.3.2 DC MGCC (Direct Current Microgrid Central Controller)

In DC microgrid, DC power sources and loads are connected. The power supply connected with DC grid can be easily operated cooperatively, because they control only the DC- grid voltage. The most of alternative energy sources as well as energy storage devices produce and store electrical energy in DC. Thus the design of DC microgrid is fundamental if the DC loads and micro sources are to be easily integrated on the network. The system cost and losses are reduced. The DC system also eliminates the use of multiple converters which reduce the system efficiency. Skin effect are absent in DC system and no reactive power forms. Efficiency of DC is 10-22% more than AC system. In DC microgrid, there is no need of voltage synchronization and effect of phase imbalance illustrated in [24-25].

DC microgrid using different techniques

An autonomous-control method is proposed for DC-microgrid based distributed power generation system. A 10-kW DC microgrid system is designed to suppress the circulating current using only the DC-grid voltage. This shows the high reliability and flexibility of the system reported in [24]. To provide reliable supply to the loads, a new system is developed to control and operate DC microgrid. The different control and operation modes are discussed which shows the satisfactory performance of the DC microgrid operation in [26].To regulate the grid voltage and to control the load sharing between different sources, a voltage droop control method using Proportional (P) and Proportional-Integral (PI) controller is adopted with DC microgrid. The P and PI controller shows a good load sharing characteristics shown in .A droop based controller is used for equal sharing of load among different sources in DC microgrid. The Controller has high reliability and it lowers the cost. Steady state mathematical model is developed which is applicable to any interconnecting structure of load and sources. The effects of branch resistance and droop constants on the sensitivity of source currents are studied. To verify the results simulation is carried out in [25].

A DC microgrid is applied for residential house. All houses have a cogeneration system such as gas engine and fuel cell and share the power among the houses by the DC distribution line. A laboratory scale DC microgrid was constructed to examine the fundamental characteristics of the system. The results show that the system is able to supply high quality power to the loads against a sudden load variation. Also short circuit occurrence on one load does not affect the power supply to the other loads reported by author in [27].A low-voltage bipolar-type DC microgrid is proposed for high efficiency and high-quality power supply in which DC power is distributed through 3-wire lines. A DC microgrid for a residential complex is presented having Cogeneration system (CGS) like gas engine and fuel cell in each house and the power is shared among the houses with DC distribution line. By changing the number of CGS, total power can be controlled. The results showed that the proposed system can supply high quality power under several conditions in [28].

To form an autonomous DC microgrid, several distributed generation have been merged together with a pair of batteries and loads. A double layer hierarchical control strategy was proposed for the co-ordination of multiple-batteries. The results shows the performance of developed control in [29].System stability is analyzed by using state-of-charge (SOC) based adaptive droop control method illustrated in [30].A high speed differential protection schemes adopted in DC system for fast fault detection within microseconds in [31].Also a model is proposed to solve the problem of disturbances due to uncertain load changes in DC microgrid. The disturbance changes the parameters of microgrid. The proposed model is used to calculate the characteristics parameters of DC microgrid in [32].

2.4 Role of MGCC in the Area of Power Quality, Protection and Stability of Microgrid

2.4.1 Power Quality

Harmonic content, voltage unbalance frequency regulation are major power quality problem. Filters are introduced to eliminate the harmonics. Particle Swarm Optimization (PSO) algorithm is designed to regulate grid frequency and voltage flexible distributed generation are developed to control active and reactive power flow, also to mitigate voltage flicker and harmonics in [33]. In island-mode, as the main grid is disconnected, reactive power variation of the loads will lead to voltage fluctuation, because to improve the power quality in island-mode, a combined system is constructed by SVC and SAPF (shunt active power filter). The microgrid is connected to main grid by inverter which leads to current harmonics. The combined system can compensate reactive power and mitigate the harmonic currents simultaneously and therefore the power quality is improved in [34]. Also to improve power quality of microgrid in emergency condition, a micro source control algorithm and simulation using EMTP/RV is proposed. The micro-source controller proposed by simulation is more efficient than existing micro source control method for voltage-sag compensation ability or local high quality power supply shown in [35]. The power problems like THD and unbalanced voltages occur in microgrid due to non-linear and unbalanced loads. The control strategy is proposed to eliminate the non-linear and unbalanced loads based on d-q reference frame. To eliminate the unbalanced voltage disturbance a back-to-back converter is adopted in [36]. The power quality problems like voltage sags and unbalanced voltages are compensated by a 3-phase, 4-wire grid interfacing compensator. The compensator is used with each individual DG consists of two 4-leg inverter using shunt and series together to improve the power quality and current flowing between the microgrid and main grid illustrated in [37].Also to improve the power quality in a microgrid, a dynamic voltage restorer (DVR) connected with the point of common coupling (PCC) and grid by a rectifier is proposed in [38].

2.4.2 Protection

Protection is the major challenge in microgrid. Whenever fault occurs on microgrid, protection system should isolate the microgrid from main grid fast to protect the microgrid. There is various protection issues related to microgrid. When Distribution Generation units are connected to grid it changes the fault current level. Also relay operation is affected. The reverse power flow is main challenge for microgrid operation. The injection of 1-phase power into distribution grid affects the balance 3-phase currents, due to increase in unbalance current, stray current flows to earth. It should be limited. There are some possible solutions for protection issues like protection of inverter interfaced Distribution Generation units, differential protection scheme, balanced combination of different types of Distribution Generation units and adaptive microgrid protection system. Adaptive protection is the best solution as there is automatic readjustment of relay in both modes reported in [39-41]. MGCC is the main component of adaptive protection system. MGCC is used to update relay settings. MGCC will monitor the state of microgrid by polling all individual directional over current relays in [41].A differential scheme based on time-frequency transform is proposed for shunt and high-impedance faults for the protection of microgrid in [42].A protection scheme is employed for a microgrid which detects the location of faults and then use trip action in [43].

2.4.3 Stability

Energy storage system, control strategies of the micro-sources and the energy storage system, types of load in the microgrid, location of the fault and inertia constant of the motors are the major factor which effects the stability of the system. To improve the stability, simulation is carried out. The results proved that by using under voltage load shedding on motors and through control of the flywheel stability can be obtained in [44].A small signal stability analysis of rectifier inverter fed induction motor drive are performed by neglecting the harmonics. The stability study has been carried out using Eigen value criterion. The result shows that oscillatory modes are well damped shown by author in [45]. The dynamic model is presented with active load control to provide stability of microgrid. Active loads are modelled in non-linear state-space linearized around an operating point are joined to microgrid. Due to unstable operation of inverter & to obtain steady-state voltage regulation, rectifier controller is designed by using conventional frequency domain analysis in [46]. A small-signal model of a microgrid is proposed to find out stability of a microgrid by author in [47].

2.5 Inference

This chapter covers the brief literature survey on microgrid central controller. There are number of factors on which operation of microgrid depends. In this review work, the feasibility of microgrid operation, its advancements are investigated. For the worldwide research on DERs, environment friendly and cost effective technologies are needed. The power quality, protection and stability study has been carried out. All these factors are necessary to increase the acceptability of microgrid as an emerging power scenario.

CHAPTER 3

DESIGN AND SIMULATION OF A CENTRAL CONTROLLER FOR MICROGRID

3.1 Microgrid: Use of Renewable and Non-renewable Energy Resources Efficiently

3.1.1 Concept of Automated Microgrid

Microgrid is designed to supply the power for a village or a small town etc. in which small resources of power like solar cell, fuel cell, bio-gas plant, micro hydro plants, wind power are the generating units. Some of power resources generate d.c power and we have to use rectifier and inverter for desired a.c voltage level and frequency. Then all these different type of power resources should be synchronized to same frequency, voltage level and same phase difference. Then the synchronized unit is connected with the central controller of microgrid. The microgrid can also be connected with large grid of infinite power source like thermal power plants. Smart microgrid ensure that first of all its own energy sources will fulfill the demand and if the demand is more than generation then the microgrid take supply from large grid and fulfill the demand of its own load.

It can work efficiently in islanded mode. Islanded mode means that when the large grid is disconnected due to some fault or transients, then smart microgrid have to work in the way that it should first full fill its critical load demand. Examples of critical load are Hospitals, Petrol Pumps etc. Then it will serve another load according to the priority [2].

3.1.2 Renewable and Non-renewable Energy Resources

In this section, different types of energy resources are described which can be used in microgrid.

(i) Wind Turbine: Wind Turbine can be used to generate power in microgrid. The range of wind turbine units is within 700-1200 kW. The total maximum capacity ranges 200-500 MW. The cost of wind turbine per MW is less compared to photovoltaic cell power.

(ii) Photovoltaic Systems: Size of photovoltaic system can be range from 2 kW-6 kW for a residential unit by combining the several solar units. We can achieve several MW by combining large number of cells but it needs a large space. Its installation cost is high but running cost is very low due to free of solar energy.

(iii) Fuel Cells: The operating principle of fuel cell is to convert electricity from hydrogen gas. It produces DC voltage and inverter can be used to convert in AC voltage. The ratings are near than 300 kW.

(iv) Combustion Gas Turbine: Combustion gas turbine capacity ranges from 30 kW to 10 kW. As the rotating speed of combustion gas turbine are generally higher than our 50hz/60hz power system but we can convert higher speed to our usable synchronize speed by using gear system.

(v) Diesel Generator Set: Diesel engine generators have ratings from 5 kW to 300 kW. They can be installed near the most important load. The initial cost is low but operating cost is high. In case of emergency when the microgrid is not able to supply power, they can supply the desired power to load.

3.1.3 Need of Renewable Energy Sources

Renewable energy sources can be installed near the consumer site. This reduces pollution and transmission losses. The benefit of this scheme is that we can easily increase our capacity and when the demand is lower than the generation, then we can sell the energy to large grid and smart meter is used for keeping the record of energy pooling.

3.2 Central Controller Simulation for Critical and Non-Critical Loads in Microgrid

As the power systems in microgrid have many different types of loads in which some loads which need 24 hours power supply. They are concluded as critical load whereas some residential units can be concluded as non-critical loads. When the demand is higher than the generation of renewable energy source then we connect large grid and supply the power to all loads in microgrid. If any fault or transient occurs at the grid end, then we have to switch off non critical loads and have to give immunity to critical load. If it does not occurs than the frequency will drop considerably and it affects the voltage level also. In that case the consumer end electrical devices may damage and to avoid this, we have to do switching off the load which has less importance. In this central control scheme, first we start the critical load and if the power generation is more than the critical loads then we switch on second load & the same algorithm follows. The loads will switch on according to their priority.

3.2.1 Assumptions for Smart Microgrid Modelling

(i) Lossless Distribution Line: We have made assume that the transmission losses are negligible. Because the microgrid functions in a small area, the transmission losses are not so much high and they do not affect the modelling calculations considerably. If this model is used for a large and complex grid system, then we should need to include the transmission losses.

(ii) Transmission Line is Resistive and Less Inductive: In low voltage microgrid, the transmission lines are resistive. But in long transmission lines, the resistance R may be neglected and reactance X is many times greater than that of resistance (X>>R). So in this central controlling technique we have considered the transmission line as a highly resistive and less inductive. However we have also connected the load as a parallel RLC branch, but the value of inductance is taken small [2].

(iii) Single Phase System: In this central controlling scheme, we have used only single phase system to simplify the modeling. This model measures and compares the power by the command of central controller that controls the circuit breakers. In the three phase system, we can use this same modelling approach.

(iv) System is Synchronized: As in the microgrid, we can have many types of renewable energy sources. We have assumed that all that energy sources are connected with the grid after synchronization. The voltage level, frequency level & phase difference are in same level.

(v) Large Grid as Infinite Power Source: We have assumed that the large grid as an infinite power source i.e. whatever the demand of the microgrid load, the large grid will deliver the power.

3.2.2 Description of Microgrid Central Controlling Technique

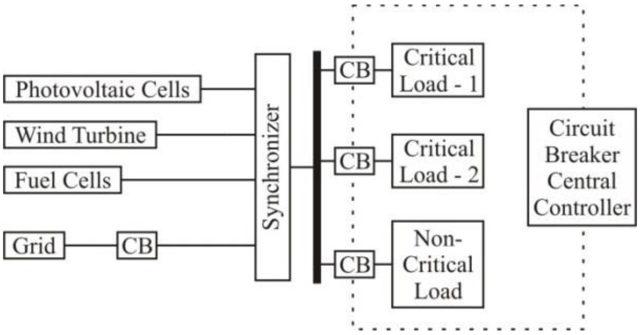

Fig. 3.1 Microgrid Structure with Central Controller

The microgrid structure is shown in Fig. 3.1 has different types of renewable energy resources, any one of them or all of them can be employed in microgrid. The renewable resources generate different voltage amplitude and different frequency. They should be synchronize in same voltage amplitude and should have same frequency. This work is done by the synchronizer. The grid is also connected with synchronizer. Then the microgrid main bus is connected with the synchronizer. In a microgrid, there may different kind of loads like some critical loads, and some non-critical loads. Different kinds of loads are connected with circuit breakers and the central controller control the circuit breaker's operation.

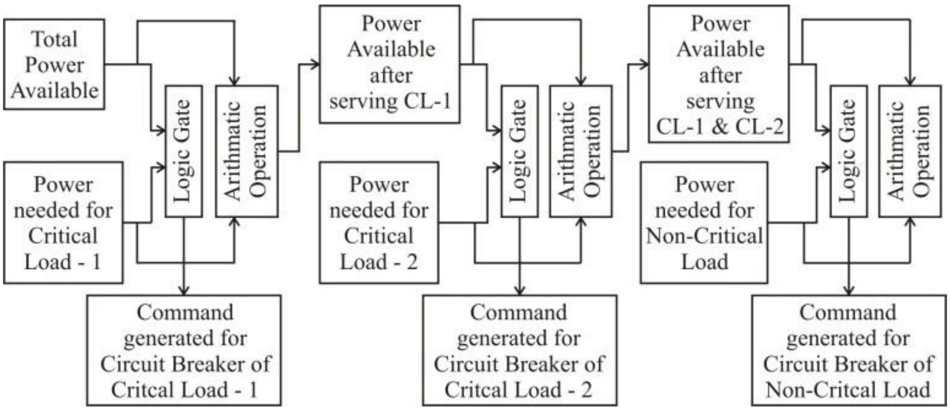

Fig. 3.2 Central Controller for Microgrid

In this central controlling technique shown in Fig. 3.2, we have used the measuring and comparison technique to control the circuit breaker of different load areas. We have assumed three different types of renewable energy sources for microgrid and one diesel generator for the critical load system when the power generation is not adequate to fulfill critical load demand.

The logic gates are used for comparison of power generation and load demand and the generated code will instruct the circuit breaker accordingly. Sample and hold technique is used for measuring the power after half cycle, so this technique can only be used for ac load. If the load is dc, then the sample and hold technique should be removed.

(i) Steady State Analysis of Microgrid in Grid Connected Mode

In this mode, the microgrid is connected with the grid, and we have assumed that the main grid is connected with infinite power bus. So the microgrid will work in normal mode in grid connected mode.

Fig. 3.3 shows total power and Fig. 3.4 to Fig. 3.6 show the Critical Load-1, Critical Load-2 and Non-Critical Load power waveforms. The steady natures of the waveforms show that the system is healthy.

