INTEGRATED SCHEME FOR RENEWABLE HYBRID ENERGY CONVERSION SYSTEM

By

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INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY 2013

INTEGRATED SCHEME FOR RENEWABLE HYBRID ENERGY CONVERSION SYSTEM

Major Project Report

Submitted in Partial Fulfillment of the Requirements

For the degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(ELECTRICAL POWER SYSTEMS)

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UNDERTAKING FOR THE ORIGINALITY OF THE WORK

I **Ms. SHRUTI K. KHATRI**,(**Roll No: 11MEEE09**), give undertaking that the Major Project entitled **"INTEGRATED SCHEME FOR RENEWABLE HYBRID ENERGY CONVERSION SYSTEM"** submitted by me , towards the partial fulfillment of the requirement for the degree of Master of Technology in **Electrical Power Systems** ,**Electrical Engineering**, under Institute of Technology,Nirma University,Ahmedabad is the original work carried out by me and I give assurance that no attempt of Plagiarism has been made.I understand that in the event of any similarity found subsequently with any published work or any Dissertation work elsewhere; it will result in severe disciplinary action.

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Date: May 2, 2013

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Ahmedabad

CERTIFICATE

This is to certify that the Major Project Report entitled **"INTEGRATED SCHEME FOR RENEWABLE HYBRID ENERGY CONVERSION SYSTEM"** submitted by **Ms. SHRUTI K. KHATRI** (**Roll No: 11MEEE09**) towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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ACKNOWLEDEMENT

It is a matter of extreme honor and privilege for me to offer my grateful acknowledgement to my guide **Prof.Chintan R.Mehta**, Nirma University, Institute of Engineering and Technology, Ahmedabad for his valuable time,encouragements, inspiring and excellent guidance.It is his zeal and visionary approach that made this work to reach this level.

Also I would like to thank **Prof. S. S. Kanojia**, Nirma University, Institute of Engineering and Technology, Ahmedabad for her guidance and continuous support.I express my sincere appreciation and thanks to **Dr. S.C. Vora** for constant encouragement and guidance during various stages of work.

I would like to thank to **Dr. P. N. Tekhwani**, Head of Electrical Department for providing the infrastructure to carry out the project work.I would like to thank to **Dr. K. Kotecha**, the Director of Institute of Technology,Nirma University for allowing me to carry out my project work in institute.I am also thankful to Nirma University for providing all kind of required resources and all those who directly and indirectly helped me during my project work.

I would like to thank my friends for their continuous support and encouragement. Also I would like to thank my parents for their selfless love and support and Almighty God for showering his blessings upon me.

- SHRUTI K. KHATRI

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ABSTRACT

In the last few decades the development of electricity market has accelerated use for higher power quality and better stability.Energy reserves like coal, oil are likely to get extinguished in the near future. Moreover environment pollution has given rise to problems like green house emissions, acid rains and global warming. Due to this renewable energy systems such as wind, solar, fuel cell or geothermal power have gained popularity.

Renewable sources of energy require high capital cost and also their output is quite variable. So to overcome these problems a hybrid AC-DC interface for photovoltaic (PV)-Wind Energy Conversion System (WECS)-Battery connected to the grid .Wind turbine is coupled with Doubly Fed Induction Motor. The output of wind turbine is DC which is converted into AC with help of an inverter. An additional battery is provided so that when power is not available then the battery can supply the power.the output of PV panel is DC. The output of wind turbine is DC which is converted into AC with help of an inverter.

A model in MATLAB software is developed for sample study system to validate effectiveness of hybrid photovoltaic (PV) - Wind Energy Conversion System (WECS)-Battery smart grid interface. A PV module is developed with the help of MATLAB programming. Wind turbine is coupled to induction generator. Control scheme are developed to increase the efficiency of the system

Contents

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ABBREVIATIONS

PV .... Photo-voltaic
VSI .... Voltage source inverter
PWM .... Pulse width modulation
APWM .... Asynchronous Pulse Width Modulation
MI .... Modulation Index
WECS .... Wind Energy Converter System
Isc .... Short circuit current
Voc .... Open circuit voltage
Irs .... Reverse saturation current
Iph .... Photovoltaic current
Io .... Saturation current
IM .... Induction Motor
PID .... Proportional Integral Derivative
SOC .... State of charge

NOMENCLATURE

I_{pv} .... Photovoltaic current .... [A]
I_{ph} .... Photon current .... [A]
I_{rs} .... Reverse saturation current .... [A]
I_o .... Saturation current .... [A]
V_{pv} .... Photovoltaic voltage .... [V]
N_p .... No.of cells connected in primary ....
T_{ak} .... Module operating Temperature .... [kelvin]
T_{ref} .... Module reference temperature .... [kelvin]
R_s .... Series Resistance .... [Ohm]
R_p .... Shunt Resistance .... [Ohm]
V_{mp} .... Voltage at maximum power .... [V]
I_{mp} .... Current at maximum power [A]
A .... Diode ideality factor
K .... Boltzmann constant .... [J]
G .... Insolation .... [W/m^2]
P_w .... extracted power from the wind .... [W]
ρ .... air density .... [kg/m^3]
V_w .... wind velocity .... [m/s]
C_p .... the power coefficient .... [A]

Chapter 1

INTRODUCTION

In the last few decades the development of electricity market has accelerated use for higher power quality and better stability. A major concern of electric power utilities is to maintain the reliability of the grid. Increased power transfers raise concerns about steady-state overloads, increased risks of voltage collapses, and potential stability problems [1]. Thus the increasing demand for electric energy and growing use of nonlinear loads have created new power quality and stability challenges which leads to requirement for safe, efficient and clean AC grid.

Energy reserves like coal, oil are likely to get extinguished in the near future. Moreover environment pollution has given rise to problems like green house emissions, acid rains and global warming. Due to this renewable energy systems such as wind, solar, fuel cell or geothermal power have gained popularity. But these sources have variable output as they are dependent on weather condition. Also they have high capital cost. Moreover their connection into grid leads to instability security issues due to aspects like efficiency, reliability, cost of energy conversion, safe connection to grid and availability of good and reliable tools for modeling.

Renewable sources are still limited as they cannot offer ancillary services to electrical grid system where stable active and reactive power exchange requirements should be fully attributed to the generators. To overcome these problems hybrid power system (Photovoltaic-Wind Energy conversion System-Battery smart grid) are proposed.

1.1 LITERATURE SURVEY

An integrated self regulating hybrid(Wind-Photovoltaic-Battery) smart grid energy conversion system [2] describes an interface scheme of Photovoltaic-Wind Energy Conversion System-Battery smart grid utilizing FACTS devices. The hybrid Photovoltaic-Wind Energy Conversion System-Battery smart grid system is regulated to maximize the power transferred to the AC grid within the device ratings and ensure voltage regulation. An additional back-up battery unit is provided to provide compensating power during low solar insulation (night time) and emergency loading conditions. FACTS devices interfaced with six pulse Voltage Source Inverter utilizes Asynchronous Pulse Width Modulation switching strategy which is controlled by Multiple Objective Particle Swarm Optimization algorithm for dynamic PID gain adjusting. This interface scheme helps in reducing distribution losses, improves voltage stability and power quality.

Modeling and control for smart grid integration of solar / wind energy conversion system [3] describes a novel model of smart grid-connected PV/WT hybrid system. It comprises photovoltaic array, wind turbine, induction generator, controller and converters. The output characteristics of the PV model with different solar irradiance and cell temperature are nonlinear. The solar irradiation is unpredictable, which makes the maximum power point (MPP) of the PV module changes continuously. Therefore, a maximum power point tracker (MPPT) technique is needed to operate the PV module at its maximum power point (MPP). The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module was integrated with the wind turbine system. The rotor shaft is driven by the WT which produces the mechanical torque according to the generator and wind speed values. Due to the variations in wind speed, the output power of the wind turbine induction generator experiences variations in frequency and amplitude. Therefore, a controllable ac/dc converter is used to smooth the wind turbine output power. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding.

A Novel Hybrid Isolated Generating System Based on PV Fed Inverter Assisted Wind driven Induction Generators [4] describes that the PV array charges a battery bank. A hybrid scheme employing wind-turbine permanent-magnet (PM) alternator and PV array was proposed, in which the sources were connected in series through dc-dc converters. The battery acts as a constant voltage load line on the PV array and is charged both by the IG and the PV array. Under conditions of low wind speed, the induction generator is isolated from the system and the load is fed by the PV array and the battery. The load is fully supplied by the battery in situations where there is inadequate wind speed and irradiation. During nights and under high wind penetration, the IG supplies the load, the excess energy if any being used to charge the battery. On the other hand, during the daytime, in the event of the battery being disconnected to prevent overcharging, the IG and PV array feed the load. In such conditions, the PV array in addition to supplying power to the load also provides the needed reactive power to the IG. The battery would be deeply discharged only in the event of long duration of both low wind speed and irradiation. The battery voltage is inverted through a three-phase, six-step quasi-square-wave IGBT inverter, fixed frequency supply is obtained to form the local grid to which the IG is integrated. The battery bank, which is charged during the daytime, will supply the inverter during the night to provide necessary reactive power for the induction generator.

Hybrid Renewable Energy System with Wind Turbine and PV Panels [5] describes that Doubly fed induction generators (DFIGs) are increasingly used in wind generating systems as the rotor speed need not be maintained constant. These systems use a wound-rotor induction machine to convert the mechanical power from the wind turbine into a fixed-frequency ac output supplied to the grid. The frequency of the voltage injected into the rotor is adjusted such that the sum of rotor frequency and the equivalent frequency corresponding to mechanical rotation is equal to the desired stator frequency (50Hz). Thus the system uses power converters as well as filters with correspondingly lower ratings. The inverter provides a sinusoidal voltage to the rotor terminals at a frequency determined by the mechanical speed of the rotor. The dc link voltage for the inverter is usually provided by a converter/rectifier. It is a hybrid scheme in which the injection power can be drawn from (a) ac mains at unity power factor if available or (b) a set of PV panels and a back-up battery in the absence of ac mains. During night or when sunlight is absent, the battery may be charged by rectifying the 3-phase ac voltage output of the DFIG. The converter system uses a current-based maximum power point tracking (MPPT) scheme which uses the fact that the PV current is linearly related to the short-circuit current at maximum power point. This scheme senses the short circuit current.

