“Design and control of Microgridfed by Renewable Energy Generating Sources”

A

Project Report

Submitted in the partial fulfillment of the requirements

For the Degree of

Bachelor of Engineering

In

Electrical (Electronics & Power)

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CERTIFICATE

Certified that the project report entitled, **"Design and control of Microgrid fed by Renewable Energy Generating Sources"** is a bonafied work done under my guidance by

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In partial fulfilment of the requirements for the award of degree of Bachelor of Engineering in Electrical (Electronics & Power).

Date: 19/05/23

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In the present trend, Renewable energy sources are attractive choices for providing power in the places where an association to the utility network is either not possible or unduly costly. As electric distribution technology steps into next century, several trends have become noticeable which will modify the necessities of energy delivery. The ever increasing energy consumption, soaring value and exhaustible nature of fossil fuels, and also the worsening international environment have created enhanced interest in green power generation systems. Renewable sources have gained worldwide attention because of quick depletion of fossil fuels in conjunction with growing energy demand.

There are many remote locations in the world, which don't have access to electricity. There are also many places, which are connected to the grid, however, they don't receive electricity for up to 10-12 hours in the day and as a result of it, economic activities of inhabitants suffer. Many of such places are rich in renewable energy (RE) sources such as wind, solar and bio-mass. An autonomous generation system utilising locally available RE sources, can greatly reduce the dependency on the grid power, which is predominantly fossil power. Wind and solar energy sources, are more favorite than bio-mass based system as latter is susceptible to supply chain issue. However, wind and solar energies suffer from high level of power variability, low capacity utilization factor combined with unpredictable nature. As a result of these factors, firm power cannot be guaranteed for autonomous system. While the battery energy storage (BES) can be helpful of lowering power fluctuation and increasing predictability, utilisation factor can be increased by operating each energy source at optimum operating point. The optimum operating point also called as maximum power point tracking (MPPT), requires regulation of the operating point of wind energy generator and solar PV (Photovoltaic) array in term of speed and voltage to extract maximum electrical energy from input resource.From the customer point of view, microgrids deliver both thermal and electricityrequirements and in addition improve local reliability, reduce emissions, improve powerexcellence by supportive voltage and reducing voltage dips and potentially lower costs ofenergy supply. From the utility viewpoint, application of distributed energy sources canpotentially reduce the demand for distribution and transmission facilities. Clearly, distributedgeneration located close to loads will reduce flows in transmission and distribution circuitswith two important effects: loss reduction and ability to potentially substitute for networkassets. In addition, the presence of generation close to demand could increase service qualityseen by end customers. Microgrids can offer network support during the time of stress byrelieving congestions and aiding restoration after faults. The development of microgrids cancontribute to the reduction of emissions and the mitigation of climate changes. This is due tothe availability and developing technologies for distributed generation units are based onrenewable sources and micro sources that are characterized by very low emissions.

OBJECTIVE :

Develop simulation model for various conditions e.g. unviability of wind or solar energies, unbalanced and nonlinear loads, low state of charge of the battery etc

LITERATURE REVIEW

H. Zhu, D. Zhang, H. S. Athab, B. Wu and Y. Gu[1], describes a photovoltaic (PV)-based stand-alone power system is usually used to manage the energy supplied from several power sources such as PV solar arrays and battery and deliver a continuous power to the users in an appropriate form. Traditionally, three different dc/dc converters would have been used. To reduce the cost and improve the power density of the power system, an integrated solution of PV isolated dc/dc three-port converter (TPC) is proposed. Zero current switching can be achieved for all main diodes and MOSFETs to improve the efficiency, and a continuous input current of solar array is maintained by adding a magnetic switch derived from a fourth winding of the half-bridge transformer. Based on the energy-balancing part formed by boost, the control methods for the single module to realize maximum power point tracking

(MPPT), battery charge control, and main bus regulation are proposed. The power system control method for multi modules in parallel is also derived, and the operation of the TPC power system can be transited between conductance mode and MPPT mode automatically.

M. Das and V. Agarwal[2], proposes a novel 3Φ stand-alone solar photovoltaic (PV) system configuration that uses high-gain high efficiency (≈ 96%) dc-dc converters both in the forward power stage and the bidirectional battery interface. The high-voltage gain converters enable the use of low-voltage PV and battery sources. This results in minimization of partial shading and parasitic capacitance effects on the PV source. Series connection of a large number of battery modules is obviated, preventing the overcharging and deep discharging issues that reduce the battery life. In addition, the proposed configuration facilitates “required power tracking (RPT)” of the PV source as per the load requirements, eliminating the use of expensive and “difficult to manage” dump loads. High-performance inverter operation is achieved through abc to dq reference frame transformation, which helps in generating precise information about the load's active power component for RPT, regulation of ac output voltage, and minimization of control complexity. Inverter output voltage is regulated by controlling the modulation index of sinusoidal pulse width modulation, resulting in a stable and reliable system operation.

A. B. Ataji, Y. Miura, T. Ise and H. Tanaka[3], presents the control system for stand-alone doubly fed induction generator (DFIG) is commonly based on the “sensorless” direct voltage control. It adopts the direct voltage control and employs negative-sequence compensation through rotor-side converter to support asymmetric “unbalanced” loads. It demonstrates the limitation of the conventional direct voltage control to obtain the slip angle, and the consequent limitation of the negative-sequence compensation control to support full range of asymmetric loads. To overcome these limitations, it proposes a new estimator of the angle of the rotor current in the synchronous reference frame. The proposed estimator requires one DFIG parameter only which is the stator inductance, which can be measured allowing using real machine parameter. It proposes a simple method to integrate the proposed estimator into the direct voltage control, which enables it to obtain the slip angle, and it enables the negative-sequence compensation to support full range of asymmetric loads.

N.A. Orlando, M. Liserre, R.A. Mastromauro and A. Dell'Aquila[4], presents the field of wind energy generation particular interest has been focused in recent years on distributed generation through small wind-turbines (power unit 200 kW) because of their limited size and lower environmental impact. The field of small generation was dominated by the use of asynchronous generators directly connected to the grid, while recently permanent magnet synchronous generators (PMSG) with power converter, either partially or fully controlled, became popular. It reviews the control issues related to these small wind-turbine systems: generator torque control, speed/position estimation, pitch control, braking chopper control, dc/dc converter control, and grid converter control. Specific issues for small wind-turbines arise in the wind energy extraction optimization and limitation and in the innovative concept of "universal" wind-turbine operation, that leads these system to operate grid-connected, standalone or in load supporting mode.

T. Hirose and H. Matsuo[5], proposes a unique standalone hybrid power generation system, applying advanced power control techniques, fed by four power sources: wind power, solar power, storage battery, and diesel engine generator, and which is not connected to a commercial power system. Considerable effort was put into the development of active-reactive power and dump power controls. It revealed that amplitudes and phases of ac output voltage were well regulated in the proposed hybrid system. Different power sources can be interconnected anywhere on the same power line, leading to flexible system expansion. It is anticipated that this hybrid power generation system, into which natural energy is incorporated, will contribute to global environmental protection on isolated islands and in rural locations without any dependence on commercial power systems.

1.3 PROBLEM FORMULATION

A hybrid energy system consisting of two or more type of energy sources, has ability to reduce the BES requirement and increases reliability. Wind and solar energies are natural allies for hybridization. Both have been known to be complementary to each other in daily as well as yearly pattern of the behavior. The most favorite machine for small wind power application, is permanent magnet synchronous generator. It is possible to achieve gearless configuration with PMSG, however, it requires 100% rated converter in addition to costlier machine. Some authors have also used wind solar hybrid system with a squirrel cage induction generator (SCIG), Though SCIG has commercial edge regarding machine cost, however, the scheme doesn't have speed regulation required to achieve MPPT. Moreover, if the speed regulation is done, it requires full power rated converter. A doubly fed induction generator (DFIG) as a generator is commonly used for commercial wind power generation and its applications along with solar PV array. DFIG may operate variable speed operation with lower power rated converters. However, to work the system as a micro-grid, the generated voltage should be balanced and THD (Total Harmonics Distortion), must be within requirement of IEEE-519 standard at no-load, unbalanced load as well as nonlinear load. Moreover, both the wind and solar energies sources should operate at MPPT. They have not presented performance parameters e.g. power quality, system efficiency etc under the different operating conditions. Moreover, they also lack experimental verification.

1.5 ORGANIZATION OF THESIS

The thesis has been organized into six chapters. Following the chapter on introduction, the rest of the thesis is outlind as follows.

Chapter 2 explains detailed about microgrid and detail explanation is made using block diagrams and different techniques.

Chapter 3 represents explains the different energy sources in detail.

Chapter 4 represents explains the system modeling in detail. In this chapter the detail explanation is made using block diagrams and different techniques.

Chapter 5 presents all the simulation results which are found using MATLAB/ SIMULINK environment.

Chapter 6 provides conclusions of the work undertaken in this thesis. The references taken for the purpose of research work are also the part of this chapter.

CHAPTER 2

MICROGRID

Inter-connection of two or more sources of Renewable generations like wind power, photo voltaic power, electric cell and micro turbine generator to generate power to local load and or connecting to grid/micro grid forms Hybrid Energy Systems. Because of characteristics of solar energy and wind energy, the electric power generation of the PV array and also the wind turbine are corresponding the reliability of combined power generation which is much higher when compared to the power generated by an individual supply. A sizable battery bank is needed for load so that most power is drawn from Wind and photo voltaic array. Recently, DC grids are resurging because of the development and deployment of renewable DC power sources and the advantage for DC loads in commercial, industrial and residential applications. To integrate with the various distributed generators DC microgrid has been proposed. However, AC sources need to be converted into DC before connected to a DC grid and DC/AC inverters are needed for conventional AC loads. When power can be absolutely provided by the renewable power sources. HV long distance transmission is no longer necessary. AC Microgrids are proposed to facilitate the association of renewable power sources to AC systems. However, photovoltaic (PV) panel's DC output power must be converted into AC using DC/DC boosters and DC/AC inverters connect to an AC grid. In an AC grid, embedded AC/DC and DC/DC converters are needed for various home and office facilities to provide different dc voltages. A hybrid AC/DC micro grid is proposed in this paper to reduce multiple processes of reverse conversions in an individual AC or DC grid and to facilitate the association of various renewable AC and DC sources and loads to the power grid. The coordination control schemes among various modes are proposed to harness most power from renewable power sources to attenuate power transfer between AC and DC networks, and to maintain the stable operation of both AC and DC grids under variable supply and demand conditions once the hybrid grid operates in both grid-tied and islanding modes . The advanced power electronics and control technologies employed can create a future grid much smarter. Due to the fact that solar and wind power is intermittent and unpredictable in nature, higher penetration of their types in existing grid could cause and build high technical challenges, especially to weak grids or stand-alone systems without correct and enough storage capability. By integrating the two renewable resources into an optimum combination, the impact of the variable nature of solar and wind resources will be partially resolved and the overall system becomes more reliable and economical to run. There are several configurations which presents a review over the state of the art of both grid-connected and stand-alone hybrid solar and wind systems.

