CONTROL OF MINIGRID

A DISSERTATION

Submitted in partial fulfillment of the
requirement for the award of degree

of
MASTER OF TECHNOLOGY
in
ALTERNATE HYDRO ENERGY SYSTEMS

By

MAHENDRA DUTT DWIVEDI

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE
ROORKEE, 247667 (INDIA)
MAY 2016

CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in this dissertation report, entitled, "**CONTROL OF MINIGRID**", submitted in partial fulfillment of the requirement for the award of the degree of Master of Technology in "**Alternate Hydro Energy Systems**" in **Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee**, is an authentic record of my own work carried out during the period from July 2015 to May 2016 under the supervision and guidance of **Dr. D. K. Khatod**, Assistant Professor, **Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee (India)**.

I also declare that I have not submitted the matter embodied in this report for award of any other degree.

Date: May, 2016
Place: Roorkee (**MAHENDRA DUTT DWIVEDI**)

CERTIFICATE

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

Dr. D. K. Khatod
Assistant Professor
Alternate Hydro Energy Centre,
Indian Institute of Technology,
Roorkee – 247667.

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Date: May, 2016

Place: Roorkee (**MAHENDRA DUTT DWIVEDI**)

ABSTRACT

The remote areas far away from grid supply are electrified by the autonomous power supply which are based on diesel-engine generator sets and work at relatively high cost. Integration of renewable energy sources (RESs), such as, photovoltaic (PV) and wind, with autonomous system can substantially reduce the cost of electricity generation. Therefore the hybrid power generation and forming the minigrid could be the best solution for electrification of remote areas.

In this report, a wind diesel hybrid system is developed for the study purpose and it's MATLAB/ SIMULINK model is analyzed for the voltage and frequency variation through the simulation results at variable wind speed and changing load conditions. Three control methodologies are proposed, for voltage control, over frequency control and under frequency control of this hybrid system. Capacitor bank is used for the voltage control, a controlled secondary dump load in the coordination of discrete frequency controller is proposed for over frequency control and a power balance controller is proposed for under frequency control of the system. All the three controls are implemented in the model and model is simulated for all the conditions like wind only, wind diesel, diesel only modes of operation and the results for all the cases were analyzed for frequency and voltage variation.

Voltage and Frequency variations are found well under the allowable range of ± 3% and thereby proposed control methodologies are validated by simulation results in the MATLAB/SIMULINK software and these controllers can be used in the wind diesel hybrid system.

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

The majority of human energy needs are currently met using petro-chemical sources, coal and natural gases but these fossil fuels are depleting at a very fast rate and their continued use had been damaging the environment very badly. World-wide energy consumption has increased more than 20 fold in the last century with the exception of hydroelectricity. Recently there has been a significant improvement in the availability of power in India but due to even increasing demand, the scenario of supply shortage and peak shortages have also been noticeable. To meet the deficit, efforts were made towards power generation by diesel estimated approximately 30000 to 35000 MW [1].

Few decades ago, an energy resource for electricity generation was primarily selected on the basis of cost effectiveness of the project and economy of maintenance, both preferably to be least expensive. Although such an approach is applicable even in present context, the grave issue of electricity shortage and other aspects of power generation such as social, environmental and technological benefits and consequences are also of great concern [2].

Therefore for most of the developing countries like India, while making selection of the type of plant for installation and commissioning the cost of project and supply of coal is of primary concern. Moreover, production of energy by using renewable resources is a considerably better alternative in spite of its higher initial cost because the effect of the pollutants on human health and environment; and extraordinary efforts required improving the path of degradation of such wastes. India is an emerging economy and comparatively constrained on financial resources to jump directly to cleaner mechanism of energy. Also, the issue of global warming has many international diplomatic and environmental consequences. Considering all these facts, it is quite evident that an urgent need for the transfer of technology. Onus is on the developed nations that they setup appropriate financial instruments for transfer of technology to the nations who are still trying to fulfill their basic energy requirements for sustenance in the 21st century [3].

The problem of global warming is being faced by the entire world due to rapid industrialization and urbanization. In terms of per capita equity India's contribution to the situation is ranked 145th in the world with a release of 1.25 tones CO_2 per annum whereas western world contributes a major share [4].

Fig.1.1 shows the energy generation by various types of fuels, highest percentage of energy generation is taken by the coal than followed by Hydro, Diesel, Gas etc. It is clear that fossil fuels are the main source of energy generation in world as well as in India also [5].

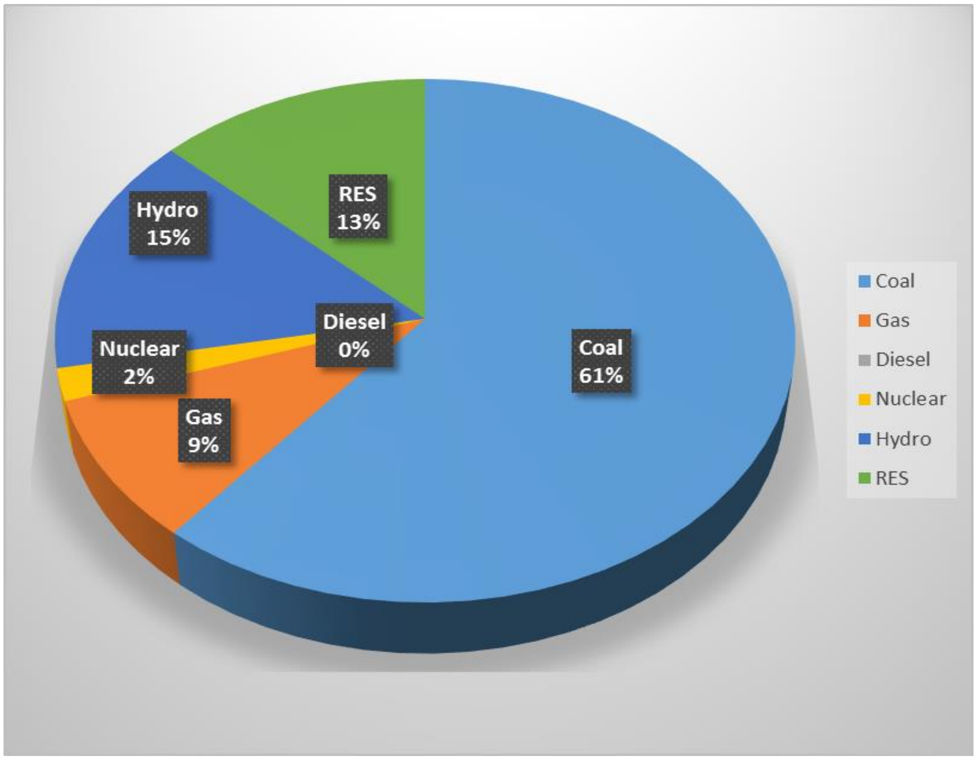


Fig.1.1: Fuel wise energy generation as 31st October 2015 in India [5]

1.2 TYPES OF ENERGY SOURCES

1.2.1 Renewable Energy

The energy always recovered by method of chemical changes e.g. biomass or physical changes e.g. water power, sun based, wind power and so on is known as Renewable Energy. This is the energy created from non-exhaustible sources which are constantly accessible and will never end, specifically the sun, the wind, the water cycle, the tides, and the warmth of the Earth. The energy sources are arranged into two types as given in Fig.1.2 [6]:

I. Renewable Energy
II. Non-Renewable Energy

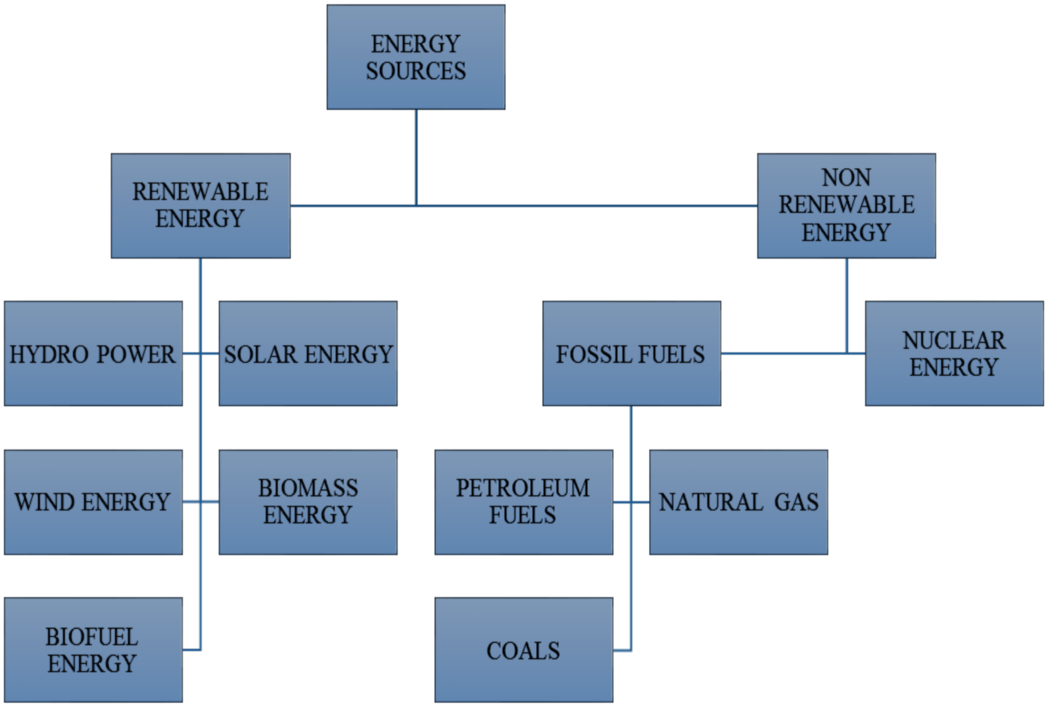


Fig.1.2: Classification of energy sources [6]

1.2.2 Non-Renewable Energy

Non-renewable energy is derived from the sources which have a very long regeneration times i.e. millions of years. Therefore once exploited, they are considered depleted. Most common of these resources are mainly fossil fuels e.g. oil, coal, natural gas and there formation can be dated back to the life of the earth. Carbon as their main element, these non-renewable energy for the most part exist in a settled sum and are expended much quicker than nature can reproduce them [7].

1.3 ENERGY CONSUMPTION IN INDIA

By the end of 2013, primary energy consumption in India was equivalent to 595.7 million tons of oil equivalent, whereas it was 637.8 million tons of oil equivalents for the year 2014. The figures signify that there is an increase of approx. 7 % every year in the energy consumption in India. India's absolute primary energy consumption is 9402.3 million tons of oil equivalents which is only 1/15th of the world. The primary energy consumption India is shown in Fig.1.3 [8].

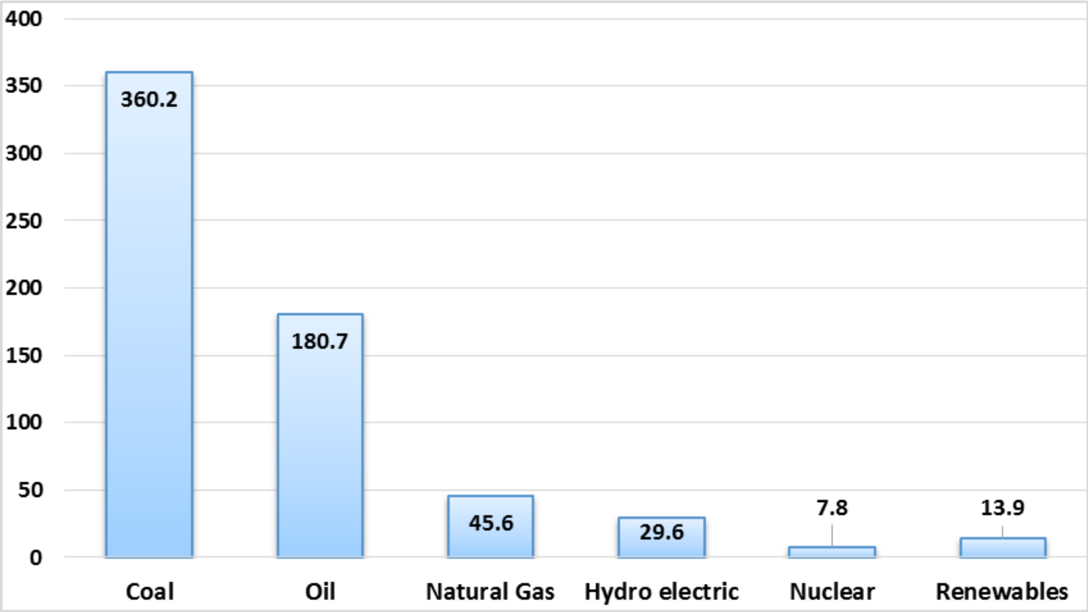


Fig.1.3: Primary energy consumption by fuel, in India 2014 [8]

Access to electric power remains a matter of concern for most of the rural areas and poor people's living in developing countries like India, where around 68.84% of population is living in towns and per capita utilization of power is less (1010 kWh) contrasted with developed countries (avg. 3044.45 kWh). Electrification of rural India is a fundamental component of poverty lessening and rural enlargement of a nation [9]. Therefore steps towards the subject are being initiated by the Rural Electric Corporation, State Electricity Boards, Ministry of Power and MNRE. Conventional grid supply cannot meet the entire load demand and hence raising the need to find an alternative. In this way the investigating the use of unconventional energy sources to meet the energy necessities has turned into a commitment. Since Power required in rural areas is very low because of distributed distribution of load, available choices for rural areas electrification are hydro, sun oriented, wind, diesel and biomass [10].

Indeed, even in remote areas that are energized by interfacing with a grid or a concentrated distribution framework, access is constrained because of different issues and all occupants of rural area are not connected to grid. Supplies are sporadic and of amazingly low quality. Along these lines the rural areas required a grid that they can nourish locally accessible energy assets instead of the main grid. For these remote zones and towns having abundance of renewable sources, there it is required to build up the innovations for viable usage of accessible renewable energy assets for electrification of remote provincial zones. Design of minigrid is ideal and efficient answer for rural electrification compare to the conventional grid extension which is not cost effective and not feasible in some cases [11].

Adjusting a customary model of energy generation and distribution is difficult for India because of intense energy deficiencies, worldwide climate issues and rare assets. Also, U.S. Division of Energy's (DOE's) National Renewable Energy Laboratory (NREL) is supporting the Indian Ministry of New and Renewable Energy's (MNRE's) Jawaharlal Nehru National Solar Mission (JNNSM) by directing an audit of the open doors and difficulties for sun oriented minigrid improvement in rural areas and town [12].

1.4 ELECTRICAL GRID

It is an interconnected system for conveying power from generating stations to the distributed loads. It comprises of generating stations that deliver electrical power, High-voltage transmission lines that convey power from producing stations to Demand loads and distribution lines that associate group of burdens or individual clients. In Electrical transmission framework two parameters must be kept under control: [13].

I. Frequency
II. Voltage

Electrical Grid Can Be Classified On The Basis Of Size:

I. International grid
II. National grid
III. Large regional grid
IV. Minigrid
V. Micro-grid

1.4.1 International Grid

Global power system interconnections provide a link between the power transmission systems of two or all the more connecting nations and subsequently permit those nations to share power generation assets [13].

1.4.2 National Grid

National power network interconnections give joints between the power transmission networks of principle regions of the nation. i.e.: Northern grid, Western grid, Eastern grid, North eastern grid are interconnected and shape national grid and so on [13].

1.4.3 Large Regional Grid

Large regional power grid provides interconnection of all the power generating sources, distribution network and transmission system of that region. i.e.: Northern grid, Western grid, Eastern grid etc. [13].

1.4.4 Minigrid

This contains small scale power capacity (from 10kW to 10MW), and the distribution of power to a particular number of clients by means of a distribution lines which can works in segregation not necessarily from national power transmission systems and supply, generally focused settlements with power at grid tie level quality [13].

This has an incorporated energy system comprising of interconnected loads and dispersed energy assets including generators and energy storage systems like batteries as a coordinated framework. It can work in parallel with the utility network or in a purposeful islanding mode. A minigrid network works ordinarily up to 11 kV and its capacity is constrained to 10kW to few MW [13].

A minigrid framework can be either disconnected or grid associated.

1.4.5 Microgrid

In a microgrid System, the delivered power (normally under 10kW) is sustained into a small scale (1 - 10kW) distribution network. This smaller scale network contains appropriated energy including sun powered photovoltaic, wind turbines, small scale hydro turbines, batteries and self-possessed power plants. The operation object of the smaller scale systems is to minimize the aggregate cost which contains the dispersed energy generation cost, power buy expense and sewage cost. From the power grid perspective, this smaller scale network can be dealt with as a negative burden [13].

1.5 OVERVIEW OF MINIGRID

Minigrid is another innovation, a work in progress which incorporates the renewable energies or hybrid energy. Minigrid can possibly turn into the most intense innovative methodology for quick and accelerated electrification, as it can give incorporated power generation at the nearby level utilizing a renewable energy. It can serve both residential and nearby organizations and gives an ideal answer for using local renewable assets. Numerous areas offers brilliant normal conditions for the utilization of sun powered photo voltaic (PV), biomass, wind or small hydro power [14].

Minigrid can fulfill the demand of electricity in particular area. It may be connected with the existing grid or serve the area in isolated mode (islanded minigrid) in order to serve the consumers which are for away from the utility grid [15].

One such appealing option that can give an arranged base of local network groups with distributed power generation is sun oriented innovations. It can possibly ease the requirement for costly, long-separate concentrated power distribution system and in the meantime can convey power to the masses [12].

Sun powered minigrid is a perfect alternate option to grid power network for remote areas which don't have grid availability. Since minigrid are autonomous entities, they can be controlled and managed without exhibiting dangers to the main network. Such distributed energy frameworks can give more stable power, as any blackouts or interferences to power supply can be immediately recognized and amended. Moreover, having the site of power generation nearer to the load demand, lessens T&D losses [16].

1.5.1 Need of Minigrid

I. If number of connections per km of distribution line is high, Minigrid is a favorable option. But if number of connection is less and distance is large then minigrid formation is best choice.

II. Sometimes grid extension is not possible then minigrid/micro grid formation is only option for provide electricity to local people [17].

1.5.2 Classification of Minigrid

There are several basis to classify minigrid as discussed below:

1.5.2.1 On The Basis Of the Types of Coupling Used:

I. Mini-Grid with DC coupling

II. Mini-Grid with AC coupling

III. Mini-Grid with DC/AC coupling.

1.5.2.1.1 Minigrid with DC Coupling

In a DC Coupled Minigrid, diesel and hydro plant initially changed over to dc through AC/DC converter, then supplied to DC bus network and electrical energy from solar system straight forward supplied to DC bus, which supplies power to DC loads specifically and AC burdens might be supplied through inverter. A battery is associated with DC bus, its charging and discharging depends on the states of load and through charge controllers to avoid the over discharging and over charging. A Minigrid with DC Coupling is shown in Fig.1.4 [10].

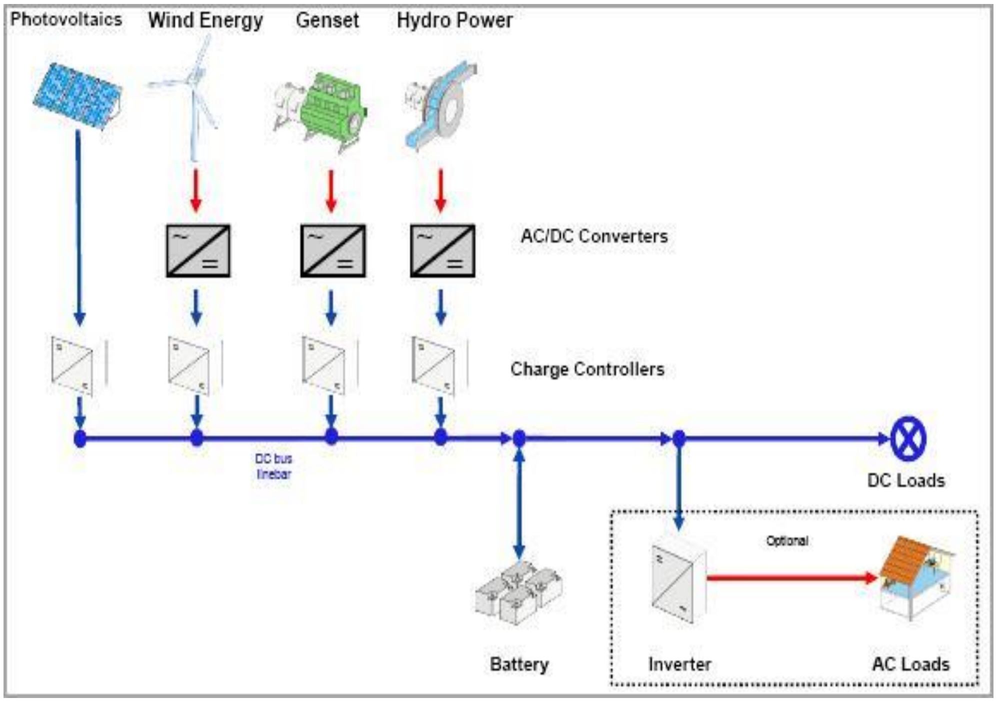


Fig.1.4: Minigrid with DC Coupling [10]

1.5.2.1.2 Minigrid with AC Coupling

In this type, AC producing sources are straight forward associated with the AC bus line or through an AC/AC converter to empower stable coupling of the segments. DC generating sources are associated with the AC bus line through inverter and a bidirectional expert inverter controls the power supply for the AC loads and the battery charging. DC loads can be supplied by the battery. Minigrid with AC Coupling is shown in Fig.1.5 [10].

1.5.2.1.3 Minigrid with AC/DC Coupling

As shown in Fig.1.6, DC power generating sources are associated with the AC bus line through an expert inverter and AC producing sources are specifically associated with the AC bus line or through an AC/AC converter to empower stable coupling of the segments. DC loads can be met by the battery [10].

