Study,Analysis,Optimization and Software Implementation Approach of Solar and Wind Hybrid System

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DEPARTMENT OF ELECTRICAL ENGINEERING

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Study,Analysis,Optimization and Software Implementation Approach of Solar and Wind Hybrid System

Major Project Report

Submitted in Partial Fulfillment of the Requirements

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IN

ELECTRICAL ENGINEERING

(ELECTRICAL POWER SYSTEMS)

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Undertaking For Originality of the Work

I **Mr. Punit Sompura**,(**Roll No: 11MEEE14**), give undertaking that the Major Project entitled **"Study,Analysis,Optimization and Software Implementation Approach of Solar and Wind Hybrid 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

Place:Ahmedabad

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Certificate

This is to certify that the Major Project Report entitled **"Study,Analysis, Optimization and Software Implementation Approach of Solar and Wind Hybrid System"** submitted by **Mr. Punit Sompura** (**Roll No: 11MEEE14**) 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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- Punit Sompura
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Abstract

In parallel to developing technology, demand for more energy makes us seek towards new renewable energy sources. The most important of this is Wind and Solar energy, because of due to popular ones owing to abundant, ease of availability freely available, environmental friendly, and they are considered as promising power generating sources.Solar and Wind energies are usually available for most of the remote areas as a renewable sources.

However, it is prudent that neither a Stand-alone Solar energy nor a Wind energy system can provide a continuous supply of energy due to seasonal and periodical variations. Therefore we use the Hybrid Power System. Solar and Wind energies have been widely used as Hybrid combination for electricity supply in isolated locations far from the distribution network, due to advancements in renewable energy technologies.

This dissertation presents Simulation, and Cost Optimization for the Stand-alone Solar Power System,Stand alone Wind Power System and Hybrid Solar and Wind Power System with Battery stotage.Simulation is done using MATLAB/Simulink Software.For Optimization purpose,one location that is Ahmedabad is selected for study with three different plant size i.e. 1 kWh/day,10 kWh/day and 100 kWh/day.and compare the Cost of energy of Solar ,Wind and Hybrid Power System and proved that Hybrid configuration is better as compare to the individual Stand-alone Solar and Wind Power System for high loading condition.

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Abbreviation

PV .... Photo-voltaic
MPPT .... Maximum Power transfer theorem
VSI .... Voltage source inverter
COE .... Cost of energy
PWM .... Pulse width modulation
PandO .... Perturb and observation
Ic .... Incremental conductance
WEC .... Wind Energy Converter
Isc .... Short circuit current
Voc .... Open circuit voltage
Irs .... Reverse saturation current
Iph .... Photovoltaic current
Io .... Saturation current
PEC .... Power Electronics Converter
IM .... Induction Motor
HAWT .... Horizontal Axis Wind Turbine
VAWT .... Vertical Axis Wind Turbine
rpm .... Revolution Per Minute
PI .... Proportional Integral
IGBT .... Insulated Gate Bipolar Transistor
MOSFET .... Metal Oxide Field Effect Transistor
SOC .... State of charge
DOC .... Death of charge

Nomenclature

P_w .... extracted power from the wind .... [W]
ρ .... air density .... [kg/m^3]
R .... blade radius .... [m]
V_w .... wind velocity .... [m/s]
C_p .... the power coefficient .... [A]
λ .... tip ratio
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]

Prefixes

Δ	Difference or Error

Chapter 1

Introduction

Over the last decade, it became apparent that the worlds resources of fossil fuel are beginning to come to an end. Estimates of energy sources vary but oil and gas reserves are thought to come to an end in roughly 40 and 60 years respectively and coal reserves could only be able to last another 200 years .The rapid depletion of fossil fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources to cater to the present day's demand. Another key reason to reduce our reliance on fossil fuels is the growing evidence of the global warming phenomena. The potential of renewable energy sources is enormous as they can in principle meet many times the word energy demand. Renewable energy sources such as Biomass, Wind ,Solar, Tidal, Geothermal, Hydroelectric can provide sustainable energy service based on the use of routinely available individual resources. Of the many alternatives, Photo-voltaic and Wind energy have been considered as promising towards meeting the continually increasing demand for energy.[19]

The Wind and Photovoltaic sources of energy are inexhaustible, freely available and it does not cause green house effect in contrary to the fossil fuels .Solar and Wind energies sources are good complementary each other. They have been widely used as Hybrid combination for electricity supply in isolated locations far from the distribution network. From the several studies of Optimization preferred an attractive alternative energy sources. However , they suffer from the fluctuating characteristics of available Solar and Wind energy sources. Therefore, properly sized Wind turbine, Photovoltaic panel and storage unit provides high reliability and ,low initial investment cost and maximize performance while minimizing the cost.

1.1 Objective Of The Project

Optimization of renewable energy hybrid system looks into the process of selecting the best component and its sizing with appropriate operation strategy to provide cheap, efficient, reliable and cost effective. Wind and Solar driven Stand-alone system have turned into one of the most promising ways to handle the electrical energy requirement of numerous, isolated consumer worldwide.
The main objective of this project is to Optimize Stand-alone Solar and Wind Hybrid Power System configuration for distributed generation.And to maximize Hybrid renewable energy generation system while minimizing the total system cost.