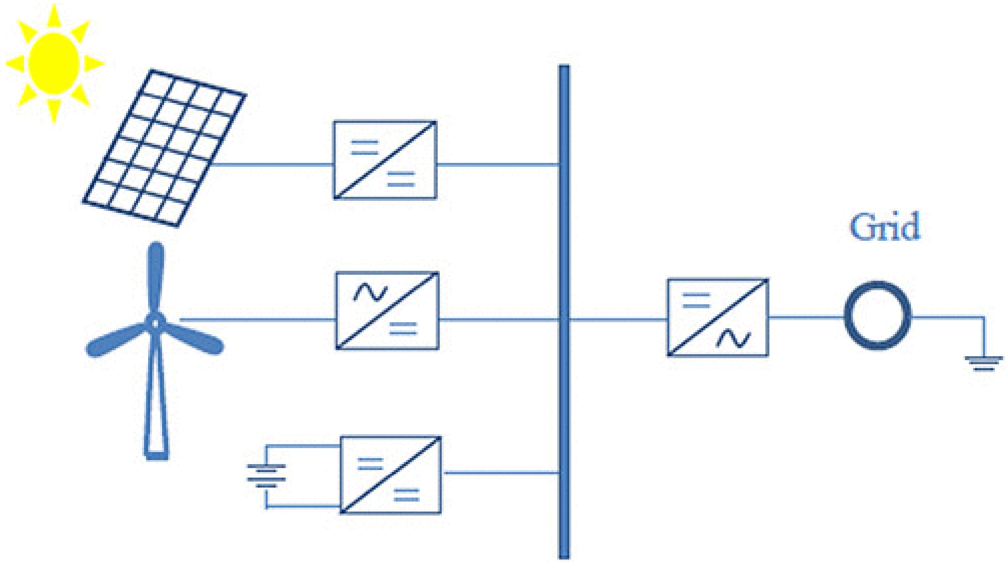

Fig.2.1 Grid connected hybrid system at common DC bus

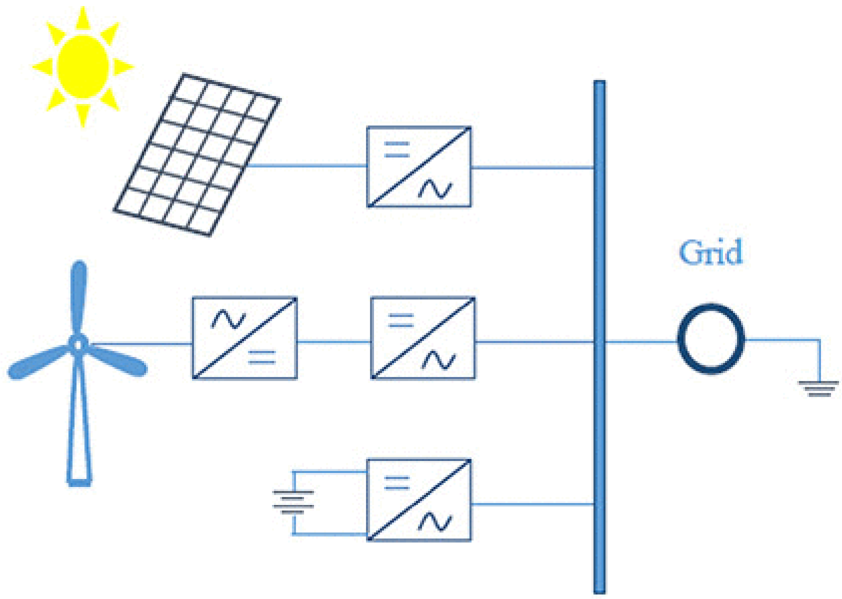

Fig.2.2 Grid connected hybrid system at common AC bus

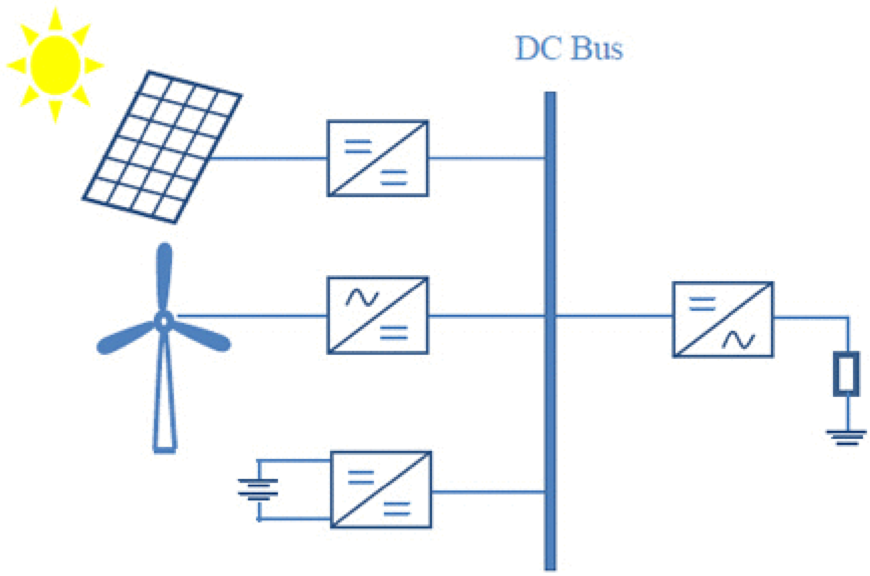

Fig.2.3 Stand-alone hybrid system at common DC bus

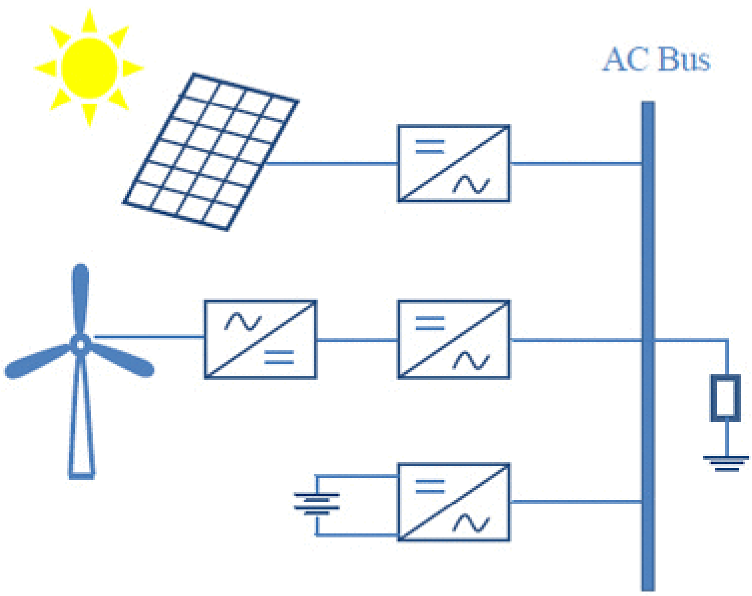

Fig.2.4 Stand-alone hybrid system at common AC bus

Voltage and frequency fluctuation, and harmonics are major power quality issues for both grid-connected and stand-alone systems with bigger impact in case of weak grid. This can be resolved to a large extent by having proper design, advanced fast response control facilities, and optimization of the hybrid systems.

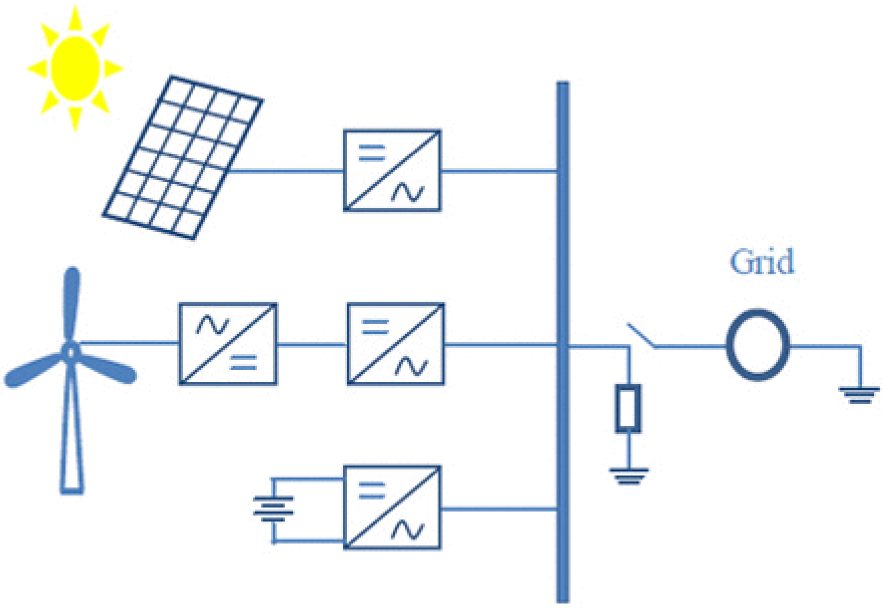

Fig.2.5 Hybrid system with AC Microgrid

Microgrid is a new concept in power generation. The Microgrid concept was a cluster of loads and micro sources operating as a single controllable system that provides both power and heat. Some models could describe the components of a Microgrid.

Following steps are proposed for implementation of Microgrid system:

- First selection of electric power supply system such as renewable energy resources according to requirement and availability of input source;
- Integrate all these resources in Microgrid such as renewable energy resources;
- Administration systems and storage of energy
- Energy control in Microgrid.

The Microgrid idea assumes a cluster of loads and small sources in operation as one governable system that has each power and warmth to its native space. This idea provides a brand new paradigm for outlining the operation of distributed generation. The small sources of interest group for Microgrids are little (100-kW) units with power electronic interfaces. These sources are placed at customers sites. They're low price, low voltage and have high dependability with few emissions. Power physical science offer the management and adaptability needed by the Microgrid concept. A properly designed power electronics and controllers insure that the Microgrid will meet the requirements of its customers also because the utilities outlined characteristics of Microgrids as that they are not centrally planned (by the utility).

- Not centrally dispatched.
- Normally smaller than 50-100 MW.
- Usually connected to the distribution system.

Implementing Microgrid may be as simple as putting in a small electricity generator to produce backup power at an electricity consumer's website or it may be a lot of complicated system that's extremely integrated with the electricity grid that consists of electricity generation, energy storage, and power management systems. They comprise a portfolio of technologies, each provide aspect and demand-side which will be set at or close to the situation wherever the energy is employed. Microgrid devices offer opportunities for bigger native management of electricity delivery and consumption. They additionally alter a lot of economical use of waste heat in combined heat and power (CHP) applications, that boosts potency and lowers emissions. The CHP systems offer electricity, hot water, heat for industrial processes, space heating and cooling, refrigeration, and wetness management to enhance indoor air quality and comfort.

2.1 CONCEPT OF MICROGRID AND DISTRIBUTED NETWORK

Essentially a Microgrid includes the joining of numerous appropriated energy accumulation sources; the power from these sources is assembled, prepared and disseminated to take care of the demand loads. At the point when control elements interfaces with miniaturized scale energy framing a solitary element, its operation requires a control network. Such a control network is required to give adaptability, and to save the particular energy system and the power quality.

2.2 CORRELATION BETWEEN A REGULAR POWER NETWORK AND A MICROGRID

The deviations between ordinary power network and Microgrid are very much accompanied:

• The yield abilities of creating power by micro sources are significantly smaller when contrasted with a regular power plant that can deliver.

• Microgrid establishments are normally nearer to the client stack which prompts low misfortune in transmission lines. Microgrids are in this manner exceptionally productive as far as voltage supply and recurrence profile instead of concentrated power plant with transmission and appropriation arrange see in figure below.

• It is more reasonable in Microgrid to supply energy to remote regions where it is nearly not appropriate for the national lattice

• The procedure of customary power network reclamation is cumbersome. It requires a quick intercession, generally physically and progressively while with a Microgrid technique the whole rebuilding procedure is simple in light of the set number of controllable factors.

2.3 FUNDAMENTALS OF A MICROGRID

Low and medium DG network is in quick improvement around the world. They are controlled by sustainable, non-regular generators which incorporate; power modules, wind turbines, and photovoltaic network. Regularly, they are utilized to increase the utility network amid pinnacle hour stack, where that time compares to a deficiency of energy. They can likewise offer help to control in cases the fundamental network lattice falls flat. As of late, the idea has become all the more intriguing where the gathering of a course of action of burdens framing a bunch, together with parallel DG units, constitute what is known as a Microgrid. Little generators can be joined into the power network, as in the conventional technique where a little generator unit was meant to decrease the effect of network operation in each interconnected microsource. For a blackout in the grid organize because of a mistake identified in the utility lattice, it will efficiently influence and close down the generator units, contrasted with a Microgrid when the network system is off, the power close down, the Microgrid will methodicallly disengage from the lattice arrange and works autonomously in giving energy to its neighborhood stack when the utility has returned to typical.

2.4 MICROGRID BENEFITS

The advancement of Microgrid fills in as a method for picking up favorable position contrasted with different networks, this is explained below:

• As of natural concerns, a Microgrid chops down contamination since it utilizes microsource that deliver low or zero discharges.

• Microgrids work in parallel to the utility Grid; by dealing with specific burdens they bolster the utility network. The additional limit given by Microgrids can help avoiding over-burden circumstances and power outages of the national grid.

• Economically, there is diminishment in long transmission line establishment and the comparing transmission. The minimal effort establishment of the Microgrid networks locally impressively spares foundation expenses and transmission misfortunes. Microgrids additionally help in decreasing the utilization of fossil energy.

• By working in both grid associated and islanded mode, it guarantees uninterruptable burdens.

This makes it more solid and conveys superb energy to the basic loads.

• The Microgrid exploits heat energy sparing when utilizing combined heat and power. This is a simple procedure to accomplish with the micro source in a Microgrid. The microsource can be sent nearer to heat and electrical loads for amplifying energy proficiency.

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2.5 TECHNICAL IMPACTS OF MICROGRIDS ON THE DISTRIBUTION SYSTEM

2.5.1 Network voltage changes and system regulation

Each conveyance utility has a commitment to supply its clients power at a voltage inside a predetermined breaking point. This prerequisite frequently decides the plan and cost of the dissemination circuit so that throughout the years procedures have been created to make the greatest utilization of appropriation circuits to supply clients inside the required voltage. Some circulation utilities utilize more advanced control of the on load tap changers of the dissemination transformer by controllers on the feeder and including the utilization of the present flag intensified with the voltage estimation at the exchanged capacitor on feeders.

2.5.2 Increase of network fault levels

The majority of the Microgrid plants utilize turning machines and these will add to the system blame levels. Both enlistment and synchronous generators will expand the blame level of the dispersion network despite the fact that their conduct under supported blame conditions contrasts. The blame level commitment can be diminished by presenting impedance between the generator and the system by a transformer or reactor however to the detriment of expanded misfortunes and more extensive voltage varieties at the generator. In urban regions where the current blame level methodologies the rating of the switchgear, the expansion in blame level can be a genuine obstacle to the advancement of Distributed Generation.

2.5.3 Power quality

Two parts of energy quality are generally thought to be essential: (i) transient voltage varieties and (ii) consonant twisting of the system voltage. The Microgrid can bring about transient voltage minor departure from the system if generally vast current changes amid association and disengagement of the generator are permitted. In this manner, it is important to utmost voltage varieties to limit the light variety. Large stack vacillation can bring about voltage variety and additionally source change. Microgrid units can possibly bring about undesirable transient voltage varieties at the neighborhood control network. Step changes in the yields of the Microgrid units with regular vacillations and the communication between the Microgrid and voltage controlling gadgets in the feeder can bring about noteworthy voltage varieties. The independent operation of Microgrid units gives more potential for voltage varieties because of load unsettling influences, which make sudden current changes the DG inverter. In the event that the yield impedance of the inverter is sufficiently high, the adjustments in the present will bring about noteworthy changes in the voltage drop, and therefore, the AC yield voltage will vacillate. On the other hand, frail ties in the network mix mode give a possibility for transient voltage varieties to happen yet bring down degrees than in the independent mode.

2.5.4 Protection

Various diverse parts of Microgrid assurance can be recognized:

- Protection of the era gear from interior flaws.
- Protection of the blamed dissemination organize from blame streams provided by the Microgrids.
- Anti-islanding or loss-of-mains insurance.
- Impact of Microgrids on existing dispersion network insurance.

2.5.5 Stability

For Distributed Generators conspires, the target of which is to produce control from new sustainable power sources, contemplations of generator transient solidness tend not to be of awesome essentialness. In the event that a blame happens some place in the appropriation system to discourage the system voltage and the Distributed Generator trips, then all that is lost is a brief time of era. The Microgrids will keep an eye on over speed and stumble on their interior security. The control conspire in the Microgrids will then sit tight for the system condition to be reestablished and restart consequently. Interestingly, if a DG is seen as offering help for the power network, then its transient dependability is the fate of extensive significance. Both voltage or potentially point solidness might be noteworthy relying upon the conditions.

2.6 TYPES OF MICROGRIDS

1) Campus Environment/Institutional Microgrids:

The concentration of grounds Microgrids totally existing in nearby era with different burdens that is situated in tight geology in which proprietor effortlessly oversee them.

2) Remote "Off-Grid" Microgrids:

These Microgrids never interface with the Macrogrid and rather work in an island mode at all circumstances in light of temperate issue or topography position. Commonly, an "off-Grid" Microgrid is inherent zones that are far removed from any transmission and conveyance foundation and in this manner have no association with the utility network.