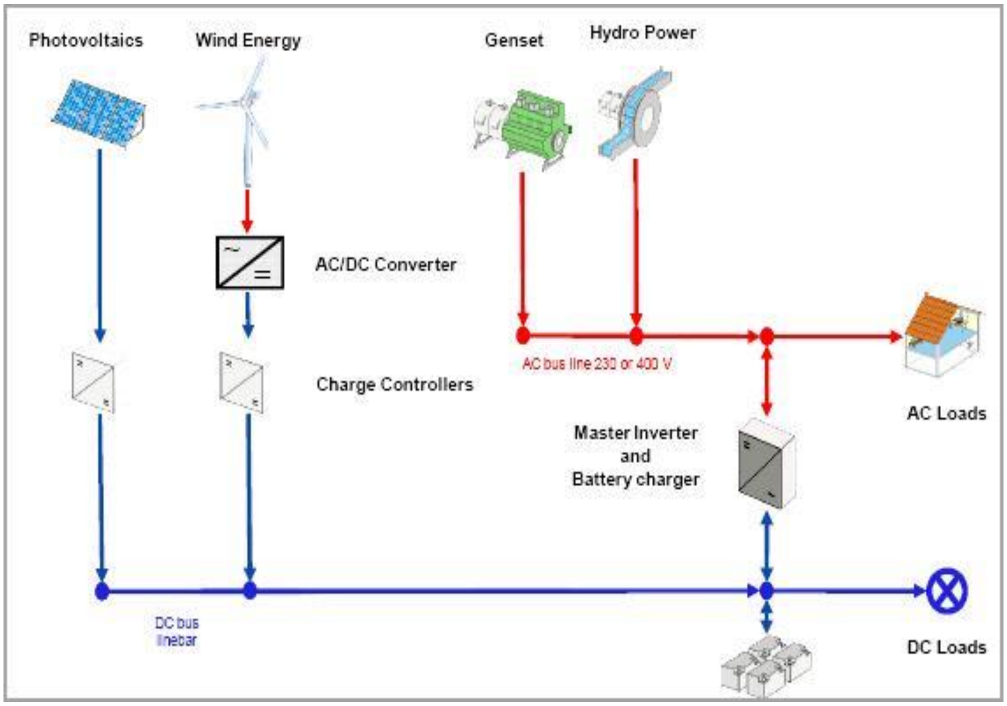


Fig.1.5: Minigrid with AC coupling [10]

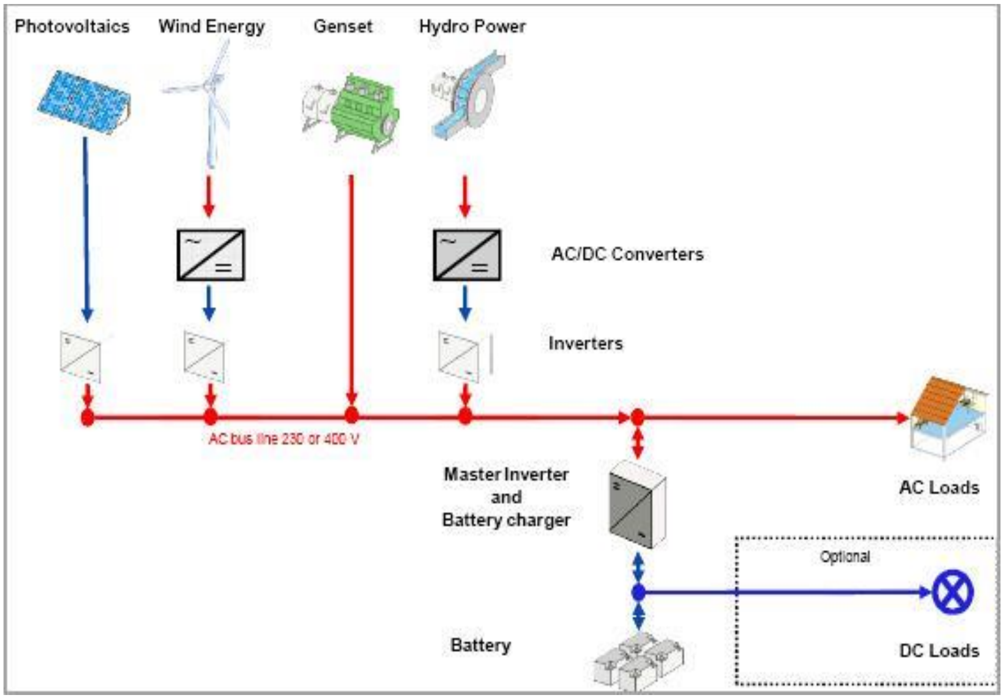


Fig.1.6: Minigrid with AC/DC coupling [10]

1.5.2.2 On The Basis Of the Grid Connection

I. Grid connected mode
II. Off-grid or isolated mode

When a minigrid is connected to the grid then it is called as the grid connected mode of operation. When minigrid is not connected to the grid then it is called as off-grid or isolated grid.

1.5.2.3 On The Basis Of the Input Source

I. Single source minigrid
II. Hybrid minigrid

1.5.2.3.1 Single Source minigrid

The single source minigrid is not a good solution from the reliability point of view and it can be costly in some cases. If we take a grid connected minigrid then during the outage of the grid supply diesel engine generator set can possess reliability but it has a high cost of operation and otherwise also reliability of any single source based minigrid cannot be trusted. If minigrid is working in isolated mode of operation then single source based minigrid design cannot serve the purpose since outage of any sources like wind, solar, biomass etc. used in the minigrid will need a backup. Therefore hybrid minigrid is the better choice in the case of minigrid formation [18].

1.5.2.3.2 Hybrid Minigrid

In a hybrid minigrid, two or more different kinds of technologies with different energy sources are combined for the power generation and distribution to consumers is through an autonomous (independent) grid. Here, minigrid is supplied by a different energy sources and a genset, usually supplied with (diesel), used as a backup. Since the advantages of each technology complement each other, it has proven to be the least-cost solution for rural communities. By providing high quality and reliable electricity for various purposes, it has proved to be a mature and cost effective technology solution [14].

Additionally the mixes of different renewable sources just make sense in many situations, for example, accommodating sources seasonal uncertainties like with sun powered PV collectors supplementing wind power amid the months with less wind, or getting when hydro generations decreases during the dry season. Where sun oriented energy has every day variation in a generation around peak noon, wind power generation especially reliant on the wind velocity and consistency of wind speed. Stability is increased in the system by the storage of access energy in batteries, particularly for the time at of peak load demand and there is inadequate generation from renewable sources e.g. to counterbalance absence of sun based power amid evening time hours.

Differences between hybrid power systems, diesel genset power systems and renewable energy power systems:

The cost structures of Gensets and renewable energy technologies (RETs) are different in many ways. Wherein RETs have a very high initial capital investment in comparison with Diesel Gensets power systems, on the other side annual running costs and the cost of maintenance for Diesel Gensets power systems are much higher due to the high operation. With the assumption that there is adequate fuel available, Diesel Gensets aim at providing energy on demand, which is indicated by the accurate needs of the remote areas [14].

Advantage with Diesel Genset is that they are theoretically dispatchable on demand as they run completely on diesel fuel. Therefore the ability to run a genset does not always match the availability of fuel to run the generator especially in rural context due to isolated and sometimes inaccessible conditions in rural areas making the delivery of fuel difficult. As far as local environmental impacts are concerned, Gensets are noisy, polluting, and have a direct health impact on users, especially when the generators are located next to the houses [14].

For the Power systems running completely on renewable energy, it is very important to rely on battery storage of the generated energy in order to make electricity available during the periods when generation is affected due to unavailability of renewable source. However, a bigger generation capacity than fossil-fuel or hybrid power systems is required to be established to ensure reliability in power supply. Renewable energy power systems also large battery storage system in order to store an excess of electricity produced. However, without a generator backup, any substantial deviation from the anticipated daily load profile and/or unusually bad weather conditions have the potential to affect such system, even collapse or necessitate load shedding [14].

1.6 CHALLENGES IN THE OPERATION OF MINIGRID

Following are the challenges faced in operation of minigrid:

I. Frequent voltage drop in the network due to imbalance or sudden increase in the load. It can be mitigated by using smart compensation.

II. Sizing and placing of voltage compensation device i.e. capacitor is difficult.

III. Fault analysis of minigrid is not described in details.

IV. Performance evaluation of minigrid has not been explained.

V. For a utility connected minigrid working in the island mode the proper arrangements required to feed the parameters of protective devices.

VI. Accuracy in the calculation of load so that minimum mismatch in generation i.e. supply and demand.

1.7 WIND ENERGY PROGRAMME IN INDIA

For catalyzing commercialization of wind power generation in the nation, the Wind Resources Assessment Program is being executed through the State Nodal Agencies, Field Research Unit of Indian Institute of Tropical Meteorology and Center for Wind Energy Technology. It incorporates wind asset evaluation exercises; innovative work bolster, execution of showing ventures to make mindfulness and opening up of new locales, contribution of utilities and industry; advancement of foundation ability and limit for producer, establishment, operation and upkeep of wind electric generators; and arrangement support. In India, existing generation limit through wind power is only 49,130 MW, at 50 meter center point stature level of the wind turbines as for 2 % land accessibility at windy areas. Installed capacity of the wind power plants in the major states of the India is given below in Table 1.1 [19].

Table 1.1: Installed Capacity of WPPs per state (MW) [19]

State	Mar-2015	Mar-2014	Mar-2013	Mar-2012	Mar-2011	Mar-2010	Mar-2009
Tamil Nadu	7456.98	7275.68	7,162.18	6,987.60	5904.4	4907	4304.5
Karnataka	2639.45	2323.85	2,135.15	1,933.50	1730	1473	1327.4
Maharashtra	4437.9	4064.95	3,021.85	2,733.30	2310.8	2078	1938.9
Rajasthan	3308.15	2783.45	2,684.65	2,070.70	1524.8	1088	738.4
Andhra Pradesh	1038.15	783.35	447.65	245.5	200.2	236	122.5
Madhya Pradesh	876.7	423.4	386	376.4	275.5	229	212.8
Kerala	35.1	35.1	35.1	35.1	32.8	28	27
Gujarat	3642.53	3447.28	3,174.58	2,966.30	2175.5	1864	1566.5
Others	4.3	4.3	4.3	3.2	0	4	1.1
Total	23439.26	21141.4	19,051.46	17365	14158	11807	10242.3

In instances of low wind speeds, torque applied by the wind on the turbine blade is deficient to make them pivot. With the increase in wind speed, the wind turbine starts to rotate and develop power. The speed at which turbine begin to turn and produce electrical power is called 'Cut-in Speed'. At a wind speed above cut-in speed, power rises quickly and meant by a power characteristics. Speed at which rated power breaking point comes is called 'rated wind speed'. In any case, the design of the turbine is configured to restrain the ability to this greatest level power with no further increase in the output power at higher wind speeds. In spite of the fact that this differs for different designs, it is controlled by changing the blade pitch angle in order to keep the output power at the consistent level, ordinarily with large capacity turbines. As the wind speed increments over the evaluated output wind speed, the forces on the turbine blade edge keep on rising bringing on a danger of harm to the rotor at certain point. Accordingly a braking mechanism is accustomed to bring the rotor to a halt, and this speed is known as the 'Cut-out Speed'. Component of a typical wind power plant are shown in the Fig.1.7 and Wind-power Curve is shown in the Fig.1.8 [20].

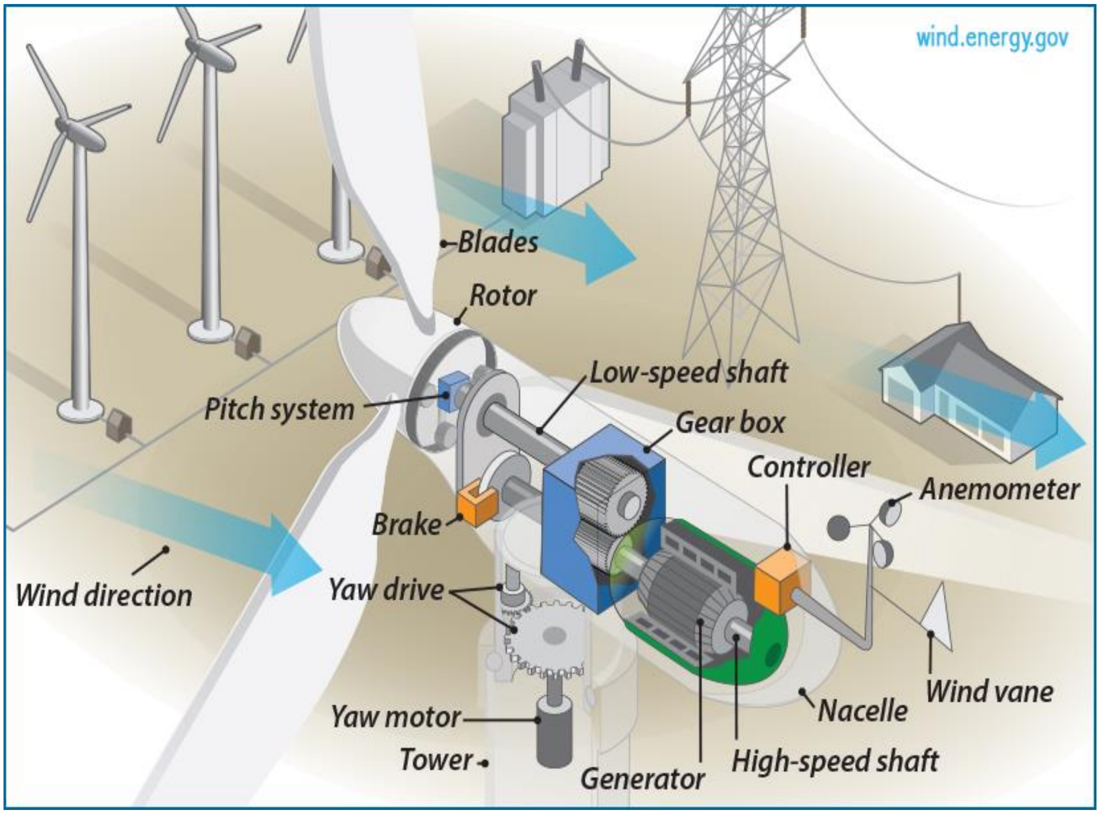


Fig.1.7: Components of Wind Power Plant [21]

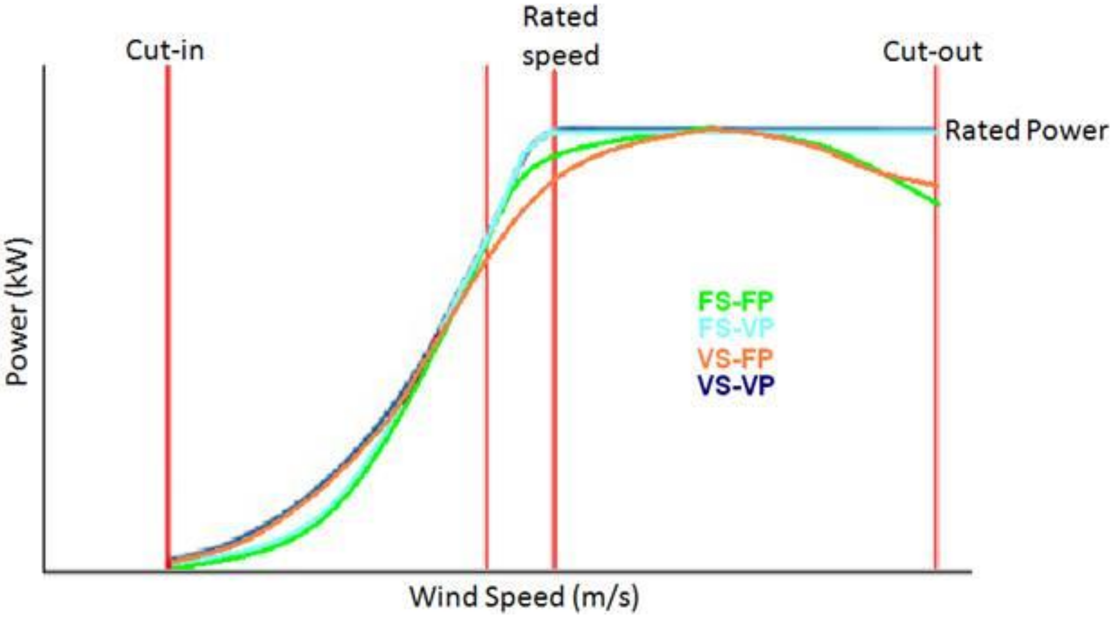


Fig.1.8: Power Curve of WTG [22]

In Fig.1.8, VS denotes variable speed, VP represents variable pole, FP denotes fixed pole and FS represents fixed speed.

1.8 TYPES OF WIND TURBINE GENERATORS

The wind turbine generators can categories in following two types

I. Constant speed or fixed speed wind turbine generators
II. Variable speed generators wind turbine generators

1.8.1 Constant Speed Wind Turbine Generator

Squirrel-cage Induction Generator (SCIG) is used for the fixed speed wind turbine, which is shown in Fig.1.9. The turbine rotation speed is fixed to the electrical network frequency. It produces real power (P) when the turbine shaft turns faster than the electrical grid frequency making a negative slip at around 2% (positive slip and power is motoring tradition). Capacitors are required for reactive power supply to the induction generators. For a given wind speed, the working speed of the turbine under steady state conditions is an almost linear function of torque. For sudden changes in wind speed, the mechanical inertia of the drive train will restrict the rate of progress in electrical output. Wind power control is by stall, pitch or active stall [23].

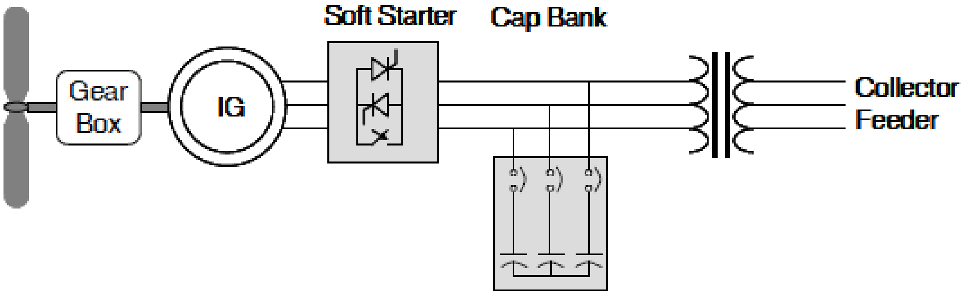


Fig.1.9: Constant/fixed speed WTG [26]

1.8.2 Variable speed wind turbine generator

1.8.2.1 Narrow Range Variable Speed

Wound rotor induction generator (SCIG) is used in the narrow range variable speed wind turbine generation. Speed range of this type of wind power plant can go up to ±10% of the rated speed. Mechanical construction of the stator is similar to the SCIG but the rotor circuit includes a variable resistor shown in Fig.1.10. This can be proficient with an arrangement of resistors and power electronics devices outside to the rotor with current flowing between the resistors and rotor by means of slip rings. On the other hand, the resistors and electronic circuit can be mounted on the rotor, this removes the slip rings. The variable resistors are associated into the rotor circuit delicately and can control the rotor current quickly in order to keep steady power even in gusting wind conditions, and can impact the machine's dynamic response of disturbing influences of grid [24].

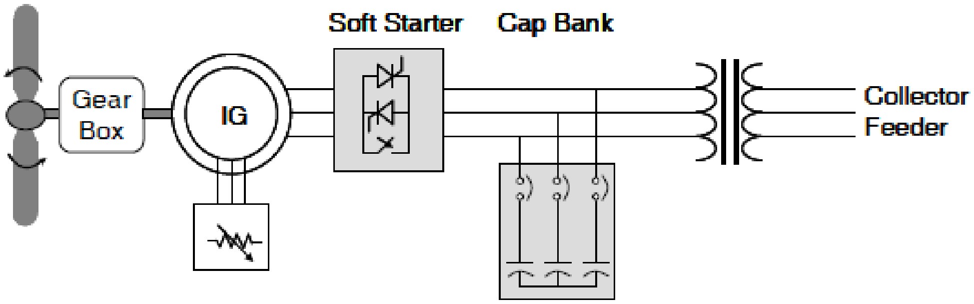


Fig.1.10: Variable speed WTG [25]

1.8.2.2 Limited Range Variable Speed

Doubly fed induction generator (DFIG) is used in limited range variable speed wind turbine generation. Speed is more variable in limited range of -30% to +40% of the rated speed.

Speed is controlled by regulation of power electronics converters (PEC) in rotor circuit. This rotor-side converter is connected back-to-back with a grid side converter given in Fig.1.11, which exchanges power directly with the grid [26].

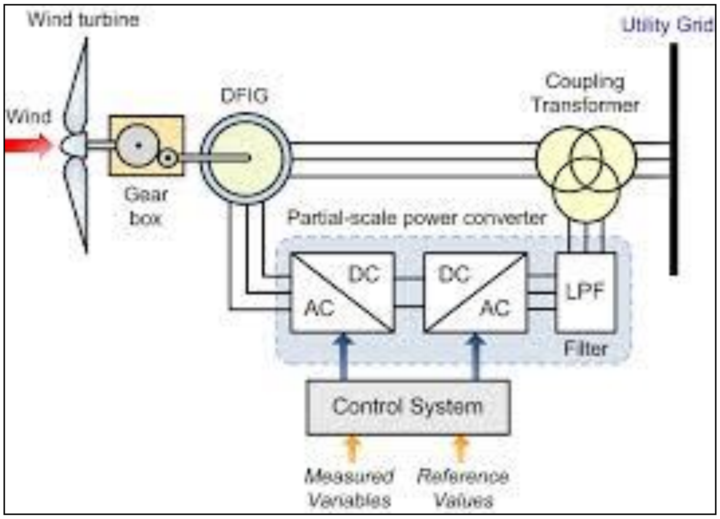


Fig.1.11: Limited range variable speed WTG [26]

1.8.2.3 Variable Speed With Full Power Electronics Conversion

These turbines offers a lot of adaptability in design and operation as the output of the rotating machine is sent to the centralized grid through a full-size back-to-back frequency converter given in Fig.1.12. The turbine is permitted to rotate at its ideal aerodynamic speed, bringing about a high AC output from the machine. Also, the gearbox might be wiped out, such that the machine rotates at the low turbine speed and produce an electrical frequency well below that of the grid.