1.2 Motivation

The disadvantage of Stand-alone Power Systems using renewable energy is that the availability of renewable energy sources has daily and seasonal patterns which results in difficulties of regulating the output power to cope with the load demand. Also, a very high initial capital investment cost is required. Combining two or more renewable energy generation will enable the power generated from a renewable energy sources to be more reliable, affordable and used more efficiently.
[15] This thesis focuses on the combination of Wind, Solar and energy storing systems for sustainable power generation. The Wind turbine output power varies with the wind speed at different conditions. The Solar energy also varies with the hourly, daily and seasonal variation of Solar irradiation. Thus, a Battery bank (energy storage bank) can be integrated with the Wind turbines and PV-system to ensure that the system performs under all con- ditions.In the proposed system, when the wind speed is

sufficient, the Wind turbine can meet the load demand. When there is enough energy from the sun, the load demands can be supplied from the PV-array system. Whenever there is excess supply from the RESs, the energy storage bank stores energy which will be used at times when there are insufficient supplies from the RESs.

1.3 Thesis Organization

Thesis of the major project entitled ́Study,Analysis,Optimization and Software Implementation Approach of Solar and Wind Hybrid System" is organized in eight chapters and references.

Chp.2: Literature Survey is literature Review of the work close to that being researched here.

Chp.3:Overview Of Solar,Wind and Hybrid System Represents Overview of Wind Power and Solar Power. It also describes Solar-Wind Hybrid Power System, its advantages and application. It also describes the brief overview about Distributed Generation.

Chp.4: Software Simulation of Solar Photovoltaic Module In this chapter a Software Implementation approach of Modeling of Solar Photovoltaic Module using Mathematical equations is described.This work is carried out in MATLAB/SIMULINK software.Then after Designing of DC to DC Boost Converter is done.after that MPPT control circuit is designed to extract the Maximum Power available from Solar PV panel.

Chp.5:Software Simulation of Battery Model Presents the Software Simulation of Battery model structure. and give the brief overview about State of Charge and Depth of charge.

Chp.6:Wind Energy Conversion System Describes Simulations of Wind Energy Conversion System(Doubly fed Induction Generator).then a Hybrid Module of Stand alone Solar Power System and Stand alone Wind Power System is developed .

Chp.7:Optimization Technique Introduce the Cost Optimization procedure for Hybrid Solar and Wind Power system.In this first the calculation for system Sizing of Solar Wind Hybrid Power System is done and then calculation for Cost of electricity for three plant size 1 kWh/day, 10 kWh/day, 100 kWh/day for Solar Power system,Wind Power system and Hybrid power system is done.and proved that hybrid configuration is better compare to the Stand alone Solar and Wind power system. Final section contains conclusions and also presents the future work.

Chapter 2

Literature Survey

"DEVELOPMENT OF POWER ELECTRONIC CIRCUIT-ORIENTED MODEL OF PHOTOVOLTAIC MODULE" This Paper describes circuit based model of photovoltaic array (PV) suitable for simulation studies of Solar power systems.As the photovoltaic source exhibits non-linear V-I characteristics, which are dependent on solar insolation and environmental factors, the development of an accurate power electronic circuit oriented model is essential to simulate and design the photovoltaic integrated system. The model is realized using power system block set under MATLAB/SIMULINK.In this paper,the production of I_{PV} which is dependent on solar insulation and environmental factors is modeled through iterative process, using the equations.A step-by-step procedure for simulating I_{PV} with user-friendly icons and dialog in MATLAB/SIMULINK block libraries is described.[1].

"Design and Implementation of a Domestic Solar-Wind Hybrid Energy System" Paper discuss the Design and Implementation of a Domestic Solar-Wind Hybrid Energy System.It represents the design and implementation of a domestic Solar- Wind hybrid energy system under micro controller. This work is expected to sustain some part of the daily domestic electricity consumption with an efficient utilization of solar and wind power.Control card controls the microprocessor by processing the information coming from all the components in real time. Measurement card simultaneously measures the current and the voltage values of the Wind, Solar, and invertor systems.A portion of the energy requirement for a home has been supplied with the electricity generated from the wind and solar power. Maximum power point tracking system used in the MPPT provided optimum benefit from the Solar energy.In the implemented system, control card in which the software was developed by experts, decides whether the energy generators would be engaged to the system or not. Real time control of the inputs and outputs was carried out by 3 current sensors and 3 voltage sensors in the system.[2].

"MODELING AND SIMULATION OF RENEWABLE HYBRID POWER SYSTEM USING MATLAB/SIMULINK ENVIRONMENT" This Paper describes Modeling and Simulation of Renewable Hybrid Power System Using MATLAB/SIMULINK Environment.This paper contains presents the modeling of a Solar-Wind-Hydroelectric hybrid system in Matlab/Simulink environment.ReGenSim library of Matlab/Simulink is used for simulation of renewable energy base power system. Solar-Wind hydro electric hybrid system is developed using Regensim library of MATLAB/Simulink and simulated.Different graphs of Evolution of active power transit between the hybrid system based on renewable energy sources and the public network,Evolution of reactive power transit between the hybrid system based on renewable energy sources and the public network,Renewable energy sources active power variation, Renewable energy sources reactive power variation etc can be obtained.[3].

"Optimization of Solar Wind Hybrid Power System for Distributed Generation" This Paper describes Optimization of Solar-Wind Hybrid System for Distributed Generation. This paper deals with the Optimize Stand-alone Solar-Wind Hybrid power system and to maximize use of renewable energy generation system while minimizing the total system cost. It conclude that the stand-alone Solar-Wind hybrid system is most suitable compared to the other configuration, for supplying the power to the ac load. Although initial cost for Solar-Wind hybrid power system is high, but it produces electricity at least cost. Due to distributed generation it eliminates installation cost transmission lines.[4].