3) Military Base Microgrids:

These Microgrids are as a rule effectively sent with concentrate on both physical and digital security for military offices keeping in mind the end goal to guarantee dependable power without depending on the Microgrid.

4) Commercial and Industrial (C&I) Microgrids:

These sorts of Microgrids are developing rapidly in North America and Asia Pacific; be that as it may, the absence of well –known models for these sorts of Microgrids cutoff points them universally. Primary purposes behind the establishment of a modern Microgrid are power supply security and its unwavering quality. There are many assembling forms in which an interference of the power supply may bring about high income misfortunes and long start-up time.

2.7 BASIC COMPONENTS IN MICROGRIDS

2.7.1 Local generation

It presents different sorts of era source that encourage power to client. These sources are partitioned into two noteworthy gatherings – ordinary vitality sources (ex. Diesel generators) and inexhaustible era sources (e.g. wind turbines, sunlight based).

2.7.2 Consumption

It essentially alludes to components that devour power which extend from single gadgets to lighting, warming arrangement of structures, business focuses, and so on. On account of controllable burdens, the power utilization can be adjusted popular of the system.

2.7.3 Energy Storage

In Microgrid, vitality stockpiling can play out numerous capacities, for example, guaranteeing power quality, including recurrence and voltage control, smoothening the yield of sustainable power sources, giving reinforcement energy to the network and assuming critical part in cost enhancement. It incorporates all of electrical, weight, gravitational, flywheel, and warmth stockpiling innovations.

2.7.4 Point of basic coupling (PCC)

It is the point in the electric circuit where a Microgrid is associated with a fundamental grid. Microgrids that don't have a PCC are called confined Microgrids which are typically exhibited on account of remote locales (e.g., remote groups or remote mechanical destinations) where an interconnection with the primary network is not doable because of either specialized as well as financial imperatives.

2.8 Connection of Microgrid to buses

Every source of energy produces an alternate power signals, i.e. Photovoltaic cells produces DC and wind produces AC. Adaption is must be needed between them. This adaption is called as coupling. Coupling can be done in two different ways: AC or DC. They can be utilized as a part of both on-grid, off-grid and also in mixed design. In AC-coupling and DC- coupling the number of parts are almost same but the only difference is dump load is used in DC whereas WTG inverter in AC- coupling.. Important is the way that the WTG inverter frequently is made with a breaking chopper, essentially a DC-DC switching hurtful current and voltages into a resistor creating heat, to protect the inverter rather than a dump load.

Depending on connection, Microgrids are divided into three types

1. DC Migrogrids
2. AC Microgrids

3. Hybrid DC and AC coupled Microgrids

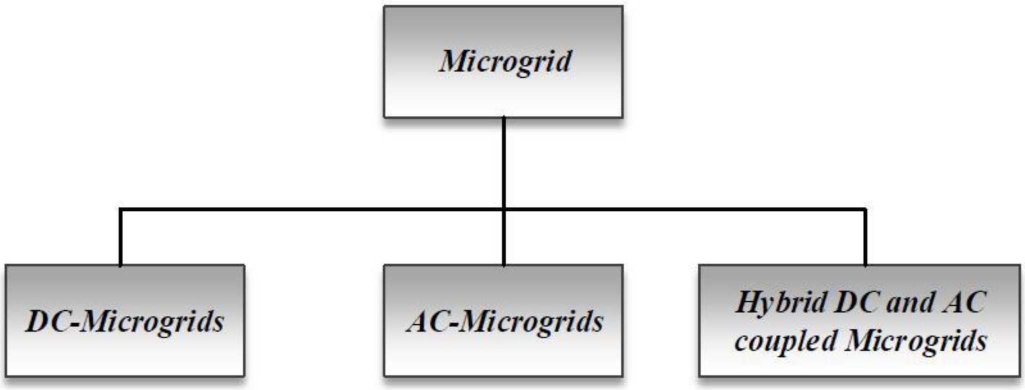


Fig.2.6. Three types of grids

2.8.1 Microgrid connection to AC Bus

In AC micro grid energy systems, every part of system connected to the standard AC voltage of the grid for example 50Hz, 230/400V, at a joint point before the local load. Expandability is the one of the main feature in this system. Recently these types of connecting systems have become greatly popular due to increased amounts of decentralized power grids. Main drawback with these systems is that they need inverter.

2.8.1.1 Inverter

The inverter is, as one with the PV-modules, a part which is basic for each grid- tied PV system. Its energy rating is relying upon the most extreme production from the PV-modules and is in this way a regularly changing quality specific for each system. Regularly most PV cell inverters have a combined DC-DC-converter and inverter, i.e. the MPPT system is coordinated in an same box as converts DC to AC. So as to connect an additional power source to these, the equipment must be adjusted electrically or must be altered with new programming. On the off chance that the network just has one MPPT for all input-ports applying new programming to the MPPT will bring about constrained power extraction from then modules and ought to in this manner just be done if the inverter has more than one MPPT. Based on connected case the search for the ideal inverter brought about guidelines which are listed in numerical order:

1. Inverter is WTG ready, i.e. it has at least one extra ports proposed for a WTG.
2. Inverter is blank completely, i.e. it has no tracking systems incorporated.

3. Inverter has separate MPPT for various association ports and where the MPPT programming is re programmable or removable.

It is additionally possible to connect a WTG to a present existing inverter that has a high power capacity, i.e. its ability to increase the aggregate power rating of both the WTG and PV modules, and if the MPPT is not connected. This kind of system has no requirement for a dump load.

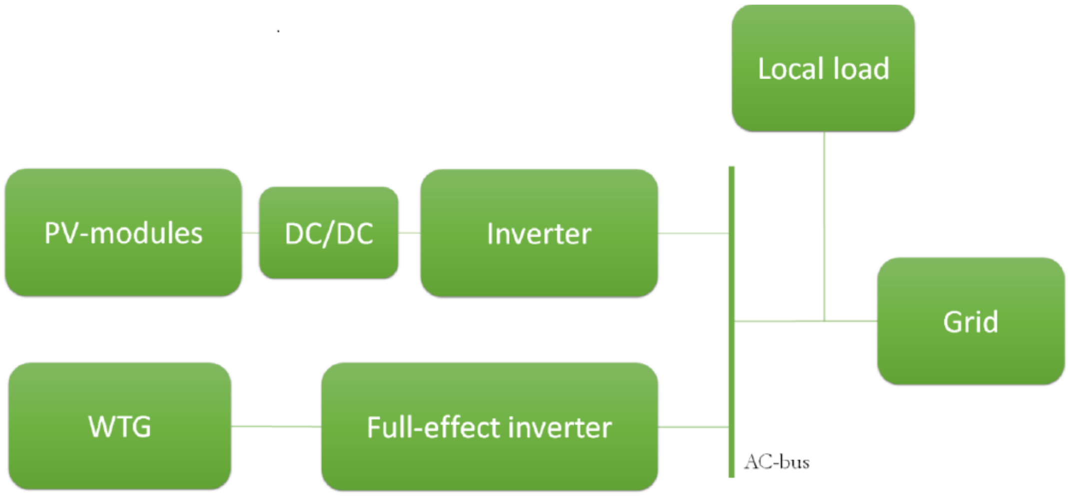


Fig.2.7. Grid connected to AC bus

2.8.1.2 Advantages

1. Dump load is not necessary when it is connected to grid.
2. Expansion is possible and easy.
3. Circuit design is simple.
4. Inverter is necessary to connect to AC bus.

2.8.1.3 Disadvantages

1. Inverter is needed and it is expensive.
2. Less efficient because of the inverter.

2.8.2 Microgrid connection to DC Bus

In DC micro grid energy systems every component of conversion systems are connected to a main DC-bus which is connected to the grid by a main inverter. There is a need of AC/DC converter able to connect DC transmission lines where all AC generating components are present in the system. Because of the way that PV-modules normally deliver DC, the conventional method for coupling has been DC.

The main drawback with DC connected microgrid system is dump load. The connection diagram is show in below fig.

2.8.2.1 Dump load

In the system that is connected to DC-bus it must have a dump load for the surplus energy production which is over the power rating of the inverter. A dump load is a part of the system with low resistivity which creates heat through power. It is utilized as a part of a system to either protect the batteries from over charging or in a grid-tied network to protect the inverter. For an off-grid system utilizing batteries the power rating of the dump load ought to be identical to the total power output of the system. In a grid tied system the general suggestion is to measurement the dump load to have an exact size from the distinction between the introduced control and the power rating of the inverter. For instance: A network has wind turbine and PV-modules with an total maximum power of 6kW. The inverter has an evaluated energy of 3.5kW; hence the dump load must be no less than 2.5kW to secure the system. On the off chance that the dump load is straightforwardly associated with a particular component, e.g. photovoltaic modules or the wind turbine generator, it ought to be of the same size as the components most extreme power generation. The dump load can for instance be utilized as an electric heater connected with the household's heat storage. If the dump load is used as an immersion heater, calculations has to be made to ensure that the tank has enough capacity to receive the heat produced from the load. For suppose a breaker, connected with a heat sensor in the tank, must installed to either switch of production for the Wind turbine generator or the PV-modules when the temperature reached to 100℃.

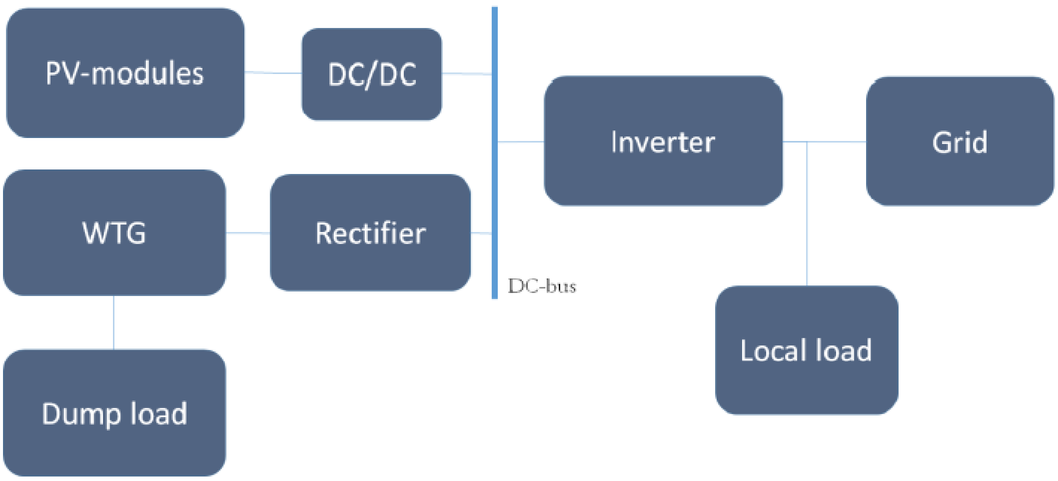


Fig.2.8. Grid connected to DC bus

2.8.2.2 Advantages

1. Frequency components are less so control is simple.

2. Less components are used this reason conversion losses are less.

3. DC transmission lines is less losses when compared to AC transmission i.e; more efficient.

4. It is cheaper

2.8.2.3 Disadvantages

1. Expansion is difficult.

2. Electrical arch while DC breaking is dangerous.

CHAPTER 3
ENERGY SOURCES

3.1 PHOTOVOLTAIC SYSTEM

The photovoltaic effect was experimentally demonstrated first by French physicist Edmond Becquerel. In 1839, at age 19, he built the world's first photovoltaic cell in his father's laboratory. Willoughby Smith first described the "Effect of Light on Selenium during the passage of an Electric Current" in a 20 February 1873 issue of Nature.

In 1883 Charles Fritts built the first solid state photovoltaic cell by coating the semiconductor selenium with a thin layer of gold to form the junctions the device was only around 1% efficient. In 1888 Russian physicist Aleksandr Stoletov built the first cell based on the outer photovoltaic effect discovered by Heinrich Hertz in 1887.In 1905 Albert Einstein proposed a new quantum theory of light and explained the photoelectric effect in a landmark paper, for which he received the Nobel Prize in Physics in 1921,Vadim lashkaryov discovered p-n junctions in Cu_2O and silver sulphide protocells in 1941. Russel ohl patented the modern junction semiconductor solar cell in 1946 while working on the series of advances that would lead to the transistor. The first practical photovoltaic cell was publicly demonstrated on 25 April 1954 at Bell Laboratories.

A solar cell, or photovoltaic cell (previously termed "solar battery"]), is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. Solar cells are described as being photovoltaic, irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

3.2 OPERATING PRINCIPLE

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells take advantage of the photoelectric effect: the ability of some semiconductors to convert electromagnetic radiation directly into electrical current. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell, as will be explained in brief below.

A solar cell is basically a p-n junction which is made from two different layers of silicon doped with a small quantity of impurity atoms: in the case of the n-layer, atoms with one more valence electron, called donors, and in the case of the p-layer, with one less valence electron, known as acceptors. When the two layers are joined together, near the interface the free electrons of the n-layer are diffused in the p-side, leaving behind an area positively charged by the donors. Similarly, the free holes in the p-layer are diffused in the n-side, leaving behind a region negatively charged by the acceptors. This creates an electrical field between the two sides that is a potential barrier to further flow. The equilibrium is reached in the junction when the electrons and holes cannot surpass that potential barrier and consequently they cannot move. This electric field pulls the electrons and holes in opposite directions so the current can flow in one way only: electrons can move from the p-side to the n-side and the holes in the opposite direction. A diagram of the p-n junction showing the effect of the mentioned electric field is illustrated in Fig.3.1.

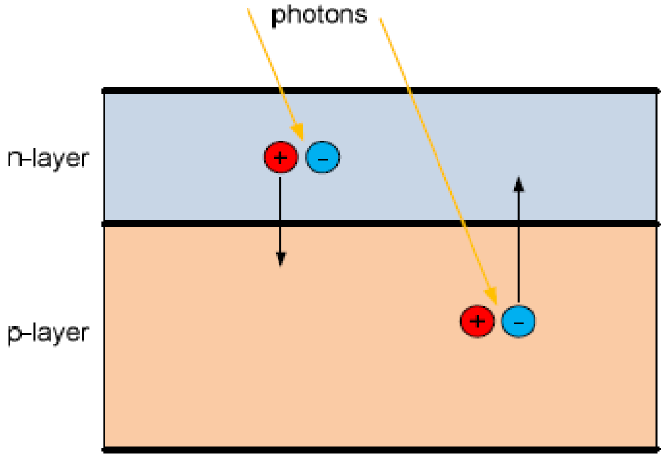


Fig.3.1: Solar cell.