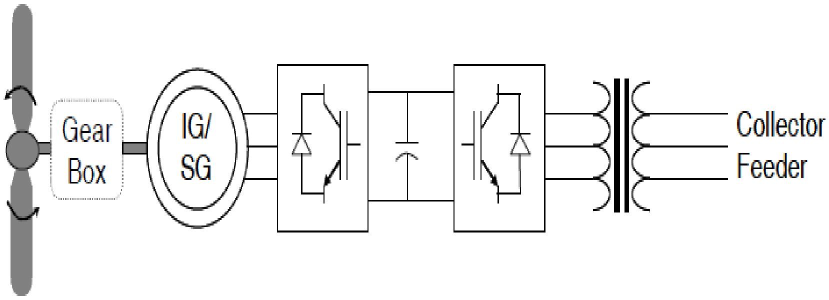


Fig.1.12: Variable speed WTG with full power electronics conversion [25]

The wound rotor synchronous machines constructed for this type are similar to traditional generators found in hydroelectric plants with control of the field present and high pole numbers, as permanent magnet synchronous machines, or as squirrel cage instigation machines [27].

1.8.2.4 Wide Range Variable Speed

Wound rotor synchronous generator (WRSG) and permanent magnet synchronous generator (PMSG) are used in wide range variable speed wind power plant. The turbines comprise of a common WTG variable-speed drive train associated with a torque/speed converter combined with a synchronous generator shown in Fig.1.13. The torque/speed converter changes the variable speed of the rotor shaft to a steady output shaft speed. The firmly coupled synchronous generator, working at a variable speed (relating to network frequency), can then be specifically associated with the grid through a synchronizing electrical switch. The synchronous generator can be design accordingly for any desired speed (commonly 6 pole or 4 pole) and voltage (normally medium voltage for higher capacities). This methodology requires speed and torque control of the torque/speed converter along with the run of the voltage controller (AVR), synchronizing system and generator security (protection) system with a grid connected synchronous generator [28].

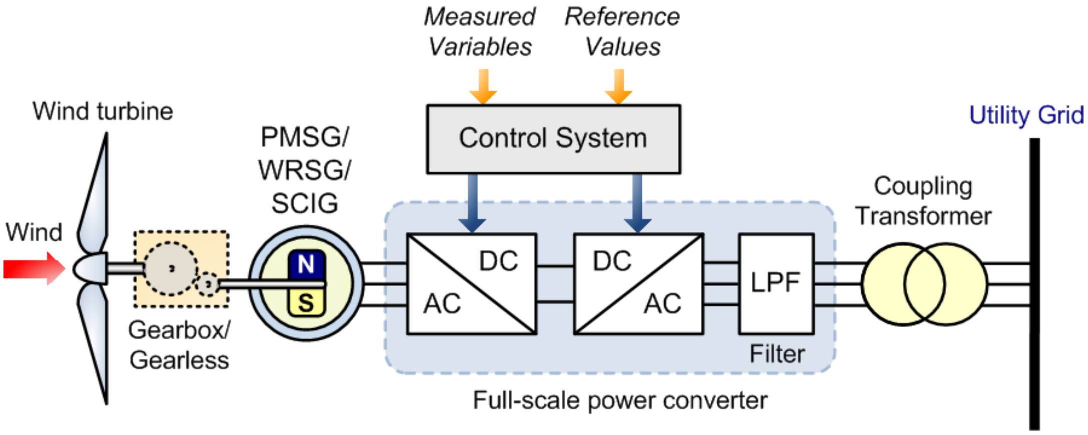


Fig.1.13: Wide range variable speed WTG [28]

1.9 POWER REGULATION METHODS

There are various methods for power regulation in a wind power plant, some of these are mentioned below in succeeding paragraph.

In the Stall control technique, wind turbine blade edges are formed such that the air foil produces less aerodynamic power at high wind speed, which inevitably gets slowed down, and turbine's torque decreases. This is a straightforward, economical, and hearty strategy of power control [29].

In the technique for Pitch control, power control is accomplished by the utilization of contributing pitching devices at the turbine center point i.e. hub. These devices curve the sharp blade edges around their own axis, and with the increase in wind speed, the edge rapidly pitches to the ideal point to control torque keeping in mind the end goal to catch the most extreme energy or to self-secure if required [25].

Another method is Active-stall regulation. This is an advanced version of stall regulated WPPs, usually adopted in WPPs of more than 1.5 MW ratings. In this method, the blades are pitched back into a deeper stall to control the rotation of the wind turbine rotor for the case of higher wind speed [28].

1.10 POWER ELECTRONICS IN WIND POWER PLANTS

Power electronics components are widely used in the Power system network and plays an important role in the Wind Power Plant. Various types of generator configuration and use of power electronic converter is given in the Fig.1.14. By acquainting the Back-to-Back power electronics converters (PECs), it is conceivable to completely control the extricated power from the wind turbines, furthermore give subordinate administrations to the grid. Power electronics turn out to be increasingly exceptional and get noteworthy execution changes for the wind turbines not just diminishing the mechanical stress and expand the energy yield, additionally empower the entire WTS to act like a totally controllable generating unit having much better capacity to incorporate the wind power into the grid network.

In these wind turbine ideas, the power electronics assume entirely distinctive parts in the WTS and has different power rating inclusions of the framework, Until now, the design of DFIG outfitted with partial scale power converter is ruling availability, yet in extremely not so distant future the set-up with synchronous generator (SG) with full scale power converter is relied upon to assume control. Now a days, the arrangements with full-scale power converter are turning into the favored innovation decisions in the top of the available power scopes of the wind turbines [28].

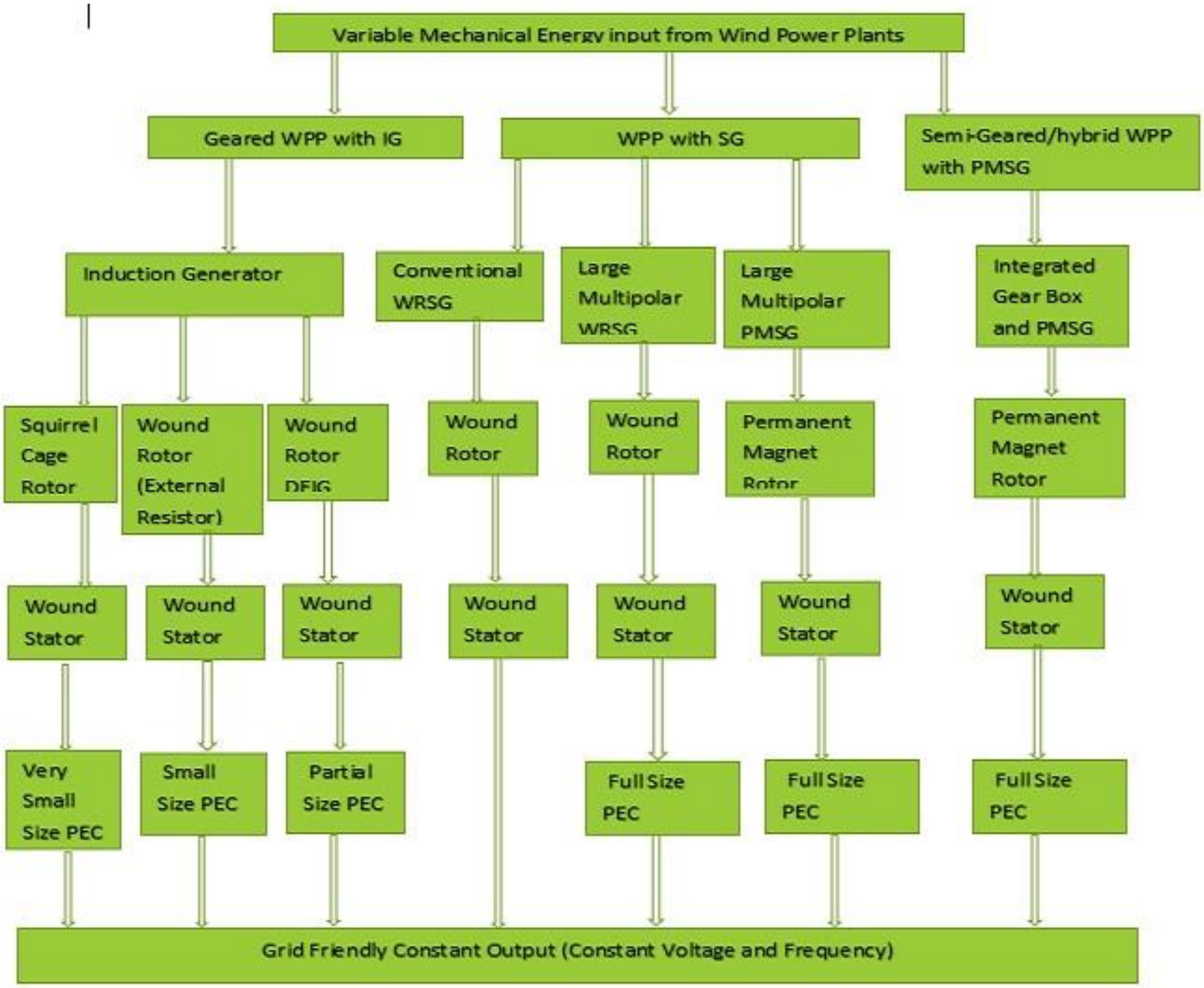


Fig.1.14: Overview of PEC application in WPPs [28]

where

WPP: wind power plant

IG: induction generator

SG: synchronous generator

WRSG: wound rotor synchronous generator

DFIG: doubly fed induction generator

PMSG: permanent magnet synchronous generator

PEC: power electronics converter

1.11 OBJECTIVE OF DISSERTATION

Objectives of this dissertation work are

I. Modelling of wind diesel hybrid minigrid in the MATLAB/Simulink environment.

II. To develop the strategies for Voltage and Frequency control of the wind diesel hybrid minigrid.

1.12 ORGANIZATION OF REPORT

This report is organized in 5 chapters and the work presented in each chapter is summarized as:

Chapter-1 gives a brief introduction about the energy scenario, types of grid, overview of minigrid technology, hybrid minigrid, and types wind power plants is given.

Chapter-2 presents literature reviews related to minigrid technology, wind energy technology, voltage and frequency control techniques, modelling and simulation of wind diesel hybrid minigrid has been done. On the basis of literature review gaps identified are also given.

Chapter-3 presents the simulation model of wind diesel hybrid system and modelling of different components of wind diesel hybrid minigrid is done.

Chapter-4 presents the developed hybrid wind diesel model, which is simulated in MATLAB/Simulink and results are analyzed with the brief discussions about the various parameters like voltage, frequency, power etc. is done. The model is simulated repeatedly for different conditions like constant load, variable load.

Chapter-5 presents conclusion and scope of future work related to this dissertation work.

CHAPTER-2

LITERATURE REVIEW

2.1 GENERAL

Minigrid can be designed to operate as an individual with or without tie up to main grid or central grid. While operating autonomously, minigrid cannot depend upon the central grid to provide stability in terms of the voltage and frequency, balance of power, manage reactive or real power [9]. Literature review has been done in following topics:

I. Minigrid technology
II. Wind energy technology
III. Voltage and Frequency control techniques.
IV. Modelling and Simulation of WTG

2.2 LITERATURE REVIEW

Verma [9] studied an existing minigrid with 18 bus and 17 lines power system of the Bageshwar district having 9 small hydro generation sites. This power system is connected to the state grid. The performance analysis of the minigrid like voltage compensation, power flow in line outage, power flow in generator outage has been calculated. With the help of contingency analysis program, he concluded that security of the system like maximum possible loading of the line which will reflects proper conductor sizing calculation, preferred location for providing the compensation by using the real power flow performance index. Recommendation on the basis of analysis done by him are that multiple contingency program should be used to increase the security of the system and for every large system neural network based program should be used to save the time.

Rajapandian *et al*. [22] presented a review on the wind resources assessment models, site selection models and aerodynamic models including wake effect. The diverse existing execution and unwavering quality assessment models, different issues identified with wind turbine segments (blade, gearbox, generator and transformer) and tie network for wind energy system have been discussed. They additionally assessed distinctive methods and burdens for configuration, control system and financial matters of wind energy transformation network.

Kamal *et al*. [23] presented a hybrid power system consisting of a wind turbine, a diesel generation unit and energy storage devices. Both the wind power generator and the synchronous generator work at variable speed to augment the wind energy catch as a power source and minimize the diesel fuel utilization for monetary reason. Both sorts of generation units are associated with the alternating current (AC) load network through Power Electronics Interface (PEI) to balance out the system frequency. The control is performed so that the power coefficient is improved.

Sebastian *et al*. [24] presented the MATLAB/Simulink models for all the wind diesel hybrid system components. The control system has shaft speed of the diesel motor (DE) and synchronous machine as inputs and applies a PID controller in wind only mode and a PD controller in wind diesel (WD). The principal part of the simulation covers the wind only (WO) mode with the system reaction to a 100 kW positive load step and shows how the battery energy storage system (BESS) changes from consuming the extra power to supplying the required power. The second part demonstrates the move from WO to WD mode by connecting with the clutch in the diesel generator (DG), so as to substitute the BESS with the DE as the active power source. In both simulations the battery energy storage system under the command of the APR smoothens the transient and improves the system response.

Sinha *et al*. [27] proposed the autonomous hybrid generation/energy storage system with an automatic generation control system to eliminate the mismatch in supply and demand under varying condition of load and generation. So as to lessen the frequency deviation i.e., reduce the difference in supply and demand, the yield power from the sources is managed by utilizing controllers (PI/PID). The gains of controllers are designed by utilizing conventional strategy and genetic algorithm (GA). Execution of every controller is inspected from the dynamic response in time-area simulation of the system under islanded operation. It has been watched that the reaction of PID controller is the best amongst PI, therefore PID controllers considered for study as far as peak transient deviation and settling time. Further, it is found that the execution of all the GA advanced controllers is superior to their individual partner’s enhanced utilizing conventional strategy.

Wies *et al.* [29] presented the application of genetic algorithm (GA) based proportional integral derivative (PID) speed control for improved frequency regulation in wind-diesel minigrid with high wind contribution using a dynamic system model. Model is designed on basis of a common wind-diesel minigrid network, established with a wind power plant connected with the principle network tie bus by means of a short transmission line with a dump load controller to take care of frequency changes because of wind pace. By utilizing the proposed control technique the better simulation results of frequency control under transient wind conditions are found.

Bauer *et al*. [30] proposed a hybrid power system network (HPS) which comprises of diesel Genset, PV exhibits and wind turbines with energy storage and power electronic gadgets. They additionally examined the various connected topologies, a portion of the sources that produce AC power and others that produce DC power. Subsequent to examining the various configurations they found that the system productivity of the Mixed-coupled power system is ideal and this format is utilized for further examination. The design/size approach for the hybrid power system has been taken by considering the burden of load, solar radiation and wind speed profile of any windy condition site. For the chosen configuration, different Power Management Strategies (PMSs) are characterized and numerical models are inferred considering that there is no difference in the power equalization between the supply and the consumer side load demand, including charging and discharging control of the battery and interchanging controls for the Genset.

Bevrani *et al*. [31] proposed the present day power hybrid system with expanding intelligence and adaptability in the control and designed to guarantee the capability of keeping up balance amongst generation and load/burden under interruptions. They also discussed the different inverter interfaced distributed generation (IIDGs) with confined and all around control loops in a minigrid. Voltage and frequency of MGs are profoundly subject to the active and reactive burden/load changes.

They described the voltage and frequency control of IIDGs by droop characteristics and if there is an occurrence of serious changes in burden, the IIDGs might fail and the MG could collapse. Therefore they utilized the fuzzy logic technique to optimally tune the generalized droop control (GDC) structure and also secondary voltage and frequency controllers. They simulated the MATLAB model and results obtained exhibits high performance and desirable response for different scenarios of change in load while using fuzzy logic technique. It has been found that while using fuzzy logic technique based generalized droop control dependency on minigrid line parameters are also reduced.

Ketabi *et al*. [32] proposed under-frequency load shedding UFLS scheme for the minigrid which used the first derivative of frequency for load shedding. Under-frequency protection is very important for a healthy stable power system. They discussed the sudden connection/disconnection of load or power generation sources might cause the system unbalance due to variation in parameters and finally minigrid may collapse. Some distributed energy resources such as photovoltaic/wind turbine generators, output power might change during load shedding process which can influence the performance. Subsequently, they proposed an under-frequency load shedding plan which is free of the minigrid parameters and change in power generation during the process is also considered. Output results of this load shedding scheme demonstrates that it is free of MG parameters, especially inertia constant.

Hong *et al*. [33] discussed about various procedures, techniques and algorithm to screen the execution of wind turbine and also for early fault recognition to keep away the wind turbines from disastrous conditions because of sudden breakdowns. To separate the greatest measure of energy capture authenticity of wind turbine is critical. To keep the wind turbine in operation, implementation of condition monitoring system (CMS) and fault detection system (FDS) is of great importance and therefore a detailed investigation has been made towards the CMS and FDS concepts. These techniques needs initial investment but investment can be recovered by the additional benefits of continuous production, minimum downtimes and more time available for an early planning to replace the defected parts. Hence it is found that implementation of CMS and FDS are beneficial and can increase the profit margins substantially.

Singh *et al*. [34] proposed a system to control the pace of a self-sufficient wind diesel battery mixture power framework having a squirrel cage induction generator (SCIG) for a wind energy conversion system. They discussed about the adaptive linear control algorithm for the control of voltage and frequency by load side voltage source inverter. Throughout the fluctuating loads and wind speed an arrangement of consecutive connected voltage source converters (VSCs) and battery energy storage are utilized to control the speed of IG and to keep the frequency and voltage consistent. The generator side VSC controls the SCIG torque utilizing a field based control. The complete control system is produced for wind diesel hybrid network and has been tested in the MATLAB/SIMULINK programming and it is found that execution of the system is enhanced by the frequency and voltage control, load adjusting, and harmonic disposal under various load conditions and changing wind speeds with proposed control calculations.

Jansuya *et al*. [35] discussed the MATLAB model of fixed-pitch angle wind turbine conversion system containing wind turbine profiles, which are mechanical power and torque characteristics. The main purpose of work has been to develop and design the fixed-pitch angle wind turbine in MATLAB/Simulink environment followed by analysis of the output of the wind power in terms of torque to propel the induction generator thus to produce the electrical power and to verify the effectiveness of the fixed-pitch angle wind turbine simulator at over rated rotational speed. Simultaneously simulation has been done to analyse the analytical model output at different load conditions and variable wind speeds. Finally results are validated by the simulation results.

McGowan *et al*. [36] proposed an overview of medium-sized wind turbines design requirements especially for use in a remote hybrid power system. The example is taken from the existing wind turbine model of 250kW installation, operation and upgradation in the university of Massachusetts test site. Their work summarizes that for any remote site a lot of constraints needs to be taken care like sensors, communication, and control capabilities, grid connection issues and weather-related problems. The design requirements in the remote locations should be ensured for successful installation, faster maintenance and repairs. Geological conditions should be studied in details for the pole installation.

Haque *et al*. [37] introduced the dynamic operation and control techniques of a hybrid wind-diesel-battery energy storage based power supply system for rural area. Control methodologies for voltage and frequency adjustment and effective power flow among the hybrid system components are produced. The voltage and frequency of the hybrid wind-diesel system is controlled either by a load side inverter or by diesel generator relying upon the wind conditions.

A battery energy storage system is connected with the dc-link to adjust the power produced from the wind turbine and the burden/load power. A power sharing method is produced to assign power generation for diesel generator in low wind conditions. Control methodologies work exceptionally well under dynamic and steady state condition to supply energy to the load. From the contextual analyses results, it is found that voltage and frequency can be controlled in the wind-diesel hybrid network inspite of variable wind and load conditions.

Cooperman and Martinez [38] reviewed a range of sensors for monitoring wind turbine blade loads and for active load control. Wind turbine dynamic burden control requires sensors that can recognize loads as they happen, to empower a brief incitation of control gadgets. Sensors utilized for burden observations on wind turbines incorporates auxiliary sensors, for example, strain sensors, accelerometers and shape sensors, and inflow sensors, for example, pitot tubes, weight transducers and LIDAR. Auxiliary sensors can be exceptionally precise yet just react to loads after they happen. Inflow sensors distinguish changes sooner, however are susceptible to blunders in the models that relate aerodynamic variables to loads. For new sensor advances to pick up acknowledgment in the wind business, straightforward and decisive systems are required that can give an exact evaluation of the loads experienced by a turbine. In the event that these objectives can be proficient, enhanced monitoring of wind turbines will give chances to advanced control and enhanced execution.

Gampa and Das [39] proposed a wind diesel hybrid system in isolated mode operation and the dynamic analysis of this power system is done by using different control schemes. The investigation is done in time domain considering improved models of the system component by considering the wind turbine pitch controller and the diesel generator speed governor. For better element exhibitions of wind–diesel system under wind and load disruption conditions, two control plans are proposed.

In the primary case, a proportional–integral (P–I) controller and in the second case a proportional–integral–derivative (P–I–D) controller are utilized. Pick up parameters of these controllers are upgraded utilizing genetic algorithm (GA) and Particle swarm optimization (PSO) considering two distinctive objective functions and the outcomes are compared. The decisive investigation of the wind diesel system is completed for parameter instabilities and the strength of the system is dissected utilizing D-stability rule. The closed loop is demonstrated robustly stable as indicated by D-stability rule.

They did the investigation to look at the impact of power infusion to a 69 bus radial network by wind–diesel in islanded mode. Investigation reveals that the gain parameters enhanced utilizing PSO and GA give pretty much comparative dynamic responses. They found that particle swarm advancement is computationally more effective than genetic algorithm.

Murthy *et al*. [40] proposed wind diesel framework with variable wind speed turbine and its dynamic execution. To enhance the system attributes, a variable speed wind generator DFIG alongside diesel generator in the confined hybrid system is utilized. The simulation results of the proposed hybrid system are introduced to exhibit its viability in taking care of progress in load demand alongside change in wind speed. The execution of the proposed system is analysed utilizing MATLAB/SIMULINK and it is found that the change in power and frequency are least. Frequency and voltage quality of the power supplied to the self-governing system is enhanced by controlling the frequency to the reference value. Power variation has diminished much by utilizing variable rate wind turbine generator contrasted with constant rate wind turbine. The feedback of the system outfitted with DFIG during wind changes and burden/load changes, is steadier and the capacity for reactive power output of DFIG is improved.