"MODELING AND SIMULATION BASED APPROACH OF PHOTOVOLTAIC SYSTEM IN SIMULINK MODEL " In this paper taking the effect of irradiance and temperature into consideration, the output current and power characteristic of PV model are simulated.Detailed modeling procedure for the circuit model with numerical values is presented.it can be seen that the PV current is a function of the solar irradiation and is the only energy conversion process in which light energy is converted to electrical energy.This paper provides a clear and concise understanding of the, I-V and P-V characteristics of PV module, which will serve as the model for researchers and expert in the field of PV modeling. [5].

"USING HOMER POWER OPTIMIZATION SOFTWARE FOR COST BENEFIT ANALYSIS OF HYBRID-SOLAR POWER GENERATION RELATIVE TO UTILITY COST IN NIGERIA " This Paper describes Using Homer Power Optimization Software For Cost Benefit Analysis Of Hybrid-Solar Power Generation Relative To Utility Cost In NigeriA.This paper discuss cost benefit analysis of solar-wind hybrid power system at Nigeria. cost benefit analysis of a wind turbine-solar hybrid system was done using HOMER software and comparison was also made with the cost per kilowatt of central grid or utility supply. The hybrid system have a pay-back period of about thirty-three years and at current costs, central grid power is the least expensive option but may not be available to most rural households far from the grid. Simulation is done using Homer software and found that wind-solar cell hybrid energy system would be cost effective if there is reduction in component cost by installation of many of this hybrid system in a farm thereby lowering the investment cost per kilowatts.[6].

"Modeling and Simulation of Wind Energy Conversion System in Distributed Generation Units" In This paper presents the modeling and simulation of Wind turbine driven by doubly-fed induction machine as a part of distributed generation which feeds ac power to the distribution network. A stator flux oriented vector control is used for the variable speed doubly-fed induction machine operation. By controlling the generator excitation current the amplitude of the stator EMF is adjusted equal to the amplitude of the grid voltage. To set the generator frequency equal to the grid one, the turbine pitch angle controller accelerates the turbine/generator until it reaches the synchronous speed. The system is modeled and simulated in the Matlab/Simulink environment in such a way that it can be suited for modeling of all types of induction generator configurations. [7].

"Possibilities of Distributed Generation Simulations Using by MATLAB" This paper deals about modeling possibilities of distributed sources connected to power systems using by MATLAB program. Simulations performed by MATLAB/Simulnik can have an important role in terms of evaluation of connecting conditions depended on small short-circuit power, which is usually in most places where distributed sources can be connected, very small. [8].

"The Modeling and Simulation of Wind Energy Based Power System using MATLAB " in this paper Modeling and simulation of a grid connected wind-driven electricity generation system or WECS (an acronym for Wind Energy Conversion System) has been done. In this paper also various problem facing during the simulation is described and also give some suggestion to mitigate them.like Phase sequence of the supply is important. It should be kept such that the stator magnetic field rotates in the same direction as the turbine. Otherwise, the generator will not rotate and no torque will be produced. and so on. [9].

"Modeling and Dynamic Behaviour of Variable Speed Wind Turbines Using Doubly Fed Induction Generators (DFIG)" this paper conclude that dynamic behaviour of a wind turbine equipped with a doubly fed induction generator (DFIG) in case of disturbances in the interconnected grid. The transient performance of DFIG wind turbines is evaluated under super-synchronous and sub-synchronous operation during different grid voltage dips. In the present investigation, the dynamic DFIG performance is presented for both normal and abnormal grid conditions. The control performance of DFIG is satisfactory in normal grid conditions and is found that, both active and reactive power maintains a steady pattern in spite of fluctuating wind speed and net electrical power supplied to grid is maintained constant. During grid disturbance, considerable torque pulsation of DFIG and torsional oscillation in drive train system has been observed. [10]

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"Simulink Model of a Lithium-Ion Battery for the Hybrid Power System Test bed " this paper This paper investigates the identification of model parameters for a Simulink model of the 60Ah Lithium Technology Corporation Lithium-ion battery used in the hybrid power systems.also this paper concluded from the derivation of VOC-SOC Relationship.[11].

"Optimization of Renewable Energy Hybrid System by Minimizing Excess Capacity" it represents The techno-economic analysis usually looks at the cheapest cost of energy produced by of system components while neglecting the excess capacity of the combination. This paper discusses the optimization of the hybrid system in context of minimizing the excess energy and cost of energy. The system configuration of the hybrid is derived based on a theoretical domestic load at a remote location and local solar radiation, wind and water flow rate data. The results show that the cost of energy can be reduced to about half if the demand load is increased to the maximum capacity.[12]

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"Economic Cost Analysis of Hybrid Renewable Energy System using HOMER " in this paper it deals with the optimal cost analysis of hybrid renewable energy system (HRES).In this paper work, real time optimal cost analysis of HRES is done based on the load profile, solar radiation and wind speed.Moreover, the optimization of system is obtained by varying the sensitivity variables like solar radiation, wind speed etc. Cash flow summary of the HRES system is obtained which will be useful for the optimal cost allocation of each individual component present in the system.[13]