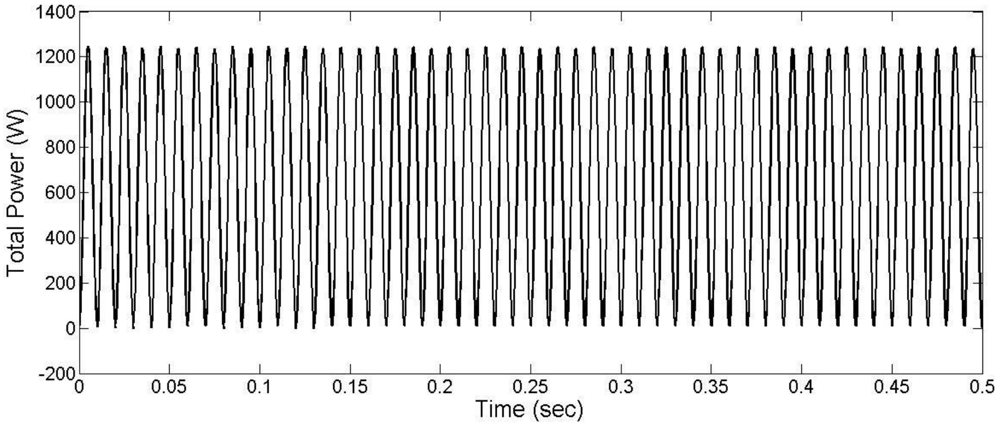

Fig. 3.3 Waveform of Total Power taken by Microgrid in Grid connected Mode

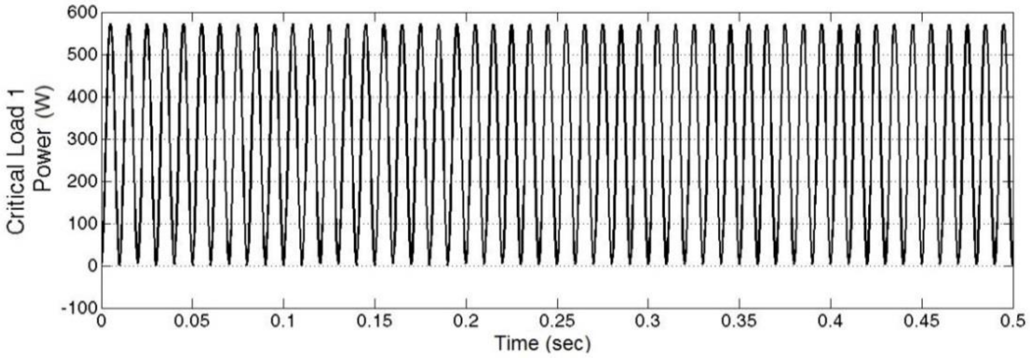

Fig. 3.4 Waveform of Power taken by Critical Load-1 in Grid connected Mode

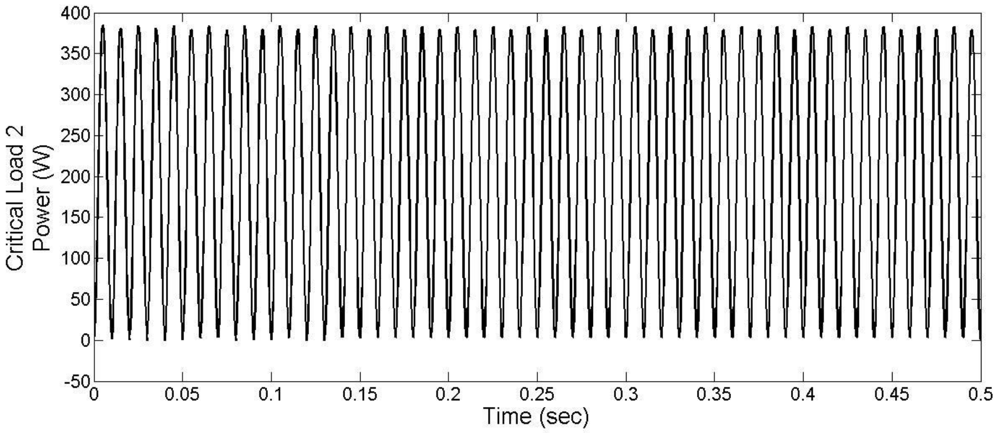

Fig. 3.5 Waveform of Power taken by Critical Load-2 in Grid connected Mode

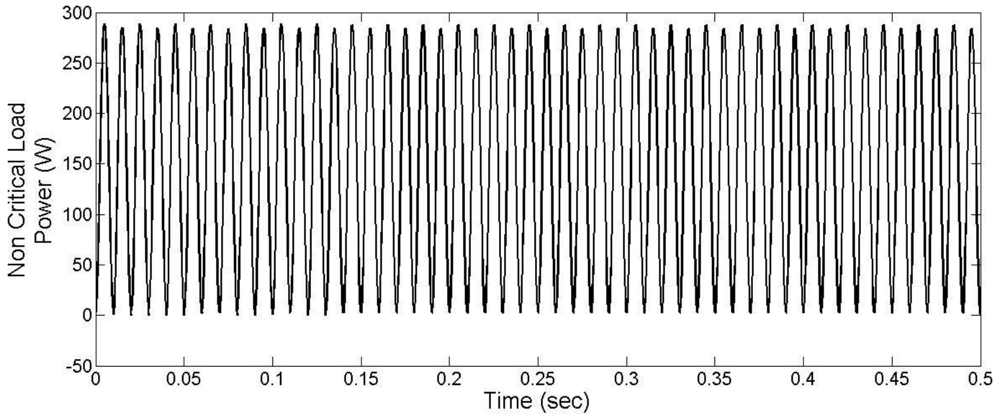

Fig. 3.6 Waveform of Power taken by Non-Critical Load in Grid connected Mode

(ii) Steady State Analysis for Islanded Mode

(a) Total Load is More than Generation

When the main grid is disconnected, and if the load becomes more than the renewable generation then the less important load should be disconnected and the most important load should be immune. In Fig. 3.7- Fig. 3.10, show that the Non-Critical load is disconnected after half cycle, because the total power generation cannot support the non-critical load. Whereas the Critical Load-1 and Critical Load-2 can be supplied by the renewable energy resources.

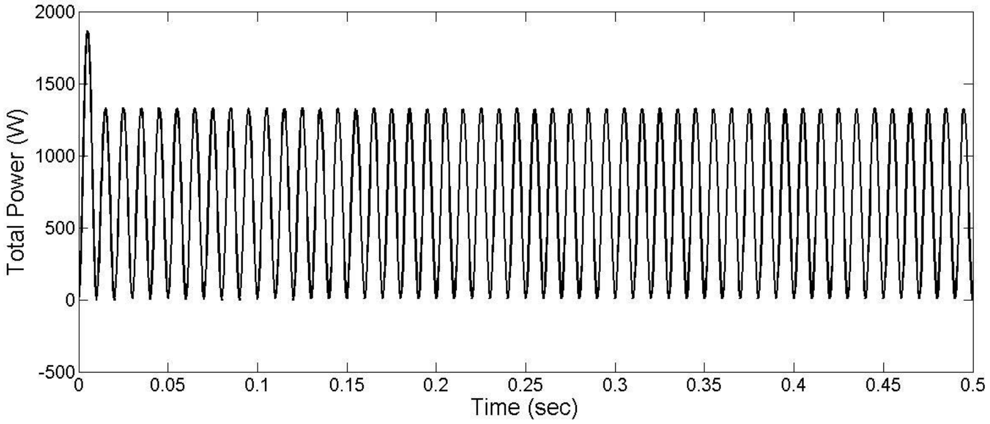

Fig. 3.7 Waveform of Total Power taken by Microgrid in islanded Mode

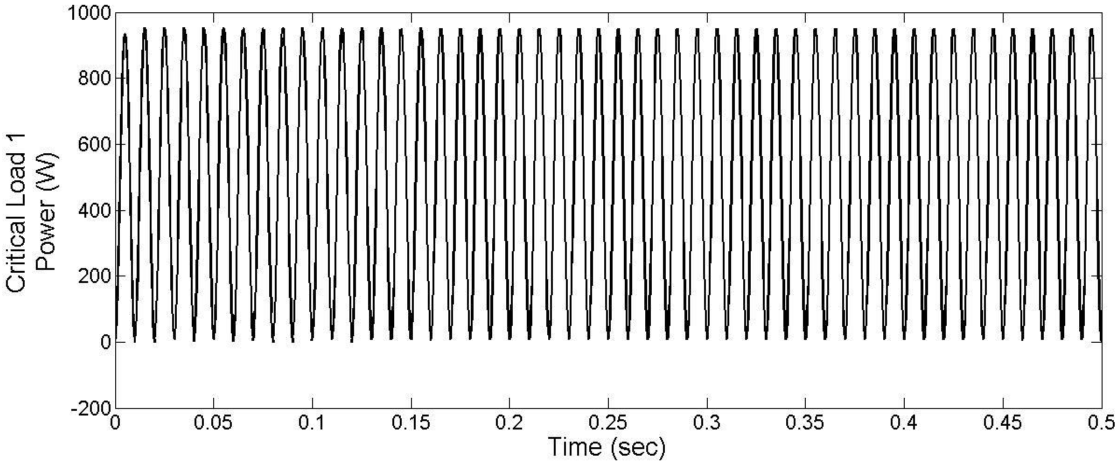

Fig. 3.8 Waveform of Power taken by Critical Load-1 in islanded Mode

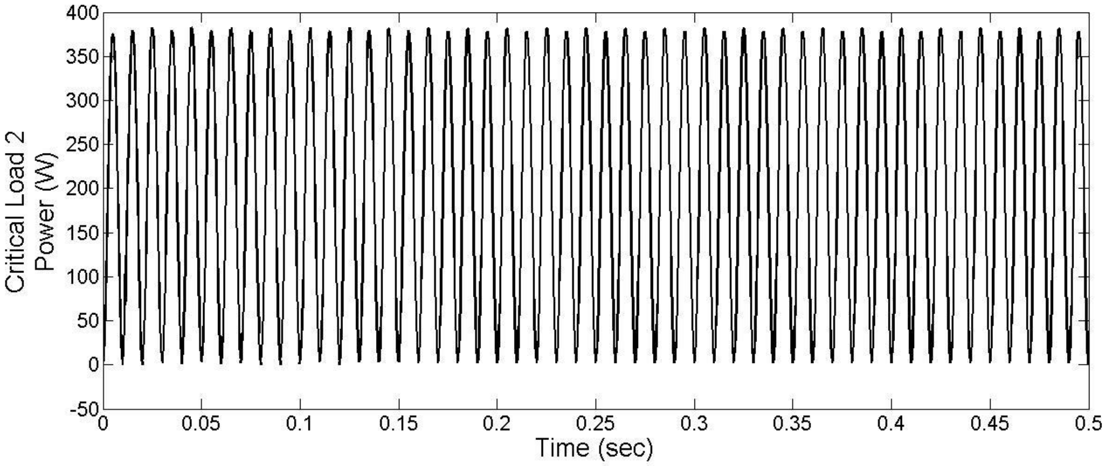

Fig. 3.9 Waveform of Power taken by Critical Load-2 in islanded Mode

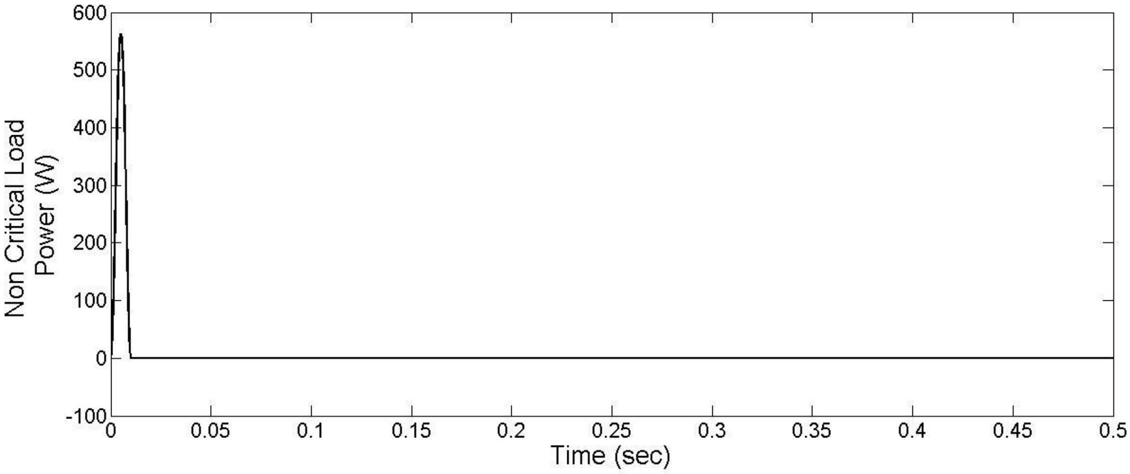

Fig. 3.10 Waveform of Power taken by Non-Critical Load in islanded Mode

b) Total Load is Less than Generation

The output will be similar to the steady state analysis in grid connected mode.

c) Outage of Renewable Energy Resources in Islanded Mode

In islanded mode, when any of the renewable energy resource is out then the command signal 1 will be sent by the MGCC to the diesel generator to participate in power sharing.

iii) Transient State

This study shows that whenever some fault occurs on any resource or the main grid, then that part will be isolated by the circuit breaker itself. Then it will calculate the total power available and compare to the load demand. If the demand is less than the power available then it behaves like steady state analysis as discussed, and if the demand is more than the available power then it will be shifted to islanded mode switching off the load according to priority.

3.3 Response of the Central Controlling Technique

The response of the central controlling technique will appear within half cycle of the power system for one load area. If the frequency is 50 Hz then the time taken by this model is 10 milli-seconds. It can decide the controlling of 100 load areas in one second.

This process works according to priority setting for the different load areas. The higher priority load will be switched on first and after 10 milli-second it again measures the power demand of second priority load, if it is in limit then it will be on otherwise it will remain switch off.

3.4 Inference

This chapter presents the smart microgrid analysis at the stage of designing and planning. The modelling is done in the Matlab/Simulink and has given the desired output result. This technique helps us to ensure the switching “off” or “on” the loads according to the generation of power in a very short time. This modelling can be increased to more number of loads by repeating the previous process and it does not slow down the computation process, because at one time it only measure one load and remember the previous condition. So in case of a more complex microgrid system, satisfactory results could be expected.

CHAPTER-4

MODELLING AND SIMULATION OF WIND TURBINE BASED MICROGRID

4.1 Overview on Wind Turbine based Microgrid

The conventional sources of electrical power generation are fossil fuels like coal, natural gas & oil. Which are limited in nature. They are being exhausted at a very fast rate due to large generation units based on fossil fuels. We are also looking forward with nuclear energy. But there is also a serious health hazard by using nuclear fuel because there is always a chance of accident in nuclear power generation plant and the radioactivity still last for 1000 years in nuclear waste [48]. As we can see nuclear power for our future energy but they are also limited in nature. So we have to move on unlimited energy. Wind energy and solar energy are unlimited to us with respect to time. Whereas fossil fuels and nuclear fuel increasing the health hazards by polluting the environment. Wind energy and solar energy are referred as clean energy in this regard [49].

The investment cost of coal, thermal, nuclear, gas combined cycle power plant are less than wind and solar energy but the operating cost is very much high if compared on the basis of equal amount of power generation.

In India, the aggregate Transmission and Distribution losses of all the states is nearly about 27%. The microgrid concept can help to reduce the T&D losses as well as the capital cost requires installing the transmission infrastructure. The area which is closer to coastal line should prefer the wind energy and the plain area should install solar energy. The cost of wind energy has declined at a very high rate and it is cheaper 4 to 5 times than the PV array. Since the space required by wind generator is much less than photovoltaic cells. The height required by a 100 kW is approximate 25 m, for 600 kW it is nearly 40 m, for 1500 kW it is nearly 70 m and for 5 MW the height which is approximate 125 m. The average size of the wind turbine is 1 MW worldwide. The rotor diameter of 5 MW turbines is 13 m. Its base is 12 m with tapering to top width of 4 m.