Metallic contacts are added at both sides to collect the electrons and holes so the current can flow. In the case of the n-layer, which is facing the solar irradiance, the contacts are several metallic strips, as they must allow the light to pass to the solar cell, called fingers. The structure of the solar cell has been described so far and the operating principle is next. The photons of the solar radiation shine on the cell. Three different cases can happen: some of the photons are reflected from the top surface of the cell and metal fingers. Those that are not reflected penetrate in the substrate. Some of them, usually the ones with less energy, pass through the cell without causing any effect. Only those with energy level above the band gap of the silicon can create an electron-hole pair. These pairs are generated at both sides of the p-n junction. The minority charges (electrons in the p-side, holes in the n-side) are diffused to the junction and swept away in opposite directions (electrons towards the n-side, holes towards the p-side) by the electric field, generating a current in the cell, which is collected by the metal contacts at both sides. This can be seen in the Fig.3.1. This is the light-generated current which depends directly on the irradiation: if it is higher, then it contains more photons with enough energy to create more electron-hole pairs and consequently more current is generated by the solar cell.

3.3 EQUIVALENT CIRCUIT OF A SOLAR CELL

The solar cell can be represented by the electrical model shown in Fig.3.2. Its current voltage characteristic is expressed by the following Eqn.(3.1).

$$I = I_L - I_O\left(e^{\frac{q(v-IR_S)}{AKT}} - 1\right) - \frac{V - IR_S}{R_{SH}} \qquad \ldots(3.1)$$

Where I and V are the solar cell output current and voltage respectively, I0 is the dark saturation current, q is the charge of an electron, A is the diode quality (ideality) factor, k is the Boltzmann constant, T is the absolute temperature and R_S and $R_{SH}$are the series and shunt resistances of the solar cell. $R_S$is the resistance offered by the contacts and the bulk semiconductor material of the solar cell. The origin of the shunt resistance R_{SH} is more difficult to explain.

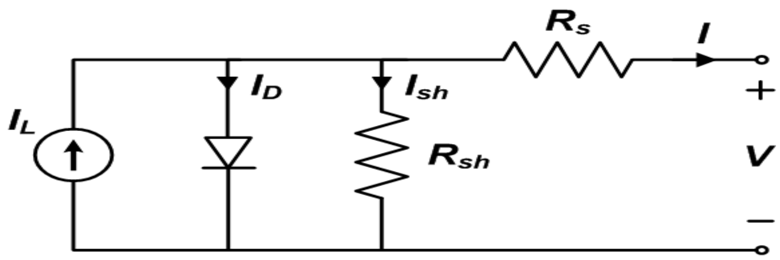


Fig.3.2: Equivalent circuit of a solar cell.

It is related to the non ideal nature of the p–n junction and the presence of impurities near the edges of the cell that provide a short-circuit path around the junction. In an ideal case $R_S$would be zero and R_{SH}infinite. However, this ideal scenario is not possible and manufacturers try to minimize the effect of both resistances to improve their products.

Sometimes, to simplify the model, as in the effect of the shunt resistance is not considered, i.e. $R_{SH}$is infinite, so the last term in Eqn.(3.1) is neglected. A PV panel is composed of many solar cells, which are connected in series and parallel so the output current and voltage of the PV panel are high enough to the requirements of the grid or equipment. Taking into account the simplification mentioned above, the output current-voltage characteristic of a PV panel is expressed by Eqn.(3.2), where $n_p$and ns are the number of solar cells in parallel and series respectively.

$$I = n_p I_L - n_p I_O \left(e^{\frac{q(v - IR_S)}{AKTn_s}} - 1 \right) \qquad \dots (3.2)$$

3.4 OPEN CIRCUIT, SHORT CIRCUIT CURRENT AND MAXIMUM POWER POINT

Two important points of the current-voltage characteristic must be pointed out: the open circuit voltage $V_{OC}$and the short circuit current I_{SC}.

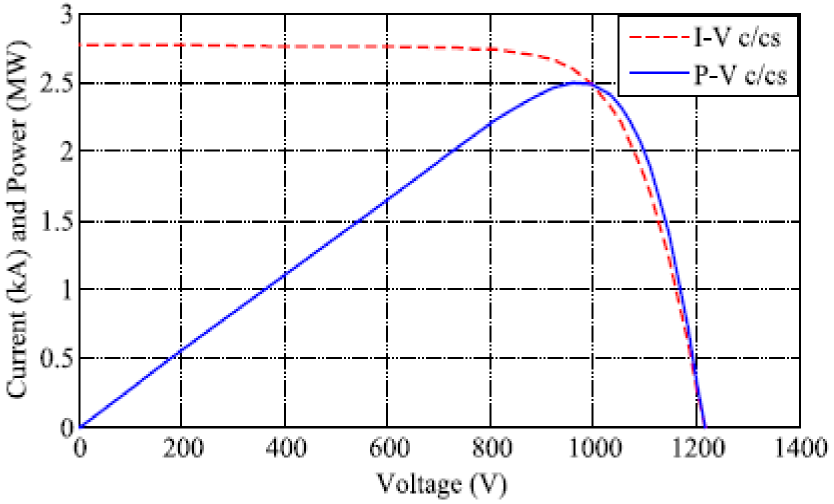


Fig.3.3 Important points in the characteristic curves of a solar panel.

At both points the power generated is zero. V_{OC}can be approximated from Eqn.(3.1) when the output current of the cell is zero, i.e. I=0 and the shunt resistance $R_{SH}$is neglected. It is represented by Eqn.(3.3). The short circuit current $I_{SC}$is the current at V = 0 and is approximately equal to the light generated current $I_L$as shown in Eqn.(3.4).

$$V_{OC} = \frac{AKT}{q} \ln\left(\frac{I_L}{I_O} + 1\right) \qquad \dots (3.3)$$

$$I_{SC} = I_L \qquad \dots (3.4)$$

The maximum power is generated by the solar cell at a point of the current-voltage characteristic where the product VI is maximum. This point is known as the MPP and is unique, as can be seen in Fig.3.3, where the previous points are represented.

3.5 FILL FACTOR

Using the MPP current and voltage, $I_{MPP}$and V_{MPP}, the open circuit voltage (V_{OC}) and the short circuit current (I_{SC}), the fill factor (FF) can be defined as:

$$FF = \frac{I_{MPP}V_{MPP}}{I_{SC}V_{OC}} \qquad \dots (3.5)$$

It is a widely used measure of the solar cell overall quality. It is the ratio of the actual maximum power ($I_{MPP}V_{MPP}$) to the theoretical one ($I_{SC}V_{OC}$), which is actually not obtainable. The reason for that is that the MPP voltage and current are always below the open circuit voltage and the short circuit current respectively, because of the series and shunt resistances and the diode depicted in Fig.3.2, The typical fill factor for commercial solar cells is usually over 0.70.

3.6 TEMPERATURE AND IRRADIANCE EFFECTS

Two important factors that have to be taken into account are the irradiation and the temperature. They strongly affect the characteristics of solar modules. As a result, the MPP varies during the day and that is the main reason why the MPP must constantly be tracked and ensure that the maximum available power is obtained from the panel.

The effect of the irradiance on the voltage-current (V-I) and voltage-power (V-P) characteristics is depicted in Fig.3.4, where the curves are shown in per unit, i.e. the voltage and current are normalized using the $V_{OC}$and the I_{SC}respectively, in order to illustrate better the effects of the irradiance on the V-I and V-P curves. As was previously mentioned, the photo-generated current is directly proportional to the irradiance level, so an increment in the irradiation leads to a higher photo-generated current. Moreover, the short circuit current is directly proportional to the photo generated current; therefore it is directly proportional to the irradiance. When the operating point is not the short circuit, in which no power is generated, the photo generated current is also the main factor in the PV current, as is expressed by Eqn.(3.1) and (3.2). For this reason the voltage-current characteristic varies with the irradiation. In contrast, the effect in the open circuit voltage is relatively small, as the dependence of the light generated current is logarithmic, as is shown in Eqn.(3.4).

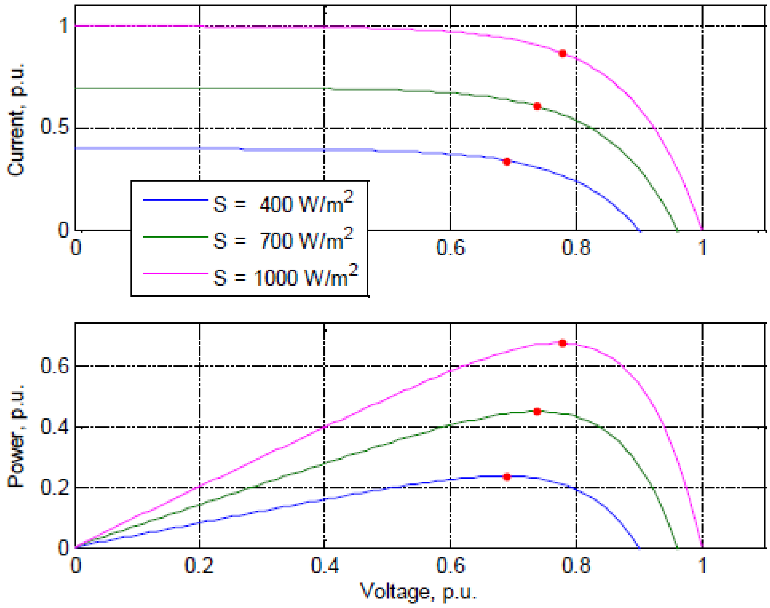


Fig.3.4 V-I and V-P curves at constant temperature (25°C)

Fig.3.4 shows that the change in the current is greater than in the voltage. In practice, the voltage dependency on the irradiation is often neglected. As the effect on both the current and voltage is positive, i.e. both increase when the irradiation rises, the effect on the power is also positive: the more irradiation, the more power is generated. The temperature, on the other hand, affects mostly the voltage.

The open circuit voltage is linearly dependent on the temperature, as shown in the following equation:

$$V_{OC}(T) = V_{OC}^{STC} + \frac{K_{V\%}}{100}(T - 273.15) \qquad \dots(3.6)$$

According to Eqn.(3.6), the effect of the temperature on $V_{OC}$is negative, because $K_V$is negative, i.e. when the temperature rises, the voltage decreases. The current increases with the temperature but very little and it does not compensate the decrease in the voltage caused by a given temperature rise. That is why the power also decreases. PV panel manufacturers provide in their data sheets the temperature coefficients, which are the parameters that specify how the open circuit voltage, the short circuit current and the maximum power vary when the temperature changes. As the effect of the temperature on the current is really small, it is usually neglected. Fig.2.5 shows how the voltage-current and the voltage-power characteristics change with temperature. The curves are again in per unit, as in the previous case.

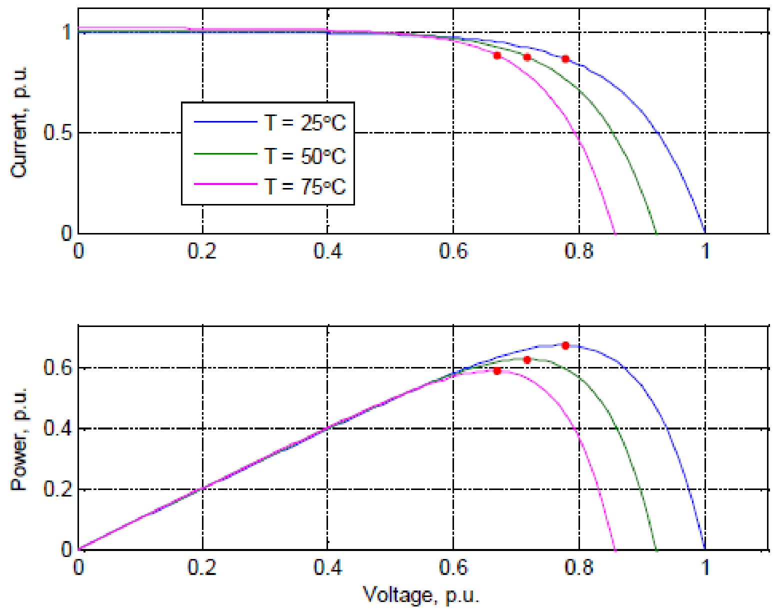


Fig.3.5 V-I and V-P curves at constant irradiation (1 kW/m^2) and three different temperatures.

As was mentioned before, the temperature and the irradiation depend on the atmospheric conditions, which are not constant during the year and not even during a single day; they can vary rapidly due to fast changing conditions such as clouds. This causes the MPP to move constantly, depending on the irradiation and temperature conditions. If the operating point is not close to the MPP, great power losses occur. Hence it is essential to track the MPP in any conditions to assure that the maximum available power is obtained from the PV panel. In a modern solar power converter, this task is entrusted to the MPPT algorithms.

3.7 WIND-DIESEL ENERGY CONVERSION SYSTEM

A new technological energy solution provided by wind energy system is experiencing a high growth rate in recent days. Wind energy systems are omnipresent, freely available and environment friendly. The combined wind-diesel operation is being popular all over the world since the availability of wind is unpredictable and depends on geographical and meteorological conditions. Hybrid operation increases the reliability of stand-alone system, reduces the production cost and ensures the availability of power. This type of system is often used as a potential source of electric power supply for off-grid communities and facilities. This chapter demonstrates the fundamentals of wind energy conversion system (WECS), mathematical modeling of wind power extraction, electrical generator and power electronic converter interface. A maximum power point tracking method is applied to optimize the operation of wind turbine and the machine side converter controller allows access to control the speed. The modeling of diesel generator and control system for diesel energy conversion system (DECS) is explained in this chapter.

Wind energy has been used for hundreds of years for milling grains, pumping water and sailing the seas. The use of windmills to generate electricity started in late nineteenth century with the development of a 12kW DC windmill generator. Over the last two decades, a variety of wind power technologies have been developed, which have improved the conversion efficiency of and reduced the costs for wind energy production. The size of wind turbines has increased from few kilowatts to several megawatts each. In addition to on-land installations, large wind turbines have been pushed to offshore locations to harvest more energy and reduce their impact on land use and landscape.