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Chapter 3

Overview Of Solar,Wind and Hybrid System

3.1 Introduction Of Solar Power

The most useful way of harnessing Solar energy is by directly converting it into electricity by means of Solar photo-voltaic cells .When sunshine is incident on Solar cells ,they generate DC electricity without the involvement of any mechanical generators, that is in these system of energy conversion there is direct conversion of Solar radiation into electricity. In it the stage of conversion into thermodynamic form is absent. The Photo voltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by the use of photovoltaic effect are called Solar cells.[15]

In actual usage, the Solar cells are inter connected in certain series /parallel combinations to form modules. these modules are hermetically sealed for protection against corrosion, moisture , pollution and weathering .A combination of suitable modules constitute an array. A general data for $1m^2$ of a fixed array kept facing south yields nearly 0.5 kWh of electrical energy on a normal sunny day.If it is required to be used during non-sunshine hours, a suitable system of storage will be required.[19]

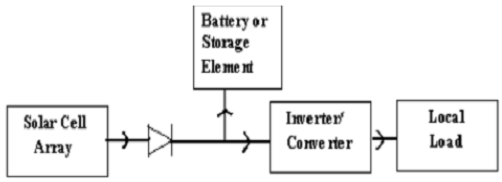


Figure 3.1: Basic Solar System

3.1.1 Direct And Diffuse Light

The Earth's atmosphere and cloud cover absorbs, reflects, and scatters part of the Solar radiation entering the atmosphere. Nonetheless, an enormous amount of the sun's energy reaches the Earth's surface and can there-fore be used to produce electricity by using the photovoltaic effect. Some of this radiation is direct and some is diffuse, and the distinction is important because some PV systems (flat-plate systems) can use both forms of light, but concentrator systems can only use direct light.

Direct Light

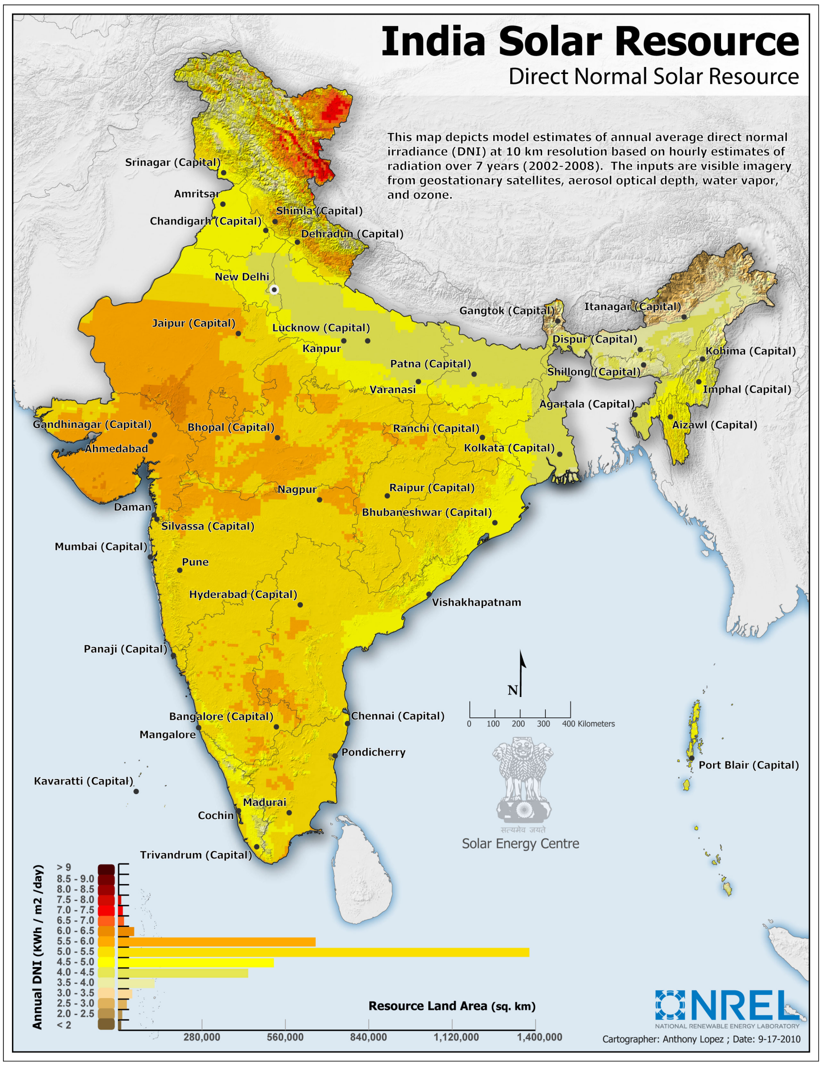
consists of radiation that arrives from the sun, without reflecting off clouds, dust, the ground, or other objects. Scientists also talk about direct-normal radiation, referring to the portion of sunlight that comes directly from the sun and strikes the plane of a PV module at a 90^o angle.

Diffuse Light

is sunlight that is reflected off clouds, the ground, or other objects. It obviously takes a longer path than a direct light ray to reach a module. Diffuse light cannot be focused with the optics of a concentrator PV system.

3.1.2 Solar energy utilization in India

India has a total land area of $3.28 * 10^{11}\ m^2$. On an average 5 kW $/m^2$/day Solar energy is falling on this land for over 300 days per annum: in certain areas the bright sunny day may be more . Even if 1 % of these land is used to harness Solar energy for electricity generation at an overall efficiency of 10% .$492 * 10^9$kWh/year electricity can be generated.These is an enormous amount of energy and can be generated using thermal or photovoltaic routes of power generation.