Regulation of Grid Voltage by the Application of Photovoltaic (PV) Solar Farm as STATCOM [6] focuses on night-time application of a PV solar farm by which the solar farm inverter is employed as a FACTS device for voltage control in order to improve power transmission capacity during nights. PV solar farm is basically inactive during night-time and the bidirectional inverter used to deliver the PV DC power as three-phase AC power to the grid, remains unutilized as well. The night time usage of a PV solar farm where a PV solar farm is utilized as a FACTS device for performing voltage control, thereby improving system performance and increasing grid connectivity. The bidirectional inverter of PV solar farm is utilized as a battery charger especially during the night-time to charge the batteries.

Novel Control of Grid Connected Photovoltaic(PV) Solar Farm for Improving Transient Stability and Transmission Limits Both During Night and Day. [7] presents control of a grid connected photovoltaic solar farm to improve transient stability limit and hence improve power transfer capability of the transmission line. In the night, when the solar farm is completely idle, this control technique makes the solar farm inverter behave like a Flexible AC Transmission System (FACTS) device. The DC power output of solar panels is fed to the DC bus to inject real power to the inverter during daytime operation. The amount of real power injection from the solar farm to the grid depends upon the magnitude of DC input voltage. The voltage source inverter comprises of six IGBTs. A large size DC capacitor is used to reduce the DC side ripple. Each phase has a pair of IGBT devices which convert DC voltage into a series of variable width pulsating voltages according to the switching signal, which are generated from the amplitude comparison of variable magnitude sinusoidal signal known as 'modulating signal' with high frequency fixed-magnitude triangular signal known as 'carrier signal' as. The variable magnitude and the phase angle of sinusoidal modulating signals are controlled by an external controller, which modifies the switching signal width duration. The modulating signals used for three phases are equally spaced and thereby shifted by 120^o whereas the same carrier wave is used for all three phases. This technique is known as sinusoidal pulse width modulation (SPWM) technique. With this scheme power transmission during nighttime can be increased.

1.2 OBJECTIVE

The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module is developed. Wind turbine is coupled with an induction generator. This wind energy conversion system is integrated with the PV module. Moreover an additional battery storage device is used so that when there is no power or during night time the DC from this battery can be used to supply uninterrupted power.

The main objective of project is to integrate Photovoltaic -Battery-Wind Energy Conversion System to the grig. to maintain reliability of the system

1.3 SCOPE OF WORK

Initially the photovoltaic model is developed by coding it in MATLAB by programming. The photovoltaic modeled developed is then connected to a six pulse voltage source inverter to convert DC into AC. The controlling of six pulse voltage source inverter is done by Asynchronous Pulse Width Modulation. The voltage obtained after converting DC into AC is then stepped up by using three phase transformer. On the other hand wind turbine is coupled to a doubly fed induction generator and the voltage obtained is stepped up by using three phase transformer. Both solar and wind schemes are integrated and connected to the grid which supplies power to the load. An additional battery storage system is provided so that DC generated is used to charge battery back-up unit in order to provide additional power during emergency load condition or weather change. If the total power from Wind Energy Conversion System and Photovoltaic is unable to supply load demand then this battery back- up supplies extra load. But if battery back-up cannot supply sufficient power to meet the load demand then the demand is met by electric utility grid. In case of excess power from Wind Energy Conversion System and Photovoltaic source energy will be used to charge battery back-up unit for future use.

1.4 THESIS OUTLINE

This chapter gives the basic idea about importance of renewable energy,its integration with the grid and the problems related to it. It also give a brief idea about the objective of project and the scope of work.

Chapter 2: This chapter gives a detailed idea about integration of solar and wind system. Also it gives idea about the battery which is used as a storage purpose in cse excessive load or less load. The integrated solar-wind-battery is then connected to grid which supplies power to various load.

Chapter 3: This chapters shows modelling of PV module, six pulse voltage source inverter, APWM and MI.Modeling of PV module is dobr by programming in MATLAB. Controlling of six pulse voltage source inverter is done by APWM by using MI. Also brief introduction about Lead-Acid battery charging and discharging and its modeling is described.

Chapter 4: This chapter gives brief introduction about wind turbine, principle of operation of induction generation and grid connected induction generator.shows simulation of PV module connected to six pulse voltage source inverter which is controlled by APWM. also the results obtained are shown.

Chapter 5: This chapter shows overview modellind of how pv-wind energy conversion system and battery are connected. This entire hybrid scheme is conne ted to the grid.

Chapter 6: This chapter shows simulation of PV module connected to six pulse voltage source inverter which is controlled by APWM, model of battery connected to photovoltaic panel and model of wind energy conversion system. Also the results obtained are shown.

Chapter 7: This chapter gives conclusion that the hybrid Photovoltaic-Wind Energy Conversion System-Battery smart grid improves voltage stability, power quality and reduces distribution losses. Also the the work to be carried out in future is mentioned in this chapter.

Chapter 2

OVERVIEW OF HYBRID SYSTEM

Hybrid systems are drawing attention due to high reliability, high performance, acceptable power quality and reduced cost. Moreover this system has the merit of supplying uninterrupted power for resident and also communication facilities in remote areas. This hybrid system is an interfacing Photovoltaic-Wind Energy Conversion System-Battery connected to the grid [8].

A hybrid AC-DC generation system comprising of Photovoltaic-Wind Energy Conversion System- Battery connected to the grid is shown in figure given below.

Wind turbine is coupled with Doubly Fed Induction Motor. The output of wind turbine is DC which is converted into AC with help of induction motor. When machine acts as a generator [9] the rotor rotates at a speed more than the synchronous speed and it will generate power that is pushed into the grid. But the power generated by rotor will first get converted into DC and then again into AC. In case of Doubly Fed Induction Motor, most of the power goes directly to the grid only the power generated by rotor will pass through AC-DC-AC arrangement and then to the grid. So this arrangement carries less power and is less expensive.The induction generator does not generate reactive power. But the grid will be loaded, i.e, it must have that

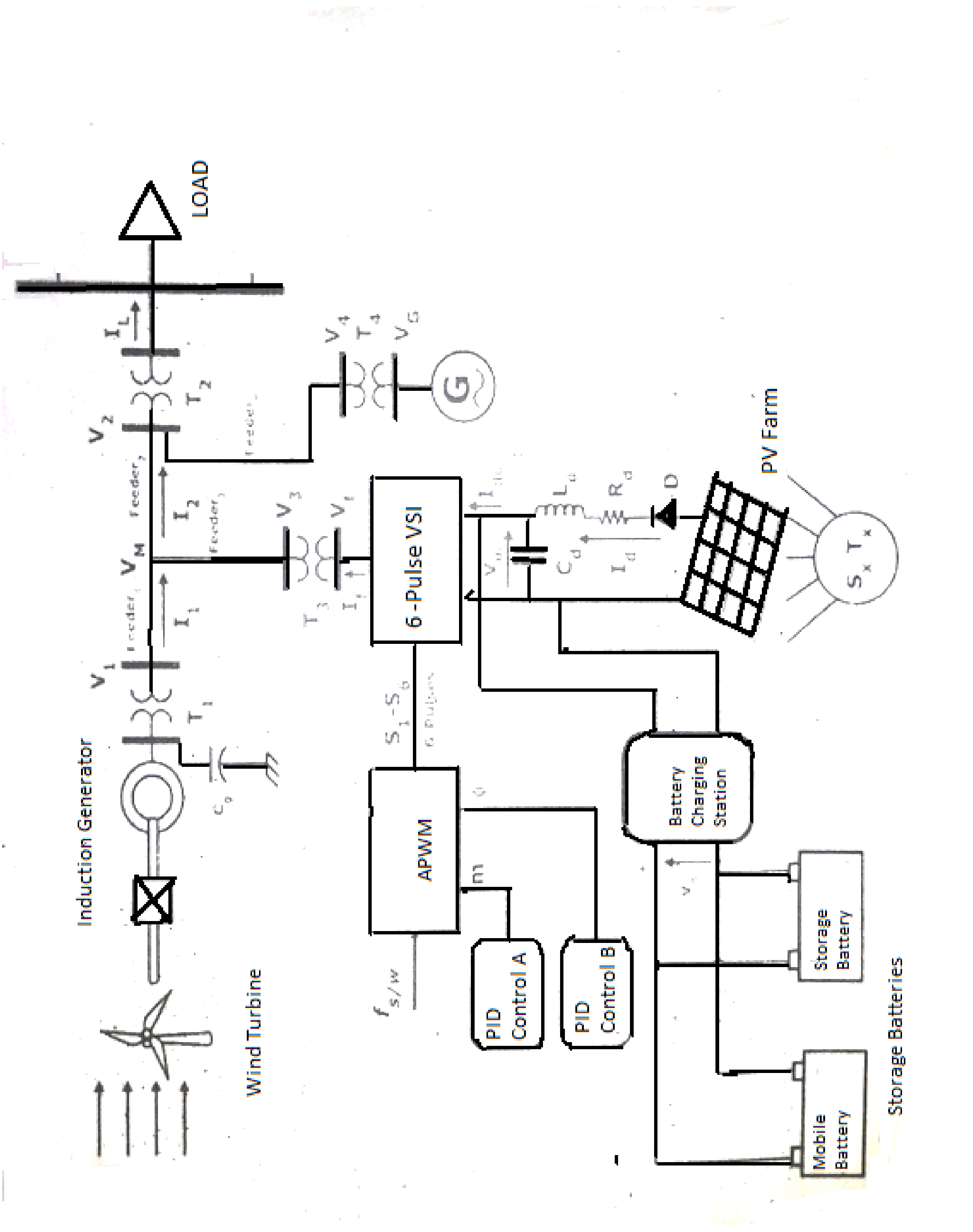

Figure 2.1: Interface scheme

much capacity to generate reactive power. So in large wind farms big capacitors are placed so that they can generate reactive power.

Induction machine are preferred as they are able to operate at variable speed with constant frequency. Moreover they are cheaper, rugged, strong and more durable.

The power given to grid is further stepped-up and stepped down according to requirement and supplies power to the load.

On the other hand, the output of PV panel is DC. This DC generated is used to charge battery back-up unit in order to provide additional power during emergency load condition or weather change. If the total power from Wind Energy Conversion System and Photovoltaic is unable to supply load demand then this battery back- up supplies extra load. But if battery back-up cannot supply sufficient power to meet the load demand then the demand is met by electric utility grid. In case of excess power from Wind Energy Conversion System and Photovoltaic source energy will be used to charge battery back-up unit for future use.

Large DC capacitors are used to reduce DC ripple. The PV modules are interfaced with with DC capacitor via DC bus, which is represented by Rdc and Ldc.. The DC from PV panel is converted into AC with the help of FACTS Voltage Source Converter AC-DC power electronic source converter scheme utilizing a 6-pulse Voltage Source Inverter. The hybrid AC-DC FACTS scheme interface employs an asymmetrically controlled sinusoidal pulse width modulated voltage source inverter. This Asynchronous Pulse Width Modulation is controlled by PID controller with error squared compensation loop. PID controller is used for enhancing dynamic performance of this hybrid scheme under transient conditions including wind gusts and sun irradiation changes.