Turbine rating of 300 kW needs wind speed of 7m/sec and 450 kW needs 8m/sec. The distance between the wind turbines facing the wind in 1 horizontal line should be 2 to 4 times the rotor diameter and the wind turbine behind the other wind turbines should be placed at a distance of 8 to 12 times the rotor diameter. We also have to consider the number of plates as the more number of plates do not give more power but they help to give more torque so the construction become heavier. The number of blades ranging from 1 to 40 or even more. A one blade wind turbine is technically feasible but it will give excessive vibration and highly pulsating torque. Modern rotors have two and three blades.

We have to control the speed to protect the rotor, generator and power electronic equipment at the time of very high wind speed. It can be controlled by controlling the pitch angle. It has also effect on environment as the speed at the tip of blade can be more than 350km/hr and it is danger to birds. It has also electromagnetic interference with radio, TV tower signals. A 600 kW machine has 55 dB noise levels. If we compare it, the noise level of average office is 50 dB, average factory noise is 60 dB and average Street is 70dB.

In India, we have many sites with 25 to 30 km/hr wind speeds at annual average level at 10-25 m height. Earth is covered by 71% ocean and the wind speed is 30-40% higher in the oceans. An offshore wind generation can generate 50-70% more power. But cost 50-100% more than on land wind turbines.

HVDC cable is use in the oceans and it is well established technology. Normally the single-fed induction generator is used with the wind turbines but the machine with higher rating from 3 to 5 MW Doubly Fed Induction Generator is used. There is a grid related problem with Doubly Fed Induction Generator (DFIG). Because instantly disconnecting a large wind power generator during emergency condition could lead to grid blackout [48].

In this chapter, we have used grid connected Induction generator coupled with wind turbine and one synchronous generator which is synchronized with wind turbine and grid. At the time of grid failure, synchronous generator will still work in parallel with wind turbine.

4.2 Components of Wind Turbine based Microgrid System

The different components of wind turbine based microgrid system are shown below:

4.2.1 Induction Generator

Induction machines are mostly used in the industry and it is invented in 1880 by Nikola Tesla and financed by George Westing house, represents a well-established technology [49]. Advantage of the induction machine is its rugged brushless construction, so it does not require separate DC field. This results a low capital cost, low maintenance and better transient performance. This is the reason that, it is widely used in small and large wind turbines and small hydro project. The machine is available in several megawatt ratings. The schematic diagram of Induction generator is shown in Fig. 4.1.

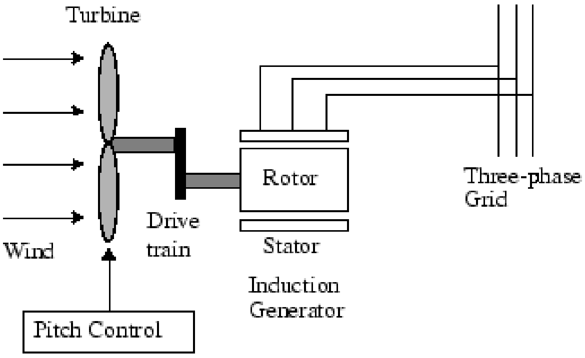

Fig. 4.1 Schematic Diagram of Induction Generator

The principle of the induction generator is when voltage is applied to the stator, then current set up in the rotor. Stator flux and the rotor flux interaction produce torque. The magnitude of torque is given by:

$$T = k\,\phi\,I\cos\phi_1 \qquad \ldots.\ (4.1)$$

Rotor will start accelerate at this torque. If we assume that the rotor bearings are frictionless in a vacuum and no load is attached to the shaft, then it will rotate freely with zero resistance. Then rotor will attain same speed as the stator flux, i.e. synchronous speed. In this condition, the current produced at rotor is zero, hence no torque will produce and none is required. It will continue to run at synchronous speed.

Now if the rotor is attached with external mechanical load like a fan, it will slow down. The machine will act as a motor. But if we attach a wind turbine to the rotor, it will drive the rotor faster than synchronous speed via a step-up gear system, the torque and the induce current in the rotor reverses it direction. Now the machine will act as a generator.

4.2.2 Doubly Fed Induction Generator

The doubly fed induction generator as shown in Fig. 4.2 is also an emerging technology and it is presently used for large wind turbines, 2 MW to 3 MW General Electrical company machines are the examples [50]. In this, a voltage source frequency converter feeds slip frequency power to the three phase rotor. The motor is fed from the stator and the rotor. Power electronic frequency converters are used in this process.

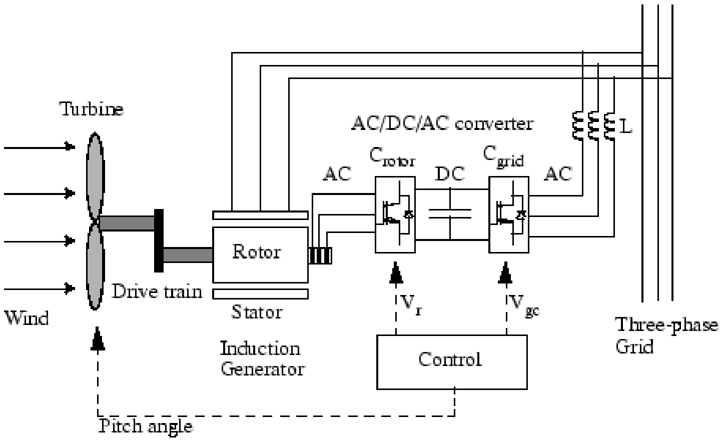

Fig. 4.2 Schematic Diagram of Doubly Fed Induction Generator

The attractive feature of the doubly fed induction generator is that 20% -30% of power needs to pass through the frequency conversion where as 100% is to pass through in variable speed synchronous generator. Hence this is a cost advantage. But instantly switching off of the large doubly fed induction generator may cause grid blackout.

4.2.3 Synchronous Generator

Most of the electric power is produced by the synchronous generators. Synchronous generator works at constant speed related to fixed supply frequency so it cannot be used at variable speed operation such as in wind turbines without power electronic equipment. However the reluctance machine can be used for small wind turbines, rating up to tens of kW. It is suited for constant speed systems and can be used at solar thermal power generation plant. In grid connected mode, it does not require reactive power as in the case of induction generator.

4.3 Microgrid System

4.3.1 Description of Simulink Model

The model is simulated in MATLAB / Simulink which consists of three wind turbines with 1.5 MW each and one synchronous generator with 1 MVA capacity. There are eight loads of 500 kW each. Which are assumed as critical load. There is one 4 MW load. It is non-critical load. The whole system is considered as grid-connected system.

The wind turbine is of single-fed induction generator as it needs grid connection to generate the power. At the time of grid-connection failure, the synchronous generator will act as grid connection to wind turbine. However, at the time of grid-failure, the wind turbine is not able to generate with its full capacity, because its output decreases if it is disconnected from the main grid and shifted to the weak grid [51]. The load is connected with 3-phase 415 V (rms) supply voltage.

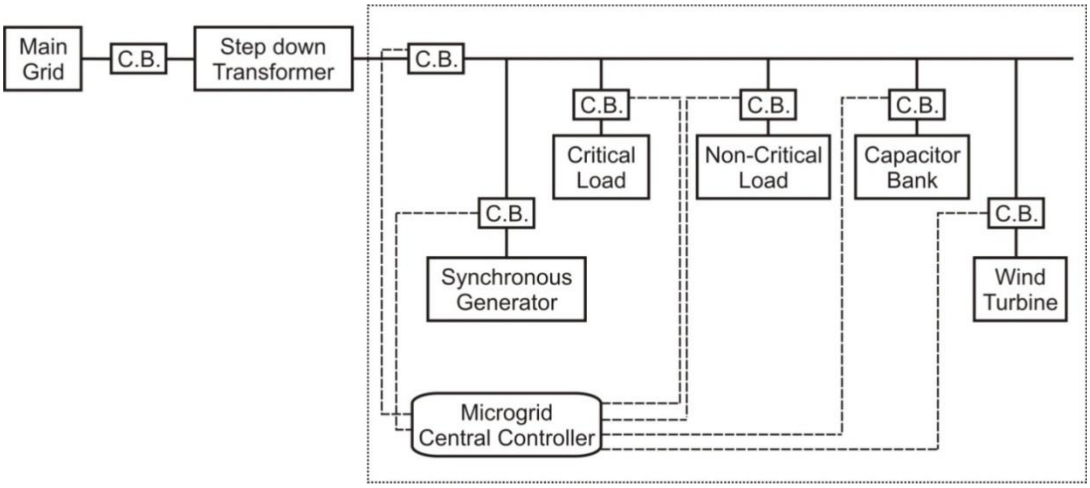

Fig. 4.3 Block Diagram of Microgrid Model based on Simulink

Two different loads connected in parallel with the power line. Load-1 is considered as critical load and load-2 is considered as non-critical load. Critical load is the most important load and it is given the first priority. Critical load operates in any condition. For example, in a locality the ‘Hospital’, ‘Petrol pump’, ‘Water pump’ may serve as critical loads. For an Industry, their ‘UPS’ system may be a critical load supplying the computers.

TABLE 4.1: Specification of Wind Turbines

No. of machines	3
Nominal power	1.5 MVA
Line-line voltage	415 V
Frequency	50 Hz
Stator resistance	0. 004843 p.u.
Stator inductance	0.1248 p.u.
Rotor resistance	0.004377 p.u.
Rotor inductance	0.1791 p.u
Mutual inductance	6.77 p.u
Inertia constant H(s)	5. 04 p.u
Pole pairs	3

The different types of equipment and their specifications are presented in tabular form. The specification of wind turbine and synchronous generator are presented in Table 4.1and Table 4.2 respectively. The details of loads and capacitor bank are given in Table 4.3 and Table 4.4. The grid and transmission line parameters are described in Table 4.5 and Table 4.6 respectively.

TABLE 4.2: Specification of Synchronous Generator

Rotor type	Salient-pole
Nominal power	1 MVA
Line-line voltage	415
Frequency	50 Hz
Reactances Xd, Xd’,Xd’’’	1.305, 0.296, 0.252 p.u
Reactances Xq, Xq’’, Xl	0.474, 0.243, 0.18 p.u
d axis time constants	Open – circuit
q axis time constants	Short – circuit
Time constant Tdo’, Tdo’’, Tq”	4.49, 0.0681, 0. 0513 s
Stator resistance	0. 003 p.u.
Inertia coefficient	3.7 s
Pole pairs	20

TABLE 4.3: Specification of Load

No. of identical loads	8
Line-line voltage	415 V
Frequency	50 Hz
Active power	500 kW
Inductive power	242161 VAr
Power factor	0.9

TABLE 4.4: Specification of Capacitor Bank

Location	Point of common coupling
Configuration	Delta
Line-line voltage	415 V
Frequency	50 Hz
Capacitive reactive power	One MVA

TABLE 4.5: Parameters of Main Grid

Line-line voltage	33 kV
Frequency	50 Hz
Internal Connection	Wye-grounded
Source Resistance	0.8929 ohms
Source inductance	0.01658 H
Base voltage line-line	33 kV
Generator type	Swing

TABLE 4.6: Line Parameters

Location	Between grid and point of common coupling
Frequency	50 Hz
Positive sequence resistance	0.1153 ohms/km
Zero-sequence resistance	0.413 ohms/km
Positive sequence inductance	0. 00015 H/km
Zero-sequence inductance	0. 00332 H/km
Capacitance	Negligible
Line length	5 km

4.3.2 Description of Central Controller

The model is based on the magnitude of voltage level at point of common coupling and at critical load. If the voltage level falls below certain level at point of common coupling then the central controller isolates the microgrid from the main grid. Then it measures the voltage level at critical load, if it is below its described value then it disconnects the non-critical loads. When the grid is disconnected, the wind turbine needs reactive power, and the reactive power is provided through the shunt capacitors. The central controller switch on the capacitor bank placed near the wind turbine. It maintains the voltage level at the critical load.

4.4 Description of Microgrid Simulation

The logic behind the controller is to measure the value of voltage across the load. It compares the voltage level of load with the normal limits.

If the voltage does not droop then all the loads will remain connected. When there any fault occurs on the line, (such as line to ground fault) the current increase suddenly at the fault point and the voltage level decreases. The controller senses the voltage level and takes the appropriate decision. If the voltage level fluctuate to ±15%, then the controller isolates the microgrid from the main grid. The fault is simulated the satisfactory results are observed.

4.4.1 Grid-connected Mode Operation of Microgrid in Nominal Condition:

We assume the connection of microgrid with the main grid as normal operating mode, because the grid can handle any load within the small micro grid. All the loads are connected with the power line of microgrid which is powered by wind turbine synchronous generator and grid. These possible two cases are stated below.

(i) Power Generated by Wind Turbine and Synchronous Generator is less than Load Demand.

Power generated by W.T generator + Synchronous generator power < Load power demand

(Load Demand – 8 MW)

In this case, when the load is higher than the generation in microgrid, it should take power from the main grid. We have measure the current at different locations in the system and by applying the Kirchhoff's Current Law; it shows the direction of current is flowing from main grid to the microgrid. This satisfies the expectations.

a) Voltage Profile

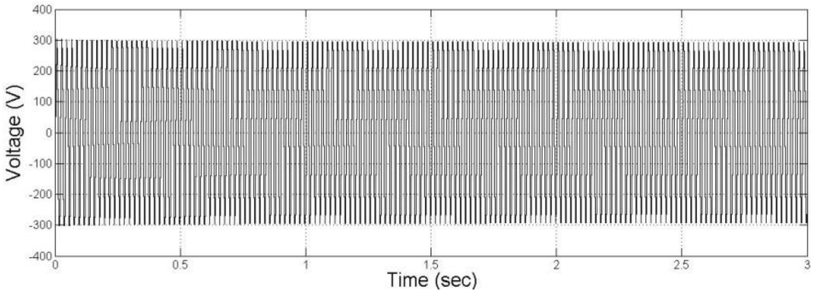

Fig. 4.4 Instantaneous voltage per phase of Wind Turbine and Load

The peak value of instantaneous voltage in steady state and the peak value is not 340 V because the 11 kV line is heavily loaded with 8 MW load. The voltage drop appears in the 5 km line. The line has some resistance which causes voltage drop across it. The result is presented in Fig. 4.4.

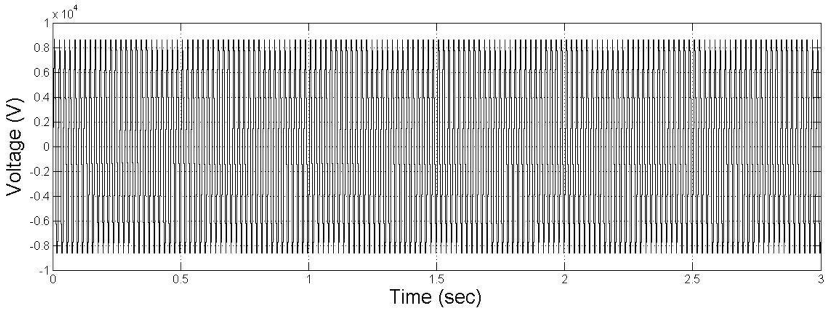

Fig. 4.5 Instantaneous Voltage per phase of Synchronous Generator

The voltage output of the synchronous generator is in limits with grid connected mode as shown in Fig. 4.5.