Solar radiant energy is being utilized through thermal as well as Photovoltaic routes in India. The thermal routes has found many applications suggest space heating and cooling using passive and /or active concepts ,refrigeration and cold storage, cooking extra. The PV Solar cell are used for electrical power generation.

3.1.3 Photovoltaic Module

Photovoltaic system consists of a PV generator (cell, module, and array). A Solar cell consists of a P-N junction fabricated in a thin wafer or layer of semi-conductor (Usually silicon). When the Solar energy (Photons) hits the Solar cell, with the energy greater than band gap energy of the semiconductor, electrons are knocked loose from the atoms in the material, creating electron - hole pairs.
These carriers are swept apart under the influence of the internal electric fields of the P-N junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit. When open circuited, this current is shunted internally by the intrinsic p-n junction diode.
Photovoltaic is known as the process between beam absorbed and the electricity induced. With a common principle and individual components, solar power is converted into the electric power.

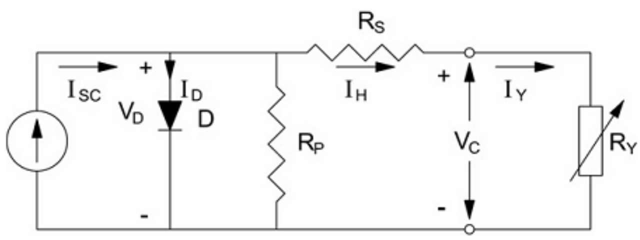


Figure 3.2: Equivalent circuit of Solar PV module

3.1.4 Equations of PV module

The photovoltaic module can be modeled mathematically as given in equations shown below[1] [5]

a. Module photo current

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \frac{\lambda}{1000} \tag{3.1}$$

b. Module reverse saturation current

$$I_{rs} = \frac{I_{scr}}{[e^{\frac{(q*V_{oc})}{(N_s*K*A*T)}} - 1]} \tag{3.2}$$

c. The module saturation current I0 varies with the cell Temperature, which is given by

$$I_o = I_{rs} * [\frac{T}{T_r}]^3 * [e^{(\frac{q*E_{go}}{B*K})*(\frac{1}{T_r}-\frac{1}{T})}] \tag{3.3}$$

d. The current output of PV module is

$$I_{pv} = N_p * I_{ph} - N_p * I_o[e^{(\frac{q*(V_{pv}+I_{pv}*R_s)}{N_s*K*A*T})} - 1] \tag{3.4}$$

3.1.5 Insolation

The actual amount of sunlight falling on a specific geographical location is known as insolation "incident solar radiation."

Insolation values for a specific site are sometimes difficult to obtain. Weather stations that measure solar radiation components are located far apart and may not carry specific insolation data for a given site. Furthermore, the information most generally available is the average daily total global radiation on a horizontal surface.

When sunlight reaches the Earth, it is distributed unevenly in different regions. Not surprisingly, the areas near the Equator receive more solar radiation than anywhere else on the Earth. Sunlight varies with the seasons, as the rotational axis of the Earth shifts to lengthen and to shorten the dark or light days with the changing seasons. The quantity of sunlight reaching any region is also affected by the time of day, the climate (especially the cloud cover, which scatters the sun's rays), and the air pollution in that region. Likewise, these climatic factors all affect the amount of solar energy that is available to PV systems.

3.1.6 Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages

a. Absence of moving parts.

b. Maintenance cost is low as they are easy to operate.

c. Direct room temperature conversion of light to electricity through a simple solid state devices.

d. Modular nature in which desired current,voltage and power level can be achieved by more integration.

e. They do not create pollution

f. They have a long effective life.

g. They are highly reliable.

h. They consume no fuel to operate as the sun's energy is free.

i. They have rapid response in output to input radiation changes:no long time constant is involved,as on thermal system.

j. They have wide power handling capabilities from microwatts to kilowatt or even megawatt when modules are combined into large area arrays.

k. They have high power to weight ratio,this characteristics is more important for space application.

Disadvantages

Their principal disadvantages are their high cost,and the fact that,in many application,energy storage is required because of no insolation at night.Efforts are being made world wide to reduce costs through various technological innovations.

3.1.7 Application of Solar Photo-voltaic system

Various Solar photovoltaic system have been developed and installed at different sites for demonstration and field trial purpose.The terrestrial application of these system include provision of power supply to:

a. Water pumping sets for micro irrigation and drinking water supply

b. Radio beacons (signal fire) for ship navigation at ports.

c. Community radio and television sets.

d. Weathering monitoring

e. Railway signalling equipment.

f. Battery charging

g. Street lightning.

3.2 Introduction to Wind Power

The Wind energy is a renewable source of energy.In this Wind turbines are used to convert the Wind power into electric power. Electric generator inside the turbine converts the mechanical power into the electric power. Wind turbine systems are available ranging from 50W to 2-3 MW.

The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind power is used to feed both energy production and consumption demand, and transmission lines in the rural areas.It is used to run a windmill which in turn drives a wind generator or wind turbine to produce electricity. Practically it is observed that the flexible three blades propeller about 35 m in diameter, in a 60 Km/hr wind pressure with a rotation speed of 47 rpm produce maximum power 12 MW. For small wind power generation system, multiple blade type (3 to 5 number blades) or Darrieus type (Curved Blade 3 to 5 numbers) is highly suitable.