The Asynchronous Pulse Width Modulation is dually controlled by the limited modulation power frequency index (m) and synchronization angle shift (ϕ) between the control modulating signal and the high frequency carrier modulated triangular signal with switching frequency selected at 1750 Hz.PID controller is used to ensure Asynchronous Pulse Width Modulation switching. PID controller is used tune the value of gain and to enhance dynamic performance of power system under transient conditions like wind gust and solar radiation changes.

The AC power obtained by conversion of DC power of PV panel into AC is then supplied to the grid which further steps-up or steps-down the voltage level as per requirement and supplies power to the load at consumer's side.

The main goal of this hybrid scheme is to maintain the required balance between energy supply and demand while improving the net energy utilization, system security as well as the power quality.

Chapter 3

MODELING OF PV SYSTEM AND BATTERY

The model designed consists of a PV array, a resistor, a capacitor, six pulse voltage source inverter and transformer. The solar PV modules are connected in a series-parallel configuration to match the required solar voltage and power rating. The six pulse voltage source inverter converts the DC input voltage into AC sinusoidal voltage by means of appropriate switch signals and then by using transformer the voltage level is stepped up or stepped down according to requirement.

3.1 PV MODULE

The typical representation of a solar cell is based on a single diode model shown below.

I_{ph} represents the photon current.

The diode represents the positive bias of the PN junction diode and the diode current.

I_{sh} represents the leakage current due to electron hole recombination.

I_o is the load current fed into the load.

$$I_{ph} = (I_d + I_{sh} + I_0) \tag{3.1}$$

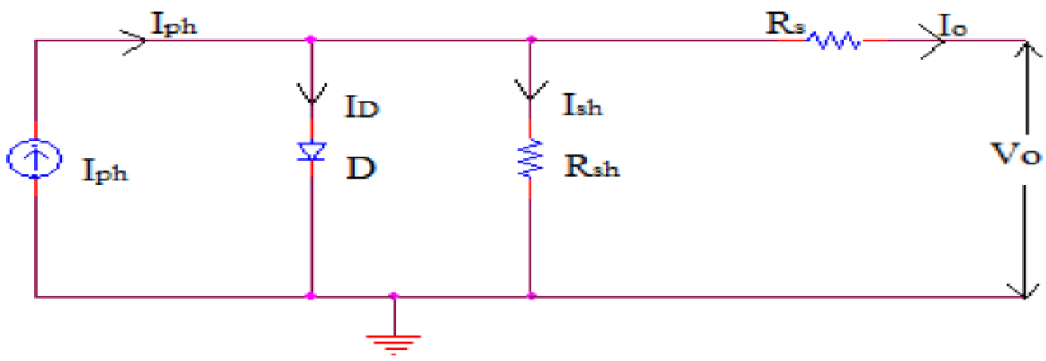

Figure 3.1: Circuit diagram of PV cell

$$I_d = I_o(e^{(qV_o/nkT)} - 1) \tag{3.2}$$

q = charge of electron

V_o = forward biased voltage

N = Ideality factor

k = Boltzmann constant

T = temperature in Kelvin

Solar cell is basically a normal PN junction diode directly converting thermal radiation of sun in to electrical energy. It has large surface and junction area. Immobile ions form the barrier at the PN junction. The voltage of this barrier is around 1.12V for Silicon and 1.42V for Germanium. As the electron hole pairs increase in number the PN junction decreases. After recombination, current flows from N to P layer. A single solar cell generates a maximum of 0.65V.

The output voltage and the output current depends on temperature and solar radiation. The efficiency of the solar cell depends on the material technology used for making solar cell. The monocrystalline silicon used earlier for power generation had efficiency in the range of 15 to 20 percent. But with use of thin film technology for solar cell fabrication the efficiency has increased.

Electrical modeling of suggested PV array system is represented in the following equations.

$$V_{PH} = (\frac{BKTN_s}{q}) \times \ln(\frac{N_P(I_L + I_{OS}) - I_{PV}}{N_P * I_{OS}}) \tag{3.3}$$

$$I_{OS} = I_{OR}[\frac{T}{T_r}]^3 \times \exp(\frac{qE_{GO}}{BK}((\frac{1}{T_r}) - (\frac{1}{T}))) \tag{3.4}$$

$$I_L = [I_{sc} + K_{1(T_c - 2_8)}] \times \frac{H}{1000} \tag{3.5}$$

$$T_c = T_{air} + 0.2 * H \tag{3.6}$$

The solar cell model provided in the MATLAB acts as an infinite power source and hence its power cannot be regulated to the practical maximum. Therefore a MATLAB EMBEDDED FUNCTION has been used in its place to achieve operation at an increased power point.[10]

The following graphs show the various characteristics of the PV array.

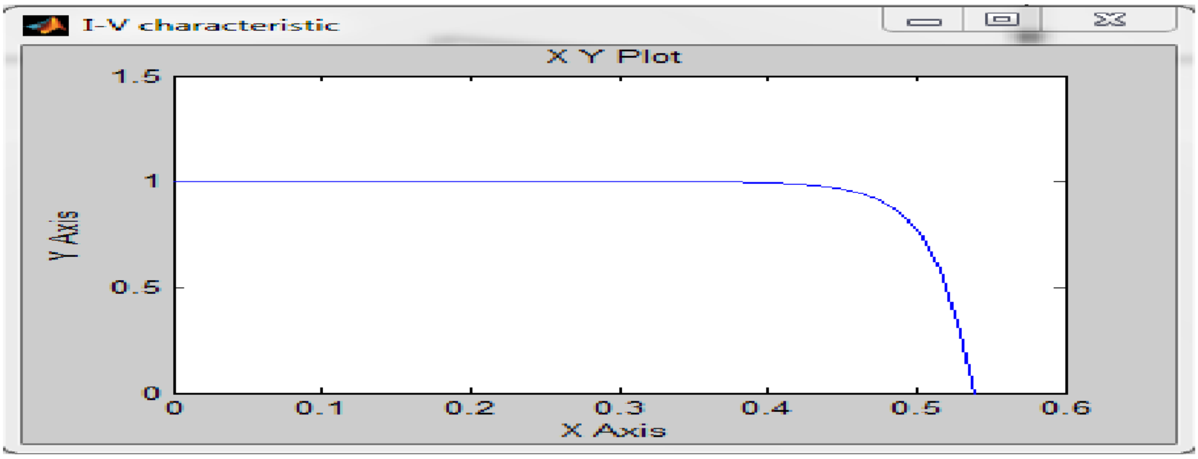

Figure 3.2: IV charateristics

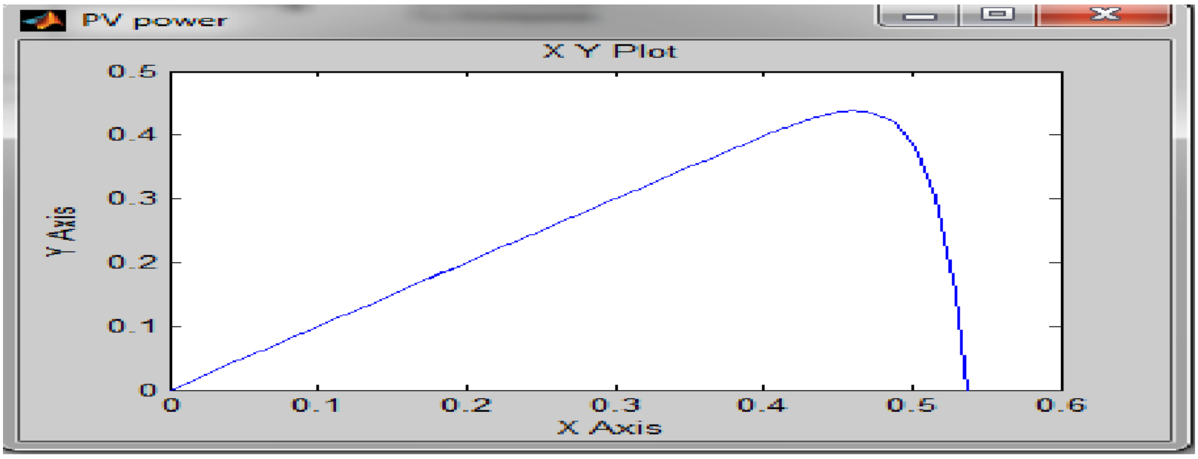

Figure 3.3: PV characteristics

3.2 SIX PULSE VOLTAGE SOURCE INVERTER

The DC voltage obtained from the PV array is converted to AC voltage with the help of inverter. Here a six-step 180 degree mode Voltage Source inverter is used. The prime reason behind using a six-step inverter is only to minimize the switching losses since the phase voltage in this case is a six-step wave. The use of IGBTs is preferred because of increased development in the power rating of the IGBTs. Besides this the use of thyristors needs additional commutation circuitry which makes the circuit further complex in control.

According to the convention a step is a change in the firing sequence of the IGBTs.For a six step inverter each step corresponds to 60 degree interval in a single cycle of 360degree which means the IGBTs required to be gated at an regular interval of 60 degree in the correct sequence to obtain a 3 phase AC voltage at the output terminals. A large capacitor makes the DC voltage constant at the input terminal.[11]

In the 180 degree mode VSI each IGBT conducts for 180 degree of a cycle. The IGBTs are paired in each arm (IGBT1, IGBT4; IGBT3, IGBT6; IGBT5, IGBT2).

Each IGBT in each arm conducts for 180 degree and the next for another 180 degree of the cycle. IGBTs in the upper group (IGBT1, IGBT3 and IGBT5) conduct for an interval of 120 degree and same is the case for lower group IGBTs.

3.3 CONTROL SYSTEM

Controls systems provide the ability to increase the efficiency of a wind energy conversion system and the quality of the output power. They are closed-loop feedback systems integrated into active power conversion stages to control the switching elements. DQ0 matrix transformations are sometime used to change the three-phase sinusoidal signals to DC signals for easier control.A supplementary controls system can also be implemented for the addition of a storage system. The storage cells will connect through the capacitor bank, requiring a DC/DC conversion and controls system. This set of controls will maintain voltage regulation when the turbine is over producing power. It will also ensure proper power delivery during low or no wind situations.