Wollny *et al*. [41] considered AC coupled MGs and discussed about the battery inverter control rule and found that battery inverter uses voltage and frequency control and the operational control of the energy supply system and found that the droop control with the power control of the generators by means of frequency deviation makes it conceivable to develop disseminated system without a quick correspondence system.

Platt and Conforth [42] concentrated on the significance of inverters affectability for the recognition of faulty conditions, while maintaining a strategic distance from false activating and discussed about the false activating which makes troublesome in MG with elevated amounts of inserted generation, as loss of a solitary generator adequately adds burden to an officially stressed system, furthermore it is recommended that if the distinguished grid voltage and frequency fluctuates outside a reach indicated by the utility, the inverter must be detached from the AC supply inside two seconds.

Berry *et al*. [43] discussed about the specialized issues identified with the minigrid innovation and they explored that the coordination of distributed energy sources and renewables specifically, into working minigrid designs is neither direct nor comprehended, with issues identifying with inverter association, islanding, control, insurance, identification, quality and unwavering quality of various source based minigrid have diverse conduct of event of issues.

Pablo *et al*. [44] suggested that the Power variation of all converter units in a minigrid is not only dictated by burden but also by the accessible power of every unit, i.e. a converter sustained by a battery. Energy administration control is crucial with a specific end goal to handle the assortment of prime movers which may incorporate diverse sorts of renewable energy sources (RES) and energy storage system (ESS).

2.3 GAPS IDENTIFIED

Based on the literature review, the following gaps have been identified:

1. The fault analysis of minigrid has not been discussed in details.
2. Sensitivity of power electronics devices to differentiate the occurrence of fault and normal working condition for inductive loads is not described in details.

3. For a grid connected minigrid, its working in the island mode has not given much attention.
4. Advanced controllers implementation for different minigrid topologies needs to be addressed.

CHAPTER-3

MODEL OF WIND DIESEL HYBRID SYSTEM

This chapter presents simulation model of wind diesel hybrid system. A simulation model of wind diesel hybrid system is developed with high penetration of wind without any storage.

3.1 WIND DIESEL HYBRID ENERGY SYSTEM

Containing wind turbine coupled with squirrel cage induction generator, diesel engine set, the hybrid energy system is operated in an isolated mode of operations, with an aim to develop strategies to control the voltage and frequency of the system. Block diagram representation of wind diesel hybrid system is given in the Fig.3.1. At low wind speeds, both the induction generator and the diesel-driven synchronous generator are required to feed the load. When the wind power exceeds the model load demand, it is possible to shut down the diesel generator and therefore a controller is designed to feed the mechanical power to the synchronous machine in such a way that combined electrical power output of the wind turbine generator and the diesel generator match the load demand power.

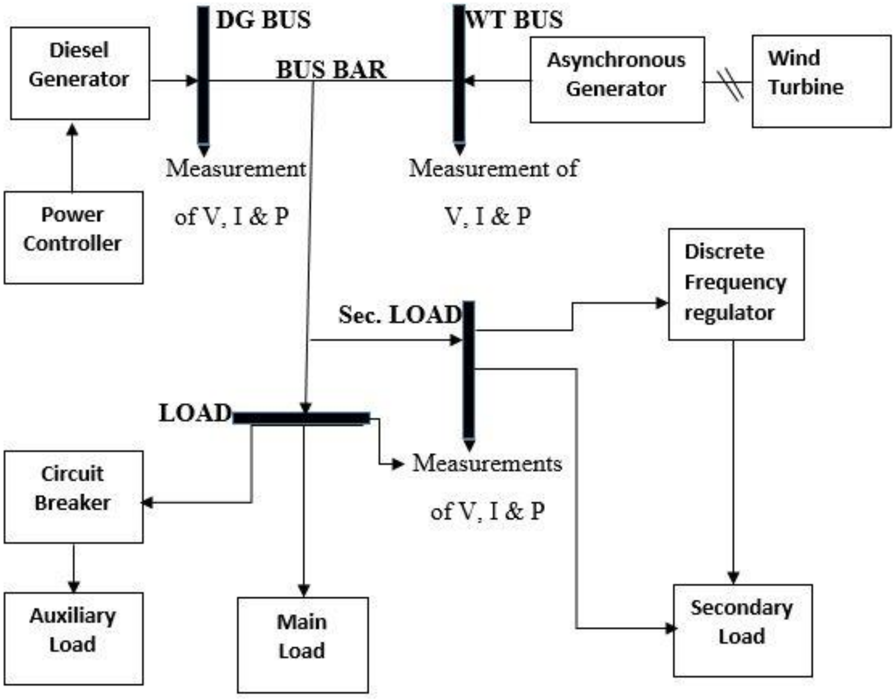


Fig.3.1: Block representation of wind diesel hybrid system

When wind speed is sufficient enough to generate the power required by the demand then system is working in all wind mode and in this all wind mode only Asynchronous generator coupled to the wind turbine is generating power and the synchronous machine is used as a synchronous condenser. A controlled secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand. Cut in speed of wind turbine model is 5 m/s and cut out speed is 25 m/s which is shown in the MPPT.

3.2 MODELLING OF DIFFERENT COMPONENTS OF HYBRID ENERGY SYSTEM

The modelling of different components of hybrid energy system is done in this chapter. Components working is explained in detail and their mathematical modelling is also explained.

3.2.1 Wind Turbine Model

The wind turbine model is taken from the Simulink library example, its MPPT curve is also incorporated in the Simulink model showing the cut in speed, operating range of speed. Wind turbine act as a prime mover for the induction generator and gives the mechanical torque as an input for the induction generator. MPPT for this wind turbine model is given in the Fig.3.2. MPPT gives the wind turbine speed characteristics and describes the relationship between wind speeds and electrical power output (pu) at corresponding rated speed of generator.

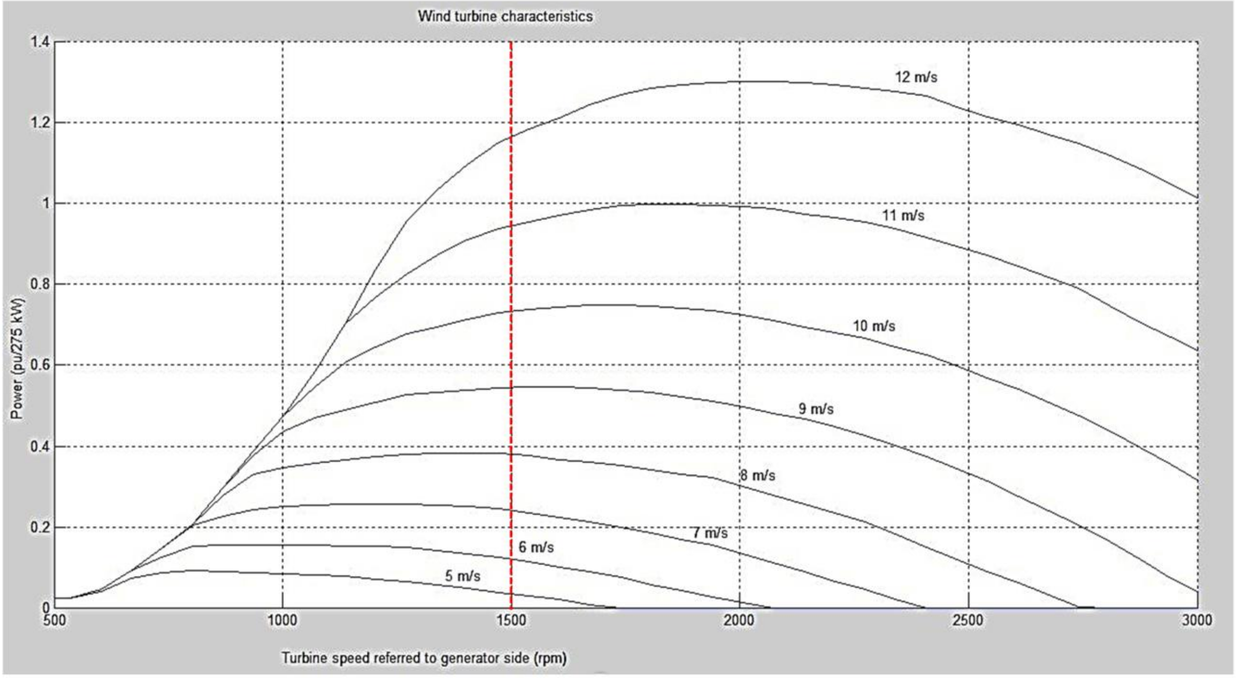


Fig.3.2: wind turbine characteristics with MPPT

3.2.2 Asynchronous Generator Model

An Induction Generator model is taken from Simulink library which is working in the pu basis. A squirrel cage rotor induction generator is used for the electrical power generation. Mechanical output power of wind turbine is applied to it in the form of mechanical torque as an input to rotate the shaft/rotor of the induction generator. Therefore at different wind speeds the mechanical power output of the wind turbine varies. Mechanical output power from wind turbine is given by;

$$P_{mech} = \frac{1}{2} \rho A V^3 C_p \tag{3.1}$$

where

C_p is the Power coefficient or Betz Limit (Cp max = 0.59)

A is the swept area of the blade in m^2

V is the wind speed in m/s

ρ is the air density in the kg/m^3

Power coefficient Cp is given by;

$$C_p = \text{(Power available in the wind) / (power extracted by the turbine)} \tag{3.2}$$

Mechanical torque applied to induction generator is given by

$$T_m = P_{mech} / W_m \tag{3.3}$$

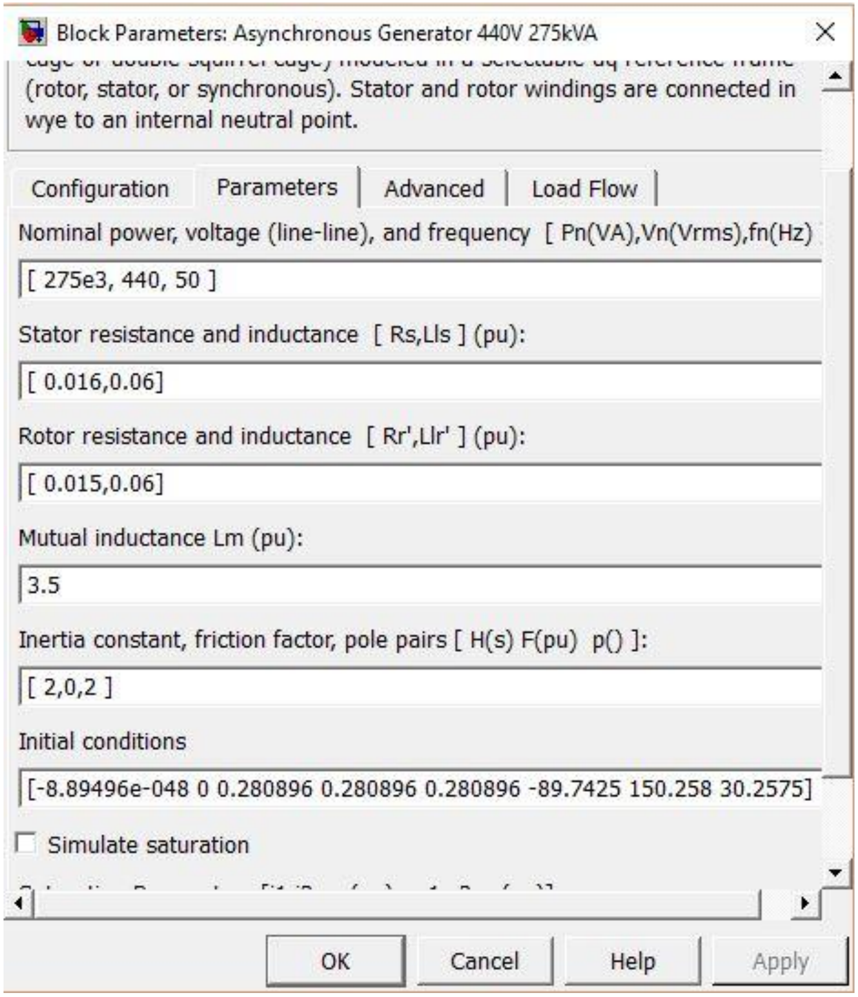
where

P_{mech} is the mechanical output power of the wind turbine in Watt

W_m is the angular velocity of the turbine in rad/sec.

The induction machine can operate in both mode i.e. Generator as well as Motor. Mode of operation of Asynchronous machine depends on the input torque supplied to it therefore a great care has to be taken when the wind speed is below cut in speed, otherwise asynchronous generator will start consuming power from the system and thereby creating the unstability in the system. Hence, only positive value of input torque is supplied to the Asynchronous machine. Asynchronous generator is working in rotor reference of frame and its rated parameters are given in Fig.3.3.

Rated Speed	:	1500rpm
Line to line Voltage	:	440V
Rated Frequency	:	50Hz
Rated Power	:	275kVA



Block Parameters: Asynchronous Generator 440V 275kVA

(rotor, stator, or synchronous). Stator and rotor windings are connected in wye to an internal neutral point.

Nominal power, voltage (line-line), and frequency [Pn(VA),Vn(Vrms),fn(Hz)

[275e3, 440, 50]

Stator resistance and inductance [Rs,Lls] (pu):

[0.016,0.06]

Rotor resistance and inductance [Rr',Llr'] (pu):

[0.015,0.06]

Mutual inductance Lm (pu):

3.5

Inertia constant, friction factor, pole pairs [H(s) F(pu) p()]:

[2,0,2]

Initial conditions

[-8.89496e-048 0 0.280896 0.280896 0.280896 -89.7425 150.258 30.2575]

☐ Simulate saturation

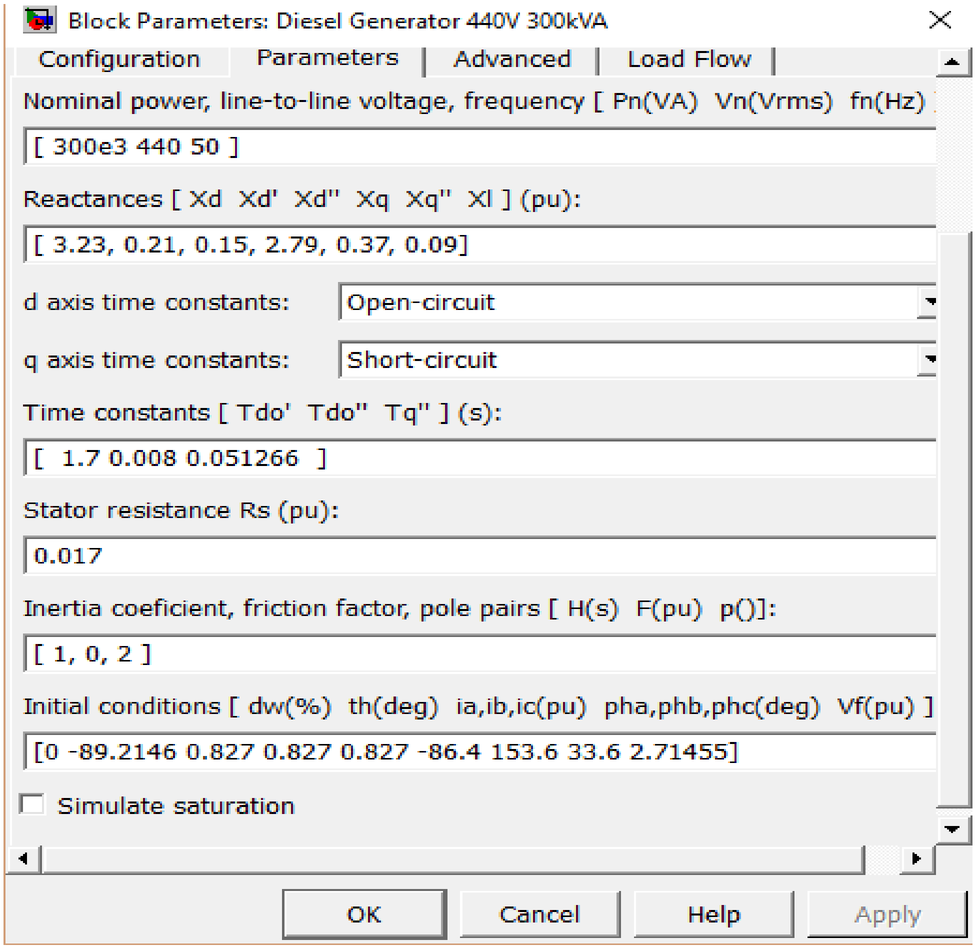
Fig.3.3: Data of Asynchronous Generator model

3.2.3 Diesel Generator Model

A synchronous generator model is used as a diesel engine set. Synchronous Generator model is taken from the Simulink library and all the parameters are given in pu values. The electrical and mechanical characteristics of machine are considered by synchronous machine model. The model takes into account the dynamics of the stator, field, and damper windings. Synchronous machine can work as a synchronous condenser when the sufficient power is generated by the wind turbine to feed the main load therefore mechanical input power to the synchronous machine is zero but it takes little active power from the system to work as a synchronous condenser and thereby helping in the improvement of the overall system voltage profile. Synchronous Machine is assumed to be a part of Diesel generator therefore the mechanical input to Synchronous Machine is supposed to be a diesel engine set but here in this model mechanical power input to the synchronous machine is given by the designed power controller which will be explained later in this chapter in under frequency control section.

The rated parameter of synchronous machine are given below and in Fig.3.4.

Rated Speed : 1500rpm
Rated Line to Line Voltage : 440V
Rated Frequency : 50Hz
Rated Power : 300kVA



Nominal power, line-to-line voltage, frequency [Pn(VA) Vn(Vrms) fn(Hz)
[300e3 440 50]

Reactances [Xd Xd' Xd'' Xq Xq'' Xl] (pu):
[3.23, 0.21, 0.15, 2.79, 0.37, 0.09]

d axis time constants: Open-circuit

q axis time constants: Short-circuit

Time constants [Tdo' Tdo'' Tq''] (s):
[1.7 0.008 0.051266]

Stator resistance Rs (pu):
0.017

Inertia coeficient, friction factor, pole pairs [H(s) F(pu) p()]:
[1, 0, 2]

Initial conditions [dw(%) th(deg) ia,ib,ic(pu) pha,phb,phc(deg) Vf(pu)]
[0 -89.2146 0.827 0.827 0.827 -86.4 153.6 33.6 2.71455]

☐ Simulate saturation

Fig.3.4: Data of Synchronous Machine Model

3.2.4 Capacitor Bank Model

A capacitor bank is connected near to the asynchronous generator end and in this hybrid energy model it is used for the reactive power compensation to asynchronous generator but it can also be used for the power factor correction if required when inductive loads are used. The Capacitor bank data is given below.

Configuration : 3-Phase Delta connected
Line voltage : 440 V
Frequency : 50 Hz
kVARs Ratings : 75 kVARs

3.2.5 Load Model

In model of Wind Diesel hybrid system there are three types of loads connected, which are purely resistive. In this model load is considered to be very near to the power generating sources therefore transmission line losses has been not considered in this minigrid formation. Main load is always connected to the minigrid whereas auxiliary load is controlled through circuit breaker and secondary load is working as a controlled dump load. The detailed explanation of Secondary load is given in the over frequency control section later in this chapter. Different types of loads and their ratings are given below.

Main Load Ratings
Line to line voltage : 440 V
Rated Power : 200 kW
Rated Frequency : 50 Hz
Type of load : Purely resistive constant load

Auxiliary Load Ratings
Line to line voltage : 440 V
Rated Power : Variable
Rated Frequency : 50 Hz
Type of load : Purely resistive constant additional load controlled by circuit breaker

Secondary Load Ratings

Line to line voltage : 440V
Rated Power : 446.25kW
Rated Frequency : 50Hz
Type of load : Purely resistive variable load in the steps of 1.75 kW, in the binary progression

3.2.6 Control Models

The control logic is applied for this hybrid system and the modelling of the voltage and frequency controllers is done MATLAB software. They are categories in following two sections

I. Voltage control
II. Frequency control

3.2.6.1 Voltage Control

Over all voltage profile of the system is collectively controlled by 75kVARs Capacitor bank and the synchronous machine. When this model is working in all Wind mode i.e. wind power is sufficient to or more than required electrical power of demand load, therefore in this condition synchronous machine work as a synchronous condenser and the excitation system of the synchronous machine is in the overexcited mode and participate in the reactive power compensation. In all wind mode of operation synchronous machine takes very few active watts from the system itself. Capacitor bank is works as a power factor correction device as well as it also supplies the required reactive power demand of the asynchronous machine.

At the time of low wind speeds, asynchronous generator cannot feed the demand alone therefore in this condition the synchronous generator is working as a companion to the wind turbine generator. At these times two conditions arise that are only diesel generator is supplying the total demand and wind turbine generator system generation is zero. Second is that both the systems participate in some proportions to supply the total load demand. In both the above explained cases synchronous machine is working as synchronous generator hence the excitation system of this generator with automatic voltage regulator (AVR) and with capacitor bank collectively contributes in the improvement of voltage profile of the system.

An IEEE type-1 synchronous machine voltage regulator combined to an exciter is used from Simulink library and implemented in this hybrid model. The output of the Excitation block is the field voltage vfd, in pu, to be applied to the Vf Simulink input of a Synchronous Machine block. Connect the Vd and Vq measurements signals of the Synchronous Machine block. The inbuilt IEEE type-1 exciter model in the Simulink library is given in the Fig.3.5.

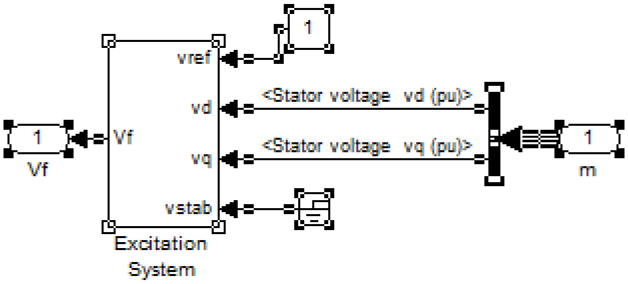


Fig.3.5: Excitation Model for Synchronous Generator

3.2.6.2 Frequency Control

Frequency plays an important role in the stability of any network what so ever may be the size of the system and whether working in grid connected mode or isolated mode of operation. A grid connected minigrid system stability can be compensated by the large capacity generating stations but in the case of an isolated minigrid, frequency control is a very critical component for the system to remain in the stable condition. Therefore there arises the requirement of a proper control mechanism for under-frequency and over-frequency control. The developed control logics are explained below.