The main drawback of this system is that as the wind speed or velocity is not constant with respect to time i.e. fluctuating, hence the electric power thus obtained is also not having predetermined value i.e. varying nature. Thus, it is better to feed the wind electricity to the battery or any power storage device i.e. accumulator circuit which supply the load accordingly, rather directly supply to the load.In wind power system, the power generation increases in proportion to the cube of the wind speed. Thus it is highly affected in rainy and stormy period when the wind speed is formidable to produce electricity. This power generation system is pollution free pure ecologically balanced one.[15]

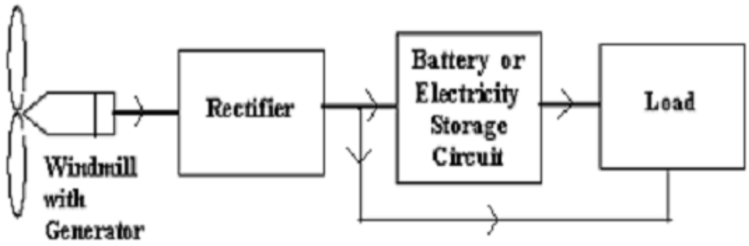


Figure 3.3: Basic Wind power system

3.2.1 Types of Wind energy systems

Horizontal Axis Wind turbine

in which the axis of rotation is horizontal with respect to the ground. The rotation is roughly parallel to the wind stream. The most common types of wind turbines are horizontal axis. The wind mills are posted around 30 to 50 meters above the ground where the wind speeds are high. Various designs of horizontal axis turbines can be found in literature. They vary from single blades to multiple blade design.

Vertical Axis Wind turbine

in which the axis of rotation is vertical to the ground. The rotation is roughly perpendicular to the wind stream. The most common type of vertical axis turbines is Darrieus turbines. The vertical axis turbines are less efficient and hence they are not widely used. The most common ones are the giant horizontal axis turbines.

3.2.2 Power Content of the Wind

The amount of power transferred to a wind turbine is directly proportional to the area swept out by the rotor, to the density of the air, and the cube of the wind speed.[8]

a. The power P in the wind is given by

$$P = 0.5 * C_p * \rho * A * V^3 \tag{3.5}$$

Where

C_p= Turbine power coefficient

ρ=Air density(kg/m^3)

A= Rotor swept area(m^2)

D=Rotor blade diameter(m)

v= Mean wind speed(m/s)

3.2.3 Wind Resources Evolution

Wind resource evaluation is a critical element in projecting turbine performance at a given site. The energy available in a wind stream is proportional to the cube of its speed, which means that doubling the wind speed increases the available energy by a factor of eight.

Furthermore, the wind resource itself is seldom a steady, consistent on. It varies with the time of day, season, height above ground, and type of terrain. Proper siting in windy locations, away from large obstructions, enhances a wind turbine's performance. In general, annual average wind speeds of 5 m/s (11 mile/hour) are required for grid-connected applications.

Annual average wind speeds of 3 to 4 m/s (7-9 mph) may be adequate for non-connected electrical and mechanical applications such as battery charging and water pumping.

Wind Power Density is a useful way to evaluate the wind resource available at a potential site. The wind power density, measured in w/m^2, indicates how much energy is available at the site for conversion by a wind turbine.