3.4 ASYNCHRONOUS PULSE WIDTH MODULATION

In APWM inverter the widths of the pole-voltage pulses, over the output cycle, vary in a sinusoidal manner. The scheme, in its simplified form, involves comparison of a high frequency triangular carrier voltage with a sinusoidal modulating signal that represents the desired fundamental component of the voltage waveform. The peak magnitude of the modulating signal should remain limited to the peak magnitude of the carrier signal. The comparator output is then used to control the high side and low side switches. The triangular and sinusoidal signals are fed to the inverting and the non-inverting input terminals respectively and the comparator output magnitudes for high and low levels are assumed to be +VCC.

3.5 MODULATION INDEX

Modulation index is the ratio of peak magnitudes of the modulating waveform and the carrier waveform. It relates the inverter's dc-link voltage and the magnitude of pole voltage (fundamental component) output by the inverter. The magnitude of modulation index is limited below one.

3.6 BATTERY

3.6.1 INTRODUCTION

Lead-acid battery cells consist of two plates, positive and negative, immersed in a dilute sulfuric acid solution. The positive plates, or anode, is made of lead dioxide (PbO2) and the negative plate, or cathode, is made of lead (Pb). The battery model is in charge mode when the current into the battery is positive and discharge mode when the current is negative.

Many models that exist predicts the battery behavior to varying degrees of accuracy.A slightly modified version of the circuit is used to model the Li-ion battery. The model consists of two separate circuits linked by a voltage controlled voltage source and a current controlled current source. One circuit represents the overall capacity of the battery, while the other circuit models the internal resistance and transient behavior of the battery using a series resistance and two RC circuits. The voltage controlled voltage source linking the two circuits is used to represent the nonlinear relationship between the State of Charge (SOC) and the open circuit voltage (VOC) of the battery.[12]

The battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries.[13] The equivalent circuit of the battery is shown in fig. 3.5

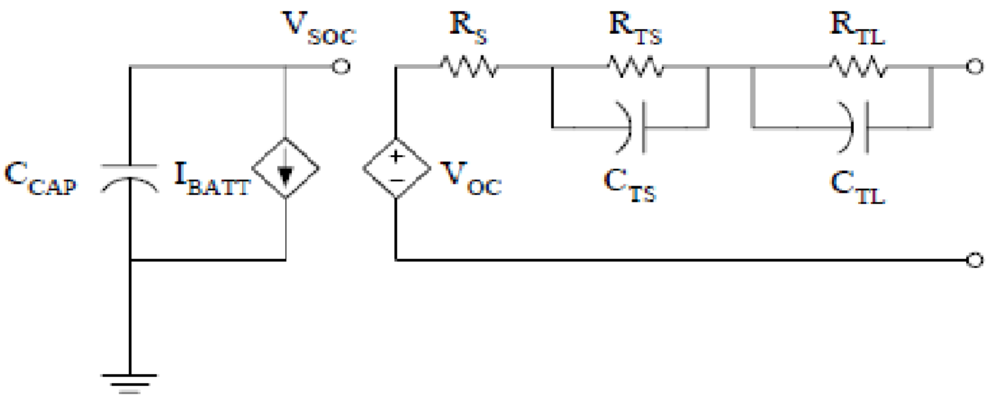

Figure 3.4: Circuit diagram of Battery

Lead acid model for discharge model with selected parameter was inserted in equation below. While for charge model with selected parameter was also inserted in equation given below.

where,

E_{Batt}= Nominal Voltage (V),

E_0= Constant Voltage (V),

Exp(s)= Exponential Zone Dynamics (V),

Sel(s) = Represents the battery mode

Sel(s) = 0 during battery discharge; Sel(s) = 1 during battery charging.

K = Polarization constant,

i_*=Low frequency current dynamics (A),

i = Battery current (A),

it = Extracted capacity (Ah),

Q = Maximum battery capacity (Ah),

A = Exponential voltage (V),

B = Exponential capacity.

The parameters of the equivalent circuit can be modified to represent a particular battery type, based on its discharge characteristics. A typical discharge curve

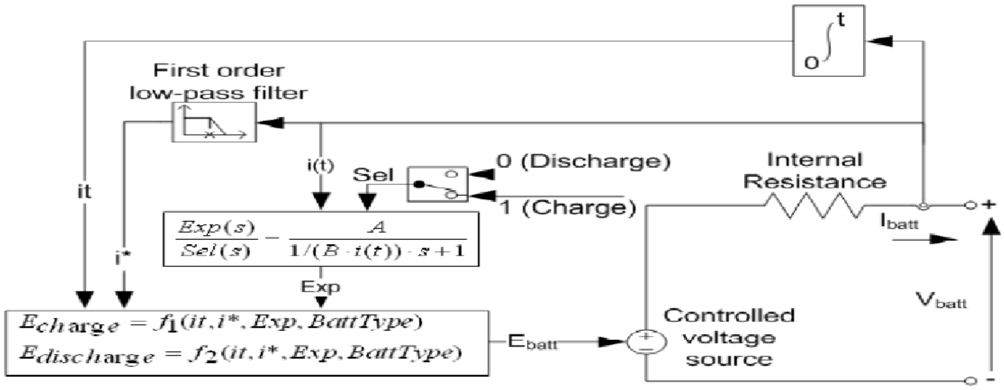

Figure 3.5: Equivalent Circuit diagram of Battery

Discharge model ($i^* > 0$)

$$f1(it, i^*, i, Exp) = E_0 - K.\frac{Q}{Q-it}.i^* - K.\frac{Q}{Q-it}.it + Laplace - 1\{\frac{Exp(s)}{Sel(s)}.0\}$$

Charge Model ($i^* < 0$)

$$f1(it, i^*, i, Exp) = E_0 - K.\frac{Q}{it+0.1Q}.i^* - K.\frac{Q}{Q-it}.it + Laplace - 1\{\frac{Exp(s)}{Sel(s)}.0\}$$

is composed of three sections, as shown fig. 3.6. The first section represents the exponential voltage drop when the battery is charged. Depending on the battery type, this area is more or less wide. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly.

The Exp(s) transfer function represents the hysteresis phenomenon for the Lead-

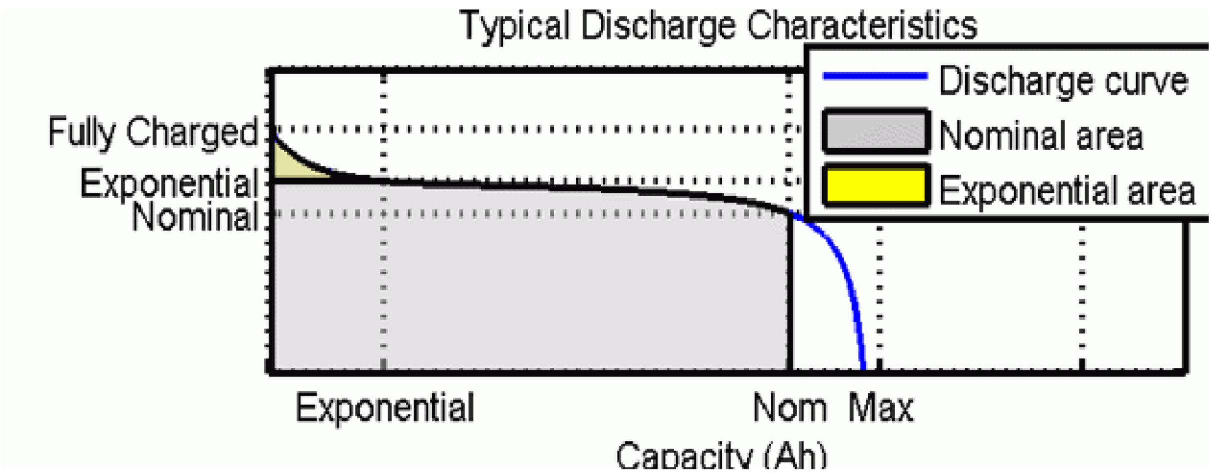

Figure 3.6: Charging and discharging characteristics of battery

Acid battery during charge and discharge cycles. The exponential voltage increases when battery is charging, no matter the SOC of the battery. When the battery is discharging, the exponential voltage decreases immediately: As shown in above

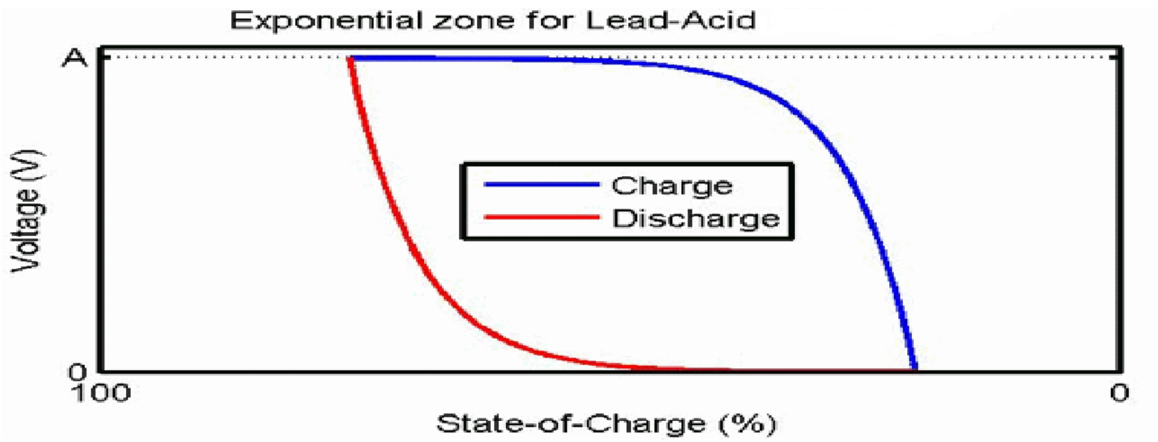

Figure 3.7: Exponential zone for Lead-Acid battery

fig. 3.7 when the State of Charge is 100 % at that time the charging voltage will increase. Upto 50 % this charging voltage will increase but when the State of Charge reduces below 50 percent then the charging voltage starts decreasing rapidly.

In case of discharging when the State of Charge is 100 % at that time discharge voltage is constant. Upto 75 percent this discharging voltage will be constant but below that it will decrease exponentially. The rated or nominal capacity should not be confused with the available or actual capacity. Nominal capacity is a measurement of the capacity specified by the manufacture, typically a discharge at constant current. Charge throughput is another term frequently used in a battery context. It is defined as the number of discharge Ah that flows throw the battery.

SOC (State of charge) is a unit that expresses, in percentage figures, the amount of capacity left in the battery. SOC is obtained by the relation between available capacity and the rated nominal capacity. Since the nominal capacity is used as a reference point in the model, the SOC can assume negative values. This has to do with that the nominal capacity in general being lower than the actual capacity of the battery.