Over the past few years, wind energy has shown the fastest rate of growth of any form of electricity generation with its development stimulated by concerns of national policy makers over climate change, energy diversity and security supply. In terms of transferring low-carbon energy sources, the electricity generated from wind is viewed as easier than other challenging sectors of the economy such as surface and air transport and domestic heating. Hence the use of cost-effective and reliable low-carbon electricity generation sources, in addition to demand side measures, is becoming an important objective of energy policy in many countries.

The availability of wind energy is very uncertain and it reduces the reliability of a power system. Although diesel generation system has many drawbacks like high maintenance, fuel supply cost, noise and hazardous gas emission issues, they are often integrated in such isolated system in order to provide reliability and maximize the profit.

3.7.1 Major Components of Wind Energy Conversion System

Wind energy technology has evolved rapidly over the last three decades with increasing rotor diameters and the use of sophisticated power electronics to allow operation at variable rotor speed. Major components of wind energy conversion systems are discussed below:

3.7.1.1 Wind Turbine

The wind turbine is one of the most important elements in wind energy conversion systems. Wind turbine produce electricity by using the power of the wind to drive an electrical generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer or power electronic converter, which converts the electricity from the generator by regulating the voltage.

3.7.1.2 Electrical Generator

The evolution of wind power conversion technology has led to the development of different types of wind turbine configuration that make use of a variety of electric generators. Depending on their construction and operating principle, the wind generators are divided in two main groups: induction generators (IGs) and synchronous generators (SGs). Both induction and synchronous generators have wound rotors, which are fed by slip rings through brushes or by a brushless electromagnetic exciter. In these days, SGs are extensively used in WECS and are classified in two types: (i) wound rotor synchronous generator (WRSG) and (ii) permanent magnet synchronous generator (PMSG). Among these two types, PMSGs are considered to be the promising option for direct driven wind turbine operation where gearboxes are not required. PMSG has advantages like higher efficiency, better thermal characteristics, solid field structure, high power to weight ratio and improved dynamic stability.

3.7.1.3 Permanent Magnet Synchronous Generator

Permanent magnet synchronous machines provide higher efficiency in lower speed applications. For given mechanical specification the use of PMSG in WECS results smaller system size and high power density leading to maximum overall efficiency. The typical construction of PMSG includes a stator and rotor. The use of permanent magnet provides brushless operation to create magnetic flux. Due to the absence of rotor windings, it is possible to achieve high power density through reduced weight and size of the machine.

The mechanical and electrical system of the machine is represented by the state space model. In order to obtain sinusoidal electromotive force, the established stator flux by permanent magnets is also chosen as sinusoidal. Due to the presence of large air gap in PMSG, it is assumed that the machine has a linear magnetic circuit and the core of either stator or rotor does not saturate.

3.7.2 Power Electronic Converter Interface

Power electronic interface provides control access to the WECS through speed and torque control. A bi-directional converter unit, known as back-to-back converter, is more popular in such system. This rectifier-inverter pair is predominantly used configuration in wind energy systems, where one converter works as rectifier and other operates as inverter. Both converters work in either direction of power flow throughout the power conversion. The converter on generator side VSC is controlled using pulse width modulation (PWM) technique.

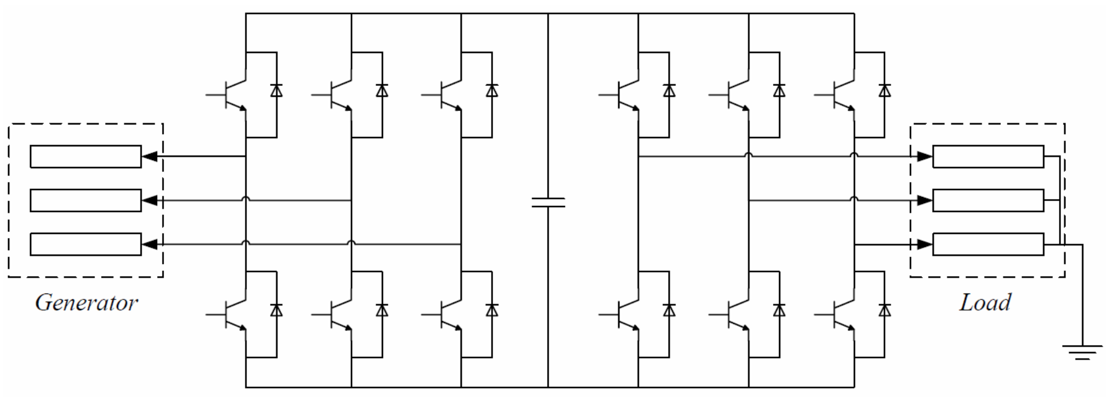


Fig.3.6 Back-to-back VSCs

A DC-link capacitor is connected in between the pair in order to achieve control access. Typically the magnitude for DC-link voltage is kept higher than the load side line to line voltage. The main advantage of using such configuration is, it is a well-established technology and has been applied for many years in machine drive based application. Moreover, the decoupling of VSCs through a capacitor allows separate control of the two converters.

3.8 ENERGY STORAGE SYSTEMS

In DC microgrid applications, energy storage systems (ESSs) are used for supplying or absorbing any power mismatch between the generation and the load. This function is particularly important for DC microgrids that are based on renewable energy resources due to the uncertainty and random nature of renewable energy sources, and it also supports the autonomous operation of microgrids because the available renewable energy can be stored and then supplied to meet the local load demand when needed. Several storage system technologies are mentioned in the literature for use with DC microgrid applications: electric double-layer capacitors, batteries, flywheels, and superconducting magnetic energy storage.

3.8.1 Electric Double-Layer Capacitors

Electric double-layer capacitors (EDLCs) are also called super capacitors or ultra capacitors. The construction of an EDLC is similar to that of a battery, with two electrodes inserted into an electrolyte, and a dielectric separator between the two electrodes. The surface of the two electrodes has a large number of micropores, creating a large surface area where the charges build up. Energy is stored in the dielectric material as electrostatic energy. Compared to battery storage, EDLCs offer faster responses, lower maintenance, and longer life cycles. However, their energy storage capability is limited, making them suitable only for short-term storage. They are typically used in power bridging for periods ranging from seconds to a few minutes, in cases when the main supply fails. In conjunction with a battery storage system, an ELDC with a one farad capacitance is described for the provision of transient compensation. The ELDC is controlled by a bidirectional chopper in order to maintain a constant DC voltage in situations in which the reference power is determined by a central controller. Battery energy storage system was also used for DC voltage regulation by maintaining generation/load power balance. Simulation results showed how the ELDC and battery system controlled the DC voltage during transients. However, the reason for using two energy storage technologies to perform the same function is not explained.

An ELDC storage system for a residential DC microgrid with dispatchable distributed generation units is presented. It was used for controlling the DC voltage of the microgrid in isolated operation mode and also for voltage clamping in grid-connected mode when the DC voltage exceeds specified upper and lower limits. A DC microgrid with ELDC and battery energy storage is presented. In the system described, designing storage device converters with different time constants enables the ELDC to be used for managing fast fluctuations in the DC voltage, while the battery handles slower transients.

3.8.2 Batteries

Battery energy storage systems (BESSs) are currently the dominant energy storage technology due to their high energy density, long lifetime, and low cost. Because of their economic energy density, lead-acid batteries are commonly used for constructing BESSs for microgrid applications. Valve-regulated lead-acid batteries are sealed batteries, which are more reliable than flooded lead-acid batteries since they do not require frequent maintenance. The authors of utilized a BESS for constant voltage control of a DC microgrid under normal operation and AC line fault condition. They used a lithium-ion battery model in which the state of charge (SOC) is determined by integrating charging and discharging power. The use of a BESS is also reported as a means of compensating for the power mismatch that occurs between the variable generation and the loads under islanding and fault conditions. The researchers used the generic battery model presented. Lead-acid batteries are commonly used for PV-based renewable systems. To deal with the uncertainty of PV generation, a battery storage system was used for the work described, in which a valve-regulated lead-acid battery was included in the experimental setup employed for the validation of the control strategy.

3.8.3 Flywheels

Flywheel storage systems are based on the fact that energy can be stored in the spinning mass of a flywheel that is coupled with an electrical machine. The energy is transferred to the flywheel when the machine is operated in motor mode in order to accelerate the flywheel shaft. Energy can then be transferred back to the electrical system when the machine is operated with regenerative braking to slow down the rotation of the shaft. As energy storage devices, flywheels offer significant capacity, high efficiency, and fast operation. However, they cannot store energy for long periods, and the energy can be retrieved from the flywheels for only short durations. A flywheel storage system is described for use with a DC microgrid application. The flywheel system was employed for controlling the DC voltage through its ability to supply or absorb the difference in power between the generation and the load. The system presented utilizes an inexpensive squirrel-cage induction machine but requires an AC-to-DC converter to enable connection to a DC microgrid. The authors of used a hybrid flywheel/battery energy storage system for a DC microgrid based on wind generation. They employed a permanent magnet synchronous machine as a flywheel and connected it to the system through a bidirectional AC-to-DC converter. A BESS is used in conjunction with the flywheel because the latter cannot regulate the DC voltage while in speed control mode: it must first be driven to a high speed before it can be switched to voltage control mode.

3.8.4 Superconducting Magnetic Energy Storage

In superconducting magnetic energy storage (SMES), energy is stored in a magnetic field created by passing current through an inductor. The inductor is fabricated using a superconducting material and is kept at a very low temperature in order to maintain its superconducting properties. Energy is transferred to the SMES storage through the application of a positive voltage across the inductor and is then transferred back to the electrical system through the application of a reverse voltage. SMES storage is costly and has a low bridging time ranging from one to two minutes. However, it also offers high efficiency and fast response times and can provide grid frequency support. The use of SMES is reported in as a means of mitigating low-voltage ride-through and power fluctuation problems in wind doubly-fed induction generators connected to a DC microgrid. However, the effect of this technique on the DC bus voltage is not indicated in the simulation results.

Chapter 4

SYSTEM MODELING

A single line diagram of the proposed renewable energy generation system (REGS) fed micro-grid is shown in Fig. 4.1. The same has been designed for location having maximum power demand and average power demand of 15 kW and 5 kW, respectively. The rated capacity of both wind and solar energy block in REGS, is taken as 15 kW. The capacity utilisation factor of 20% is considered for both energy blocks, which is enough to provide full day energy requirement of the hamlet. As shown in a schematic diagram, the wind energy source is isolated using a 3-pole breaker from the network in case of insufficient wind speed. The DC side of both RSC and LSC along with HV side of solar converter, is connected at the battery bank. RSC helps the wind energy system to run at the optimum rotation speed as required by W-MPPT algorithm. The LSC controls the network voltage and frequency. The energy flow diagram of the system is shown in Fig. 4.2.

The design methodology of major components of REGS, is shown in following sub-sections.

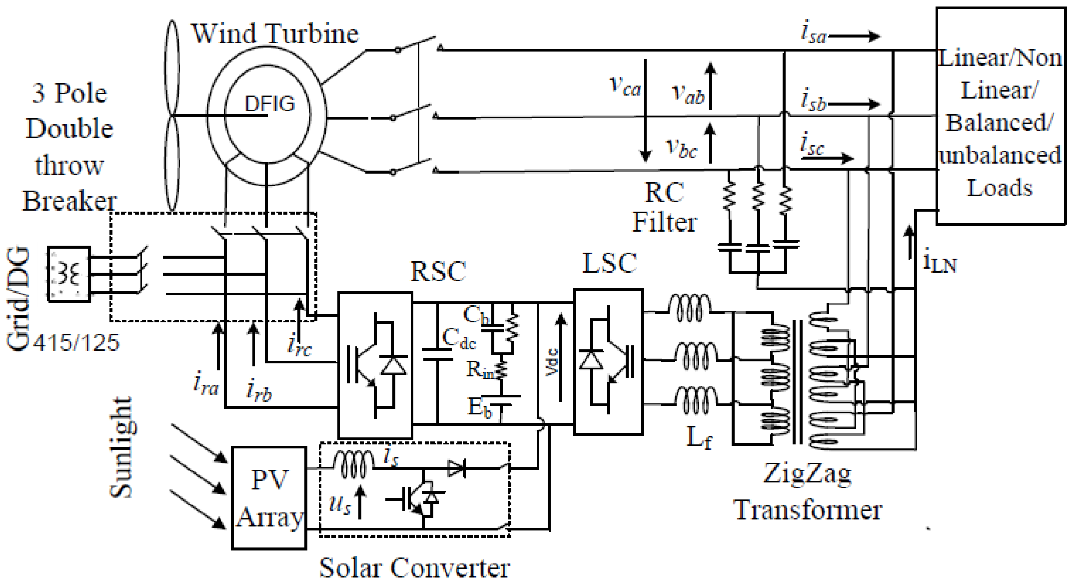


Fig.4.1. Schematic of isolated micro-grid network fed by renewable energy source using battery storage.

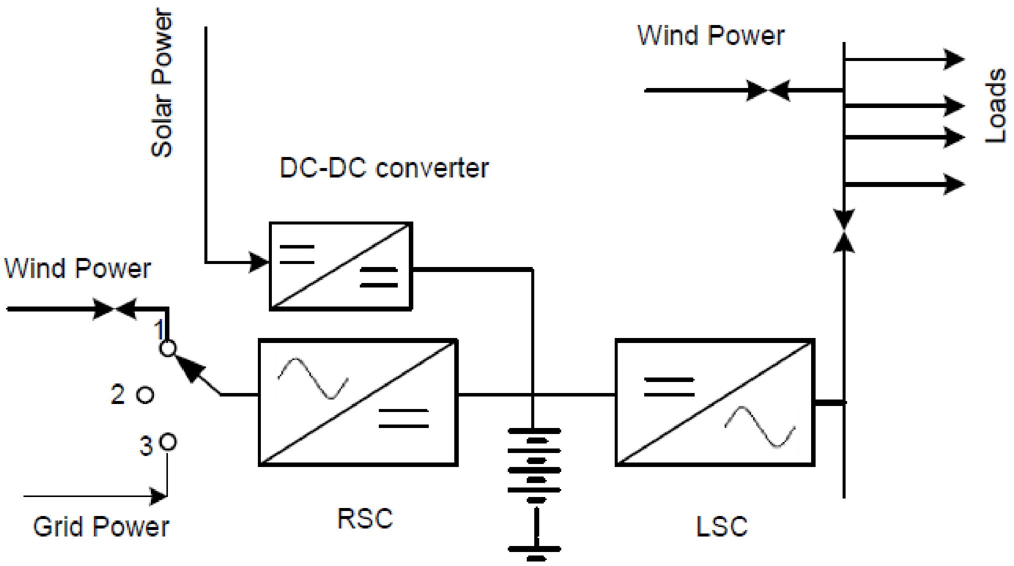


Fig.4.2. Energy flow diagram of isolated micro-grid network fed by renewable energy source using battery storage.