3.2.6.2.1 Under Frequency Control

A control strategy is being developed for this wind diesel hybrid system minigrid to clear the under-frequency conditions as soon as possible. For the system to be practically feasible high penetration of wind is desired but in the adverse conditions when generation through wind is not possible diesel generator should be used as full load source or partial load source. Therefore the difference/mismatch in load demand and wind power generation is being fulfilled by the diesel generator. Difference of load demand and wind power generation is fed as the mechanical input to the synchronous generator in pu values. Under-frequency controller is shown in the Fig.3.6.

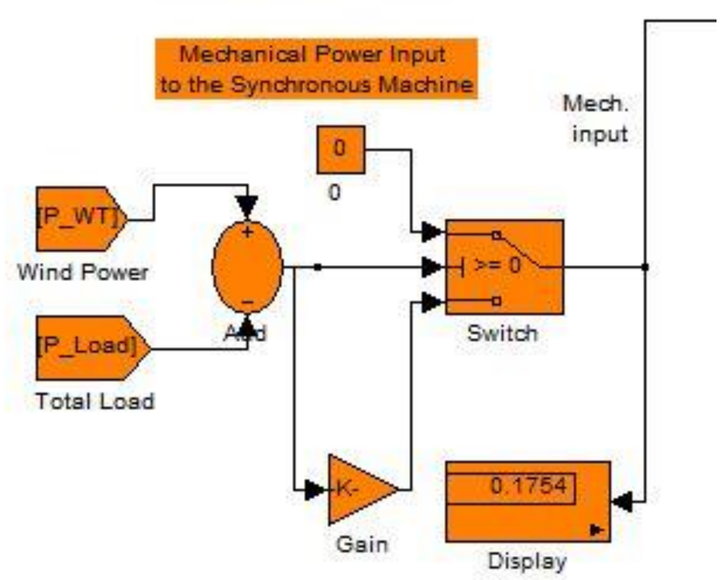


Fig.3.6: Under-frequency controller

The output power of wind turbine generator and total load demand is given to the adder with appropriate sign meaning. Difference quantity is given to the switch and the gain block. Switch has three input and one output, it connects through input 1 when input 2 satisfies the selected criterion; otherwise, pass through input 3. The input 1 processing criteria are input 2 greater than or equal, greater than, or not equal to the threshold. The first and third input ports are data ports, and the second input port is the control port. Input 3 of the switch is given through the gain and gain output is the value converted in the pu because the diesel generator model parameters are selected in the pu basis.

Case -1 $P_w - P_L > 0$ (over frequency case) (3.4)

Switch input 1 is activated and zero value is passed to the mechanical power input of the diesel generator therefore synchronous machine is working as a synchronous condenser and generating reactive power only.

Case -2 $P_w - P_L = 0$ (normal working) (3.5)

Switch input 1 is activated and zero value is passed to the mechanical power input of the synchronous generator therefore synchronous machine is working as a synchronous condenser and generating reactive power only.

Case -3 $P_w - P_L < 0$ so $P_G = P_w - P_L$ (under frequency case) (3.6)

Switch threshold reaches, so input 3 is activated and difference value in pu from gain block is passed to the mechanical power input of the synchronous generator therefore synchronous machine is working as a synchronous generator and generating active & reactive power.

where

P_w is the active power generated by the Wind Turbine Asynchronous Generator

P_L is the active power demand of total load i.e. Main Load + Auxiliary Load

P_G is the active power generated by the Synchronous Generator i.e. Diesel Generator

Gain Block

Output of the gain block is given by

$$Gout = \{-(Pw - Pl) / (\eta * \text{kVA rating of the synchronous generator})\} \quad (3.7)$$

Where

Gout is the gain output value in pu, act as input to synchronous generator mechanical power input.

η is the efficiency of the synchronous generator (95% taken for this model)

3.2.6.2.2 Over-Frequency Control

A discrete frequency regulator is designed to control the over-frequency of the system. When system is working in all wind mode i.e. at higher wind speeds and electrical power generation is greater than the load demand, due to mismatch in generation and demand frequency overshoot and can go beyond the allowable range of operating frequency that creates unstability in the system. Therefore to control the over-frequency discrete frequency regulator generates an 8 bit digital signal which is used to activate the secondary/dump load resistors. The frequency regulator block is shown in Fig.3.7.

Phase Locked Loop (PLL) takes the system voltage as its input and converts voltage phase into the corresponding frequency. Output frequency of the PLL is then compared with the reference frequency and the difference/error is given for the next block.

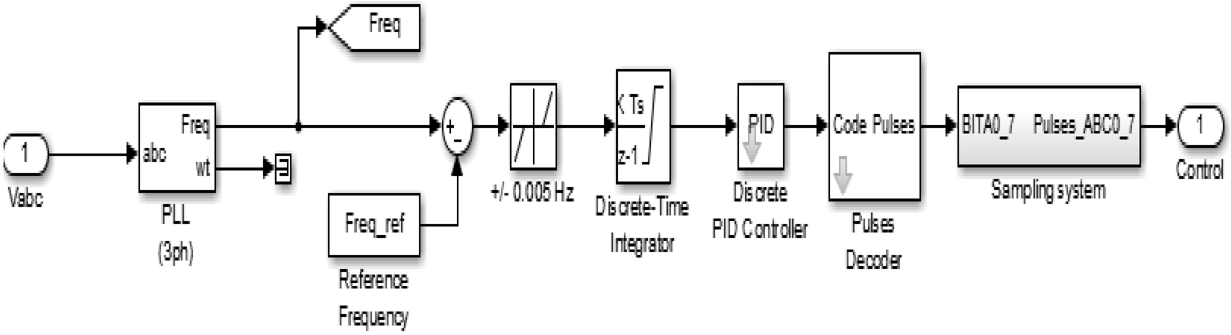


Fig.3.7: Discrete frequency regulator

The Dead zone block has the upper and lower limits, so the error signal is processed only if the error signal is above or below the upper and lower limits respectively. Discrete time integrator performs discrete time integration or accumulation of the signal. A Discrete PID controller with automatic gain set and automatic code generation storage class system is used to generate the pulses according to error.

Pulse Decoder converts the pulses available from the output of the discrete frequency regulator block into the corresponding digital 8 bit code pulses. The sampling system samples the generated discrete signal at regular intervals and collected sample is send to the secondary load control block. It consist of 8 series resistors connected through GTO switches. For every bit of the received signal one set of three phase resistor is engaged and the on off state of a particular resistors set depends upon the received signal of 8 bit digital code. If the signal is high then GTO's get the gate pulse high and it is switched on which ultimately connects the dump resistors into the line and power is balanced hence frequency over shoot comes down to reference value. The secondary load with GTO switches and control signal received from the discrete frequency regulator is shown in the Fig.3.8 and 8 set of resistors with respective activating significant bit is shown in Fig.3.9. The resistors with significant bit no. are increasing in the steps of 1.75 kW and therefore they are designed to operate in the binary progression and in the combinations as per the respective bit status, required to compensate the over frequency.

The resistors can be switch on off as per the requirement of the power so that there is balance in power supply and demand load. The resistors are switched on in the steps of 1.75 kW and can be regulated in 256 steps. Total load can be varied in the 0 to 255 steps with a step size of 1.75 kW to complete full load of 446.25 kW if required. Control scheme employed here follows the binary progression to increase the dump load power rating.

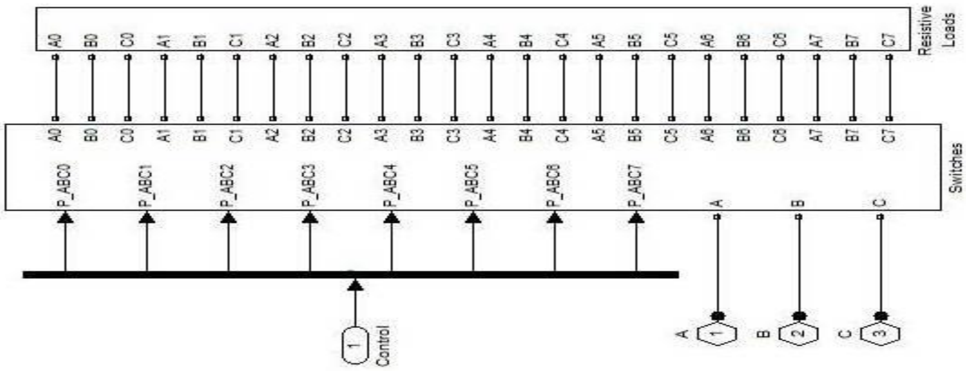


Fig.3.8: Dump Load with GTO Switches

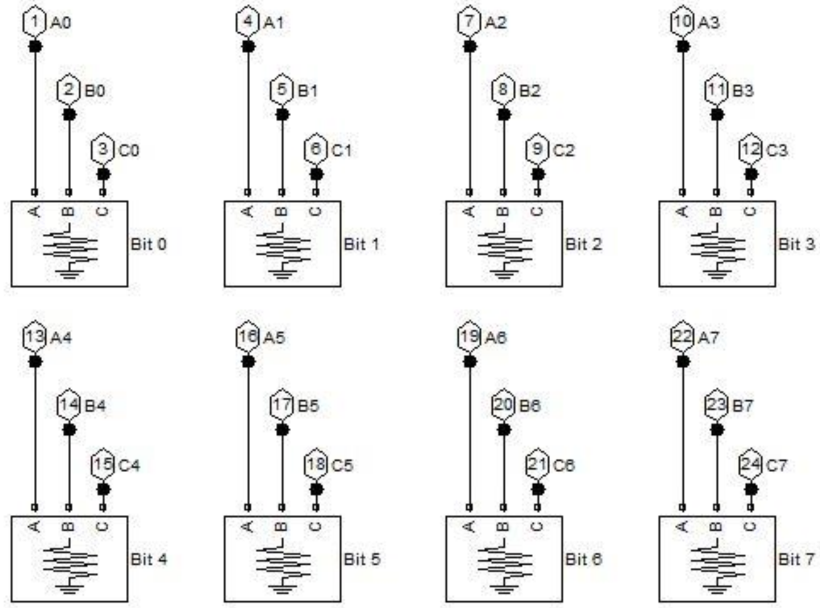


Fig.3.9: Series resistors with significant bit

Resistors with significant bit numbers active power is given by;

Total Dump Load $= \sum 1.75*2^{a}$ kW; $a = 0$ to 7 (3.8)

If all the 8 bit status is high then maximum secondary/dump load that can be connected to the system is (1+2+4+8+16+32+64+128)*1.75 kW = 446.25 kW

The developed wind diesel hybrid model working in isolated mode is shown in Fig. 3.10.

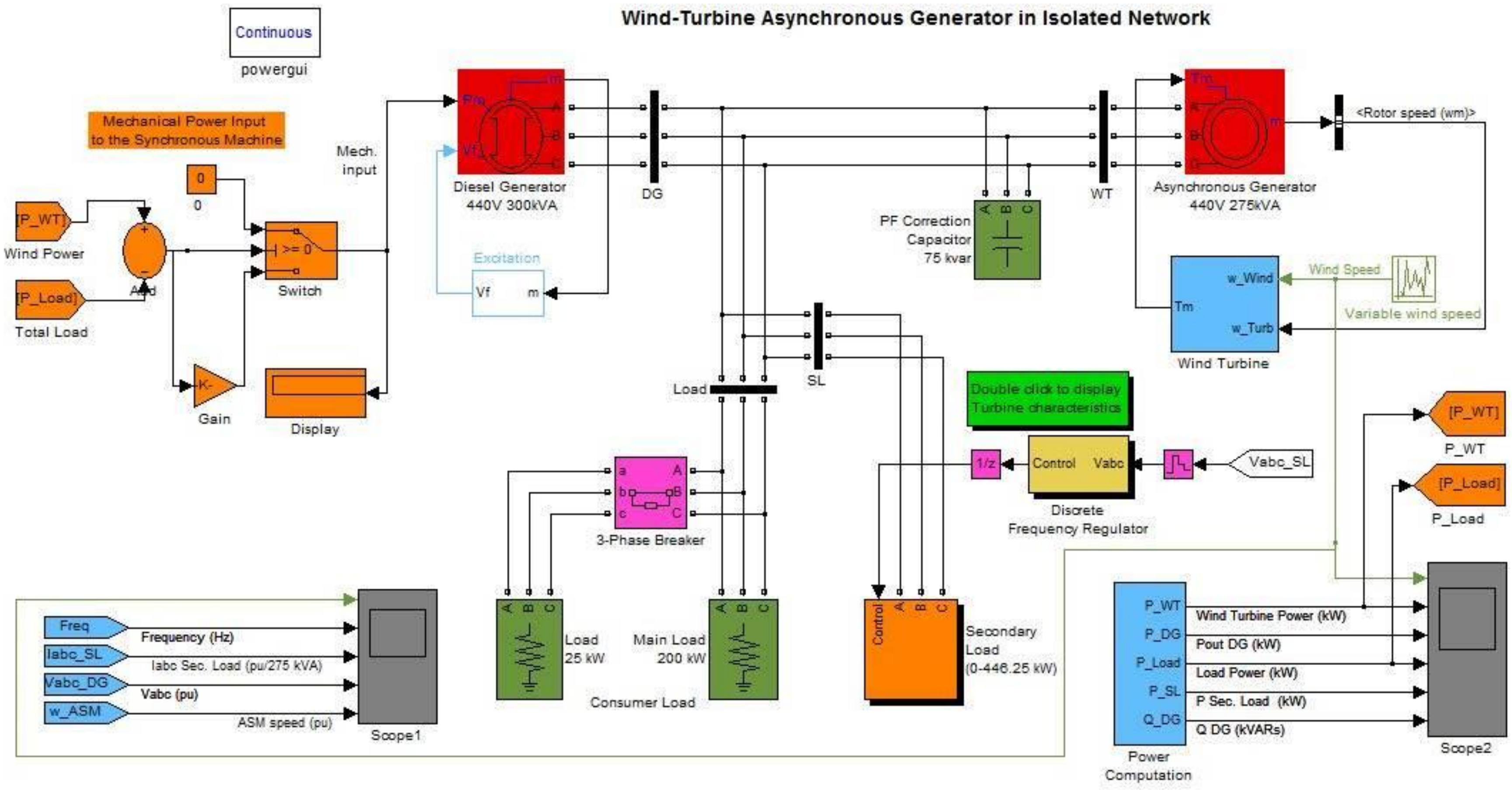


Fig.3.10: MATLAB wind diesel hybrid model

CHAPTER-4

RESULT AND DISCUSSION

The developed control strategies are applied to a hybrid wind diesel energy system. In this chapter results and discussions of simulated model are presented. The results are analyzed at different conditions like constant wind speed, variable wind speed, constant load, variable load and possible combination of these.

4.1 CONSTANT LOAD AND VARIABLE WIND SPEED

The resistive loads of 200 kW and auxiliary load of 25 kW are connected to the minigrid, they are kept constant throughout the simulation time. Wind speed is changing at an interval of 5s and wind speed might be increasing or decreasing as a uniform random number block is used for the wind variation. A uniform random number block generate the uniform random signal with in the specified range, in this model this block is used to generate the variable wind speed input for the wind turbine from 0m/s to 12m/s. The MATLAB model of wind diesel hybrid system is simulated in the MATLAB/Simulink environment for 50s. Obtained results are analyzed for voltage variation and frequency variation, divided in different time slots according to wind speed. Simulated results for hybrid system are given in Fig.4.1 to Fig.4.10.