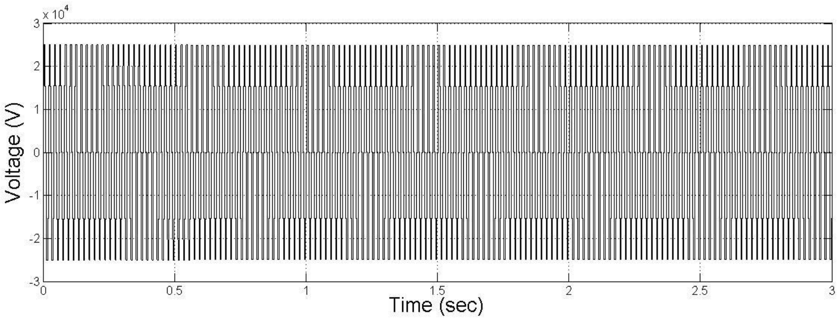

Fig. 4.6 Instantaneous Voltage at Main Grid

The voltage of the main grid is in the limits in the steady state is shown in the Fig. 4.6.

b) Current Profile

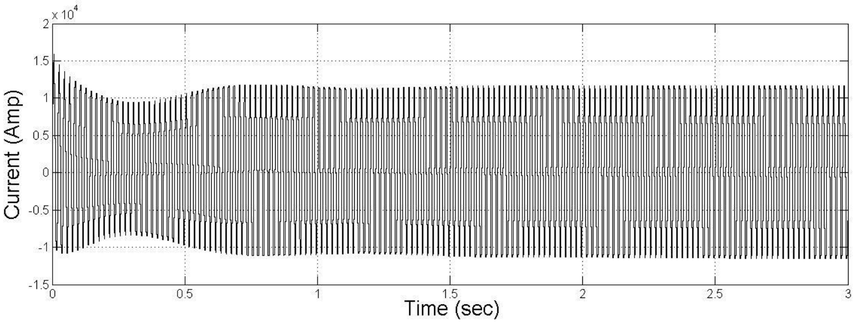

Fig. 4.7 Instantaneous Current of Wind Turbine

As shown in Fig. 4.7, the wind turbine current output is fluctuates initially and becomes stable after first second. This is due to the reactive power requirement by the grid in the starting condition.

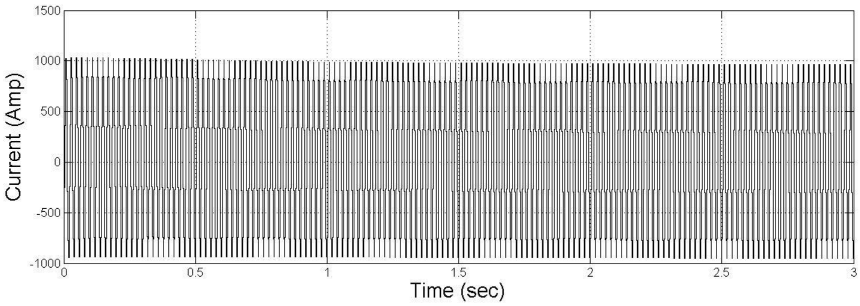

Fig. 4.8 Instantaneous Current of Critical Load

Fig. 4.8 shows the current profile of the critical load. This shows the instantaneous values satisfactory. The load power factor is 0.9. Due to this reason the peak value of critical load current in the positive half and in the negative half one not same.

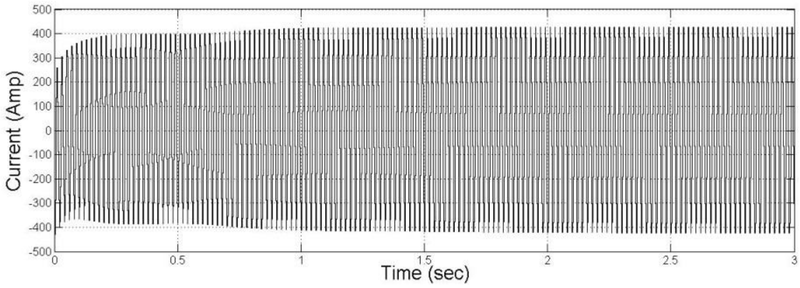

Fig. 4.9 Instantaneous Current at Point of Common Coupling of Main grid

Fig. 4.9 shows the current measured at the microgrid coupling point with synchronous generator and main grid. This fluctuates at the first half cycle because of operation of the wind turbine.

The instantaneous current showed by the synchronous generator is shown in Fig. 4.10.

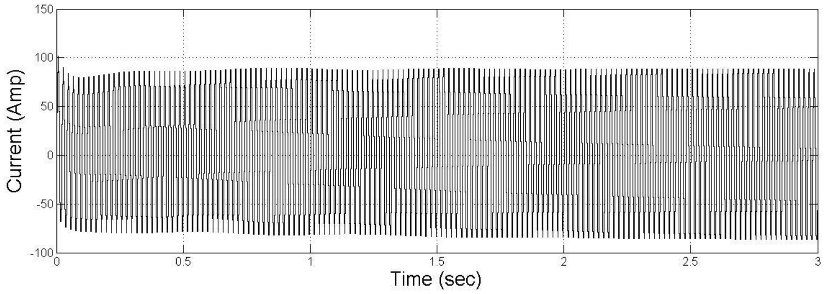

Fig. 4.10 Instantaneous Current of Synchronous Generator

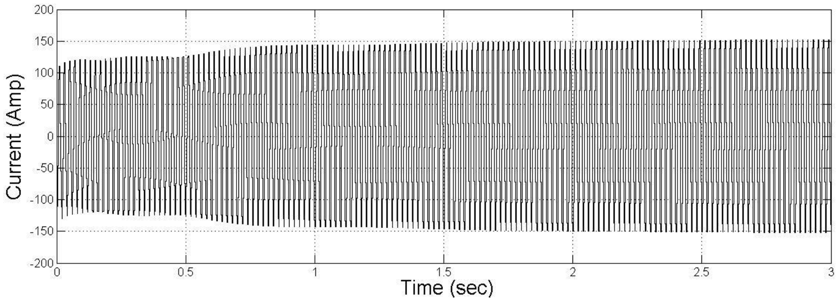

Fig. 4.11 Instantaneous Current per phase at Main Grid

The instantaneous current of the main grid is shown in Fig. 4.11. As this current is on 33 kV line and it is observed that the current at point of common coupling is the summation of the current of main grid and the synchronous generator. This shows that the demand is higher than the amount of power generation in microgrid and it draws additional power from the grid.

c) Profile of Real and Reactive Power

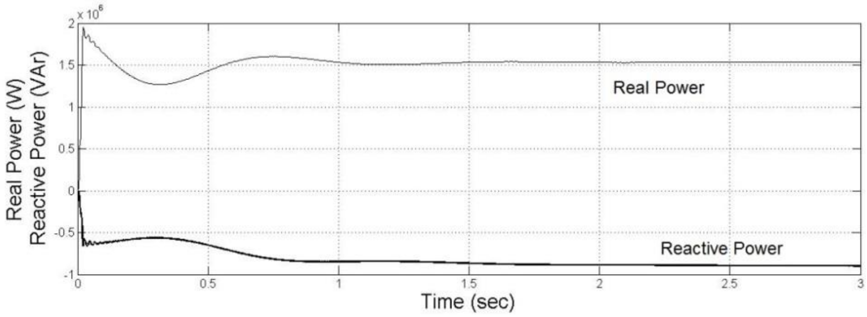

Fig. 4.12 Real and Reactive Power per phase of Wind Turbine

Fig. 4.12 shows the real (P) and reactive power (Q) of the wind turbine. The wind turbine is an induction generator and it needs some reactive power to work as a generator [51].

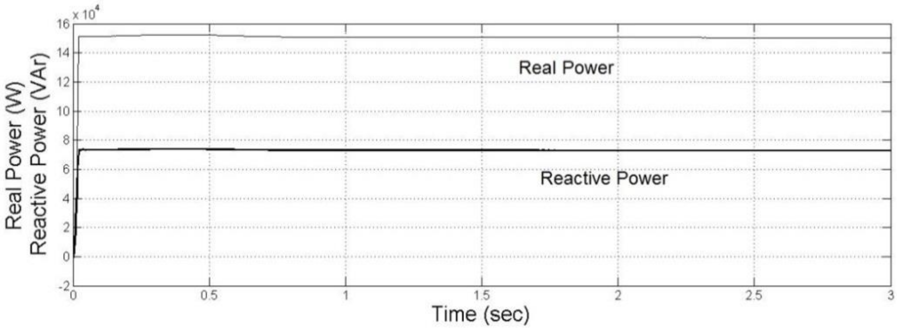

Fig. 4.13 Real and Reactive Power per phase of Critical Load

The real and reactive power of the load is shown in Fig. 4.13. The load is taken as inductive load and its power factor is 0.9. Both the real and reactive power is not fluctuating after 1 second. Hence the critical load is healthy.

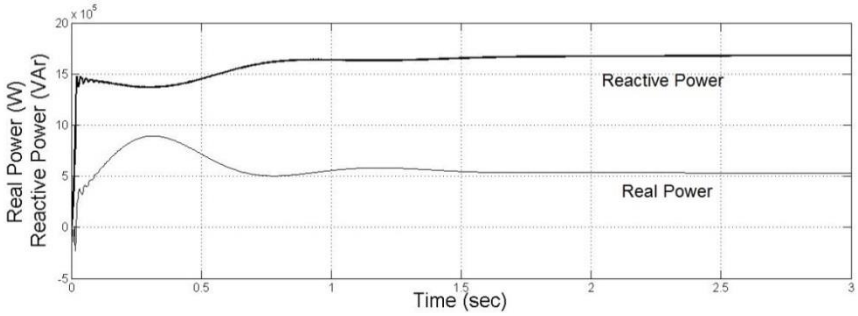

Fig. 4.14 Real and Reactive Power at Point of Common Coupling of Microgrid

Fig. 4.14 shows the real and reactive power at point of common coupling. This shows the reactive power is more than the real power. This is due to the reactive power demand by the wind turbines. In grid connected mode the reactive power is delivered by the grid to the wind turbines.

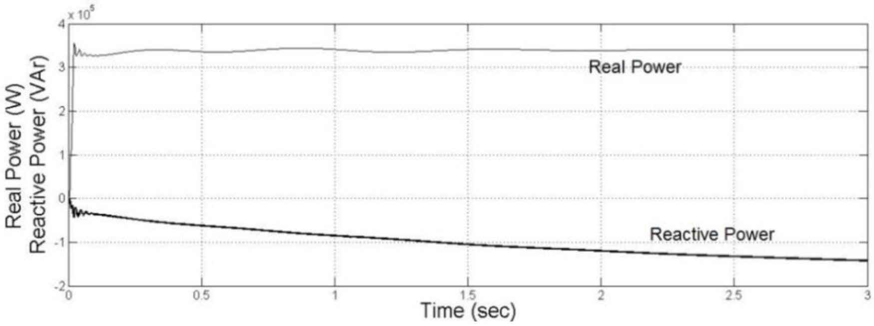

Fig. 4.15 Real and Reactive Power per phase of Synchronous Generator

The real and reactive power of the synchronous generator is shown in Fig. 4.15. Real power is in steady state after 1.5 seconds and the reactive power is slowly getting in steady state.

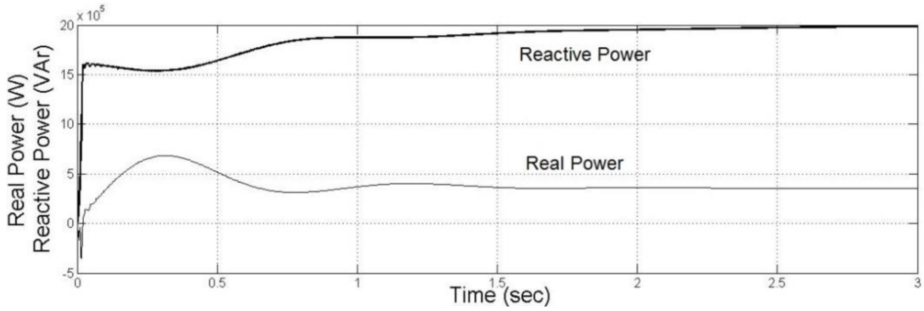

Fig. 4.16 Real and Reactive Power per phase at Main Grid

The real and reactive power of the main grid delivered to the microgrid is shown in Fig. 4.16. The reactive power is higher than the real power due to the reactive power demand by the wind turbine. We can see that the real power is slightly less than the real power shown at the point of common coupling. This shows that the power is injected in the microgrid by the synchronous generator.

(ii) Power generated by Wind Turbine and Synchronous Generator is less than Load:

Power generated by W.T generator + Synchronous generator power > Load power demand

(Load Demand – 3 MW)

In this case, the power generation in the microgrid is more than the load connected within the microgrid. The power should be fed into the grid. In the prescribed model, the direction of power is analyzed by active and reactive power flow and it shows that the power is being fed into the grid. The results are shown below.

a) Voltage Profile

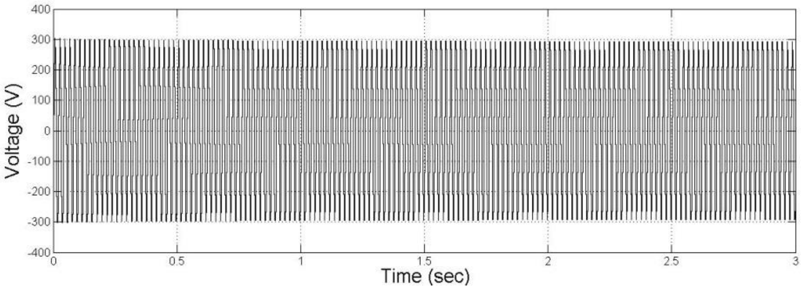

Fig. 4.17 Instantaneous Voltage per phase of Wind Turbine and Load

The voltage at the wind turbine is in normal limit when the microgrid power demand is less than its power generation. In Fig. 4.17, the voltage level is slightly improved then the previous case when the microgrid is loaded with 8 MW.

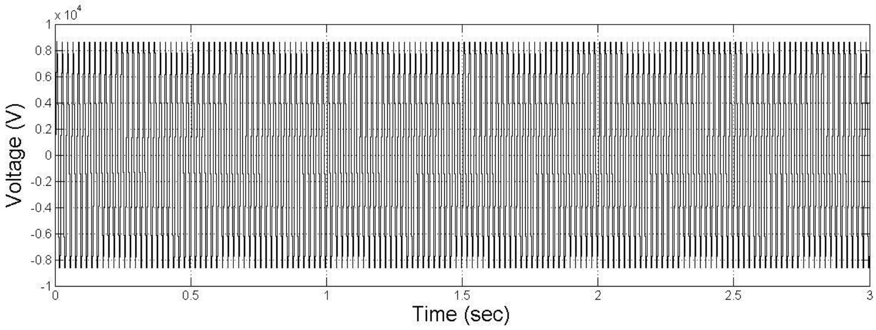

Fig. 4.18 Instantaneous Voltage per phase of Synchronous Generator

The voltage generation at the synchronous generator is also stable in grid connected mode as shown in Fig. 4.18.