Chapter 4

MODELLING OF WIND ENERGY CONVERSION SYSTEM

4.1 WIND TURBINE

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Passing over the blades, wind generates lift and exerts a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox adjusts 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, which converts the electricity from the generator to the appropriate voltage for the power collection system

A wind turbine extracts kinetic energy from the swept area of the blades. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time.[13] That is

$$P_{air} = 0.5\rho A V^3 \tag{4.1}$$

Although the above equation gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient, C [14]

$$C_P = \frac{P_{Windturbine}}{P_{air}} \tag{4.2}$$

$$P_{Windturbine} = 0.5\rho C_P A V^3 \tag{4.3}$$

Maximum value of C_p is defined by the Betz limit, which states that a turbine can never extract more than 59.3 percentage of the power from an air stream. In reality, wind turbine rotors have maximum Cp values in the range 25-45 percentage.

SOLIDITY: The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intercepted. The projected blade area is the blade area met by the wind or projected in the direction of the wind. Solidity has a direct connection with the torque and speed. High-solidity rotors have high torque and low speed, and are employed for pumping water. Low-solidity rotors, on the other hand, have high speed and low-torque, and are usually suited for electrical power generation.

TIP SPEED RATIO: Tip speed ratio of a wind turbine is defined as:

$$\lambda = \frac{\omega R}{V} \tag{4.4}$$

SPECIFIED RATED CAPACITY: Specified Rated capacity (SRC) is an important index which is used to compare a variety of wind turbine designs.

$$SRC = \frac{PowerRatingOfTheGenerator}{RotorSweptArea} \tag{4.5}$$

It varies between 0.2 (for small rotors) and 0.6 (large rotors).

4.2 INDUCTION GENERATOR

An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip. In most cases, a regular AC asynchronous motor is used as a generator, without any internal modifications.[15].

4.2.1 PRINCIPLE OF OPERATION

Induction generators and motors produce electrical power when their rotor is rotated faster than the synchronous frequency. For a typical four-pole motor (two pairs of poles on stator) operating on a 60 Hz electrical grid, synchronous speed is 1800 rotations per minute. Similar four-pole motor operating on a 50 Hz grid will have synchronous speed equal to 1500 rpm. In normal motor operation, stator flux rotation is faster than the rotor rotation. This is initiating stator flux to induce rotor currents, which create rotor flux with magnetic polarity opposite to stator. In this way, rotor is dragged along behind stator flux, by value equal to slip. In generator operation, a prime mover (turbine, engine) drives the rotor above the synchronous speed. Stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, active current is produced in stator coils, and motor is now operating as a generator, and sending power back to the electrical grid.

4.3 GRID CONNECTED INDUCTION GENERATOR

Grid connected induction generators develop their excitation from the Utility grid. The generated power is fed to the supply system when the IG is run above synchronous speed. Machines with cage type rotor feed only through the stator and generally operate at low negative slip. But wound rotor machines can feed power through the stator as well as rotor to the bus over a wide range known as Doubly Fed Induction Machines.[16]

4.3.1 FIXED SPEED GRID CONNECTED WIND TURBINE GENERATOR

The structure and performance of fixed-speed wind turbines as shown in figure depends on the features of mechanical sub-circuits, e.g., pitch control time constants etc. The reaction time of these mechanical circuits may lie in the range of tens of

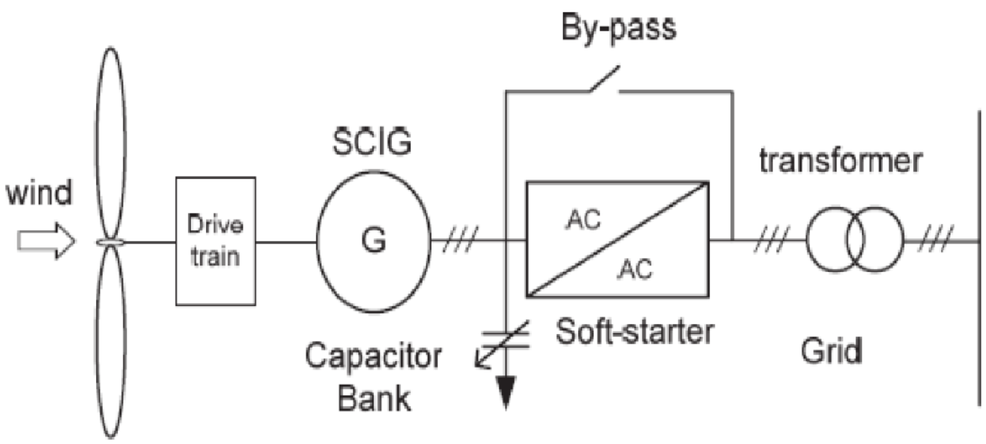

Figure 4.1: Fixed speed wind turbine with directly grid connected squirrel-cage induction generator

milliseconds. As a result, each time a burst of wind hits the turbine, a rapid variation of electrical output power can be observed. These variations in electric power generated not only require a firm power grid to enable stable operation, but also require a well-built mechanical design to absorb high mechanical stress, which leads to expensive mechanical structure, especially at high-rated power.

4.3.2 VARIABLE SPEED WIND TURBINE GENERATOR

A way to make more convenient turbines is variable speed turbines. Variable speed turbines have become the most dominating type of the yearly installed wind turbines as they can store some of the power fluctuations due to turbulence by increasing the rotor speed, pitching the rotor blades, these turbines can control the power output at any given wind speed.

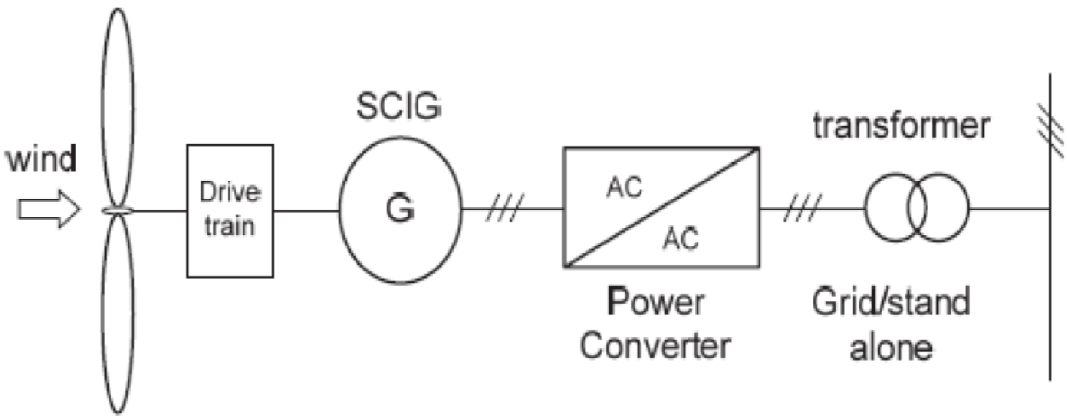

Figure 4.2: Variable speed wind turbine with squirrel-cage induction generator

4.3.3 VARIABLE SPEED WIND TURBINE USING DOUBLY FED INDUCTION GENERATOR

It consists of a stator connected directly to grid and a rotor - via slip rings - is connected to grid through four-quadrant ac-to-ac converter based on insulated gate bipolar transistors (IGBTs). This system offers the following advantages:

a. 1. Reduced inverter cost, because inverter rating is typically 30

b. 2. Improved system efficiency.

c. 3. Power-factor control can be implemented at lower cost.

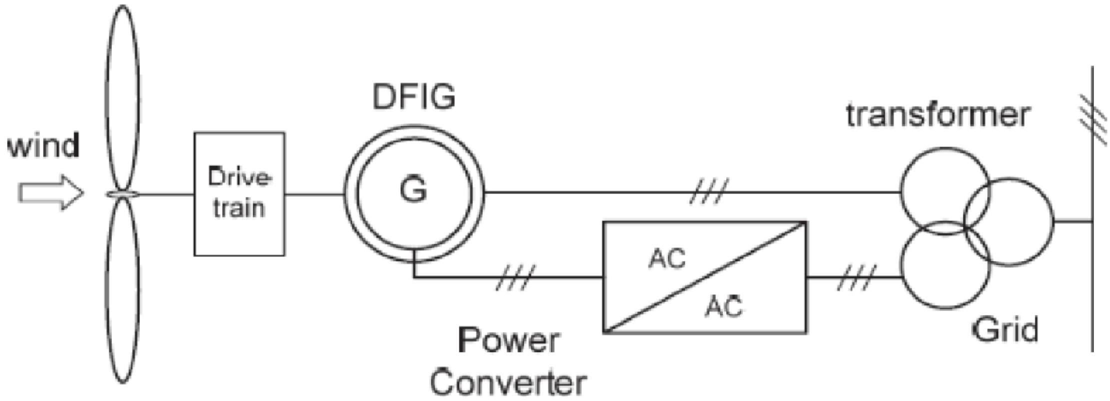

Figure 4.3: Variable speed wind turbine with doubly-fed induction generator

d. 4. It has a complete control of active and reactive power.

The doubly fed induction generator with a power converter shown in Fig. 3.3 is a simple and highly controllable way to transform the mechanical energy from the variable speed rotor to a constant frequency electrical utility grid. The main reason for the popularity of the doubly fed wind induction generators connected to the national networks is their ability to supply power at constant voltage and frequency while the rotor speed varies.