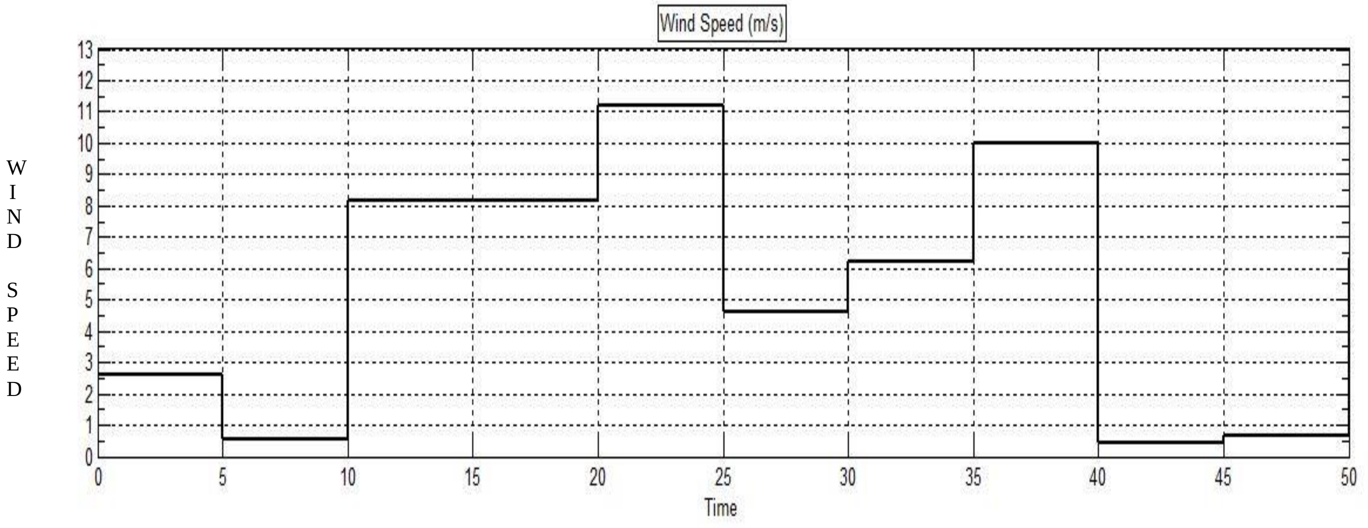


Fig.4.1: Plot of variable wind speed v/s time

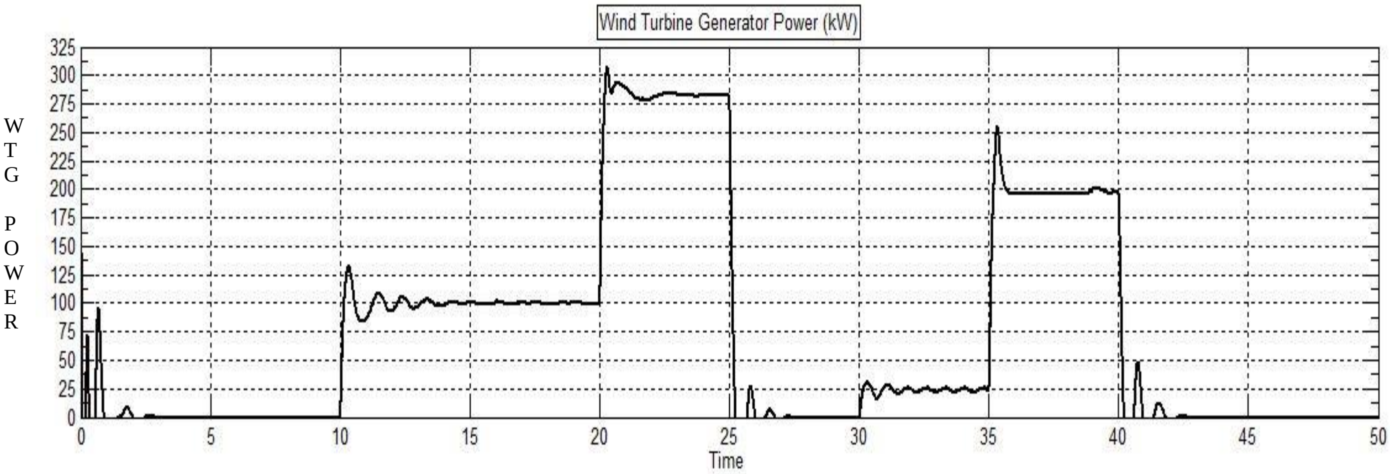


Fig.4.2: Plot of wind turbine generator power v/s time

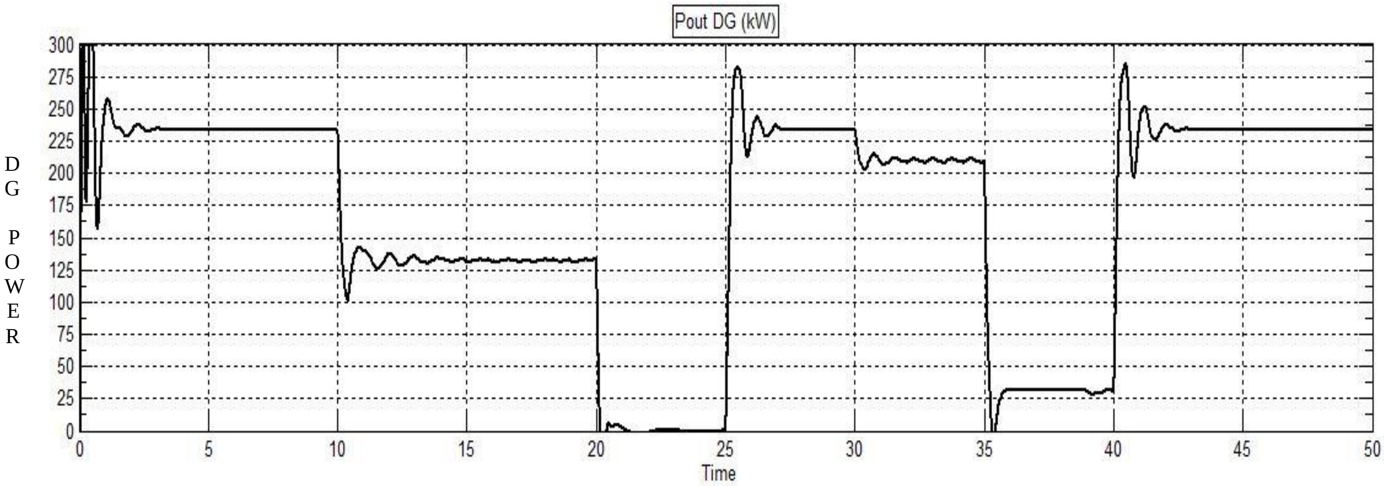


Fig.4.3: Plot of diesel generator power v/s time

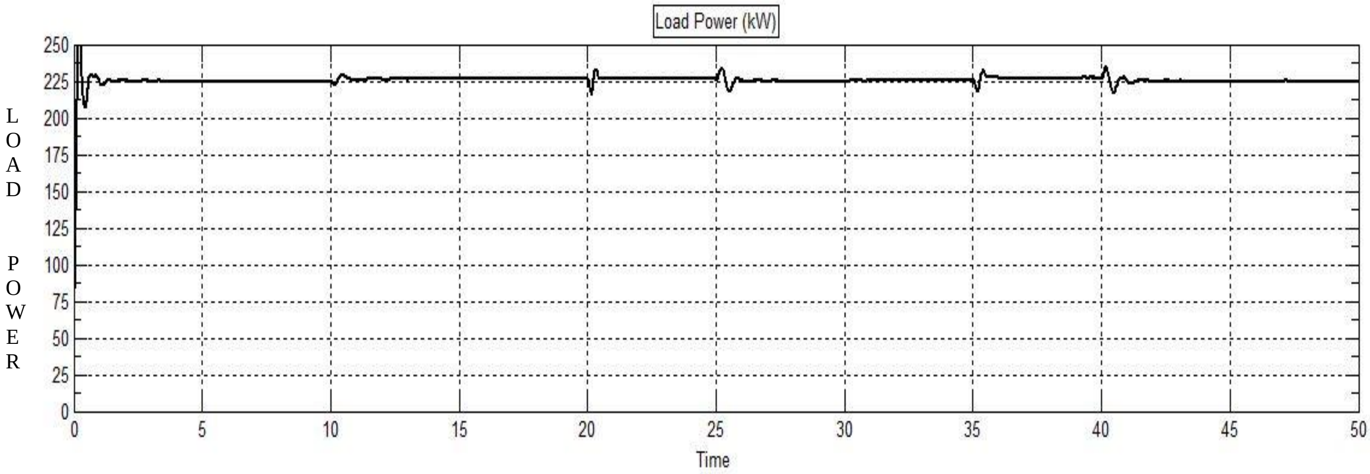


Fig.4.4: Plot of Load power v/s time

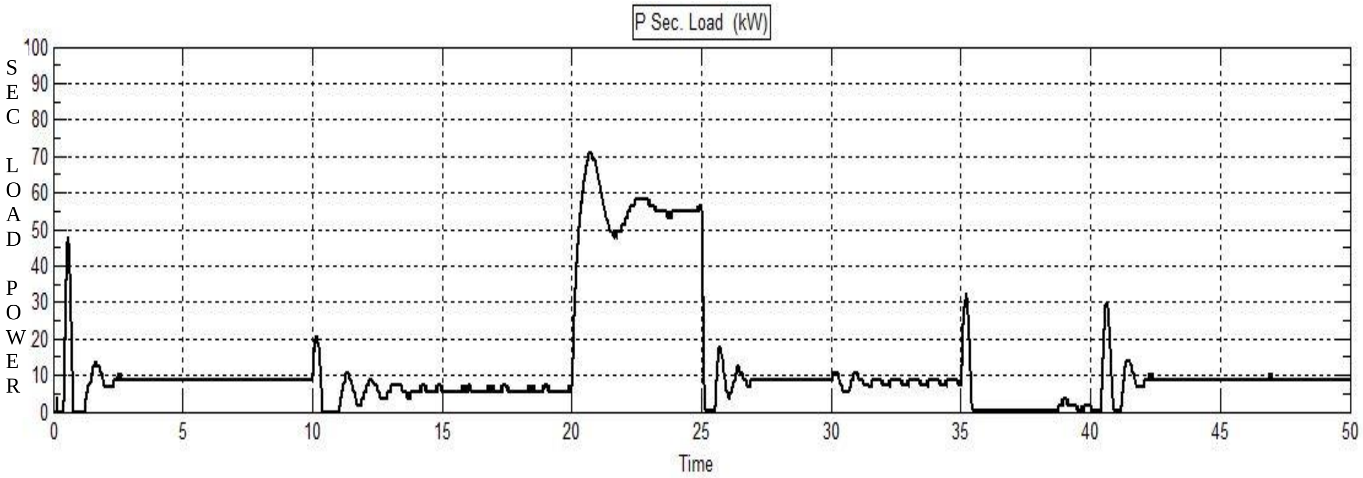


Fig.4.5: Plot of Secondary Load power v/s time

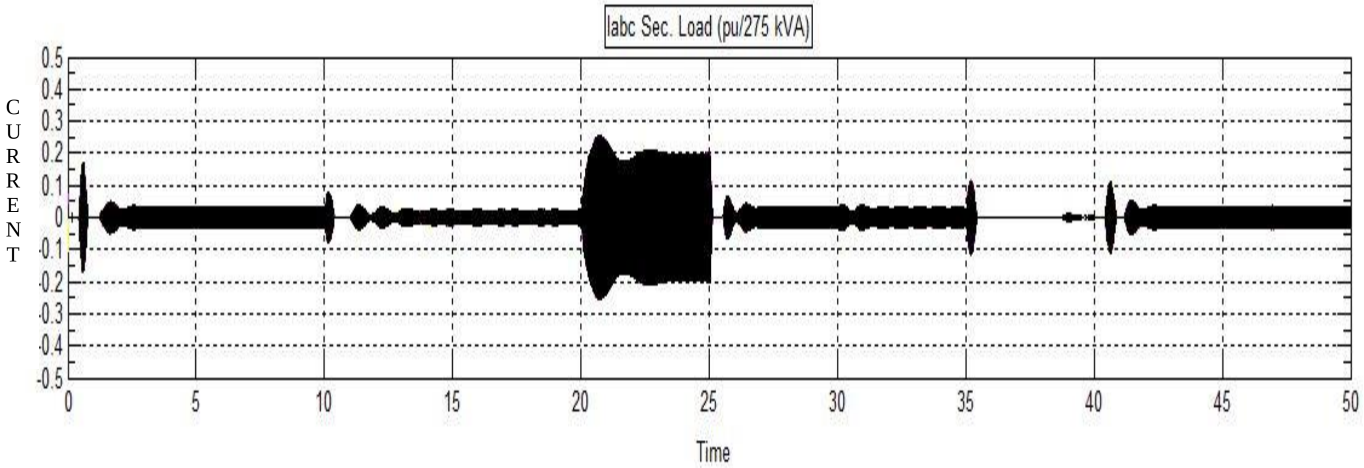


Fig.4.6: Plot of Secondary Load current v/s time

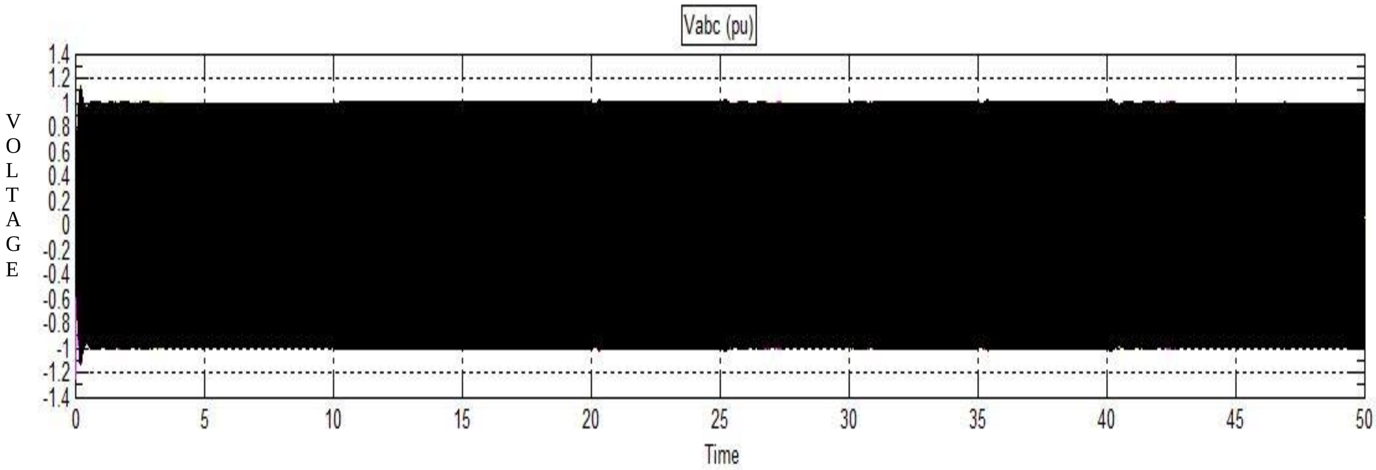


Fig.4.7: Plot of System voltage v/s time

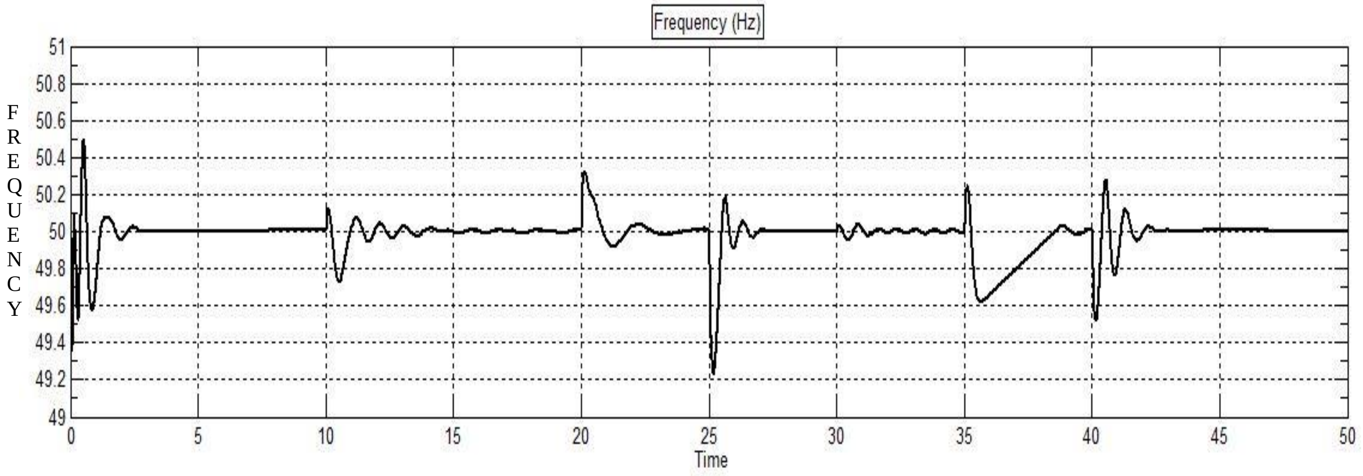


Fig.4.8: Plot of system frequency v/s time

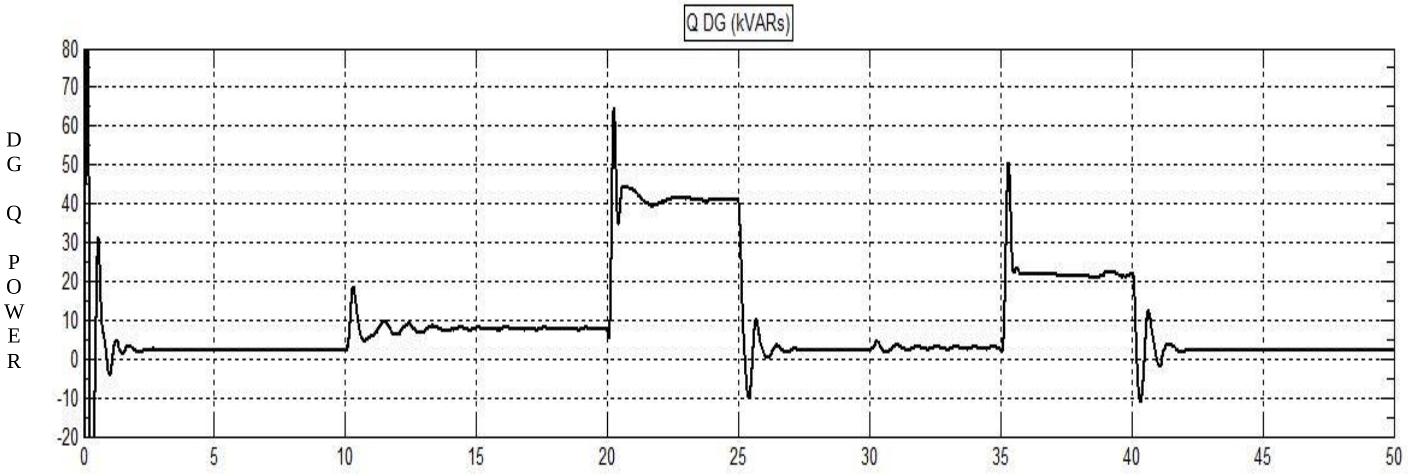


Fig.4.9: Plot of DG reactive power v/s time

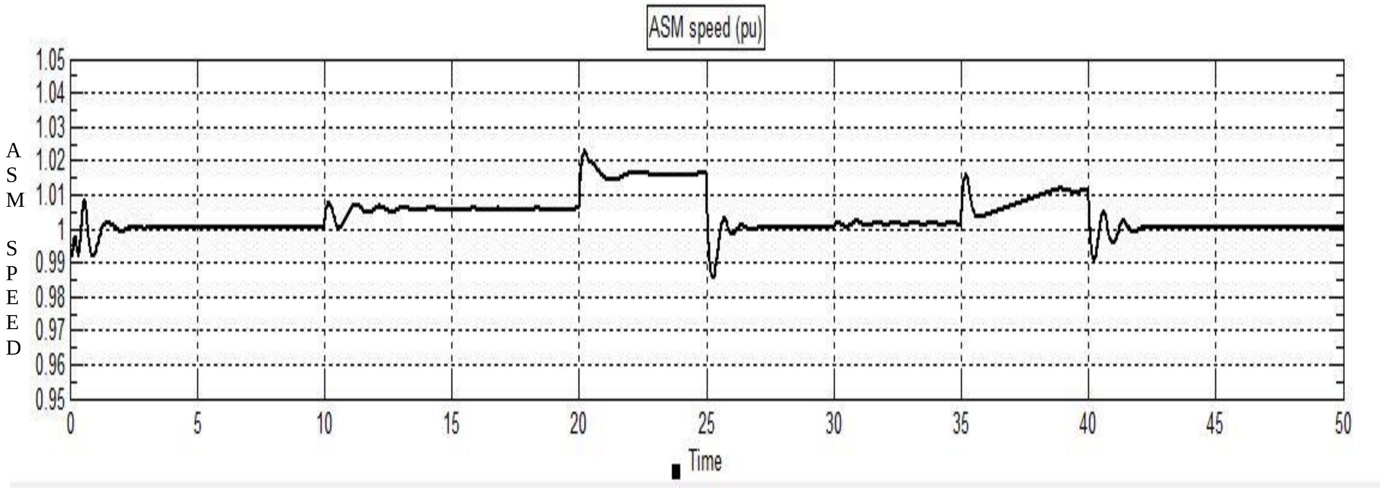


Fig.4.10: Plot of asynchronous machine speed v/s time

4.1.1 Wind speed is below 5 m/s

The main load and auxiliary load is kept constant at 200 kW and 25 kW respectively, shown in Fig.4.4. At t = 0 to 10s, t= 25s to 30s, t= 40s to 50s the wind speed is below the cut in speed i.e. 5m/s as shown in Fig.4.1, therefore total load is fed by the diesel generator shown in Fig.4.3. Initially at t= 0s there is some disturbance in the diesel generator power curve but within 1s diesel power curve finally settles at required load power corresponding fluctuations of ±.5 Hz are seen in the frequency as shown in Fig.4.8. The fluctuation at the starting time is due to PID controller action because for any minute change in system frequency it responds very quickly.

During these time slots the output power of induction generator is almost zero as shown in the Fig.4.2. In the Fig.4.3 at t = 0s, 25s, 40s it can be seen that there is fluctuation initially for 1s or 2s, until DG power finally adjust to balance the power in the system. These time slots are the cases of under frequency but it is noticed that inspite of the under frequency case the secondary load is also switched on as shown in Fig.4.5, this is due to the PID controller action. Whenever secondary load is switched on the corresponding current value is shown in the Fig.4.6. Voltage of the system is almost constant at 1 pu with negligible fluctuation when wind speed increase or decrease.

At t = 0s, 25s, 40s wind speed suddenly decrease and power is controlled by the diesel generator, during this transfer of control frequency drops for 1s and then settles at its reference value. When wind speed is below cut in speed or when wind speed suddenly drops below cut in speed of wind turbine then under frequency situation arises and power control takes the appropriate action to control the power of the system hence power is balanced and system remains in the stable condition.

4.1.2 Wind speed is between 5 m/s to 10 m/s

During this time period power is generated by the both the generators and the proportion depends upon the difference of wind power and load. It is desired to give the preference to the wind power generation therefore wind power is considered at priority.

At t = 10s to 20s wind speed is constant at 8 m/s, wind generator generates 100 kW and rest of the power (125 kW) is generated by the diesel generator. At t= 10s frequency drops to 49.7 Hz due to transfer of control from DG set to wind turbine. Although these time slots are under frequency cases but due to PID controller action secondary load is switched on and DG set is generating extra 10 kW power.

4.1.3 Wind speed is above 10 m/s

At t = 20s to 25s the wind speed is constant at 11.2m/s and the total load demand is supplied by the wind turbine generator. At t = 20s the wind generator power goes upto 300 kW but finally settles at 280 kW after 2s. The DG set power drops to zero and due to this transfer of power control frequency drops to 49.2 Hz and then rises to 50.2 Hz and finally settles at 50 Hz. This is a case of over frequency therefore at t= 25s the secondary load is switched on, initially 70kW and after 2s – 3s finally 55 kW. The ASM speed increases to 1.02 pu at t = 20s then after 2s it finally reaches 1.015 pu. Voltage is almost constant at 1 pu.

4.2 VARIABLE LOAD AND CONSTANT WIND SPEED

The developed wind diesel hybrid model is simulated for a constant wind speed of 10.5m/s and load is variable. Main load of 25 kW is constant and auxiliary load of 200 kW is initially connected to the system, at t = 15s the auxiliary load is disconnected from the system. At t = 25s auxiliary load is again connected to the system. The obtained results are shown in Fig.4.11 to Fig.4.20.

4.2.1 Load is connected to the system

At t = 0s to 10s initially total load demand is 225 kW, wind speed is constant at 10.5m/s, induction generator is generating 235 kW power at this wind speed and induction generator speed is 1.015 pu. At this wind speed system is working in all wind mode since generated power by WTG is sufficient to supply the load demand. Extra 10 kW is consumed by the secondary load, frequency is constant at 50 Hz, synchronous machine is working as a synchronous condenser generating only reactive power 30 kVAR and the system voltage is constant at 1 pu value.