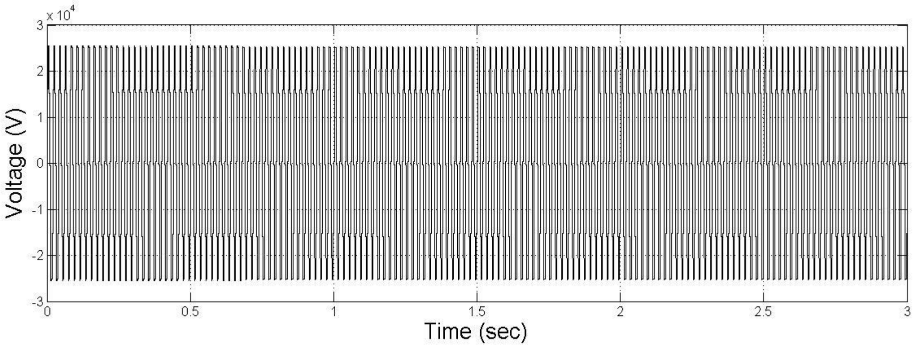

Fig. 4.19 Instantaneous Voltage per phase at Main Grid

The instantaneous value of line voltage of the main grid is shown in Fig. 4.19. This is also within the acceptable limits.

b) Current Profile

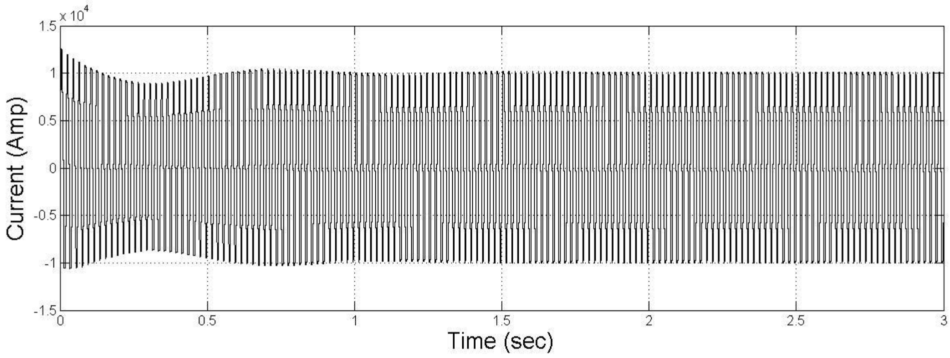

Fig. 4.20 Instantaneous Current per phase of Wind Turbine

The instantaneous value of the line current delivered by the wind turbine comes to steady state value after one second as shown in Fig. 4.20.

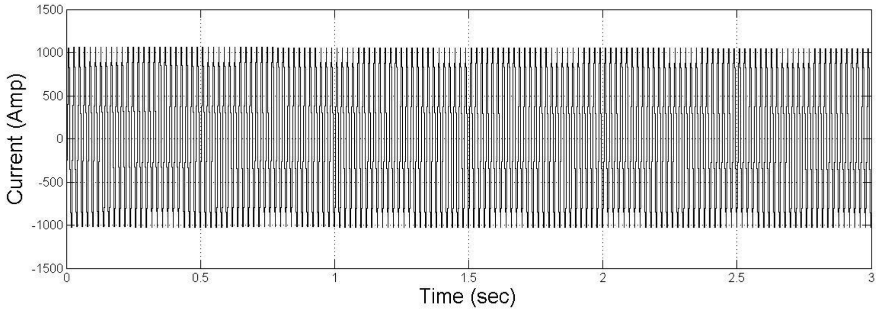

Fig. 4.21 Instantaneous Current per phase of Critical Load

The instantaneous value of the critical load current is at its nominal limit as shown in Fig. 4.21.

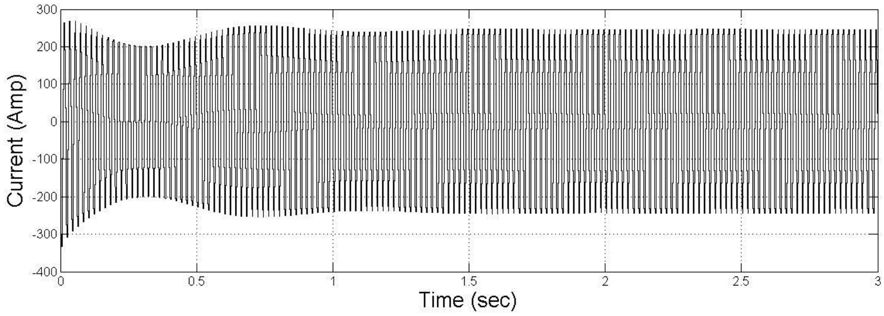

Fig. 4.22 Instantaneous Current per phase at Point of Common Coupling of Main Grid

This is the current at the point of common coupling where main grid and synchronous generator are connected to microgrid as shown in Fig. 4.22.

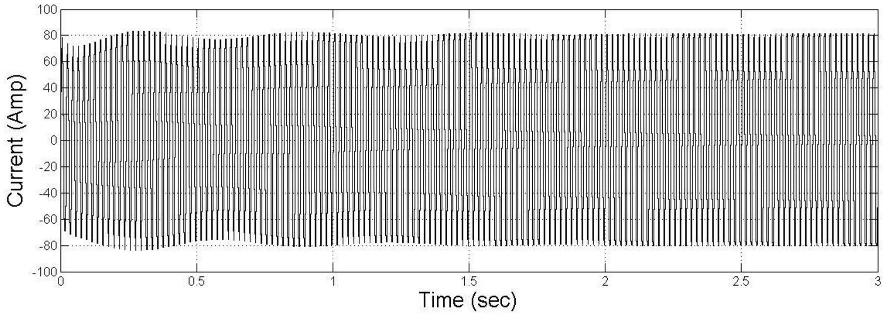

Fig. 4.23 Instantaneous Current per phase of Synchronous Generator

As shown in Fig. 4.23, the value of current is getting stable after 1.5 second which is satisfactory. The level of current generation is same as when the microgrid is heavily loaded with 8 MW.

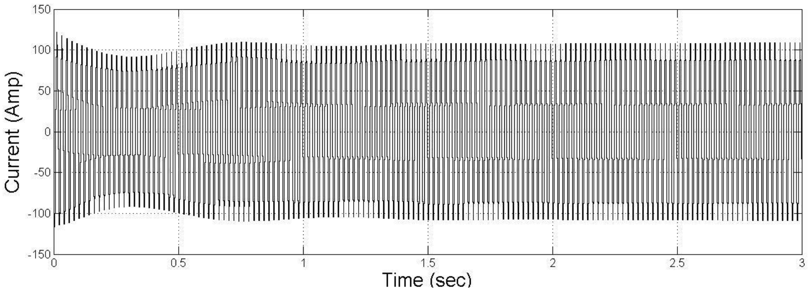

Fig. 4.24 Instantaneous Current per phase at Main Grid

This is the current at main grid as shown in Fig. 4.24. In this case we have seen that the total current level of point common coupling and the synchronous generator is equal to the main grid current, in this figure the main grid current is shown at 33 kV whereas the synchronous and point of common coupling current is shown at 11 kV, so if we convert the main grid current level to 11 kV, then the values are equal. This suggests that the extra generating power in the microgrid is delivering to the main grid. The power sharing is satisfactory in both the cases.

c) Profile of Real and Reactive Power

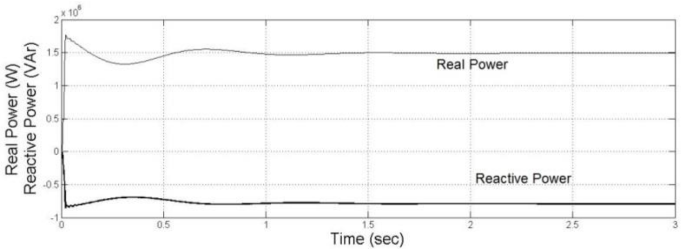

Fig. 4.25 Real and Reactive Power per phase of Wind Turbine

In Fig. 4.25, the real and reactive power generation in lightly loaded condition is same as the heavily loaded condition.

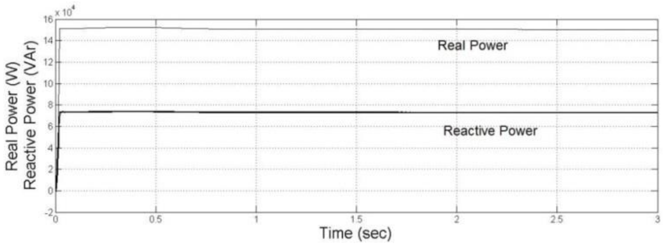

Fig. 4.26 Real and Reactive Power per phase of Load

Power profile across the load is same in lightly loaded microgrid compared to the heavily loaded microgrid. In both the cases, MG is connected with the main grid as shown in Fig. 4.26.

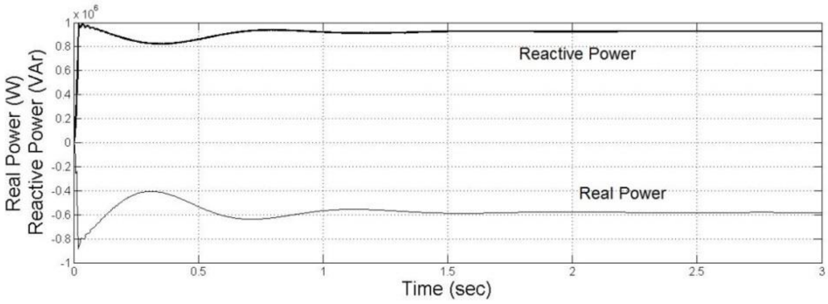

Fig. 4.27 Real and Reactive Power per phase at Point of Common Coupling of Microgrid

The reactive power at the point of common coupling is due the wind turbine as stated previous. However the real power is shown the graph is negative as shown in Fig. 4.27, which means that the real power is going out of the microgrid to the main grid.

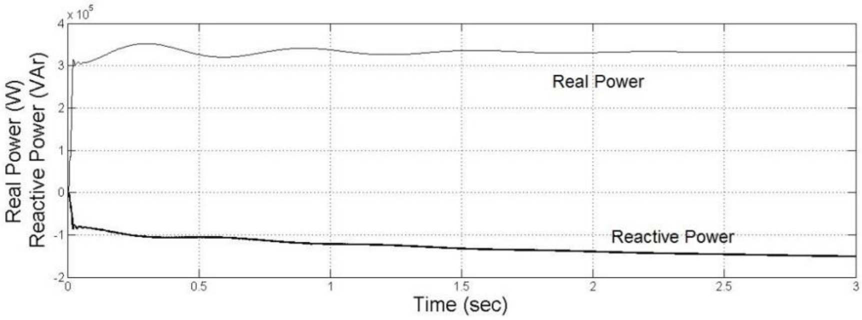

Fig. 4.28 Real and Reactive power per phase of synchronous generator

In Fig. 4.28, the real and reactive power of the synchronous generator same as in the case when microgrid is heavily loaded. This is satisfactory.

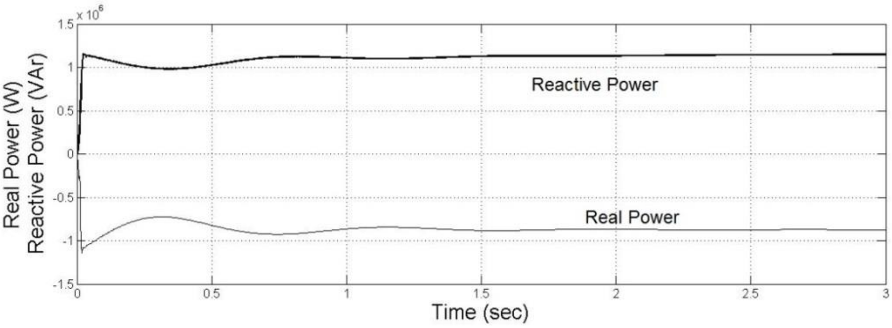

Fig. 4.29 Real and Reactive power per phase at main grid

As shown in Fig. 4.29, the real and reactive power of the main grid suggests that the real power is injecting in the main grid. This means the power is delivered by the microgrid due to lightly loading condition and its power generation is higher than its demand. The reactive power is also reduced because the load is reduced to 3 MW from the 8 MW.

4.4.2 Islanded Mode Operation of Microgrid due to Grid Outage

In this case, we have simulated fault at main grid connection and isolated the micro grid from main grid. Now the microgrid is running with 3 wind turbine of 1.5 MW and 1 synchronous generator of 1 MVA. The total available capacity is 5.5 MW and the controller should supply the critical load. When fault is generated the controller measure the voltage level at point of common coupling (PCC) and it disconnects the non-critical Load-2. But now the wind turbine is not connected to main grid, it does not generate power to its capacity. When the wind turbine is connected to weak grid, its output falls to half of its full generation capacity. It can be overcome by the use of capacitor bank. We have to connect the 2 MVAR capacitor bank for the 4.5 MW wind turbine generation. After connecting the capacitor bank, its power generation increases. This happen because the wind turbine needs reactive power to operate. This work is simulated in the Simulink environment, the results are satisfactory.

(i) When non-critical load is connected

a) Voltage Profile

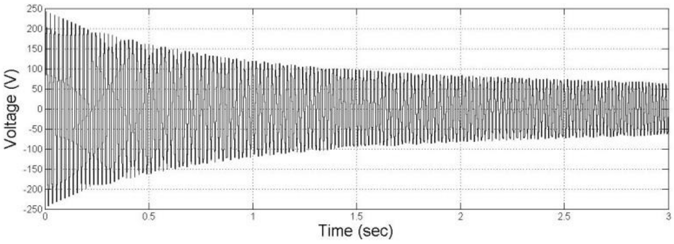

Fig. 4.30 Instantaneous Voltage per phase of Wind Turbine and Load

In Fig. 4.30, when the main grid is disconnected from the microgrid at any instant and microgrid is heavily loaded with 8 MW, but its maximum power generation capacity is 5.5 MVA then its voltage profile droops significantly.

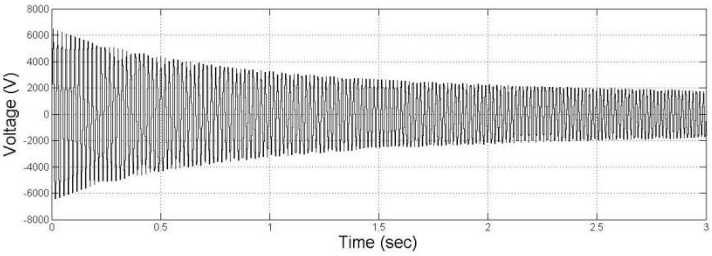

Fig.4.31 Instantaneous Voltage per phase of Synchronous Generator

The voltage at the synchronous generator is also drooping due to main grid failure and over loading condition as shown in Fig. 4.31.

b) Current Profile

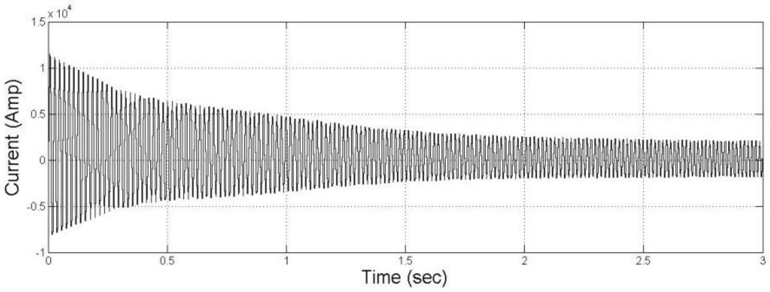

Fig. 4.32 Instantaneous Current per phase of Wind Turbine

The wind turbine current is also decreasing because for its successful operation it needs reactive power, but the synchronous generator is not capable to supply enough reactive power to the wind turbine as shown in Fig. 4.32.

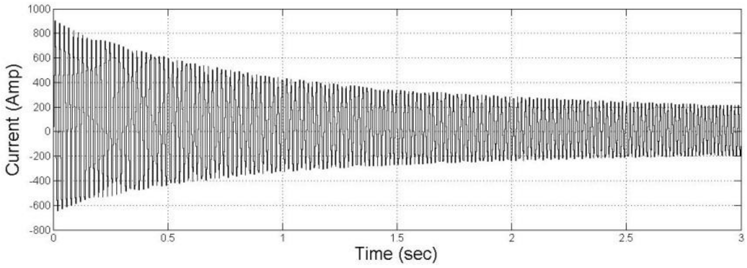

Fig. 4.33 Instantaneous Current per phase of Critical Load

The critical load current profile is also drooping due the main grid failure. The microgrid is still over loaded and the wind turbine is not getting enough reactive power from the synchronous generator as shown in Fig. 4.33.