The wind turbine captures the kinetic energy of the wind and provides driving torque for DFIG. When the wind turbine is in service, the complete magnetising power requirement of machine is provided by RSC. Hence 11.83 kW capacity of DFIG is adequate to convert mechanical power from 15 kW wind energy system to electrical energy. The load and stator terminals are connected to the LSC through a zig-zag transformer, which also provides neutral for single phase loads at 415 V side. The maximum absolute value of rotor slip, is 0.3 and accordingly, the maximum rotor voltage *Vrmax*becomes 125 V(0.3×415 V). The voltage at the LV side of zig-zag transformer is also chosen to be equal to *Vrmax*Accordingly the transformer has a voltage ratio 415/125 V and its HV windings are connected to the stator and the load. The zig-zag transformer should meet the combined kVA requirement of load as well as connected filters. Accordingly, a 20 kVA transformer is chosen, which is sufficient to transfer rated power along with meeting reactive power requirement of the connected loads and filters at peak demand.

The maximum operating slip of machine is 0.3. The DFIG speed corresponding to this slip is 110 rad/s. At this slip, the line voltage of rotor

*Vrmax*become 125 V (415×0.3). *VL* is the higher of the line voltage of low voltage (LV) side of the zig-zag transformer and the rotor voltage at highest slip. The maximum operating slip is 0.3 and accordingly the highest rotor voltage as well as LV side of zig-zag transformer is 125 V. The modulation index, *mi* is chosen to be unity. Based on these inputs, the DC bus voltage *Vdc* required for functioning of PWM control must not be less than 204 V. In the presented scheme, *Vdc* is taken 240 V. The proposed micro-grid is designed to provide load requirement of 5 kW without any generating source for an up to 12 hours. Taking additional 20% margin for energy losses during exchange of energy, the required battery storage capacity becomes 72 kWhr. At the DC bus voltage of 240 V, the Ampere-Hour (AH) rating of battery becomes 300 AH (72,000/240). This is achieved using 40 numbers of 12V, 150 AH lead acid batteries divided equally into two parallel circuits.

A lead acid battery bank can be safely operated between 2.25 V and 1.8 V per cell. This makes the maximum battery voltage *Vbmax*and minimum battery voltage *Vbmin*to be 270 V and 216 V, respectively. A battery bank can be assumed to a DC source with fictitious capacitor *Cb,* internal resistance *Rin* connected in series. In addition to it, another resistance *Rb* is connected across the battery to denote energy drain due to self discharge of battery. The basic element of a solar PV system is the solar cell. The solar panels are configured such that the open circuit voltage of the solar string remains less than the lowest downstream voltage of solar converter or DC bus voltage, *Vdc*. The value of *Vocc*based on a typical commercially available cell characteristics and its value, is taken as 0.64 V. As evaluated in sub-section (D), the minimum battery voltage can fall down upto 216 V. Solar array voltage (*us*) can vary up to 3%, which is due to manufacturing tolerance of electrical quantities of module. Hence *Vdcm*is taken as 210 V and accordingly, the required numbers of cell, *Nc* as be 328 cells. To evenly distribute the cells in a standard configuration, 324 cells are taken, which are divided in 9 modules of 36 cells each. The ratio of *Vocc*to cell voltage at maximum power point (MPP), *Vmpc*for a typical module characteristic is 1.223. Accordingly, the module voltage at MPP becomes (Vmpc x 36) 18.83 V and *us* becomes 169.47 V. At 15 kW solar array capacity, the cumulative string current at MPP becomes {15000/(9*18.83)}88.5 A. The number of string in the solar array is chosen to be 11, accordingly module current at MPP, *Imp* becomes 8.04 A. The ratio of short circuit current Isc to *Imp* for a typical module is 1.081 and accordingly *Isc*is taken as 8.69 A. To reduce voltage ripples, a high pass filter is used at stator terminal, which time constant should be less than fundamental frequency i.e. 20 ms. Moreover, it should be tuned half the switching frequency. The switching frequency is 10 kHz and accordingly the filter to be designed for 5 kHz. In the present scheme, a series RC filter consisting of 5 Ω resistance and 15 μF capacitance, is connected at the stator terminals of DFIG. The filter provides less than 5.43 Ω impedance for harmonic voltage having more than 5 kHz frequency.

A solar converter, which is a boost type DC-DC converter used to evacuate solar power with embedded S- MPPT logic. It is based on incremental conductance method. The S-MPPT through intelligent switching regulates *us* so as the solar system operates at MPP. Since the onshore wind turbine generates power only for 60-70% of the time, the system should be designed to work when no wind power is available. As shown in the control diagram in Fig. 4.3, *i*qs*consists of two components. The first component, *iqs1* corresponds to the power component of DFIG current, when wind turbine is in operation. The second components *iqs2* corresponds to the power component drawn when stator of DFIG is not connected to the load terminal. The direct component of current, *i*ds* corresponds to the reactive power requirement at the point of common interconnection of the generator and filter. The information of *i*qs*and *i*ds* provides the reference stator currents and help in maintaining the voltage and frequency through the indirect vector control.

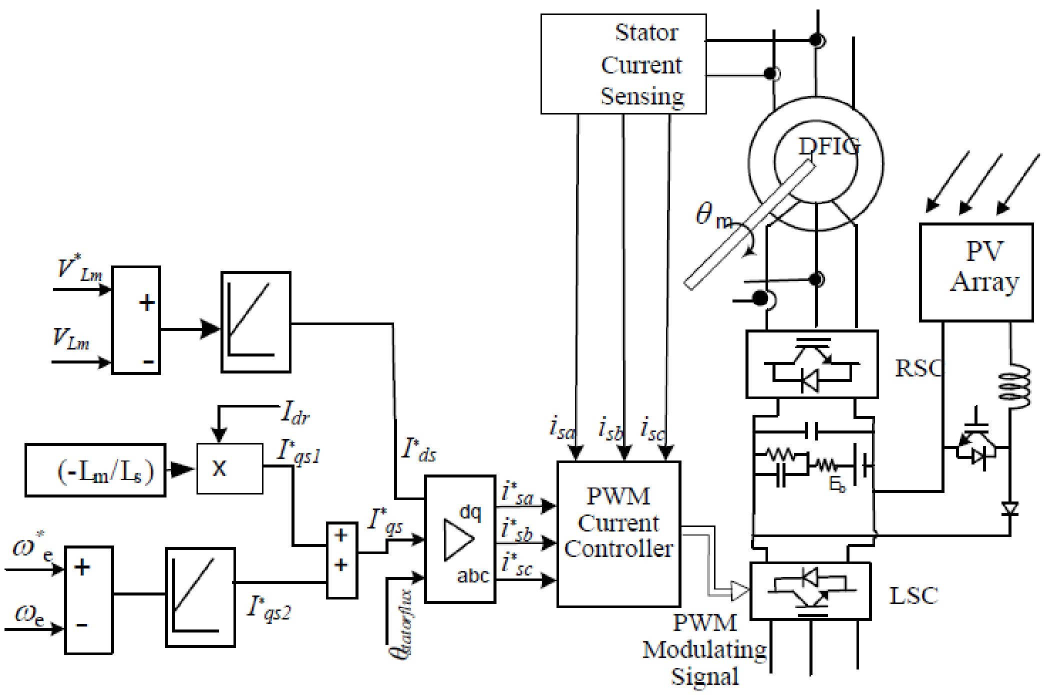


Fig.4.3. Control diagram of LSC for REGS energy fed micro-grid

The stator frequency is controlled by the LSC. Though the system has to generate rated frequency, a droop characteristic has been incorporated. Vdcmax is taken as 272.5 V, which is the bus voltage corresponding Vbmax during charging. Similarly, Vdcmin is being taken as 213.5 V, which bus voltage corresponds Vbmin and the battery being discharged. With these figures, the frequency varies from 49 Hz to 51 Hz. RSC regulates the speed of turbine so that the system operates at MPP irrespective of varying wind conditions. It also provides magnetizing power to the generator. The control philosophy as shown in Fig. 4.4, includes control algorithm for determination of quadrature and direct components of rotor currents, *Iqr*, *Idr*and transformation angle, θ*sli*p.

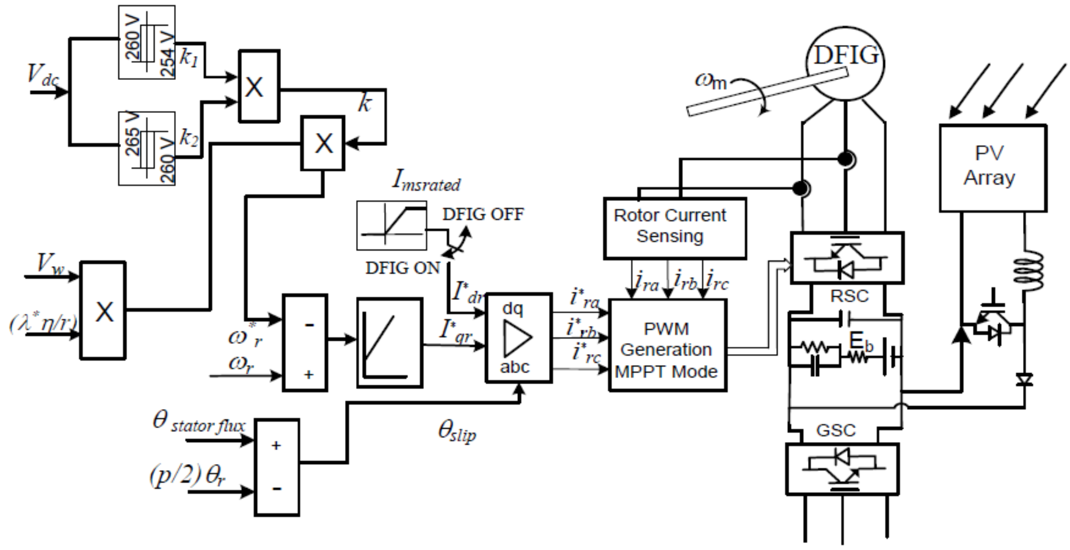


Fig.4.4. Control diagram of RSC for REGS fed micro-grid

The value of *k* is determined from the two relays namely, *k1* and *k2* as shown in Fig. 4.4. The output of relay falls to 0.85 if the DC bus voltage increases beyond threshold value. The threshold values of both relay, are kept 260 and 265, respectively. The *k* attains values of 0.85 and 0.72 as the *Vdc* exceeds 260 V and 265 V, respectively. The error signals of reference currents and sensed currents (*ira*, *irb*and *irc*) through hysteresis current regulator, generate control signals for RSC.

SIMULATION RESULTS

The Simulink model of micro-grid fed by REGS is developed in Matlab. The solar panels and wind turbine are modeled using their functions.

CASE-A: Performance of System at Constant Load and Cut-in and Cut-out of Wind Power

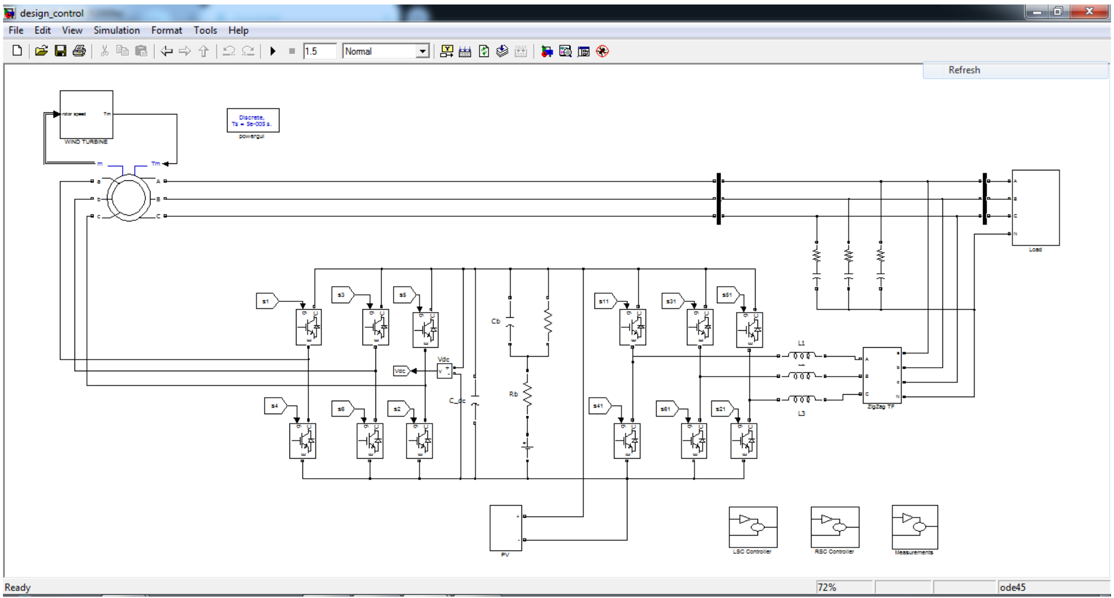


Fig:5.1. Performance of System at Constant Load and Cut-in and Cut-out of Wind Power.