4.4 WIND TURBINE INDUCTION GENERATOR

The wind turbine and the induction generator (WTIG) are shown above. The stator winding is connected directly to the grid and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction generator speed must

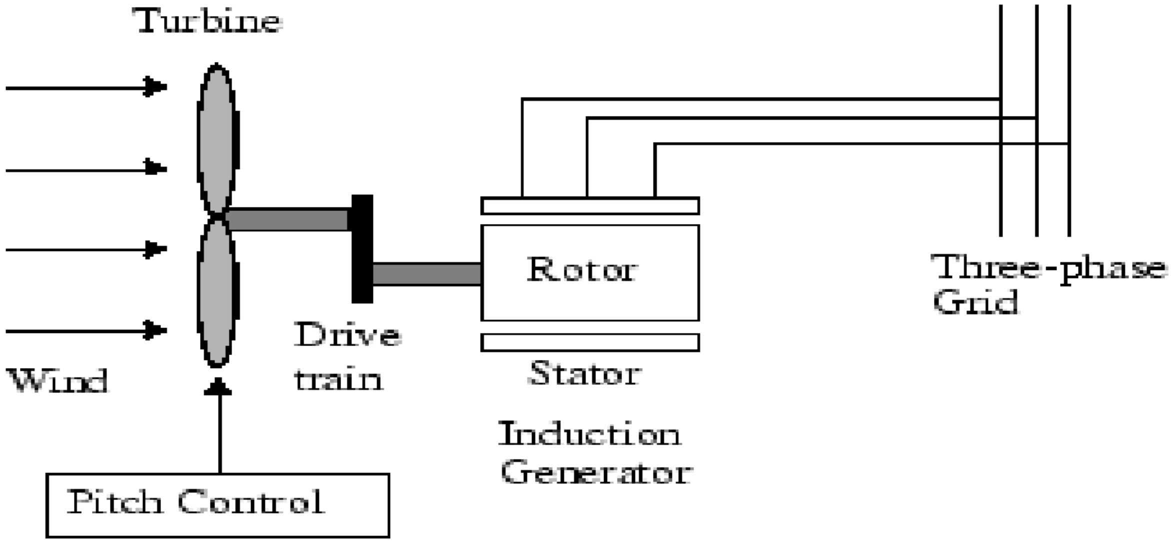

Figure 4.4: Variable speed wind turbine with doubly-fed induction generator

be slightly above the synchronous speed. But the speed variation is typically so small that the WTIG is considered to be a fixed-speed wind generator. The reactive power absorbed by the induction generator is provided by the grid or by some devices like capacitor banks, SVC, STATCOM or synchronous condenser.

Chapter 5

MODELLING OF HYBRID SCHEME

Hybrid systems are the ones that use more than one energy resources. Integration of systems (wind and solar) has more influence in terms of electric power production. Such systems are called as "hybrid systems".

Wind and solar energy are converted into electricity and then sent to loads or stored in battery bank. The topology of hybrid energy system consisting of variable speed WT coupled to a permanent magnet generator (PMG) and PV array. The two energy sources are connected in parallel to a common ac bus line. The load may be ac connected to the ac bus line or may include a PWM voltage source inverter to convert the dc power into ac at 50 or 60 Hz. Each source has its individual control. The output of the hybrid generating system goes to the ac bus line to feed the isolating ac load. A battery charger is used to keep the battery fully charged at a constant dc bus line voltage. When the output of the system is not available, the battery powers the dc load or discharged to the inverter to power ac loads. A battery discharge is to prevent the battery from being charged when the charger is opened after a full charge.

Hybrid solar-wind applications are implemented in the field, where all-year energy is to be consumed without any chance for an interrupt. It is possible to have any combination of energy resources to supply the energy demand in the hybrid systems, such as oil, solar and wind. This project is similar with solar power panel and wind turbine power. Differently, it is only an add-on in the system. Photovoltaic solar panels and small wind turbines depend on climate and weather conditions. Therefore, neither solar nor wind power is sufficient alone. A number of renewable energy expert claims to have a satisfactory hybrid energy resource if both wind and solar power are integrated within a unique body.

In the summer time, when sun beams are strong enough, wind velocity is relatively small. In the winter time, when sunny days are relatively shorter, wind velocity is high on the contrast. Efficiency of these renewable systems show also differences throughout the year. In other words, it is needed to support these two systems with each other to sustain the continuity of the energy production in the system. In the realized system, a portion of the required energy for an ordinary home has been obtained from electricity that is obtained from the wind and solar power. Experimental setup for the domestic hybrid system consists of a wind turbine, PV panel and battery as back-up. Depending on the environmental conditions, required energy for the system can be supplied either separately from the wind or solar systems or using these two resources at the same time is in show Figure below.

Control unit decides which source to use for charging the battery with respect to condition of the incoming energy. Wind turbine first converts the kinetic energy to mechanical energy and then converts it to the electricity. The wind turbine in the system consists of tower, alternator, speed converters (gear box), and propeller. The kinetic energy of the wind is converted to the mechanical energy in the rotor. The rotor shaft speed, 1/18, is accelerated in the reduction gear and then transmitted to alternator. The electricity that comes from the alternator can be directly transmitted to DC receivers as well as it can be stored in the batteries.

The solar panels in the system convert the day light directly in to electricity. The solar panels can generate major amount of electricity even in the cloudy weathers.

In the proposed scheme, the PV array is connected in parallel to the battery bank. Hence, the operating voltage of the array is fixed to the battery voltage and the corresponding current in the - characteristics of the array is the PV current . It is apparent that when the battery is available in the system, the inverter input voltage is same as the battery voltage, which is assumed to be a constant, and hence, the analysis is straightforward. Nevertheless, in the event of the battery being overcharged during daytime and is disconnected from the system, both the operating voltage and current of the PV array may vary with the wind speed and irradiation. In order to find the operating point of the PV array and to study the dynamics of the system without the battery bank, the PV array equivalent circuit has been suitably connected to the synchronously rotating reference frame equivalent circuit of the induction machine.

Both the wind and the pv systems interface the grid at the output terminals of the synchronizing breaker at the output end of the inverter. The power flows in either direction depending on the site voltage at the breaker terminals. The fundamental requirements on the site voltage for interfacing with the grid are as follows:

- The voltage magnitude and phase must equal to that required for the desired magnitude and direction of the power flow. The voltage is controlled by the transformer turn ratio and/or the rectifier/ inverter firing angle in a closed-loop control system.

- The frequency must be exactly equal to that of the grid, or else the system will not work. To meet the exacting frequency requirement, the only effective means is to use the utility frequency as a reference for the inverter switching frequency.

- In the wind system, the synchronous generators of the grid system supply magnetizing current for the induction generator.

The interface and control issues are similar in many ways between both the pv and the wind systems. The wind system, however, is more involved since the electrical generator and the turbine with large inertia introduce certain dynamic issues not applicable in the static pv system. Moreover, wind plants generally have much greater power capacity than the pv plants.

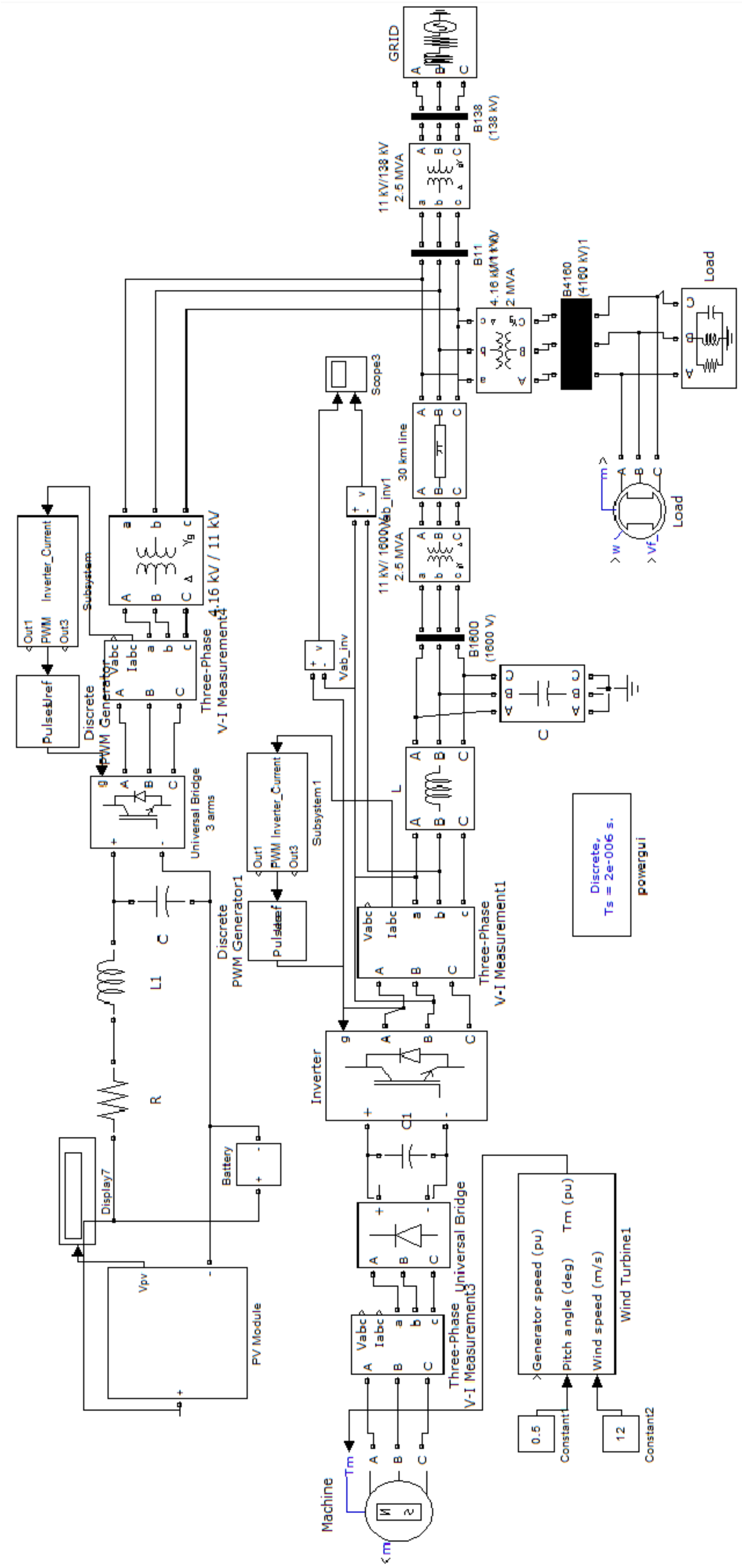

Figure 5.1: Hybrid PV-WECS-Battery scheme

Chapter 6

SIMULATION AND RESULTS

6.1 PV MODULE

The PV cell model given in the SIMULINK library is a pre-existing source block in which the irradiation is constant at 1000W/m^2. Thus it cannot be used for various levels of irradiation. Hence an EMBEDDED MATLAB FUNCTION is used in which the code for solar block is used. Below is the response it gives for various levels of insolation. Each solar cell is rated to an open circuit voltage of 0.6V and short circuit current of 3.75A.The number of cells required to be connected in series is 36 and number of such cells to be connected in parallel is 1. The output of one panel containing 36 solar cells in series is 21 V and 19 A. 33 such panels are connected in series to produce output of 700 V.The solar cell is connected to an IRRADIANCE block that accounts for the solar radiation.
When the PV array block connected to the inverter block is simulated it gives the similar output response as when the DC source of same magnitude is connected to the inverter block. This ensures that the model designed so far is right. The output of PV module must be 450KW and 700 Vdc.