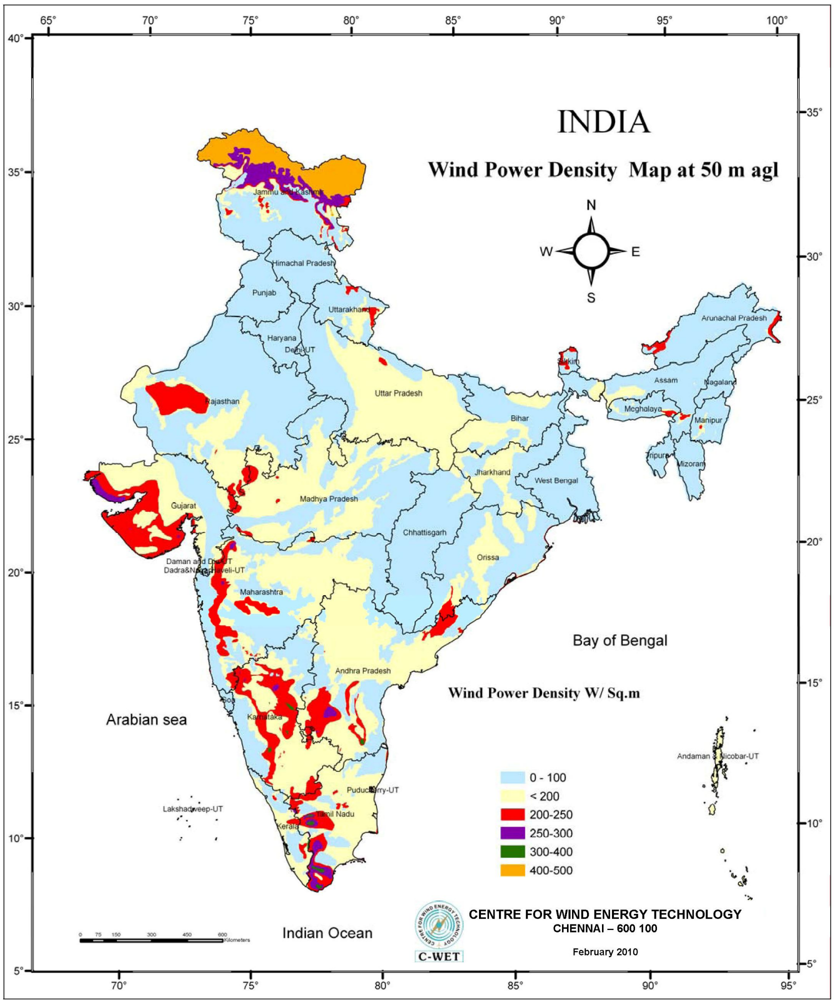


Figure 3.4: Wind resources in India

3.3 Introduction to Hybrid Power

In view of the strong complementarity of solar and wind power in the time way,Wind-solar Hybrid Generating System is considered to take full advantage of renewable energy so greatly as to improve the stability and reliability of the power system, and save the cost of the electricity to a certain extent by reducing the capacity of the battery and extending the life of the battery.

Wind solar hybrid power generation system can be broadly divided into two types: network-based and off-grid. The main difference between the two is whether the use of external grid power.

The system is mainly made up by the wind turbine, solar photovoltaic batteries, controllers, batteries, inverter, DC load as well as the exchanger of DC/AC parts.

DC was generated from wind turbines and solar panels, respectively, then changes to AC by the inverter for users. In order to meet the regulation of the electricity in different time the batteries charging in peak period and discharging in trough.[2]

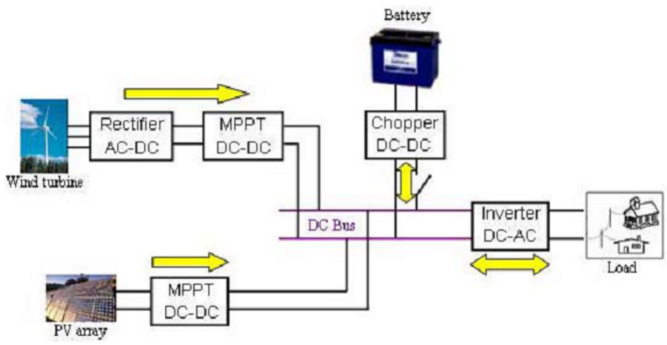


Figure 3.5: Hybrid Wind and Solar power system

3.3.1 Salient features

a. Eliminate expensive mains cable installation costs,

b. No pollution and no recurring fuel costs,

c. Easy to operate and maintain

d. Highly reliable and consistent power supply

e. Most eco-friendly and clean source of power,

f. Long life span for SPV modules and modular design

g. Simple installation

h. Very few moving parts:negligible maintenance required,

i. Lower total system cost, contribution of solar and cost-effective electric power for remote application. Wind is beneficial even on low-wind sites and smoothes out seasonal weather fluctuations

j. Environmental pollution is controlled thus improving health

k. Laying of expensive grid line, and transmission and distribution losses, can be avoided

3.3.2 Application

a. Remote and rural village electrification,

b. Ideal for cell phone recipient stations,

c. Farm houses, guesthouses, hospitals,hotels, laboratories, primary health care centers, police communications centers,literacy centers, tribal hostels, and R and D centers

d. Residential colonies and apartments for general lighting

e. Street lighting,

f. High output, making it ideal for virtually any remote battery charging application.

3.4 Introduction to Distributed Generation

Distributed Generation is electricity production that is On-Site Or Close to the load center and is interconnected to the distribution system".

Distributed Generation includes small, modular technologies for electricity generation, located close to the load. DG technologies are used both in stand-alone mode as well as in grid parallel mode.

Conventional electricity generating stations are typically located close to the fuel source and away from the loads, and electricity generated is conveyed through the transmission system to the load center, which often requires large investment.

Transmission and distribution costs account for about 30 % of the cost of delivered electricity. DG technologies obviate the need for an expensive transmission system and minimize transmission and distribution losses.

Chapter 4

Software Simulation of Solar Photovoltaic Module

A model of PV Module with moderate complexity that includes the temperature independence of the photocurrent source, the saturation current of the diode, and a series resistance is considered based on the Shockley diode equation.
Being illuminated with radiation of sunlight, PV cell converts part of the photovoltaic potential directly into electricity with both I-V and P-V output characteristics.
The model mainly contains four blocks representing four equations given above.[1][5]

a. Module photo current

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \frac{\lambda}{1000} \tag{4.1}$$