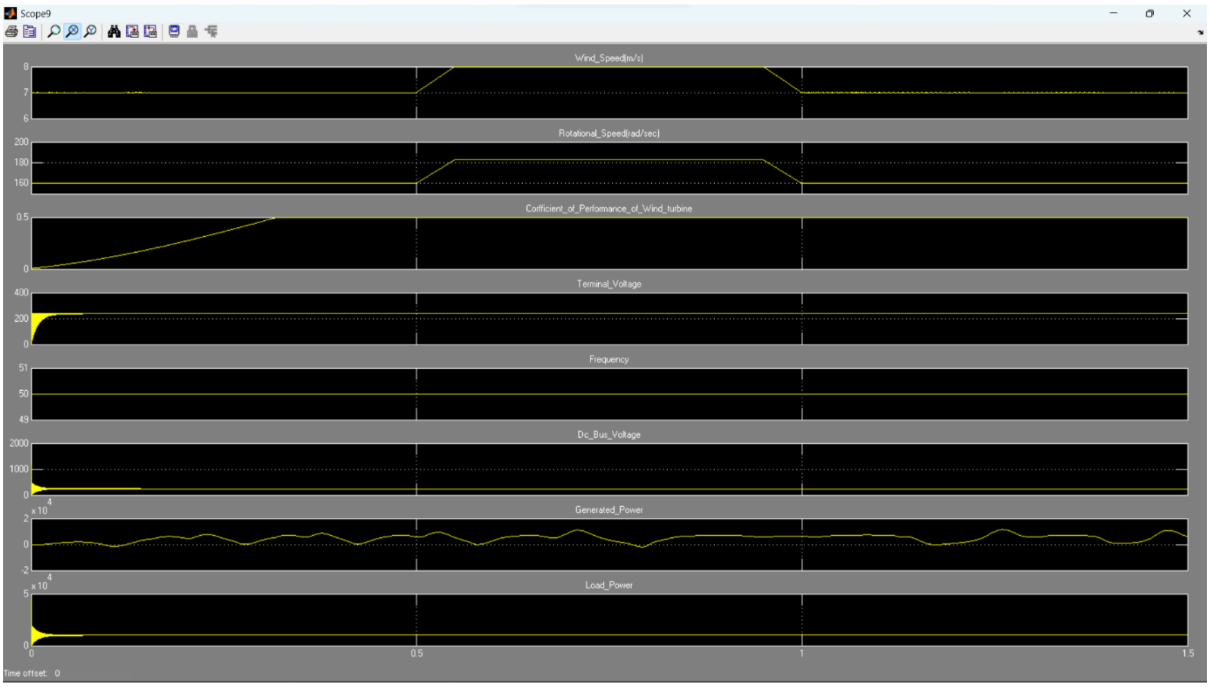
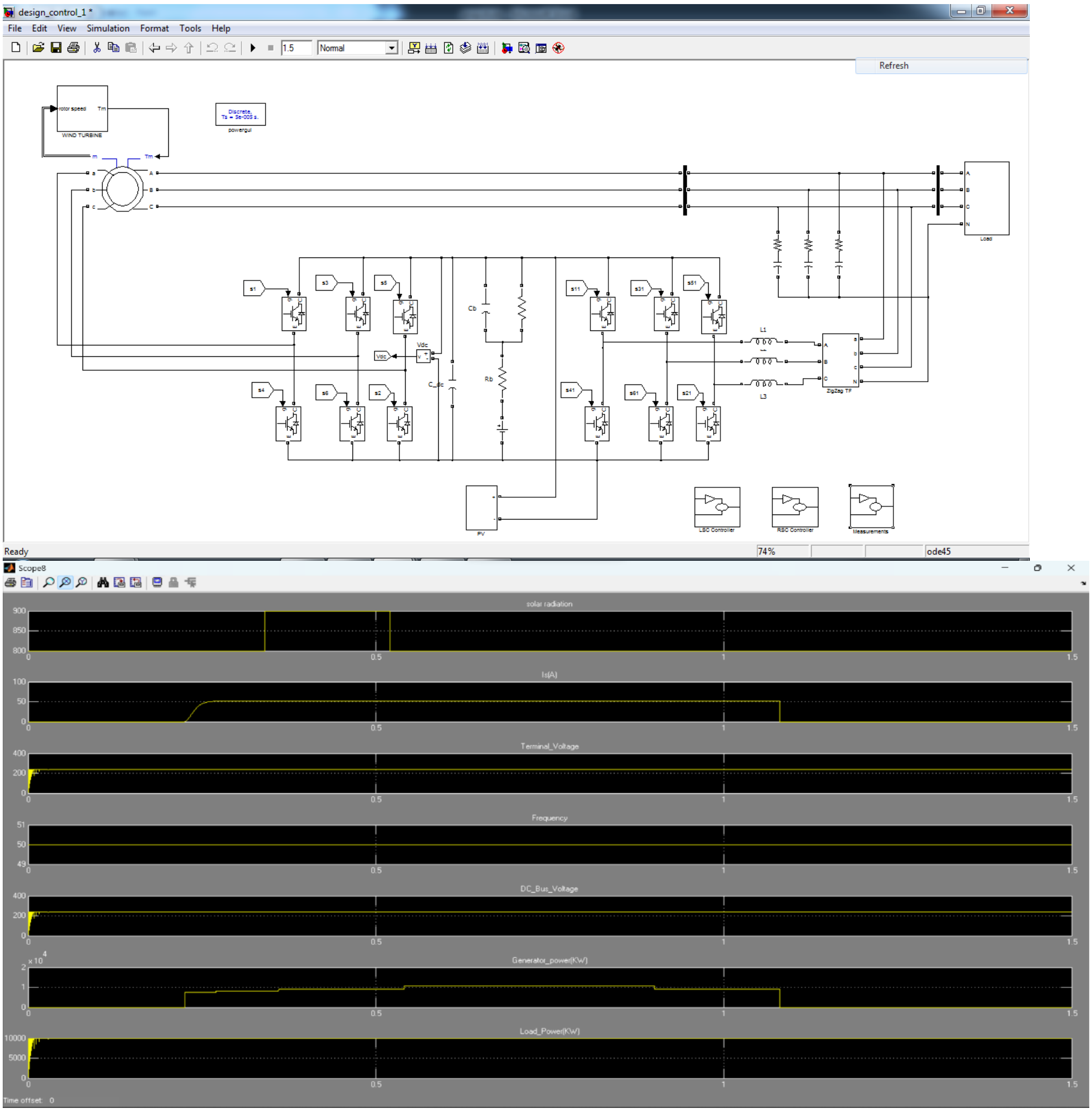


Fig:5.2- Performance of REGS fed micro-grid with wind energy source.

As shown in Fig. 5.2, the system is started with 10 kW and 6 kVAR load without wind or solar energy sources. At t=0.25 s, the wind generator at wind speed of 7 m/s, is taken in service. As a result, a momentary fluctuation in the system voltage is observed. At t=0.6 s, the wind speed of turbine is increased from 7 m/s to 8 m/s followed by reduction of the wind speed to its original value at t=0.1 s. The rotor control action, maintains the desired rotational speed as per the W-MPPT algorithm. At t=0.14 s, the wind generator is taken out of service.

CASE-B: Performance of System at Constant Load and Cut-in and Cut-out of Solar Power



The system is started with a 10 kW and 6 kVAR load without wind or solar energy. As shown in Fig. 5.4, at t=0.25 s, solar system is taken into the service at radiation of 800 W/m2. At t=0.4 s, the solar radiation is raised to 900 W/m2 and again it is reduced to 800 W/m2 at t=0.6 s. The solar converter adjusts the solar PV voltage and operates at S-MPPT. At t=0.7 s, the solar system is taken out of service. No significant variation of system voltage is observed at any transition point.

CASE-C: Performance of System at Unbalanced Nonlinear Load

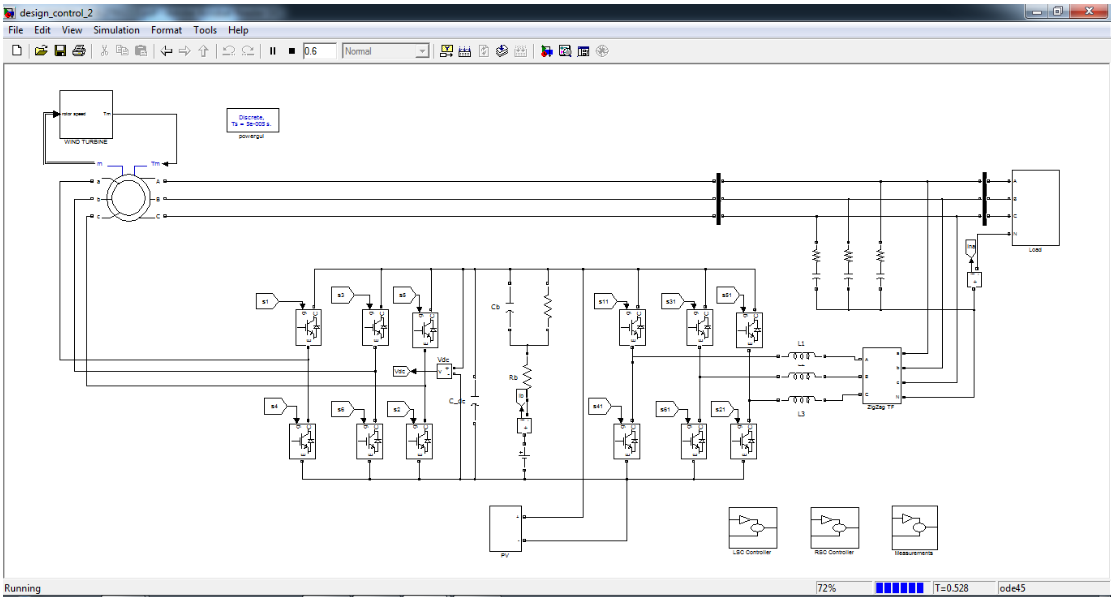


Fig:5.5. Performance of System at Unbalanced Nonlinear Load

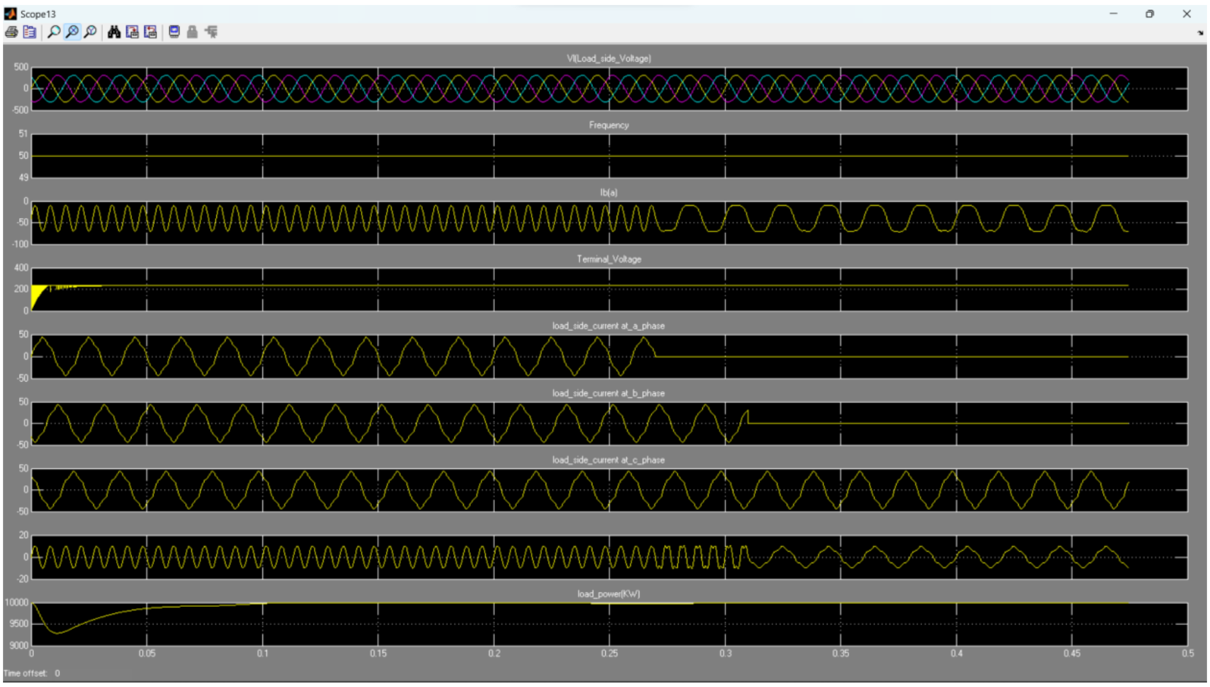
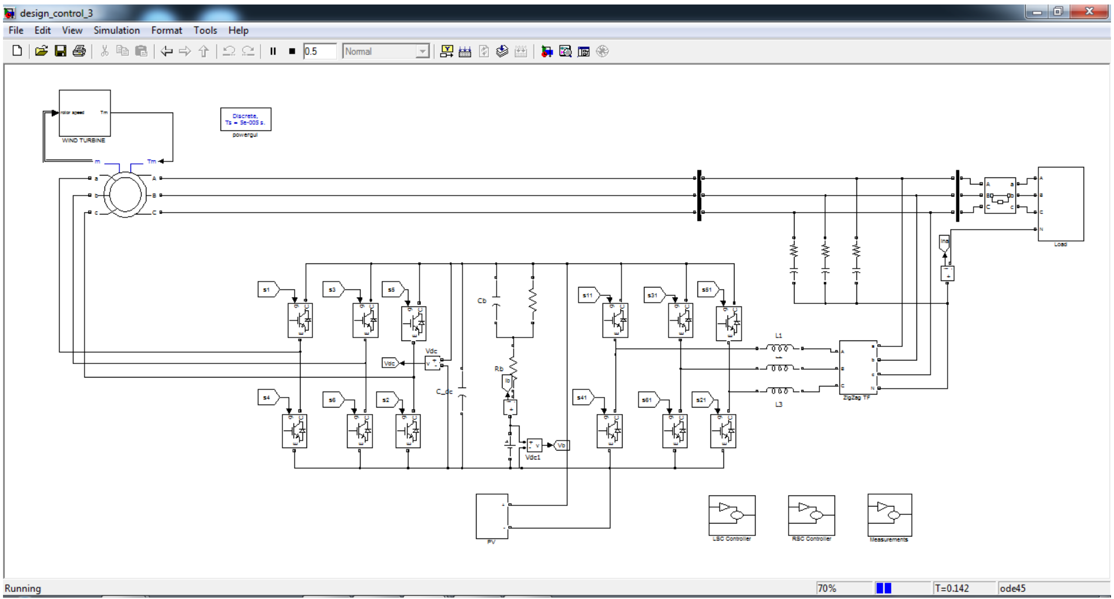
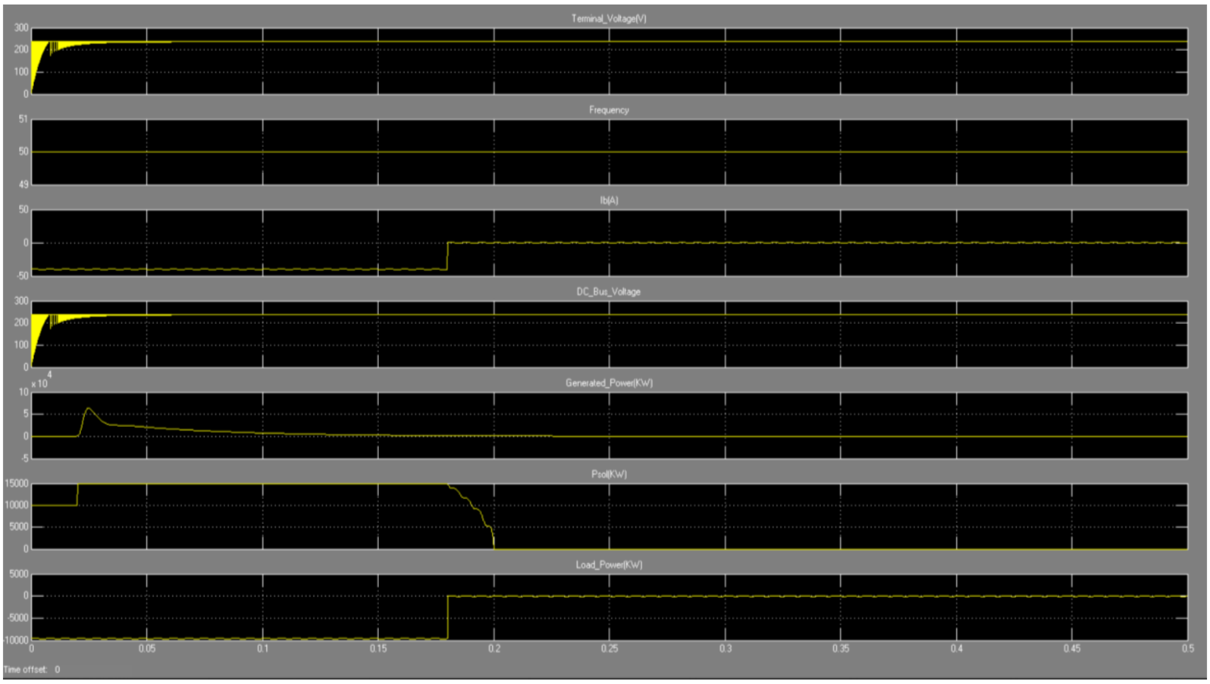