The 6.1 shows the circuit model of PV module in MATLAB.[17]

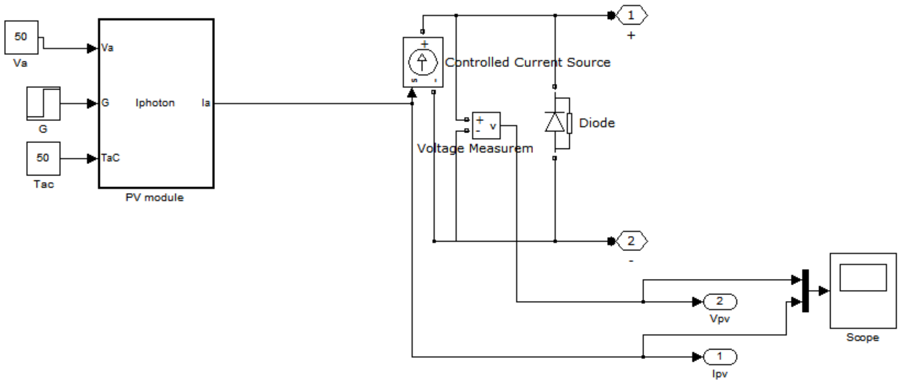

Figure 6.1: PV module

6.2 SIX PULSE VOLTAGE SOURCE INVERTER

The output of PV panel which is in DC is applied to 6 pulse Voltage Source Inverter. The IGBT inverter uses Pulse Width Modulation (PWM) at a 2 kHz carrier frequency. The circuit is discretized at a sample time of 2 us.

The load voltage is regulated at 1 pu (380 V rms). The first output of the voltage regulator is a vector containing the three modulating signals used by the PMW Generator to generate the 6 IGBT pulses. The second output returns the modulation index.

The six pulse voltage source inverter converts the DC input voltage into AC sinusoidal voltage by means of appropriate switch signals and then by using transformer the voltage level is stepped up or stepped down according to requirement.

The figure 6.2 shows the MATLAB implementation of PV module connected to six pulse Voltage Source Inverter which is further connected to a three phase transformer.[18]

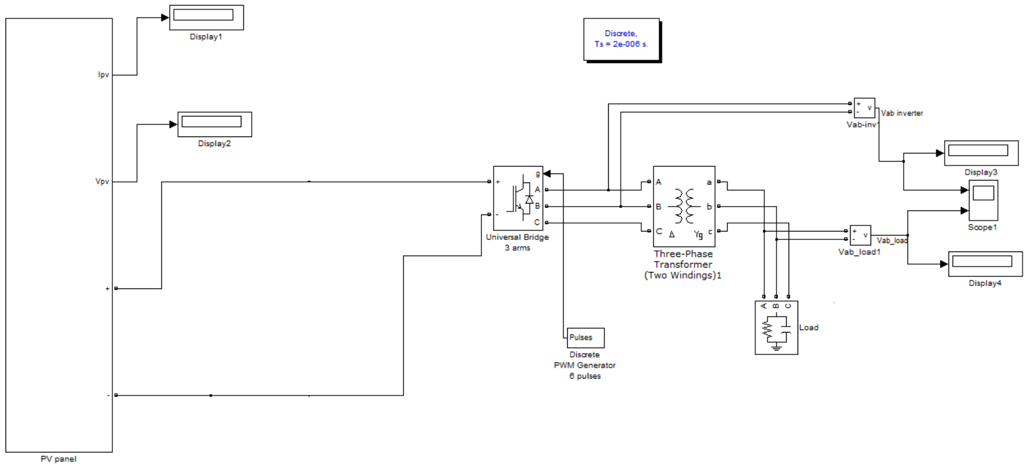

Figure 6.2: Block diagram of the system in MATLAB

6.3 MODELING OF BATTERY

The battery model in MATLAB Simulink is shown fig.6.3.

This circuit uses the Battery block of library. It models a 100 V Lead Acid battery connected to a resistor of 1000 ohms. T When the State-Of-Charge (SOC) of the battery goes under 0.4 (40) it acts as a charger to recharge the battery.

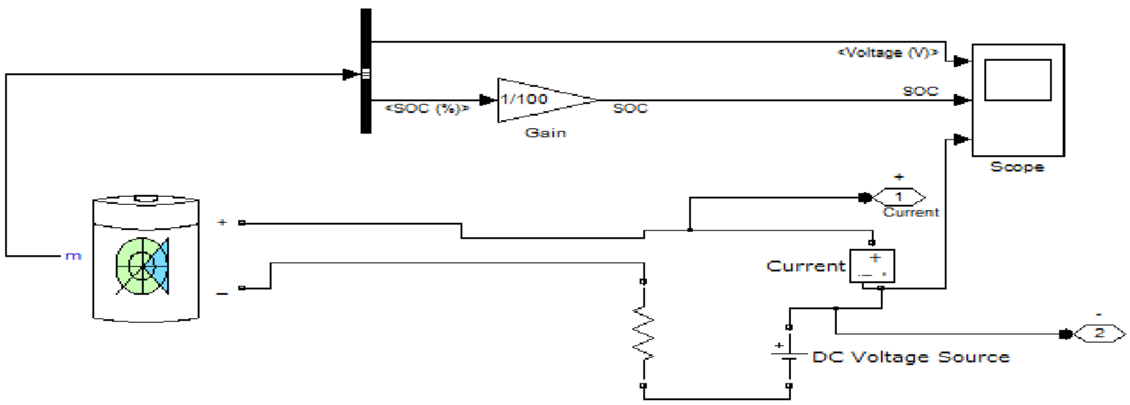

Figure 6.3: MATLAB model of Battery

6.4 MODELING OF WIND ENERGY CONVERSION SYSTEM

As shown in the fig. 6.4, a 2 MW wind farm is connected to a 1.6kV distribution system exports power to a 138 kV grid through a 30 km, 1.6kV feeder.
A wind turbine with parameters of 2 MW and wind speed of 12 m/s is connected to an asynchronous machine. When a negative torque is given to the machine it starts acting as a generator. The output of this generator which is in AC is further rectified into DC with the help of rectifier. This Dc is further inverted into AC with the help of an inverter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.[15] Here,wind turbines using a doubly-

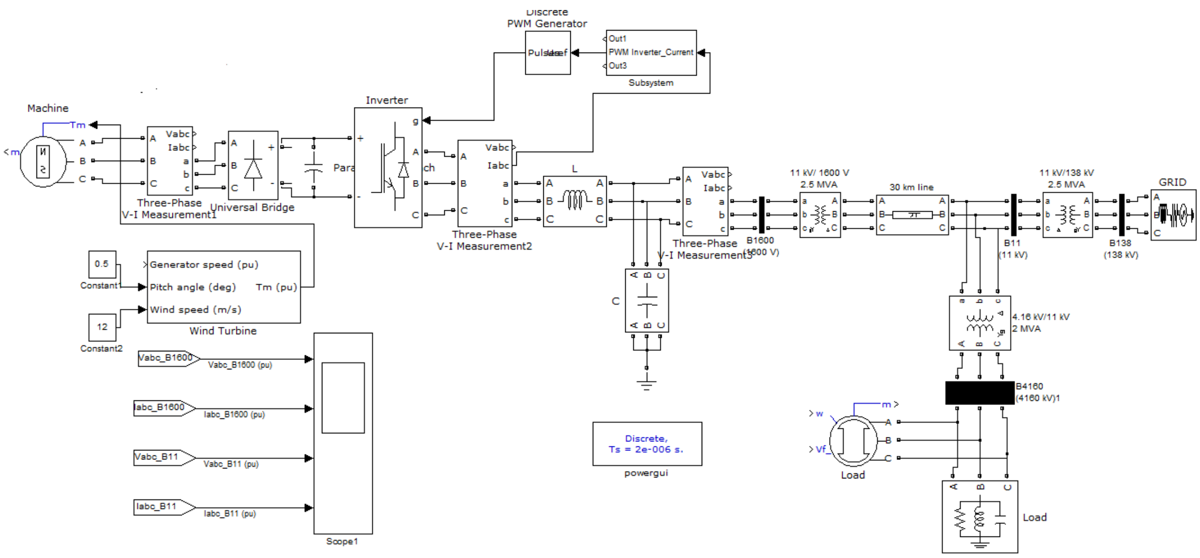

Figure 6.4: MATLAB implementation of Wind Energy Conversion System

fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter modeled by voltage sources produces power of 2 Mw and voltage of 1600 V. This voltage level of 1600V is stepped up to a voltage level of 11 kV. This 11kV voltage level is further stepped down to 4.16kV. The feefer of 4.16kV is coonected to a grid of 138kV.

6.5 CONTROL SYSTEM

Controls systems provide the ability to increase the efficiency of a wind energy conversion system and the quality of the output power. They are closed-loop feedback systems integrated into active power conversion stages to control the switching elements. DQ0 matrix transformations are sometime used to change the three-phase sinusoidal signals to DC signals for easier control.A controls system can be implemented through the grid-side inverter PWM signal. It can be used to maintain constant voltage on the DC link, which will decouple the grid from power fluctuations due to wind variations [20]. Control systems can also use output current feedback control to manage output active and reactive power for a full power factor correction approach.
The inverter is fed by a PWM signal to control the switches. The PWM signal is a series of six signals (two for each set of IGBTs), which change widths depending upon the modulation waveform. When the value of the reference signal, or the sine wave, is greater than the modulation signal, the PWM signal is in a high state (or a logical 1). Otherwise, it is in a low state.The control system in place will then detect the output current of this inverter and convert it into a per unit denotation. This three-phase sinusoidal signal will be transformed into the rotating reference frame of DQ0. Here the direct current is related to the active power output and controlled to 1 via a PID controller. The quadrature current, on the other hand, uses a similar PID controller, and is brought to 0. This will help maintain a high power factor for a better quality output power.The controlled output of the inverter will then feed into a harmonic filtering system. This filter has been tuned to the grid frequency, or 50 Hz. A multiple of this frequency, namely 20 times this frequency, was used to help better filter the harmonics created by the on/off output of the switches. This is then fed into the AC supply grid, chosen as 138 kV, which is commonly used for low

voltage transmission.

6.6 RESULTS

6.6.1 RESULTS OF PHOTOVOLTAIC SYSTEM

On starting the simulation after a transient period of approximately 50 ms, the system reaches a steady state. The harmonics generated by the inverter around multiples of 2 kHz are filtered by the LC filter.