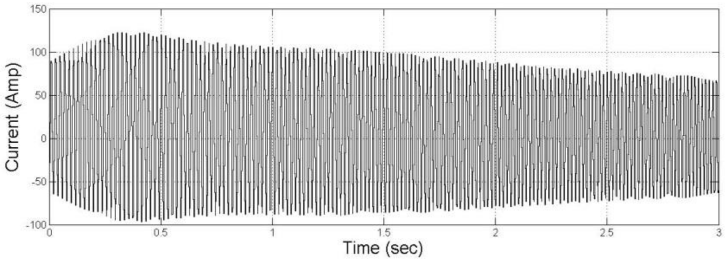

Fig. 4.34 Instantaneous Current per phase at Point of Common Coupling of Main Grid

As shown in Fig. 4.34, the current at the point of common coupling is now same as the current waveform of the synchronous generator because the main grid is disconnected hence the power delivered at the point of common coupling is only due to the synchronous generator. The current is drooping which is not satisfactory and extra load should be removed.

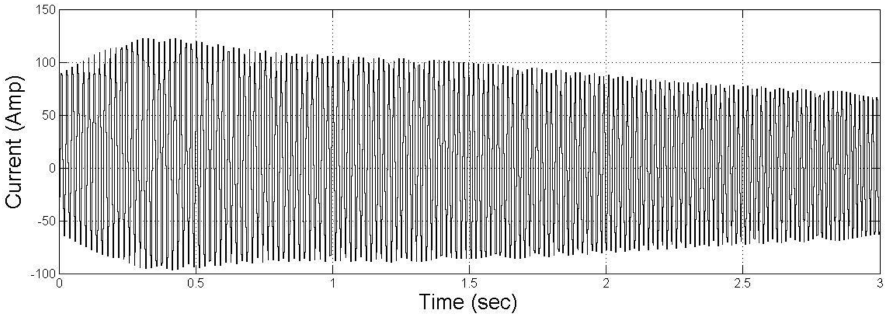

Fig. 4.35 Instantaneous Current per phase of Synchronous Generator

The drooping current waveform of the synchronous generator is shown in Fig. 4.35.

c) Profile of Real and Reactive Power

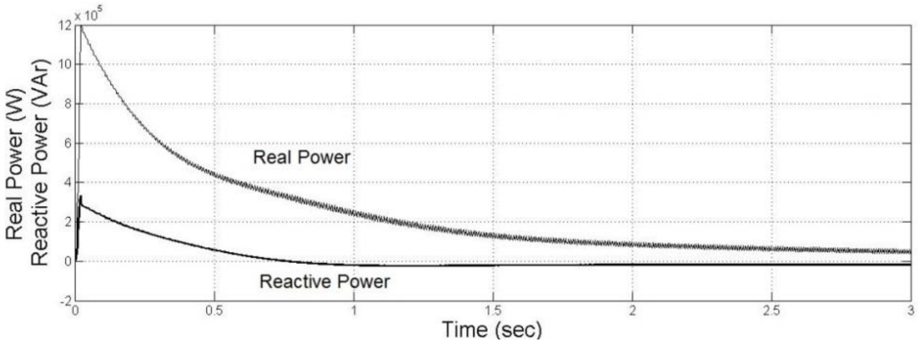

Fig. 4.36 Real and Reactive Power per phase of Wind Turbine

The wind turbine is not working properly due to lack of reactive power. The real and reactive power is approaching to zero as shown in Fig. 4.36.

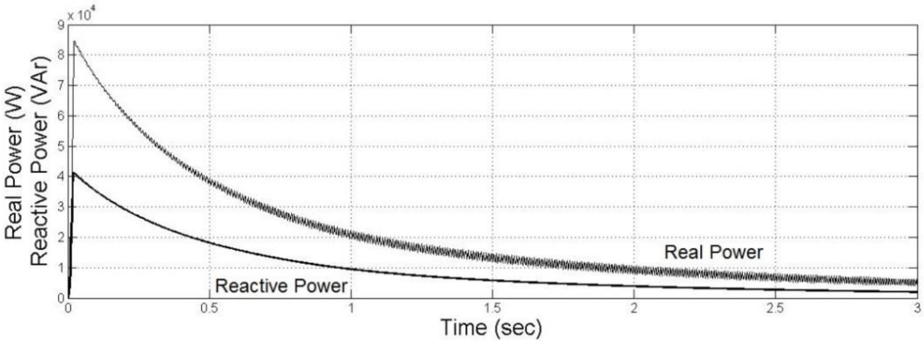

Fig. 4.37 Real and Reactive Power per phase of Load

As shown in Fig. 4.37, the real and reactive power of the critical load is drooping to zero which is not satisfactory.

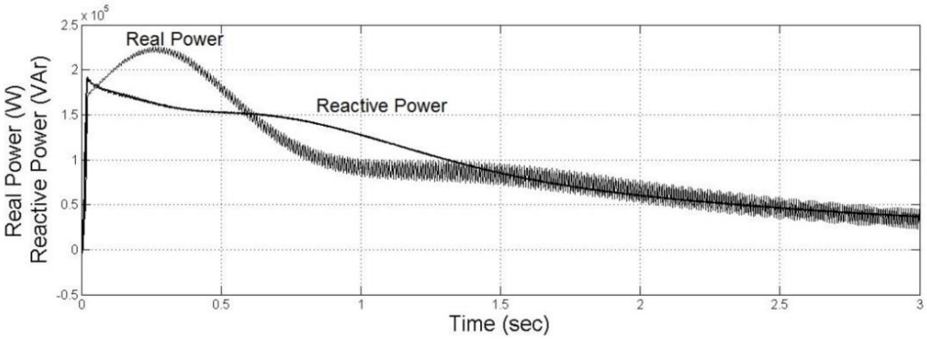

Fig. 4.38 Real and Reactive Power per phase at Point of Common Coupling of Microgrid

The power at the point of common coupling is due to the synchronous generator and it is also not stable as shown in Fig. 4.38.

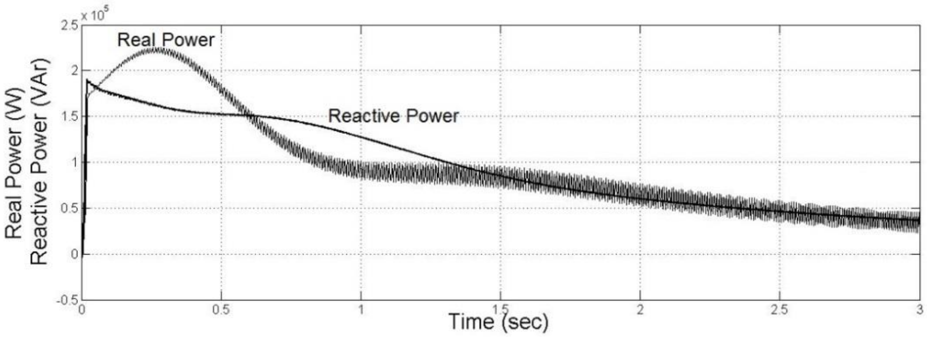

Fig. 4.39 Real and Reactive power per phase of synchronous generator

The Fig. 4.39 shows that the real and reactive power of the synchronous generator is not stable.

(i) When Non-Critical Load is Disconnected by Central Controller

a) Voltage Profile

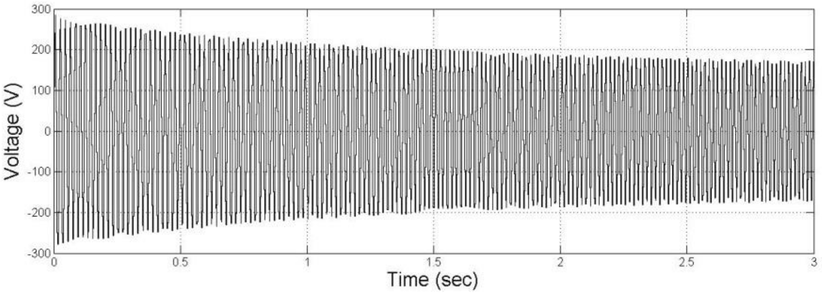

Fig. 4.40 Instantaneous Voltage per phase at Wind Turbine and Load

When the main grid is disconnected due to failure and the load is reduced to 4 MW from 8MW. The generating capacity is 5.5 MVA. But the voltage is still not improved, because the reactive power demand of the wind turbine is not delivered as shown in Fig. 4.40.

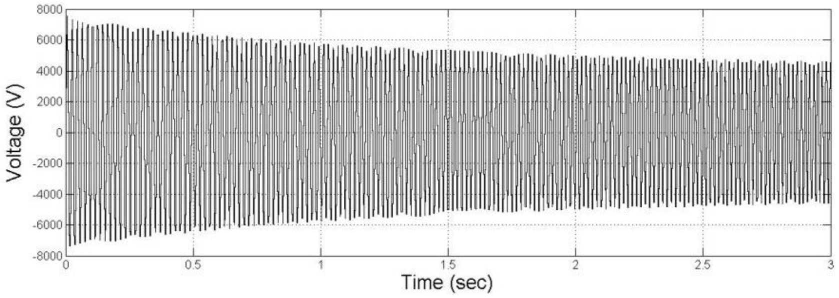

Fig. 4.41 Instantaneous Voltage per phase at Synchronous Generator

The voltage profile of the synchronous generator is not also improved so much in Fig. 4.41.

b) Current Profile

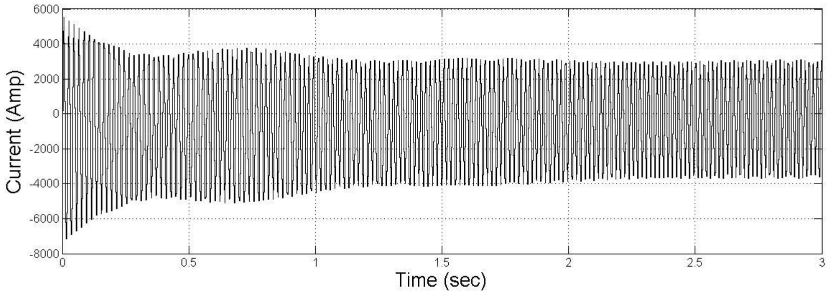

Fig. 4.42 Instantaneous Current per phase of wind Turbine

As shown in Fig. 4.42, the wind turbine current is not much high and its value at positive peak and negative peak is also not stable. The current is reduced to 2.5 times as compare to the healthy grid connection [51]. When the wind turbine is disconnected from the main grid and transferred to the weak grid, it power output decreases 2 to 3 times.

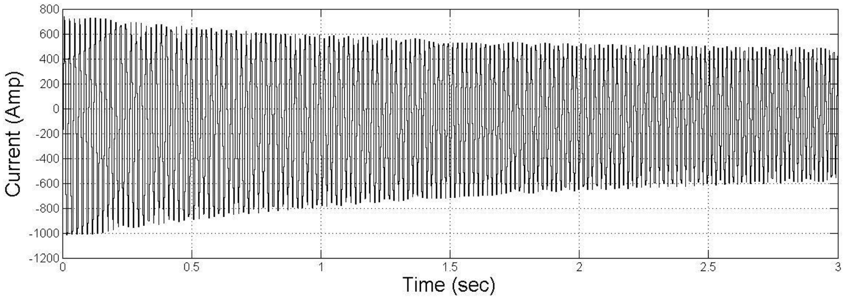

Fig. 4.43 Instantaneous Current per phase of Critical Load

The critical load current is not improved so much as it is still half of its nominal value due to the voltage instability in Fig. 4.43.

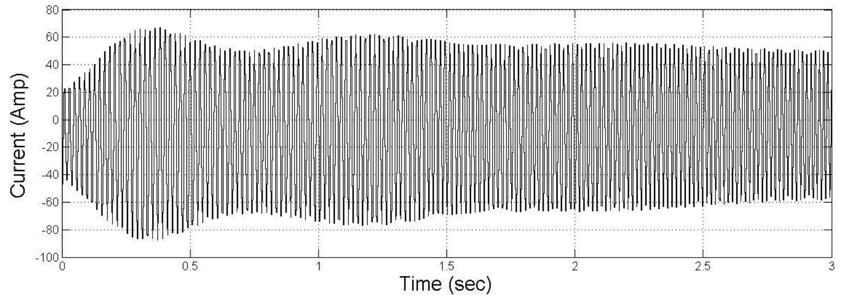

Fig. 4.44 Instantaneous current per phase of Synchronous Generator

The current of the synchronous generator output is getting stable after 2 seconds but it is not giving the current of it rated value as shown in Fig. 4.44.

c) Profile of Real and Reactive Power

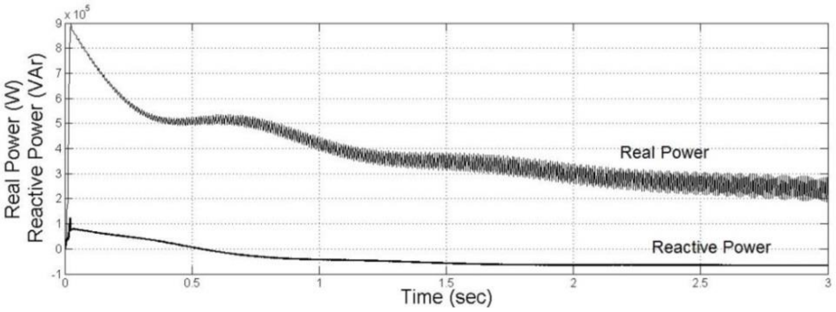

Fig. 4.45 Real and Reactive Power per phase of Wind Turbine

The real and reactive power is drooping and the wave form shows that its reactive power is getting stable at 1.5 seconds, but real power is not stable and approaching to zero as shown in Fig. 4.45.

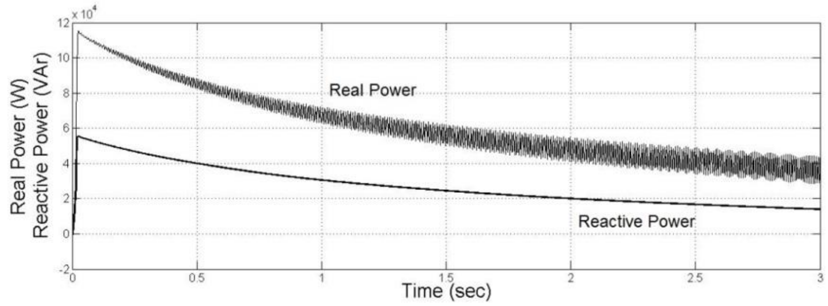

Fig. 4.46 Real and Reactive Power of Load

The real and reactive power of the critical load is drooping and not stable in Fig. 4.46.

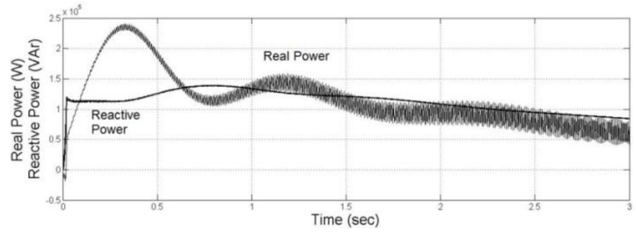

Fig. 4.47 Real and Reactive power per phase of synchronous Generator

As shown in Fig. 4.47, the real and reactive power of the synchronous generator is also fluctuating due the heavy demand of the reactive power from the wind turbine.