Fig: Performance of the system at unbalanced and nonlinear load

The performance of the system at unbalanced nonlinear is shown in Fig. 5.6. A micro-grid should be suitable to provide requirement of unbalanced nonlinear load. A worst case scenario is taken when there are no generating sources. The connected load consists of 2 kW linear load and 8 kW nonlinear load. At t=0.325 s, the load of a-phase is disconnected from the network followed by b-phase load at t=0.346 s. It is seen from the results that the system is able to provide quality power to its customer in case of unbalanced as well as nonlinear load.

CASE-D: Performance of System at Loss of Load





The performance of the micro-grid for loss of load, is shown in Fig. 5.8. A 10 kW and 6 kVAR load, is connected at the terminals prior to start of simulation. Neither wind nor solar power, is available and the load is fed by the battery. At t=0.2 s, the system load is disconnected. It is found that the system voltage and frequency remain constant of the network.

CASE-E: System Running without Generating Source and Battery Charged from the Grid

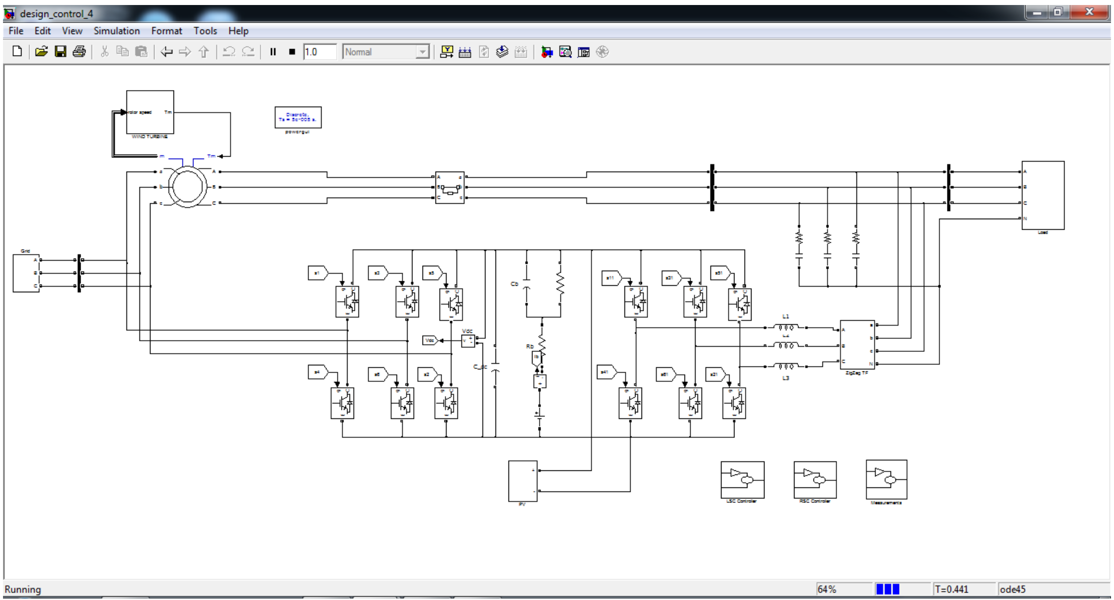


Fig:5.9. System Running without Generating Source and Battery Charged from the Grid

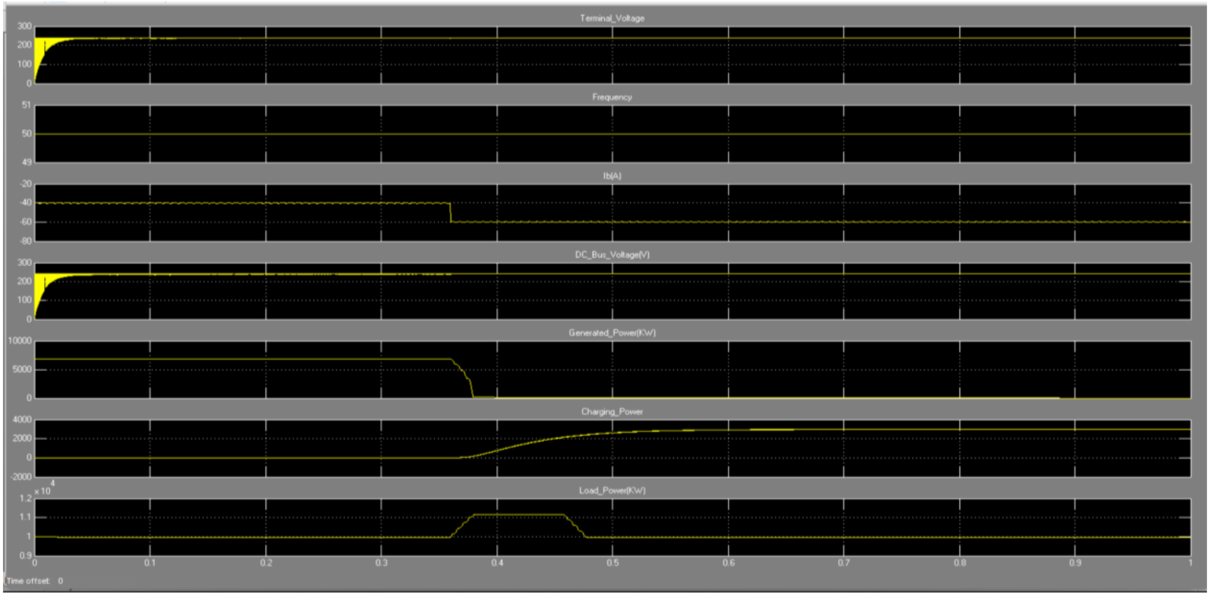


Fig. 5.10 shows the scenario when there are no generating sources feeding to the network combined with low battery. External charging is required to sustain the load requirement. Charging circuit is enabled as per the logic condition. At t=0.4 s, wind generation is taken out of service and because of lower battery voltage, the charging circuit is initiated. As a result external power is injected through the RSC to cater load requirement in addition to charging the batteries.

CASE-F. Performance of System during High Generation and Over-voltage Scenario of DC bus

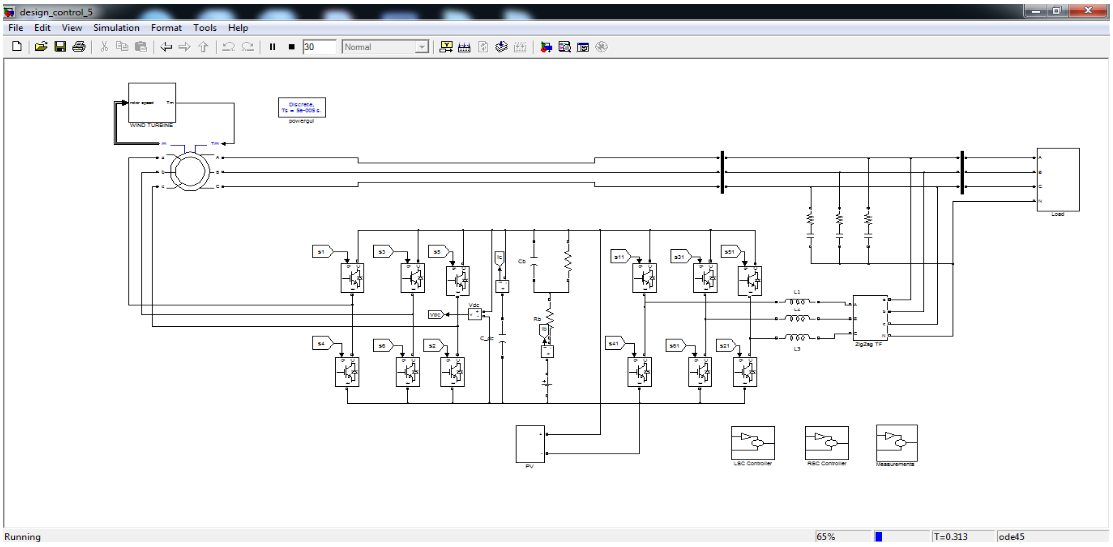
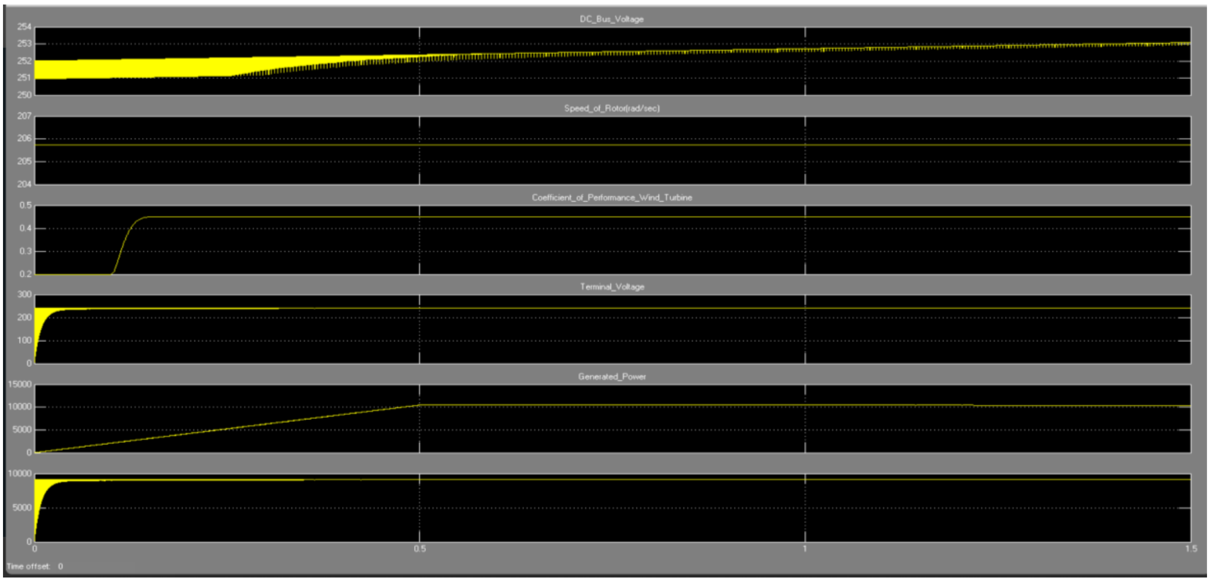


fig:5.11. Performance of System during High Generation and Over-voltage Scenario of DC bus



Performance of system at high net generation and over-voltage scenario of DC bus, is shown in Fig. 5.12. To make the effect visible, the AH of the battery is reduced by 1/200 times. The wind speed and solar irradiance, are kept 9 m/s and 700 W/m2 respectively. It is seen from the curve, that once the *Vdc* reaches 260 V, RSC control reduces the DFIG speed set point to 85% of the MPPT set point. It is seen from Fig. 5.12 that charging power, *Pc* is reduced and the voltage rise is reduced.

CONCLUTION

The proposed micro-grid system fed from REGS has been found suitable for meeting load requirement of a remote isolated location comprising few households. REGS comprises of wind and solar energy blocks, which are designed to extract the maximum power from the renewable energy sources and at the same time, it provides quality power to the consumers. The system has been designed for complete automated operation. This work also presents the sizing of the major components. The performance of the system has been presented for change in input conditions for different type of load profiles. Under all the conditions, the power quality at the load terminals, remains within acceptable limit. The effectiveness of the system is also presented with test results with prototype in the laboratory. The system has also envisaged the external battery charging by utilizing the rotor side converter and its sensors for achieving rectifier operation at unity power factor.

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[2] M. Das and V. Agarwal, "Novel High-Performance Stand-Alone Solar PV System With High-Gain High-Efficiency DC–DC Converter Power Stages," IEEE Transactions on Industry Applications, vol. 51, no. 6, pp. 4718-4728, Nov.-Dec. 2015.