The scope connected shows the graphs of constant DC voltage, inverter voltage and the voltage across the load. Figure 6.5 explains that the output obtained at

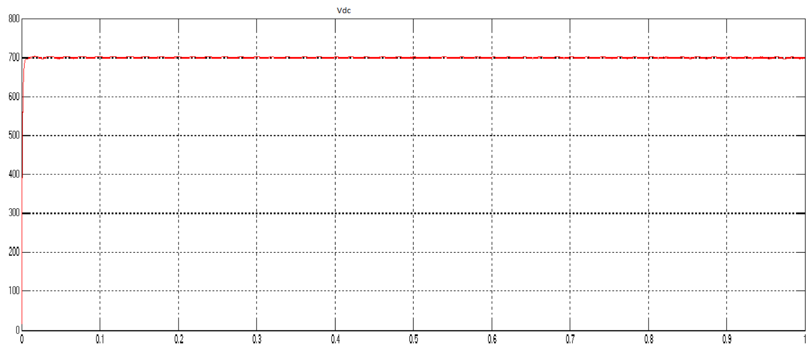

Figure 6.5: Waveform of DC voltage

PV panel is DC and the voltage is constant at 700V. This voltage is obtained by connecting 33 panels of 21 V in series to obtain voltage of 700V. Figure 6.6 shows the waveform of gate pulse that is generated when inverter is connected to the output of PV panel. PWM pulse is given to the inverter to generate gate pulse.

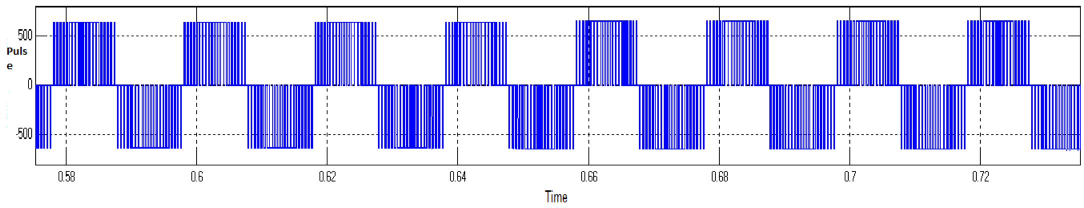

Figure 6.6: Waveform of inverter voltage

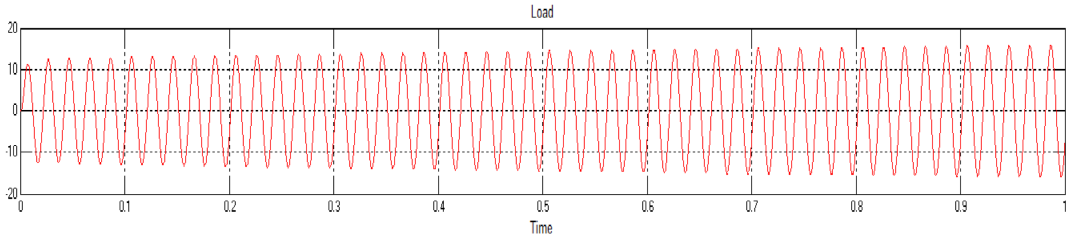

Figure 6.7: Waveform of load

Figure 6.7 is a waveform of load that is connected to the output of inverter and is sinusoidal in nature thereby verifying that the output at the inverter is in AC. This Ac voltage is given to a load of 50 kW.

6.6.2 RESULTS OF BATTERY

Figure 6.8 shows waveform of discharging of battery. Here when the State of Charge is 100% at that time the voltage is constant. But when the State of Charge is below 75 % at that time the discharge voltage starts decreasing rapidly.

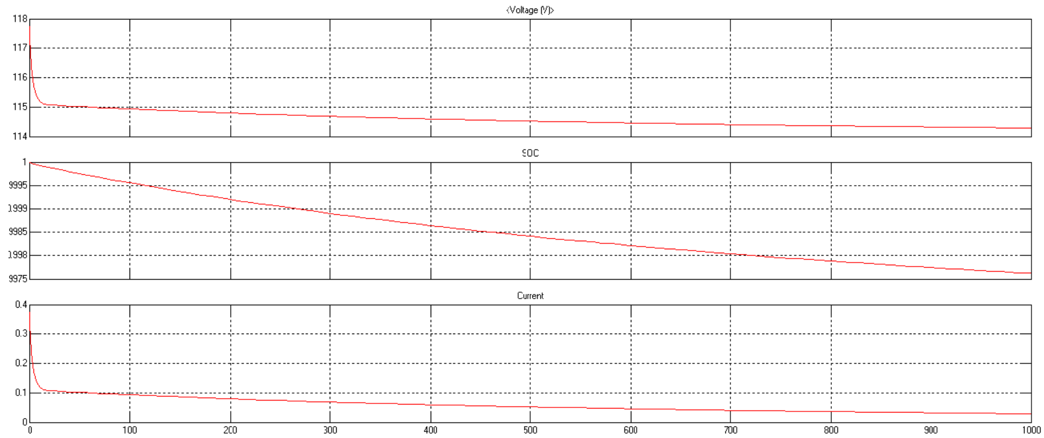

Figure 6.8: Waveform of battery

6.6.3 RESULTS OF WIND ENERGY CONVERSION SYSTEM

Figure 6.9 shows waveforms of active power, reactive power, Vdc and speed. The active power waveform becomes constant at 2 indicating that the active power generated is 2 MW. The reactive power waveform is constant at 0.25. Vdc is constant value at 1200 V and speed is 1.05 pu. Figure 6.10 shows waveform of voltage and current. These waveform results are captured at different buses like, at 1600 kV bus and 11 kV bus. These waveform are sinosoidal in nature indicating that the output of wind turbine-doubly fed induction generator is AC.

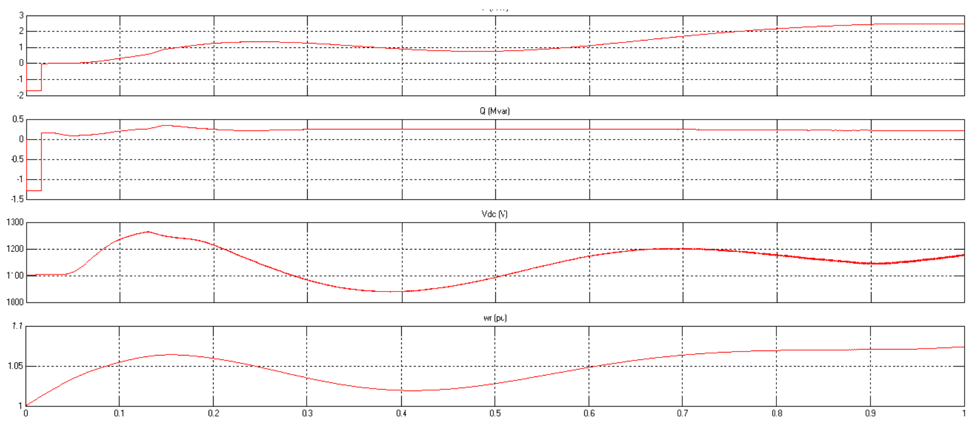

Figure 6.9: Waveform of active power, reactive power, Vdc and speed

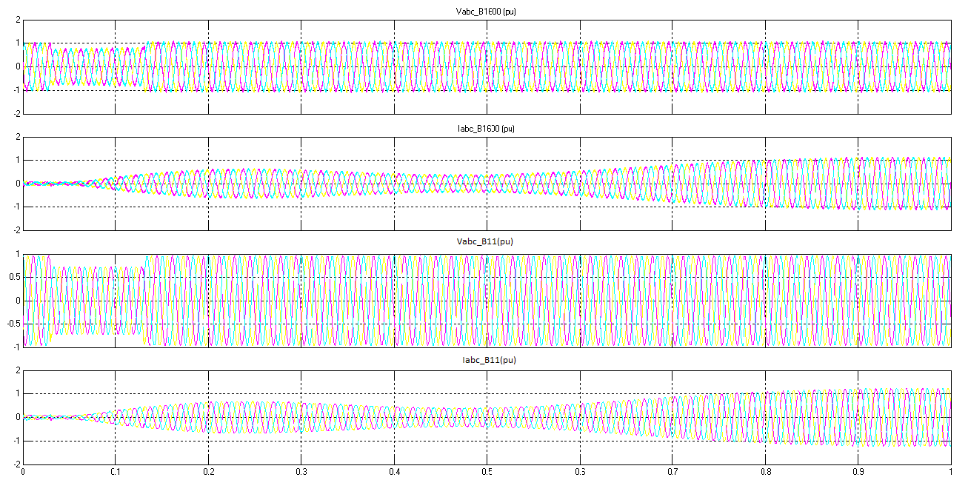

Figure 6.10: Waveform of voltage and current

Chapter 7

CONCLUSION AND FUTURE WORK

7.1 CONCLUSION

The solar photovoltaic module produces 450 kW power and 700Vdc.This DC is converted into AC and stepped up to a voltage of 11 kV. Wind energy Conversion System produces 2 MW power and 1600V. This voltage is stepped up to 11 kV to be integrated to 138 kV grid.The Hybrid scheme is integrated with Photovoltaic-Battery-Wind Energy Conversion System is connected to the grid at 11 kV bus bar. Thus the Hybrid System supplies uninterrupted power continuously and makes the system reliable.

7.2 FUTURE WORK

Integration with other renewable sources like Bio-gas and Hydro can be added to this scheme to check the reliability and stability of the system when connected to the grid.

Appendix A

APPENDIX: PV MODULE PROGRAMMING IN MATLAB

A program that simulates the V-I characteristics curves of solar panel on Matlab based is as below: k = 1.381e-23;

q = 1.602e-19;

n = 1.3;

Eg = 1.12;

Ns = 36;

Np=1;

TrK = 298;

Voc_TrK = 28.80 /Ns;

Isc_TrK = 3.5 / Np;

a = 1.33e-3;

TaK = 273 + TaC;

Vc = Va / Ns;

Is = Isc_TrK * (1 + (a * (TaK - TrK)));

Iph = G * Isc;

Vt_TrK = n * k * TrK / q;

b = Eg * q / (n * k);

$Ir_TrK = Isc_TrK$ / (exp (Voc_TrK / Vt_TrK) -1);

$dVdI_Voc$ = -1/Ns;

Xv = Ir_TrK / Vt_TrK * exp (Voc_TrK / Vt_TrK);

Rs = - $dVdI_Voc$ - 1/Xv;

Vt_Ta = n * k * TaK / q; Solve for Ia by Newton's method:

Ia2 = Ia1 - f(Ia1)/f'(Ia1)

Ia=zeros (size (Vc));

for j=1:5;

Ia = Ia - (Iph - Ia - Ir .* (exp((Vc + Ia .* Rs) ./ Vt_Ta) -1))... . / (-1 - Ir * (Rs. / Vt_Ta).* exp ((Vc + Ia.* Rs). / Vt_Ta));

end

Ia=Isc_TrK / Np;

end

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