(iii) When Capacitor Bank is also connected by Central Controller

Capacitor bank of 1.5 MVAR capacity is added to the wind turbine, when the main grid is disconnected. The reactive power is the need of the wind turbine based on induction generator [51]. This helps to increase the stability of the microgrid in islanded mode i.e. when the main grid is disconnected from the microgrid due to some fault or some outage.

a) Voltage Profile

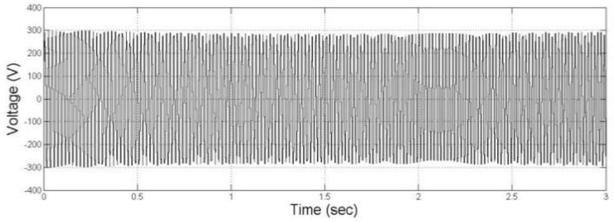

Fig. 4.48 Instantaneous Voltage per phase of Wind Turbine and Load

As shown in Fig. 4.48, the value of the voltage at the wind turbine is stable because its reactive power demand is fulfilled by the capacitor bank of 1.5 MVAR. It helps to compensate the reactive power needed for the induction generator. The values are nearly similar to the healthy grid connection.

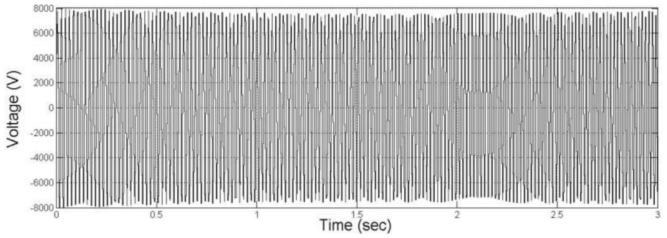

Fig. 4.49 Instantaneous Voltage per phase of Synchronous Generator

The synchronous generator voltage is stable and the value of the voltage is also in nominal range. The values are nearly similar to healthy grid connection in Fig. 4.49.

b) Current Profile

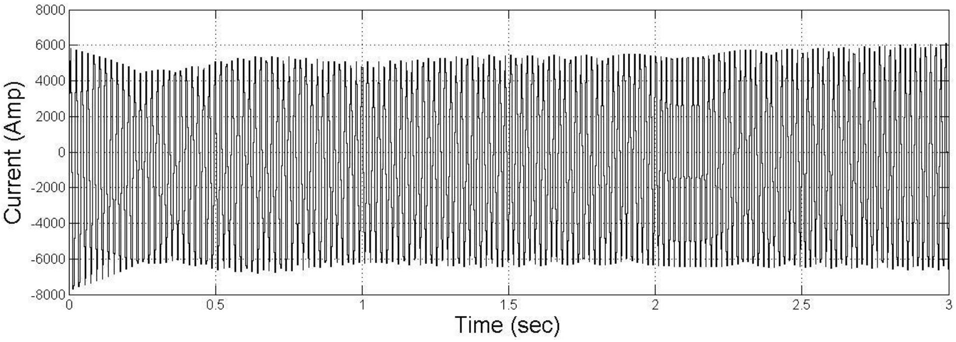

Fig. 4.50 Instantaneous Current per phase of Wind Turbine

As shown in Fig. 4.50, the current profile of the wind turbine is getting stable after 1 second and reaching to its nominal range after 2.5 seconds.

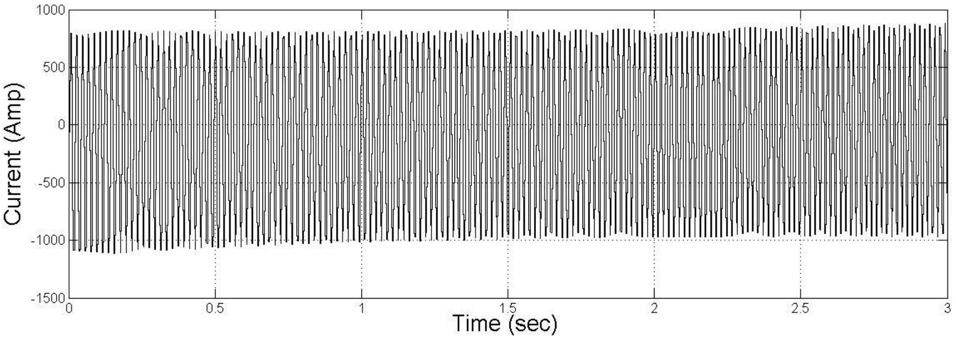

Fig. 4.51 Instantaneous Current per phase of Critical Load

The current profile of the critical load is also getting stable after 2 seconds and it is nearly similar to the healthy grid connection as shown in Fig. 4.51.

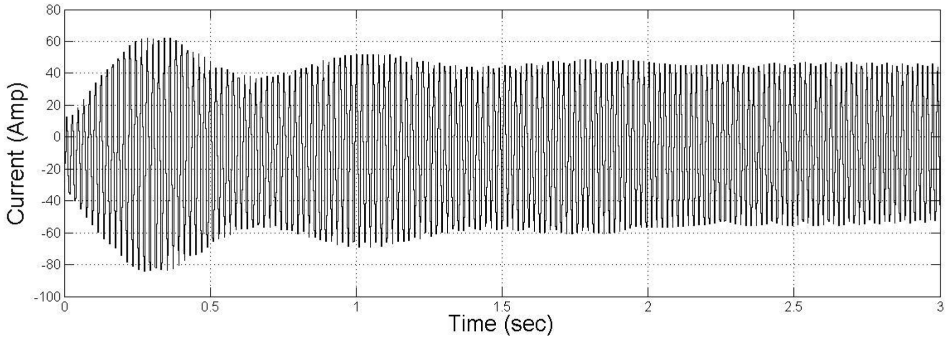

Fig. 4.52 Instantaneous Current per phase of Synchronous Generator

The instantaneous current of the synchronous generator is getting stable after 1.5 seconds and it is not drooping in Fig. 4.52.

c) Profile of Real and Reactive Power

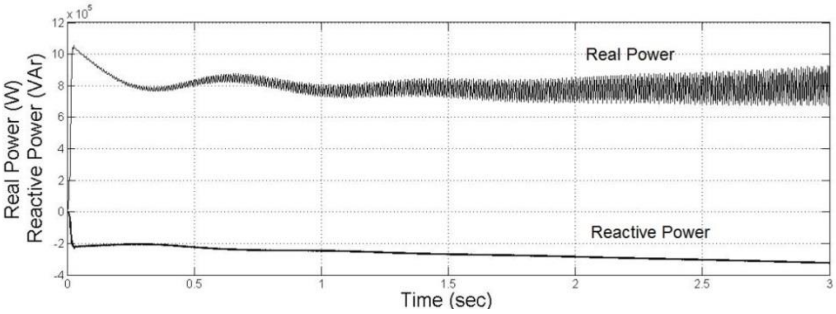

Fig. 4.53 Real and Reactive Power per phase of Wind Turbine

The real and reactive power is now not drooping and getting stable to one value after the placement of the capacitor bank shown in Fig. 4.53.

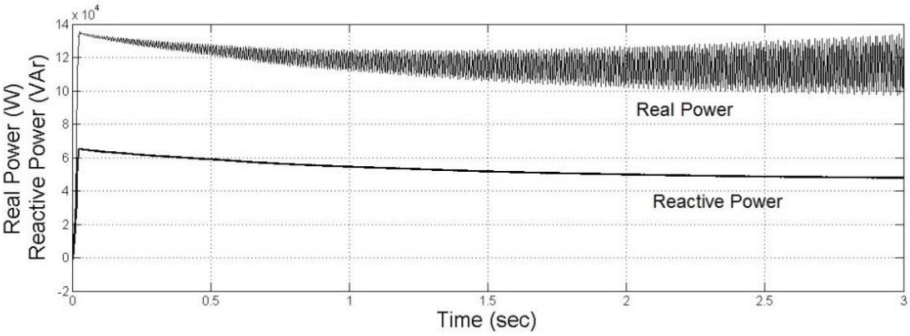

Fig. 4.54 Real and Reactive Power per phase of Load

As shown in Fig. 4.54, the real and reactive power the load are also getting stable and drooping as in the previous two cases.

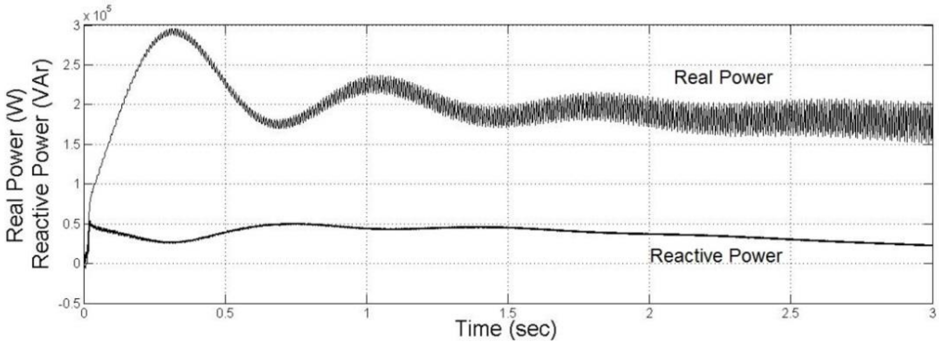

Fig. 4.55 Real and Reactive Power per phase of Synchronous Generator

As shown in Fig. 4.55, the real and the reactive power of the synchronous generator is getting stable after 2 seconds and not drooping. This is satisfactory.

4.5 Model of Microgrid Proposed for Thapar University

In this section, layout of a microgrid model is proposed considering the electrical network of Thapar University as a sample practical case. The total load of this University has been studied and the substations including the generators, control panels and other equipment are studied to get an idea of the proposed microgrid system. The critical and non-critical loads are identified and calculated on the basis of information received from the substation. The controller is designed for power distribution among the loads. This University has three substations, 8 control panels, 6 generators and nearly 60 distributed loads. Some loads are critical loads and others are non-critical loads. Whenever a grid outage occurs, the University should be isolated from the main grid. After this we have to disconnect the non-critical loads and critical loads should be connected with the DERs. This operation is proposed to be carried out by microgrid central controller. The layout of proposed microgrid is given below in Fig. 4.56.

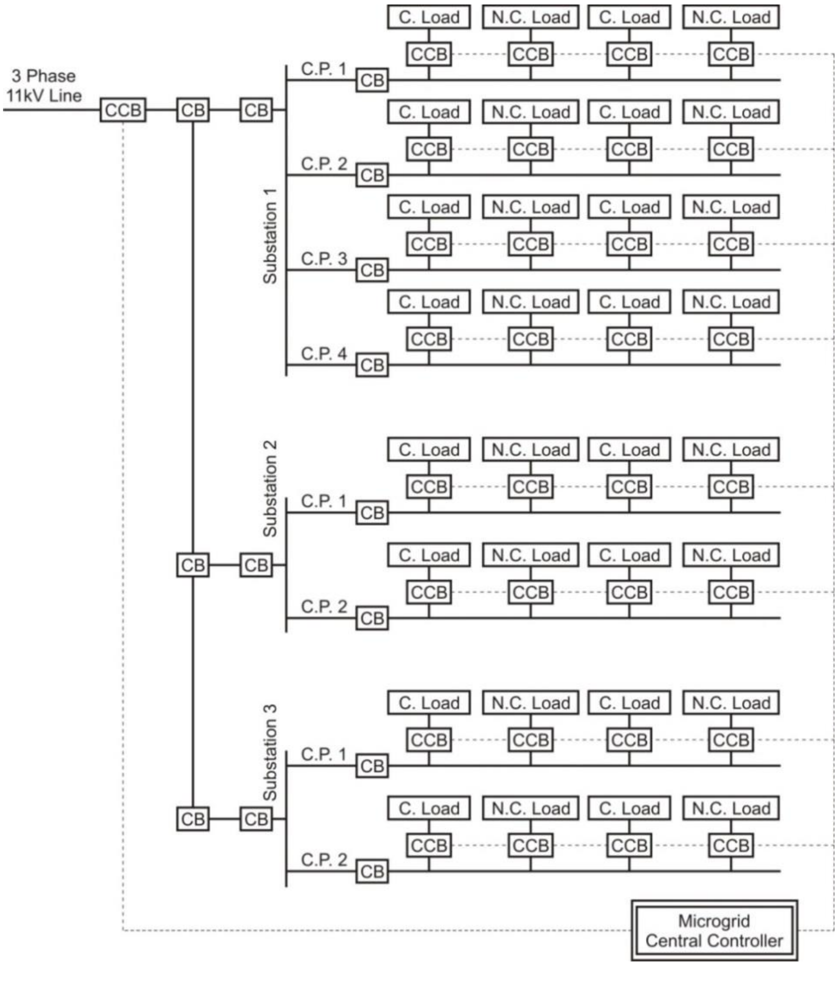

Fig. 4.56 Block Diagram of Microgrid Proposed for Thapar University

C. Load - Critical Load N.C Load – Non-Critical Load CCB–Controlled Circuit Breaker

In the University, there are 3 substations and 8 control panels. Also 6 generators of different ratings, such as one generator of 500 kVA, three generators each of 400 kVA and the remaining one is 320 kVA, are available to support the power supply at the time of grid disconnection. The details of loads connected with three numbers of substations are represented in tabular form in the Table 4.7 to 4.14.

In Table 4.7, different loads served by substation-1 and control panel-1 are given below in which some loads like Polytechnic, Architecture, Mechanical workshop are critical loads. Whereas staff colony, canteen are non-critical. The total load served by active power is 349.2 kW and in case of reactive power it is 169.06 kW. The kVA requirement by critical load is 259.97 kVA. The power factor is taken as 0.9.

TABLE 4.7: Details of Loads catered by Substation-1, Control Panel-1

Load Entity	**Active Power (kW)**	**Reactive Power (kVAr)**	**Power Factor**	**Critical/Non-Critical**
Polytechnic	30	14.52	0.9	Critical
Architecture	30	14.52	0.9	Critical
Poly. Main Building	30	14.52	0.9	Critical
Bank and Canteen	43.2	20.92	0.9	Non-Critical
Mechanical workshop	72	34.86	0.9	Critical
Staff Colony	72	34.86	0.9	Non-Critical
Block-B and C, C-Hall Light	36	17.43	0.9	Critical
CILIP Office AC and Light	36	17.43	0.9	Critical
Total Load	**349.2** **Critical – 234** **Non-Critical-115.2**	**169.06** **Critical – 113.28** **Non-Critical-55.78**		

kVA requirement of Critical load = 259.97 kVA

In Table 4.8, details of loads served by substation-1 and control panel are discussed. The total active power served by critical load is 170 kW. The reactive power in case of critical load is 82.32 kVAr. The kVA required by critical load is 188.88 kVA.

TABLE 4.8: Details of Loads catered by Substation-1, Control Panel-2

Load Entity	**Active Power (kW)**	**Reactive Power (kVAr)**	**Power Factor**	**Critical/Non-Critical**
Block-D,E and F	30	14.52	0.9	Critical
Civil Lab	70	33.9	0.9	Critical
ISD Lab	70	33.9	0.9	Critical
Mechanical A.C	30	14.52	0.9	Non-Critical
C-Hall A.C	30	14.52	0.9	Non-Critical
Total Load	**230** **Critical – 170** **Non-Critical-60**	**111.36** **Critical – 82.32** **Non-Critical-29.04**		

kVA requirement of Critical load = 188.88 kVA

The details of loads served by substation-1, control panel-3 are shown in Table 4.9 in which active power of critical load is 234 kW and reactive power of critical load is 113.3 kVAr. The total kVA required by critical load is 259.986 kVA.

TABLE 4.9: Details of Loads catered by Substation-1, Control Panel-3

Load Entity	**Active Power (kW)**	**Reactive Power (kVAr)**	**Power Factor**	**Critical/Non-Critical**
Faculty Cabin A.C	36	17.43	0.9	Critical
College UPS Supply	144	69.73	0.9	Critical
Directorate and L-Block A.C	36	17.43	0.9	Critical
Street Light	18	8.71	0.9	Critical
Auditorium A.C	60	29	0.9	Non-Critical
Guest House A.C	20	9.6	0.9	Non-Critical
Total Load	**314** **Critical – 234** **Non-Critical-80**	**151.9** **Critical – 113.3** **Non-Critical-38.6**		

kVA requirement of Critical load = 259.986 kVA

In Table 4.10, details of loads catered by substation-1, control panel-4 are given. In which the total active load power is 196 kW and reactive power is 94.88 kVAr. The total kVA requirement by critical load is 162.204 kVA.