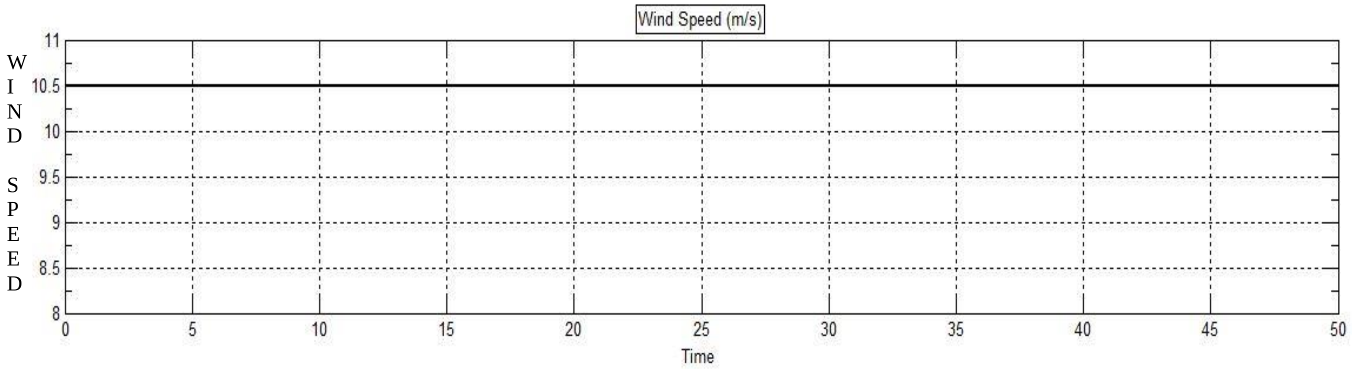


Fig. 4.11: wind speed v/s time

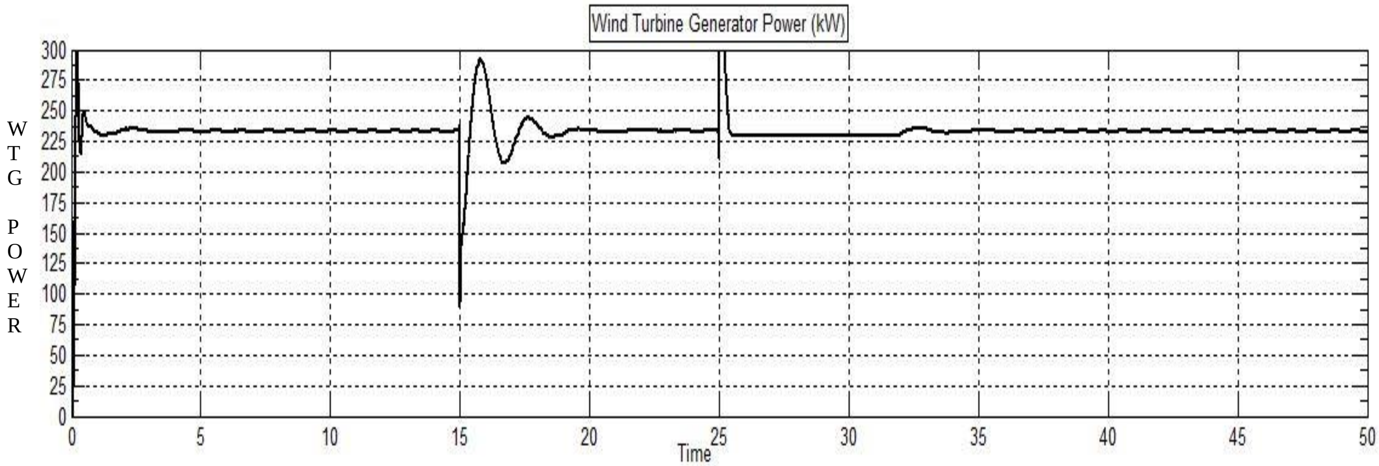


Fig.4.12: wind turbine generator power v/s time

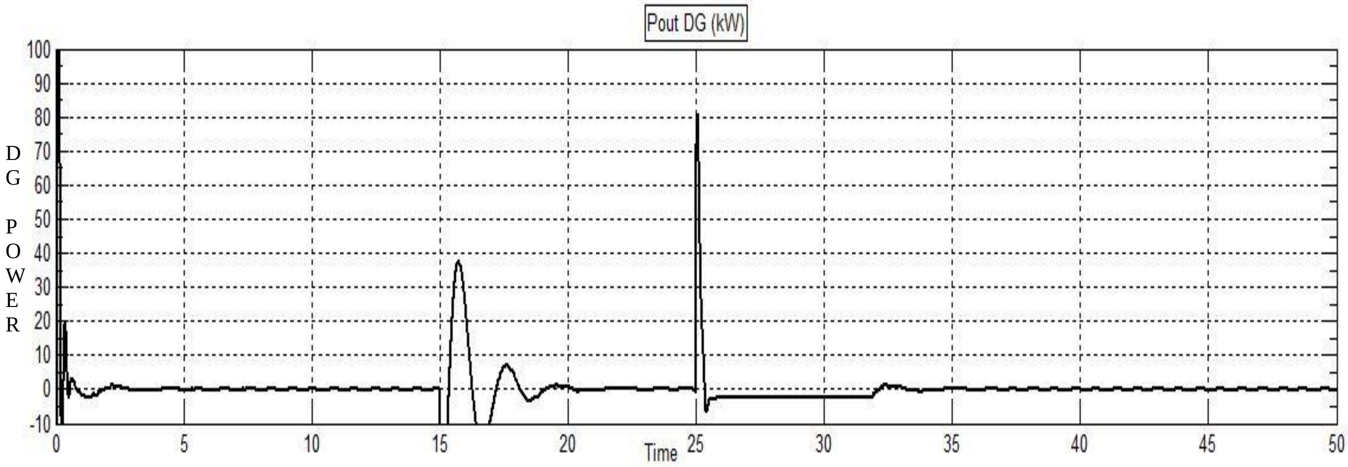


Fig.4.13: Plot of diesel generator power v/s time

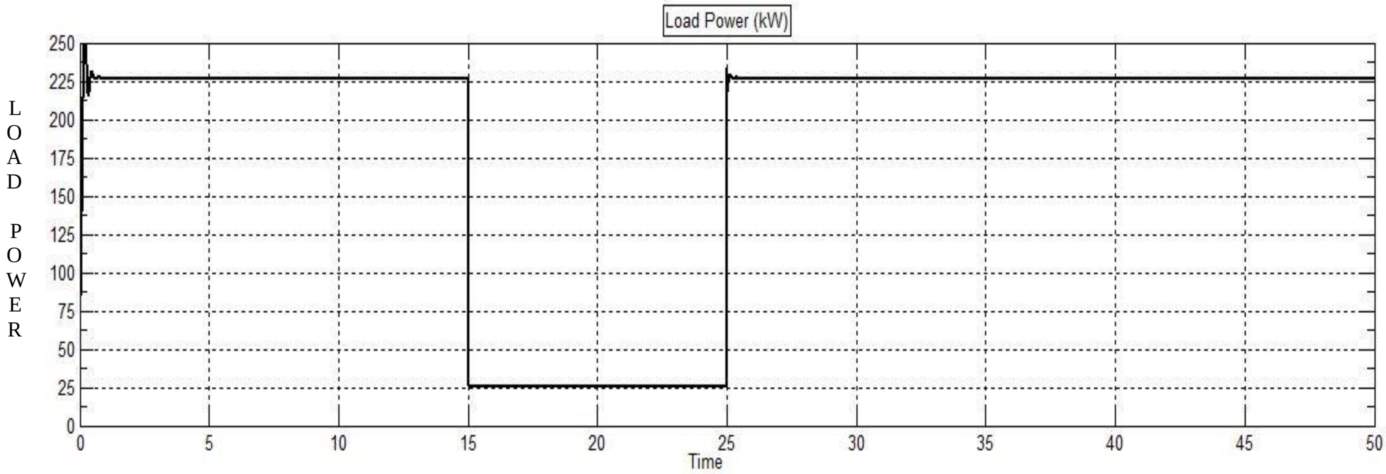


Fig.4.14: Plot of Load power v/s time

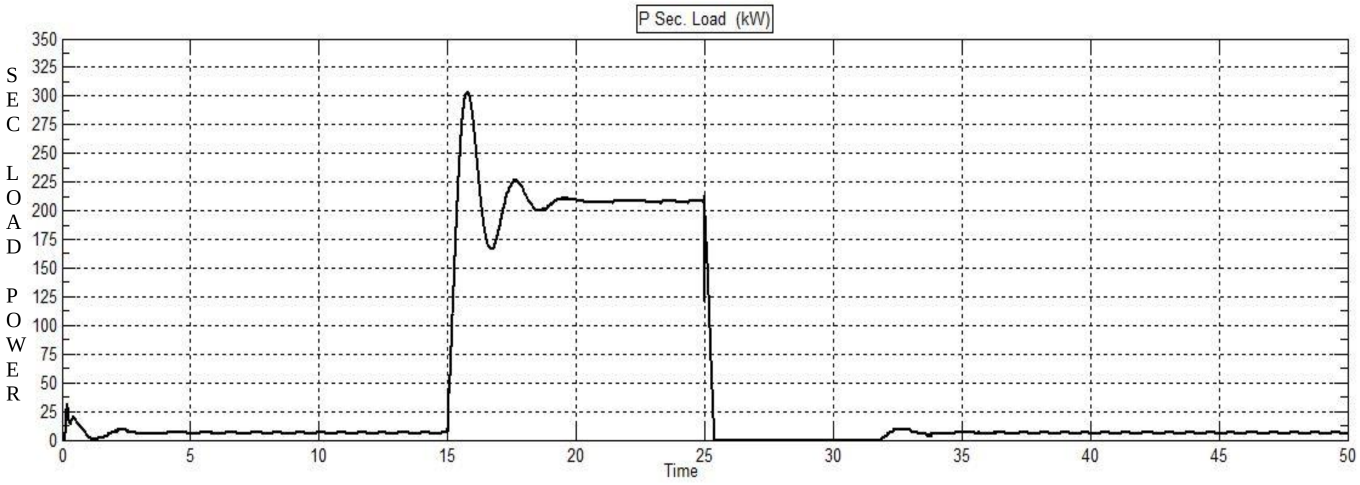


Fig.4.15: Plot of Secondary Load power v/s time

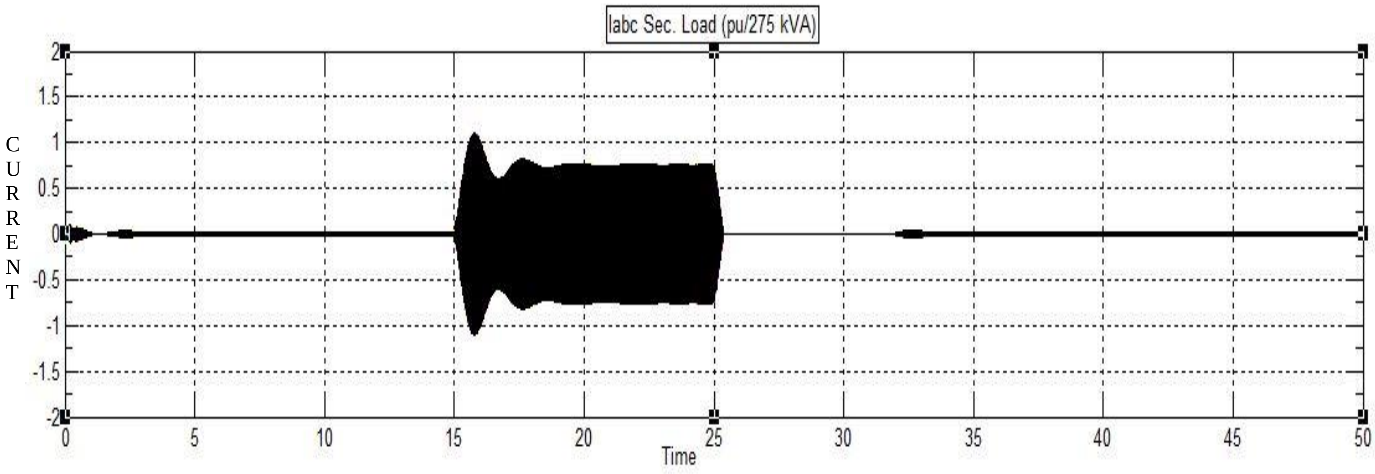


Fig.4.16: Plot of Secondary Load current v/s time

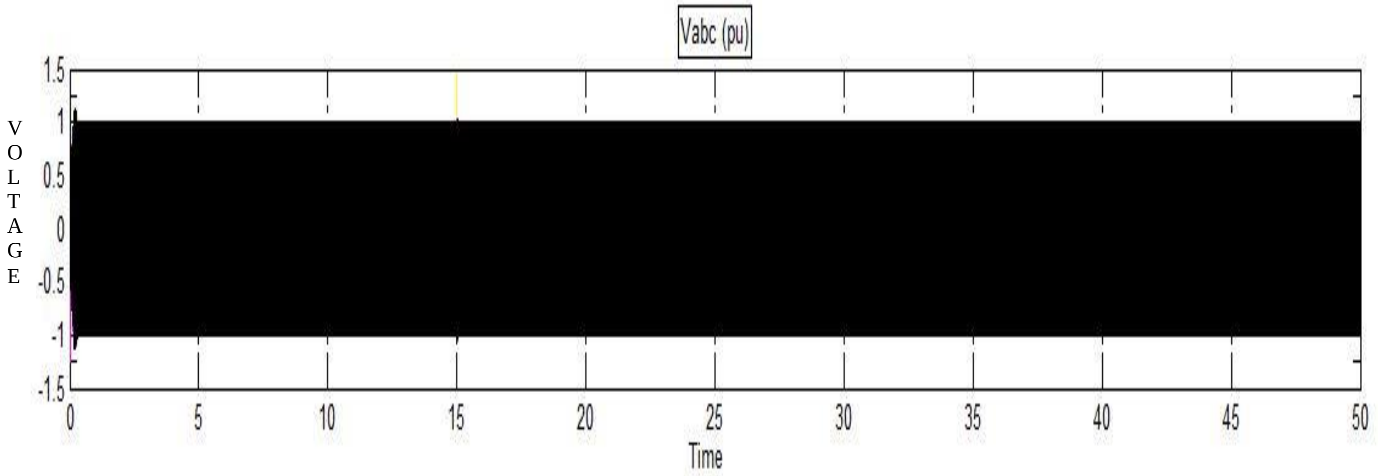


Fig.4.17: Plot of System voltage v/s time

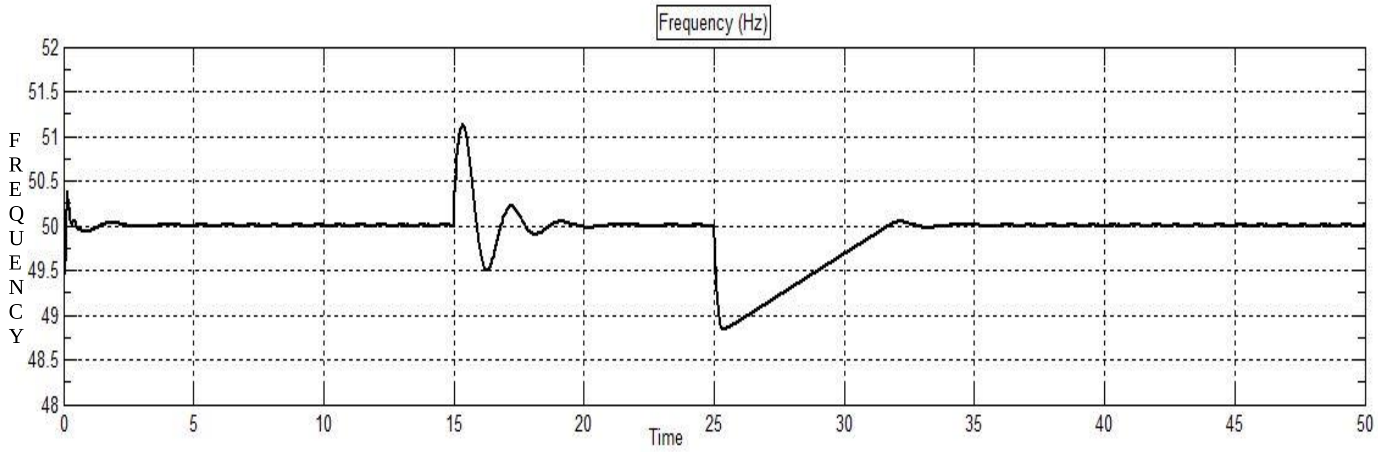


Fig.4.18: Plot of system frequency v/s time

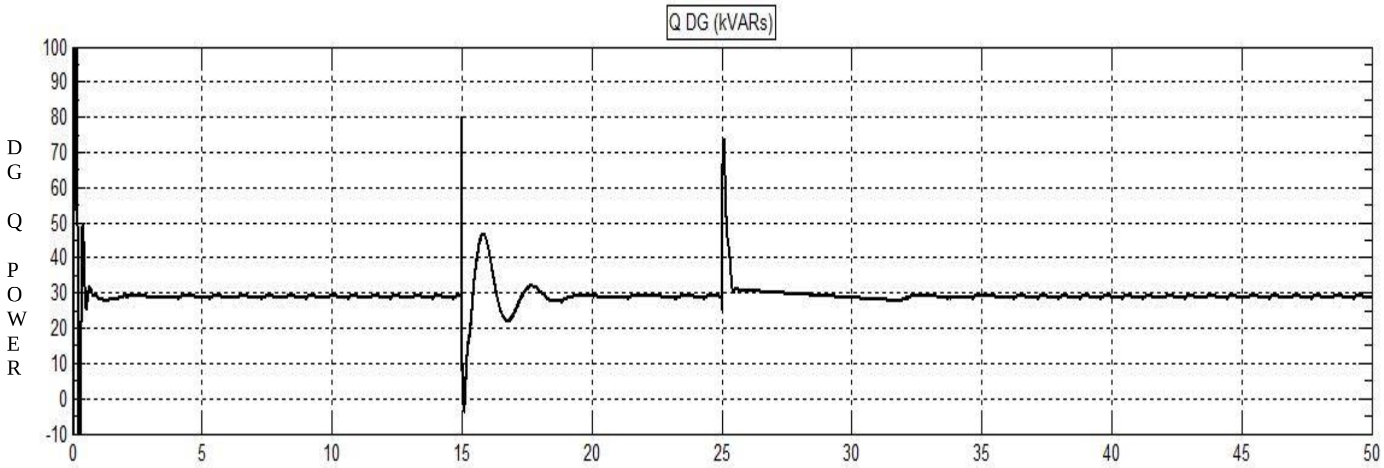


Fig.4.19: Plot of DG reactive power v/s time

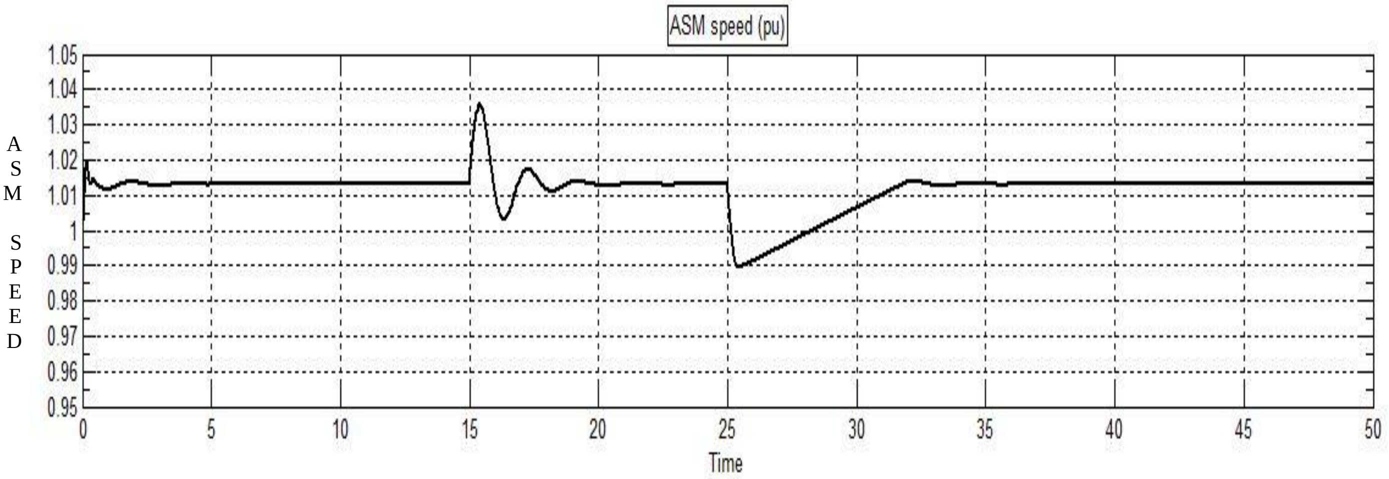


Fig.4.20: Plot of asynchronous machine speed v/s time

4.2.2 Auxiliary load is disconnected

At t = 15s suddenly the 200 kW auxiliary load is disconnected the WTG power increase to 290 kW because ASM speed increases to 1.035 pu, after 3s ASM speed settles at 1.015 pu and WTG output power comes down to 235 kW. Secondary load is switched on to compensate the loss of load, initially it increases to 300 kW and after 3s when steady state condition is reached it comes down to 210 kW. Due to PID controller action dump load takes some time to reach the exact value PID controller reacts very rapidly for any changes in frequency and it follow the frequency curve to maintain stability in the system. Initially frequency overshoot to 51 Hz and as secondary load increase comes down to 49.5 Hz, then finally after 3s it reaches the steady condition and frequency settles at reference value. The synchronous condenser reactive power increases, decreases rapidly at 15s and then after few seconds settles at 30 kVARs.

At t = 25s, suddenly a load of 200 kW is connected to the system, ASM speed drops to 0.99 pu but WTG output power decreases till the dump load comes to zero. As dump load reaches zero still system is in the transient state, the WTG increases output power due to inertia force of rotor and after 1s WTG power curve comes to its steady state value. The frequency comes down to 49 Hz and to reach its reference value it took almost 5s - 6s and similar curve is seen in the ASM speed plot where induction generator speed increases slowly to reach its steady state condition after 5s – 6s.

4.3 VARIABLE LOAD AND VARIABLE WIND SPEED

The hybrid wind diesel model is simulated in the MATLAB/Simulink environment and wind speed and load are variable. Wind speed is changing at an interval of 5s and auxiliary load is disconnected from the system at 15s and again connected at the 25s, the obtained results are given in Fig.4.21 to Fig.4.30.

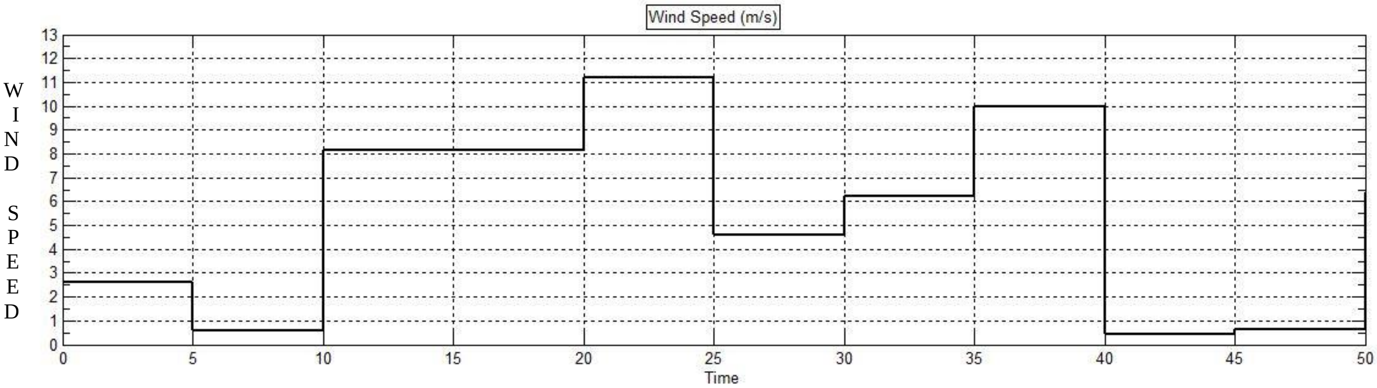


Fig.4.21: Variable wind speed v/s time

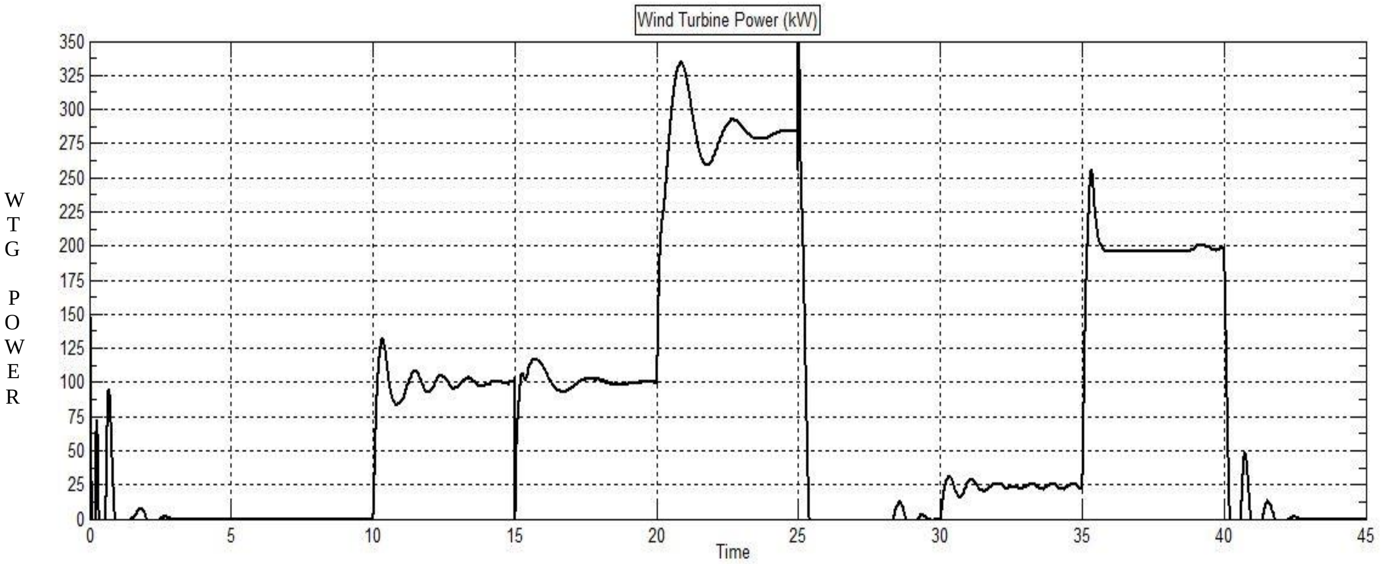


Fig.4.22: wind turbine generator power v/s time

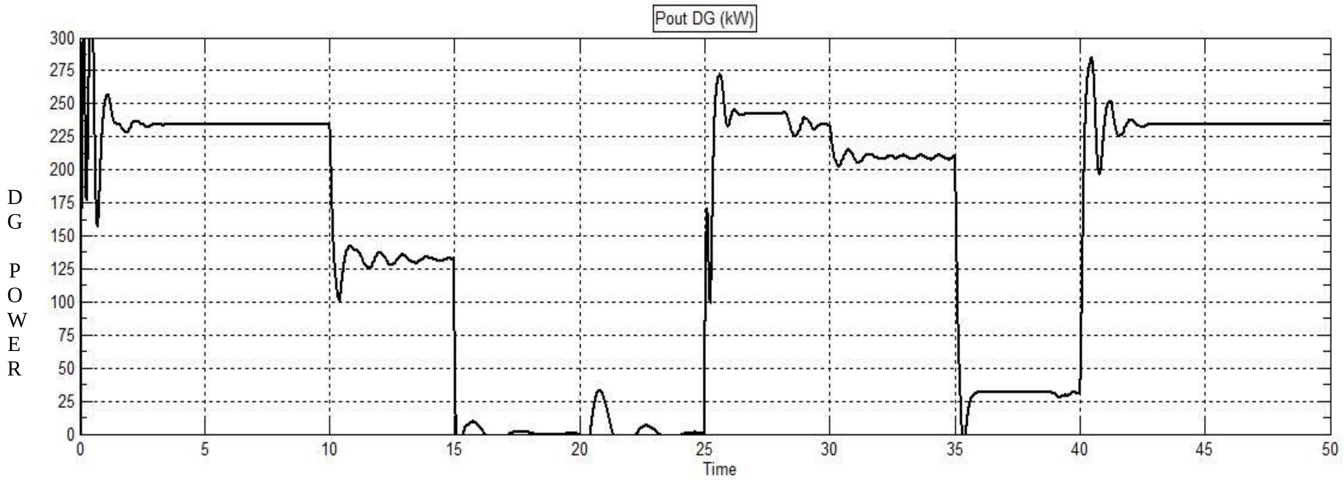


Fig.4.23: Plot of diesel generator power v/s time

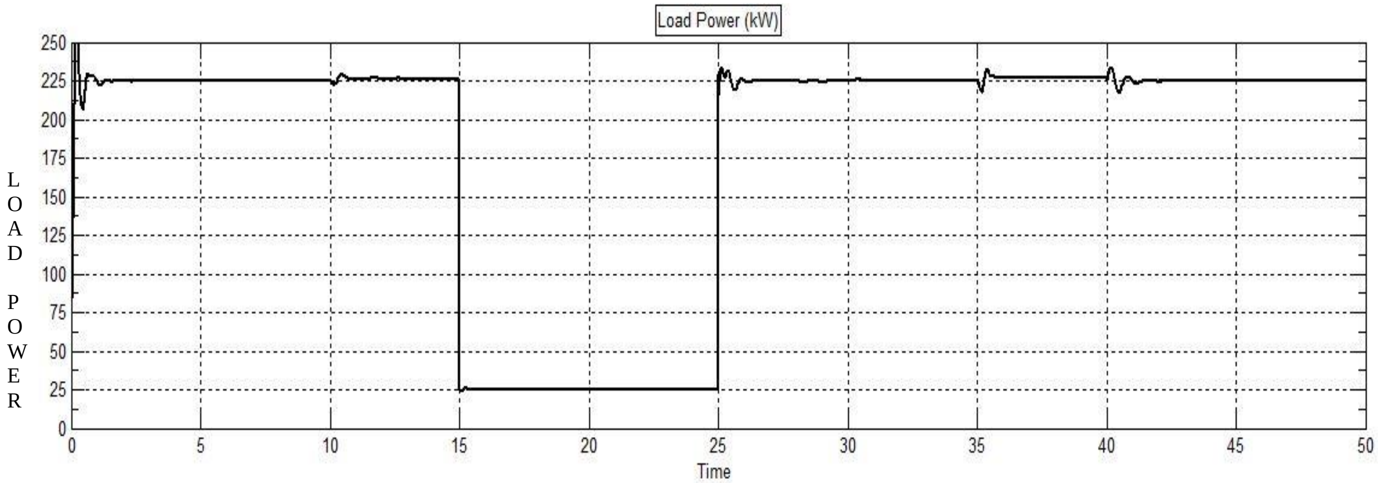


Fig.4.24: Plot of Load power v/s time

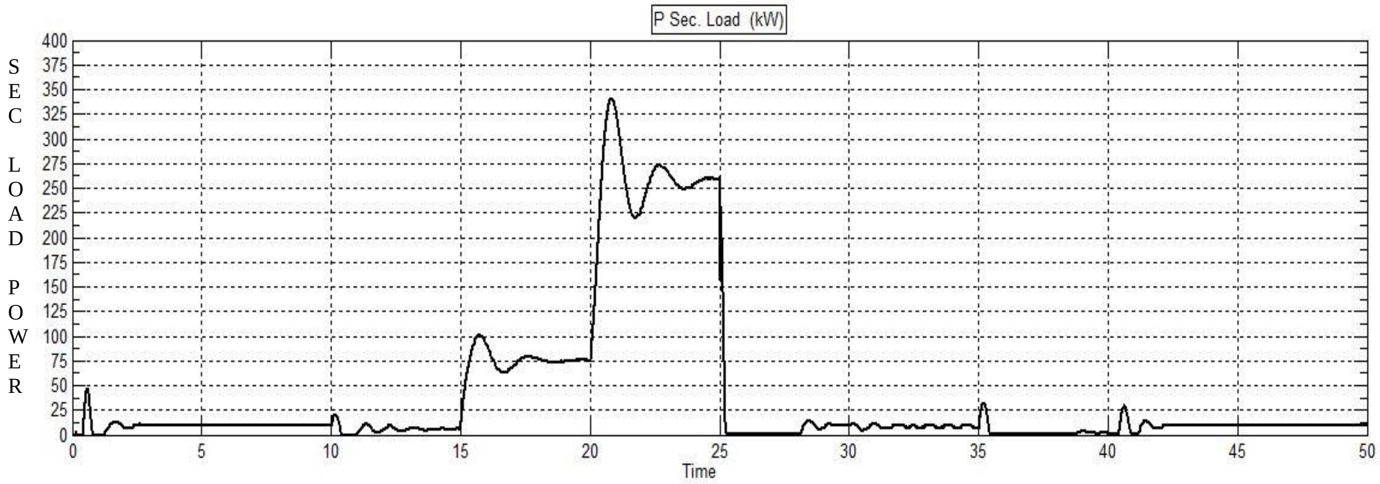


Fig.4.25: Plot of Secondary Load power v/s time

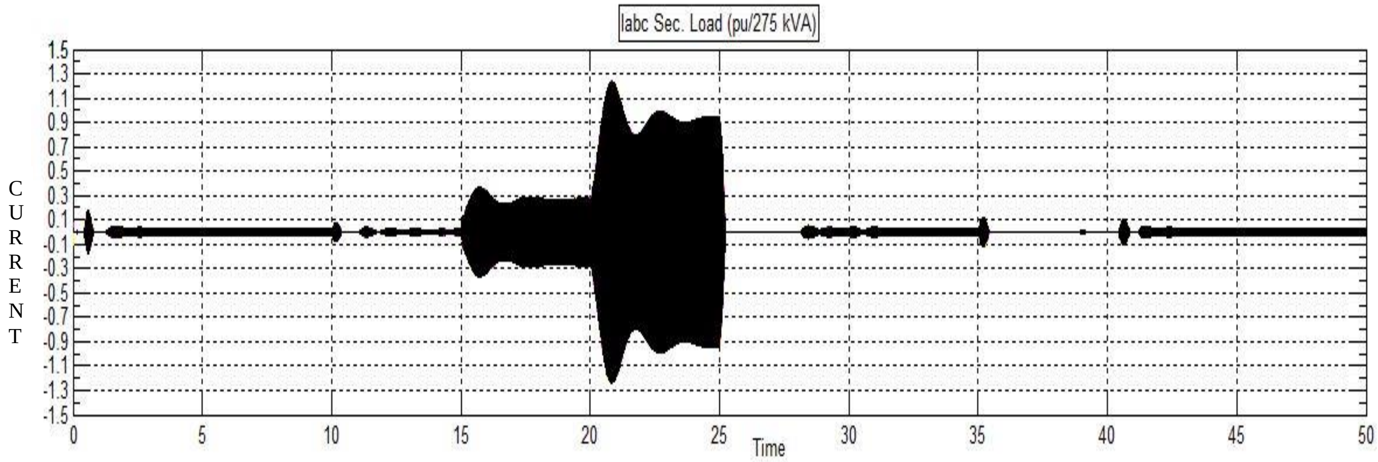


Fig.4.26: Plot of Secondary Load current v/s time

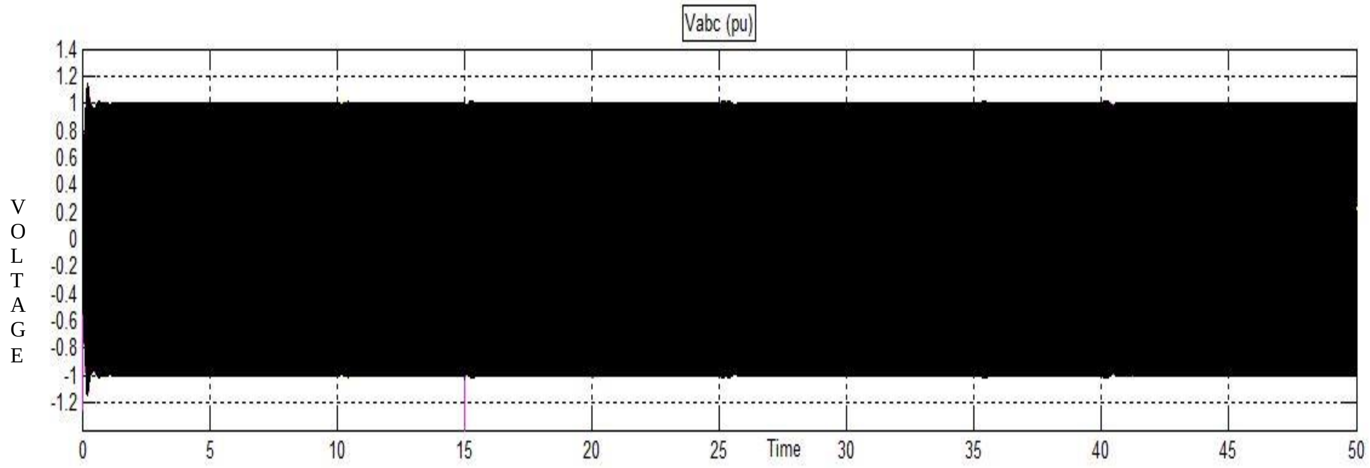


Fig.4.27: Plot of System voltage v/s time

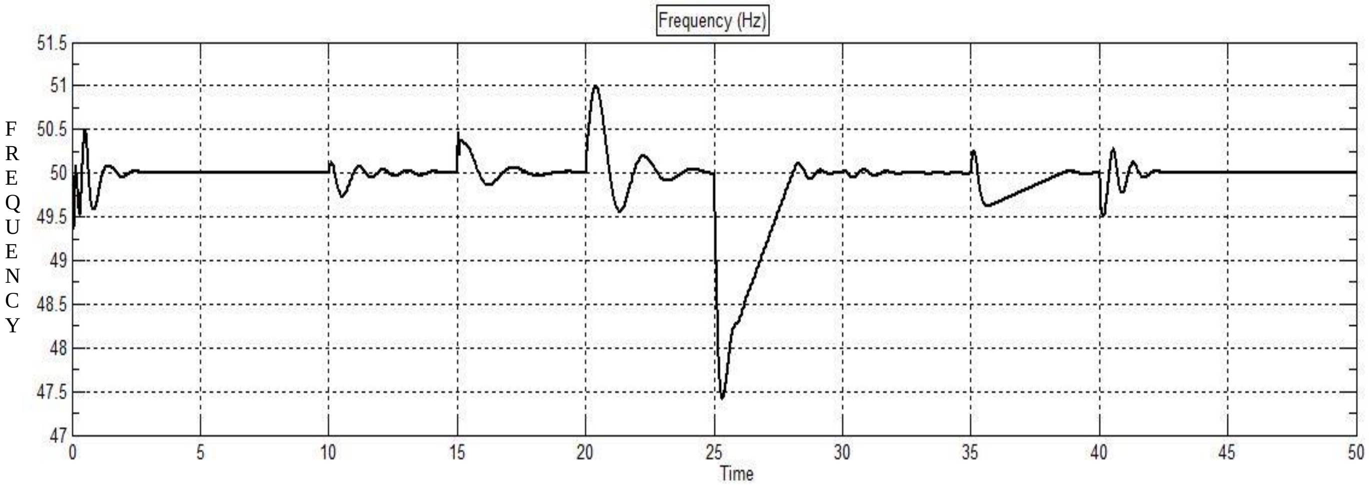


Fig.4.28: Plot of system frequency v/s time

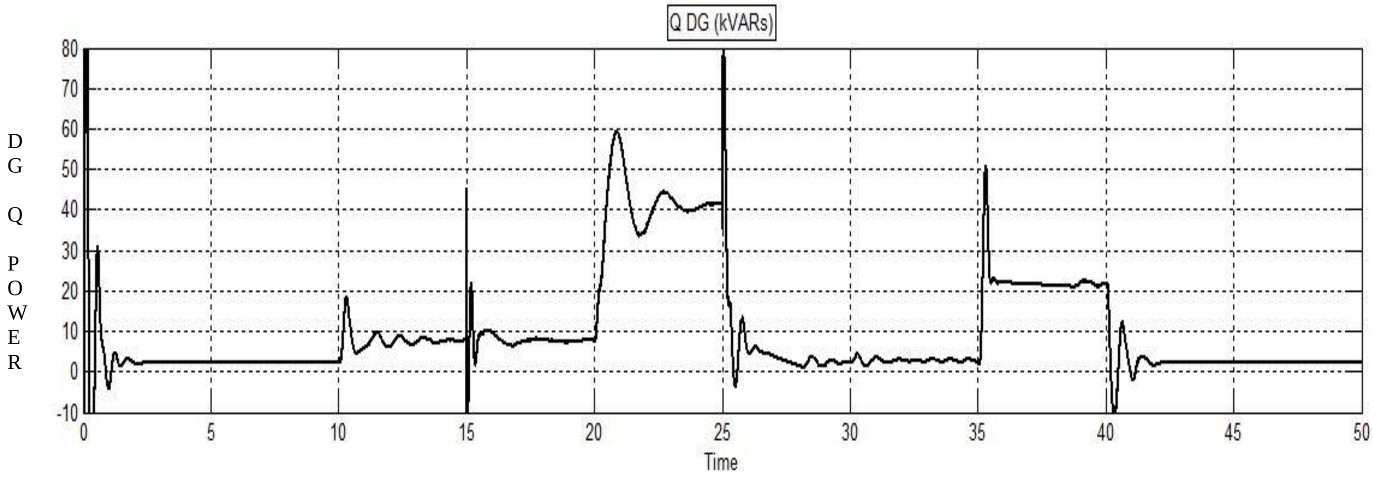


Fig.4.29: Plot of DG reactive power v/s time

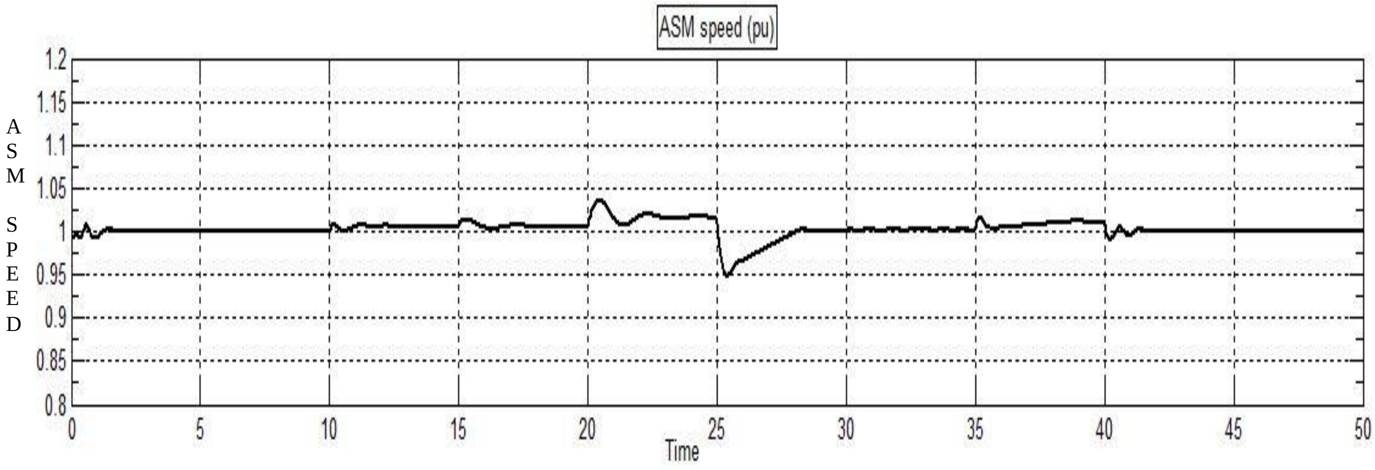


Fig.4.30: Plot of asynchronous machine speed v/s time

Simulation results of hybrid wind diesel model under variable load & variable wind speed are similar to the results of constant load & variable speed therefore results are analyzed at the moment of load rejection and load addition.

At t = 15s, wind speed is constant at 8m/s, 200 kW auxiliary load is disconnected from the system. The frequency increases to 50.2 Hz and dump load follow the frequency curve so dump load also increases to control the frequency overshoot, after 2s the frequency and dump load reaches a final value in steady state. Variation in the voltage is also seen at 15s, which is negligible.

At t = 25s wind speed decreases from 11.2m/s to 4.7m/s and at the same instant load is also connected due to which a large variation in the frequency curve is seen and frequency drops to 47.5 Hz. Since WTG output power is becomes zero at wind speed of 4.7m/s, so power is balanced by the DG set and transfer of power control takes place which is the main reason of a huge frequency drop. Due to simultaneous large disturbances in load and wind speed, a sluggish response of power control is seen, especially in the case of under frequency.

CHAPTER – 5

CONCLUSION

5.1 CONCLUSION

In this report various strategies to control voltage and frequency of hybrid wind diesel minigrid are developed under MATLAB/Simulink environment. The following cases have been considered in the proposed work.

Case-1 Constant Load and Variable speed

At the time of change in wind speed, negligible variations are found in the voltage curve otherwise system voltage remains at 1 pu value. Frequency variation are found to be 49.2 Hz to 50.5 Hz which is under the tolerance limit of ±3% of rated frequency.

Case-2 Variable load and constant speed

At the time of change in load value, negligible variations are found in the voltage curve otherwise system voltage remains at 1 pu value. When load is disconnected from the system frequency increases to 51.2 Hz and at the when load is again connected to the system frequency decreases to 48.9 Hz.

Case-3 variable load and variable wind speed

At the time of change in load value and change in wind speed, negligible variations are found in the voltage curve otherwise system voltage remains at 1 pu value. For multiple disturbances at a time system frequency curve shows a large variation. At same time when wind speed decreases sharply and load is also added to the system a sluggish response of under frequency controller is seen. In the frequency curve minimum and maximum value of frequency found are 47.5 Hz and 51 Hz respectively.

Therefore for this case over frequency performance is satisfactory whereas under frequency control scheme requires some improvement.

Voltage and frequency control strategies are working perfectly and satisfied results are obtained except in case-3 where under frequency controller shows a poor performance. The designed discrete frequency regulator and power controller block are working effectively and they are able to handle the over frequency and under frequency situations respectively. Voltage of the system is also maintained almost at 1 pu. The developed model of wind diesel hybrid system is considered for the isolated mode of operation therefore this model can be used for remote site locations with the change in the parameters as per the requirements.

5.2 SCOPE OF FUTURE WORK

The following studies can be carried out in future:

I. To increase the reliability and practicality of the system the detailed study of loads and various constraints like length of transmission lines and its parameters effect can be considered for a particular site.

II. Optimized methods should be used for the reactive power compensation for a relatively higher rating of minigrid.

III. Instead of wasting energy in the secondary load, the same can be used in power storage devices like batteries.

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