TABLE 4.10: Details of Loads catered by Substation-1, Control Panel-4

Load Entity	**Active Power (kW)**	**Reactive Power (kVAr)**	**Power Factor**	**Critical/Non-Critical**
TAN Building A.C	40	19.37	0.9	Non-Critical
Chemical Lab and Block-C	10	4.84	0.9	Critical
UPS of Substation	20	9.68	0.9	Critical
Substation-1 Supply	5	2.42	0.9	Critical
48 H.P Water Pump	36	17.43	0.9	Critical
Mechanical Lab A.C	10	4.84	0.9	Non-Critical
TAN Building Lightning Load	15	7.26	0.9	Critical
Civil Lab-1	30	14.52	0.9	Critical
Block-B Top Floor	10	4.84	0.9	Critical
Bio-tech Block Top Floor	10	4.84	0.9	Critical
Polytechnic Lab Top Floor	10	4.84	0.9	Critical
Total Load	**196** **Critical – 146** **Non-Critical-50**	**94.88** **Critical – 70.67** **Non-Critical-24.21**		

kVA requirement of Critical load = 162.204 kVA

In Table 4.11, critical loads are served by substation-2 and control panel-1. The total active power of the load is 120 kW and reactive power is 58.1 kVAr. The kVA requirement by critical load is 133.325 kVA.

TABLE 4.11: Details of Loads catered by Substation-2, Control Panel-1

Load Entity	Active Power (kW)	Reactive Power (kVAr)	Power Factor	Critical/Non-Critical
Hostel-H	40	19.37	0.9	Critical
Hostel-A	32	15.49	0.9	Critical
Hostel PG Girls	20	9.68	0.9	Critical
Hostel-B	28	13.56	0.9	Critical
Total Load	**120**	**58.1**		

kVA requirement of Critical load = 133.325 kVA

The details of loads served by substation-2, control panel-2 are shown in Table 4.12. In which there are critical and non-critical loads are connected having active power 232 kW and reactive power is 112.21 kVAr. The kVA required by critical load is 201.049.

TABLE 4.12: Details of Loads catered by Substation-2, Control Panel-2

Load Entity	Active Power (kW)	Reactive Power (kVAr)	Power Factor	Critical/Non-Critical
Hostel-J	30	14.52	0.9	Critical
Water Pump and Hostel-C,D	60	29	0.9	Critical
Hostel-H A.C Load	51	24.69	0.9	Non-Critical
Hostel-J	91	44	0.9	Critical
Total Load	**232** **Critical – 181** **Non-Critical-51**	**112.21** **Critical – 87.52** **Non-Critical-24.69**		

kVA requirement of Critical load = 201.049 kVA

Details of loads served by substation-3, control panel-1 are given below in Table 4.13 having active power of critical load is 263 kW and reactive power of critical load is 90.07 kVAr. The total kVA requirement by Critical load is 206.66 kVA.

TABLE 4.13: Details of Loads catered by Substation-3, Control Panel-1

Load Entity	**Active Power (kW)**	**Reactive Power (kVAr)**	**Power Factor**	**Critical/Non-Critical**
Hostel-G	25	12.1	0.9	Critical
Hostel-I Lightning	40	19.37	0.9	Critical
Hostel-I A.C	27	13.07	0.9	Non-Critical
COS	50	24.215	0.9	Non-Critical
Hostel-G Normal Load	100	48.43	0.9	Critical
Core Building	21	10.17	0.9	Critical
Total Load	**263** **Critical – 186** **Non-Critical-77**	**127.355** **Critical –90.07** **Non-Critical-37.285**		

kVA requirement of Critical load = 206.66 kVA

Table 4.14 describes only the non-critical loads having active power of 107 kW and reactive power of 51.802 kVAr served by substation-3 and control panel-2.

TABLE 4.14: Details of Loads catered by Substation-3, Control Panel-2

Load Entity	Active Power (kW)	Reactive Power (kVAr)	Power Factor	Critical/Non-Critical
Residence Type-3	37	17.91	0.9	Non-Critical Load
Staff Colony	40	19.372	0.9	Non-Critical Load
Swimming and Tennis Court	20	9.68	0.9	Non-Critical Load
Gym Hall	10	4.84	0.9	Non-Critical Load
Total Load	**107**	**51.802**		

4.6 Inference

The simulation helps us to realize the characteristics of the microgrid in various conditions. Simulation also helps us to reduce the R&D cost. We do not have to build a real structure to see the microgrid behavior.

The simulation shows that when the microgrid is heavily loaded and the main grid is disconnected due to any fault or outage, the voltage and current profile fluctuate abnormally. This can be reduced by disconnecting the non-critical load from the microgrid. As the wind turbine is used to generate power in the microgrid, the wind turbine needs reactive power and when the main grid is disconnected, its reactive power requirement should be provided by other means. Induction generator wind turbine needs three phase supply to generate power, as per the basic principle of the induction generator. So in main grid failure case, we need the synchronous generator to be connected with grid, which should supply reactive power to the wind turbine. For a large set of wind turbine, the reactive power is supplied by additional capacitor bank. Capacitor bank improves the power generation of the wind turbine.

So in the island mode, i.e. when the main grid is disconnected with the microgrid, the non-critical load should be removed and if the microgrid is equipped with wind turbine of induction generator then it also needs some reactive power. This is done by the combination of any power generating unit and capacitor banks.

A microgrid model is proposed which will work on the basis of control operation offered by the MGCC. The whole data is taken on peak load hours in month of May at 12:30 P.M. The power factor for the system is nearly controlled to 0.9 by automatic capacitor banks. The active and reactive powers are recorded for critical and non-critical loads. According to this, their kVA ratings are calculated.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPES OF WORK

5.1 Conclusions

In this dissertation, a microgrid central controller is designed for handling the distributed energy resources. Whenever a fault occurs on main grid, the controller isolates the microgrid from the main grid. After isolation, the controller removes the non-critical load from the microgrid. Two types of central controllers are designed based on voltage control and power control. In power control based controller, firstly it measures the power available from the distributed energy resources and switch on the critical loads in priority order according to the power availability. The second controller works on voltage stability. In this controller, it shuts down the non-critical load until the voltage does not come in the nominal limits. Working of both the controllers and results are shown in the dissertation. The voltage based controller is studied with distributed energy resources like wind turbine. A controller has to control the capacitor banks in case of main grid failure because wind turbine needs reactive power. A voltage controller based microgrid connected with wind turbine shows desirable results in islanded-mode. A sample layout of microgrid is suggested based on electrical network of Thapar University. This sample model can work on power based central controller. This MGCC isolates the main grid from microgrid, disconnects the non-critical load and connect the distributed energy resources with the microgrid.

5.2 Future Scopes of Work

1. The communication features among the different kind of loads can be explored with the help of wireless communication. In the present communication system, it is difficult to detect a fault on the controller communication lines. Wireless communication for the microgrid central controller can enhance the reliability of the central controller as well as the microgrid system.

2. The microgrid model proposed for Thapar University could be simulated using Matlab and real hardware based controller could be designed and installed based on the present work.

PUBLICATION

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1. Kaur A., Garg G., Basak P., “Design and Simulation of a Central Controller for a Sample Microgrid”, *ICTEE National Conference*, Thapar University, Patiala, 2014. (Presented)

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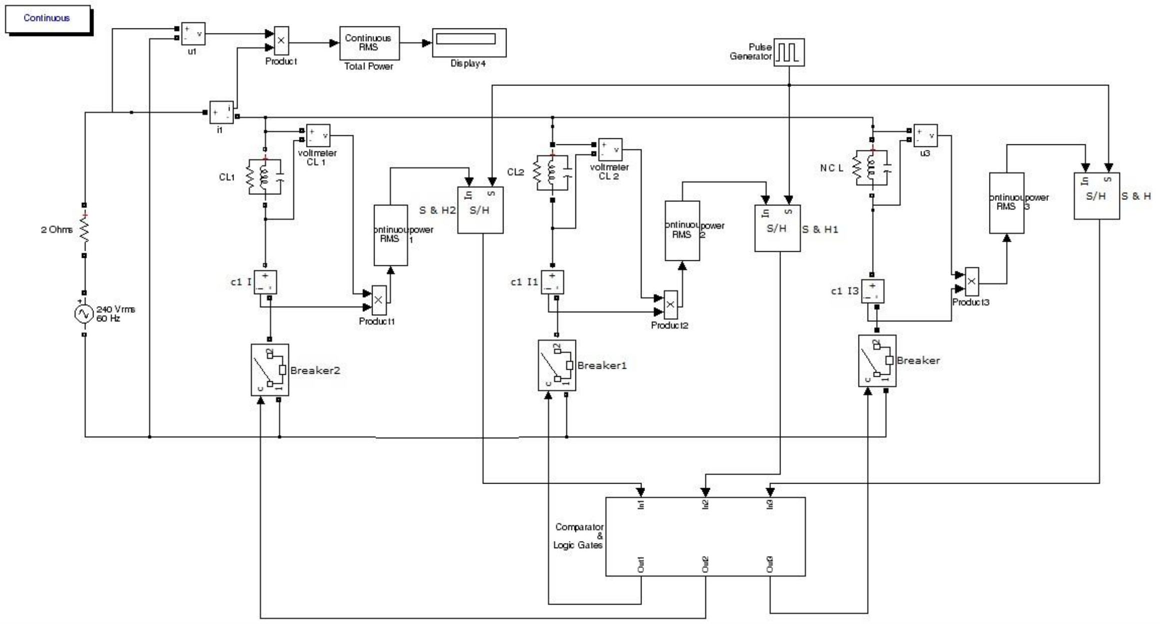
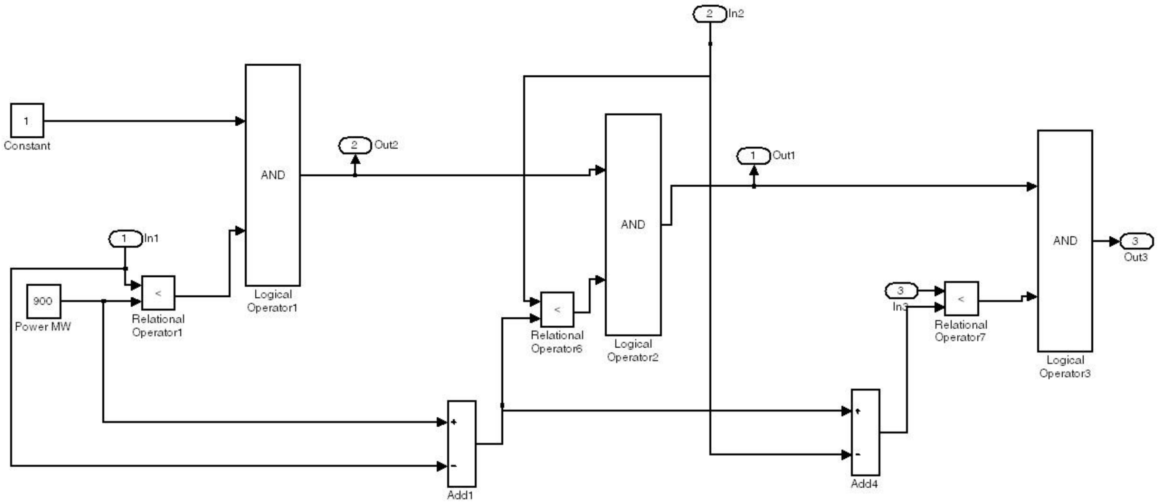
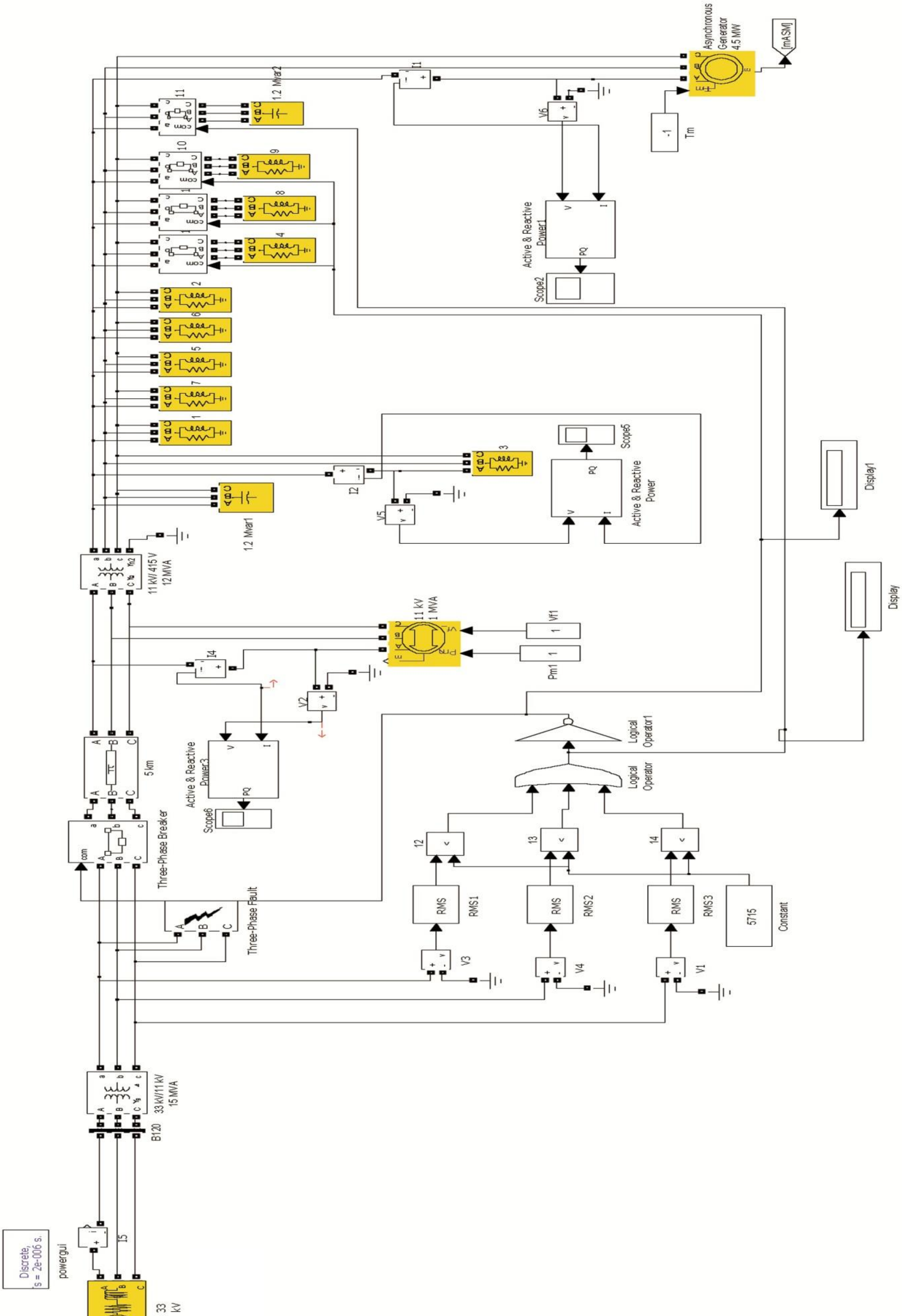
APPENDIX



Simulink Model of Microgrid Central Controller



Inside View of Logic Gates and Comparators



Simulink Model of Microgrid based on Wind Turbine