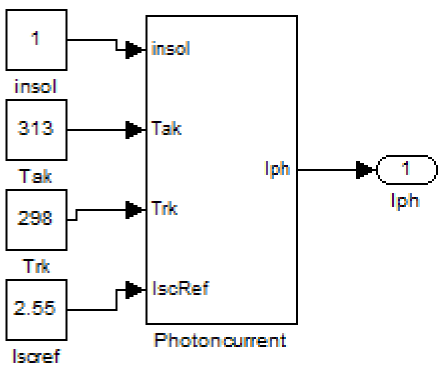


Figure 4.1: Subsystem of Photon Current

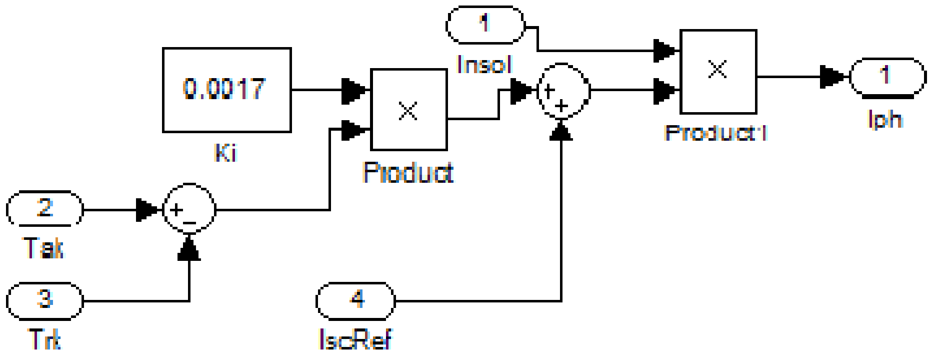


Figure 4.2: Photon current

This model takes following inputs and calculates photocurrent I_{ph}

- Insolation$(\frac{G}{1000})1kW/m^2 = 1$

- Module operating temperature $T_{ak} = 30^oCto70^oC$

- Module reference temperature $T_{rk} = 25^oC$

- Short circuit current I_{sc} at reference temperature =2.55 amp.

b. Reverse Saturation Current

$$I_{rs} = \frac{I_{scr}}{[e^{\frac{(q*V_{oc})}{(N_s*K*A*T)}} - 1]} \tag{4.2}$$

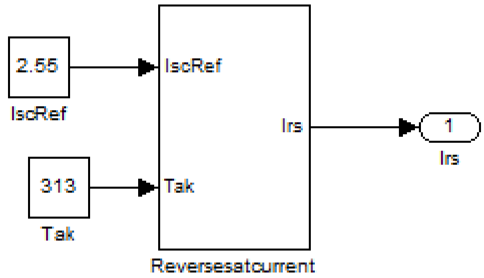


Figure 4.3: Subsystem of Reverse Saturation Current

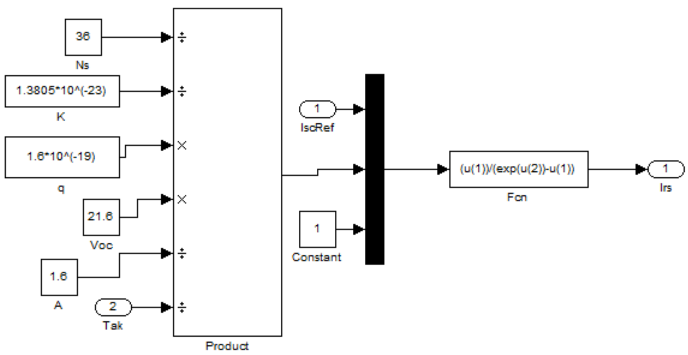


Figure 4.4: Reverse Saturation Current

c. Saturation Current

$$I_o = I_{rs} * [\frac{T}{T_r}]^3 * [e^{(\frac{q*E_{go}}{B*K})*(\frac{1}{T_r} - \frac{1}{T})}] \tag{4.3}$$

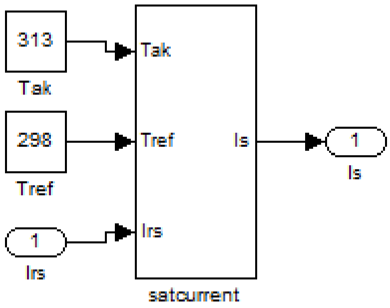


Figure 4.5: Subsystem of Saturation Current

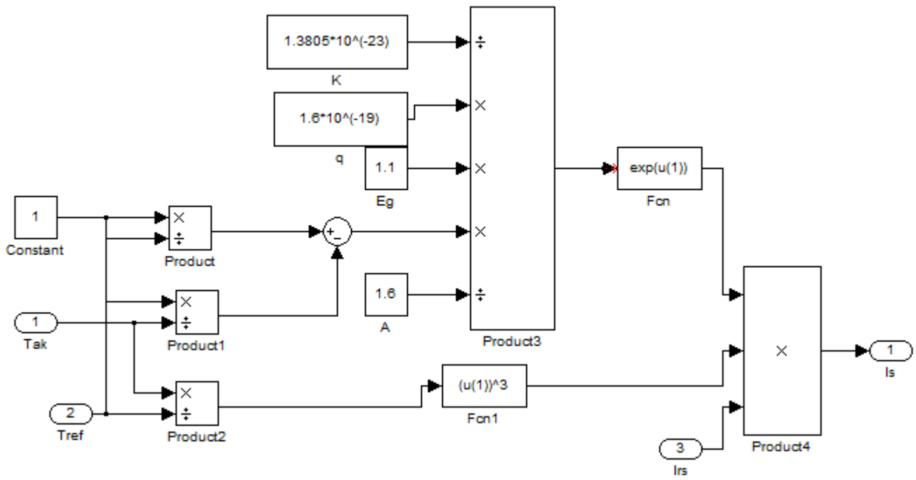


Figure 4.6: Saturation Current

d. Module Output Current

$$I_{pv} = N_p * I_{ph} - N_p * I_o[e^{(\frac{q*(V_{pv}+I_{pv}*R_s)}{N_s*K*A*T})} - 1] \quad (4.4)$$

This model takes following inputs and calculates Module output current I_{pv}

- Open circuit voltage $(V_{oc}) = 21.24volt$
- Total number of cells in series $(N_s) = 36$

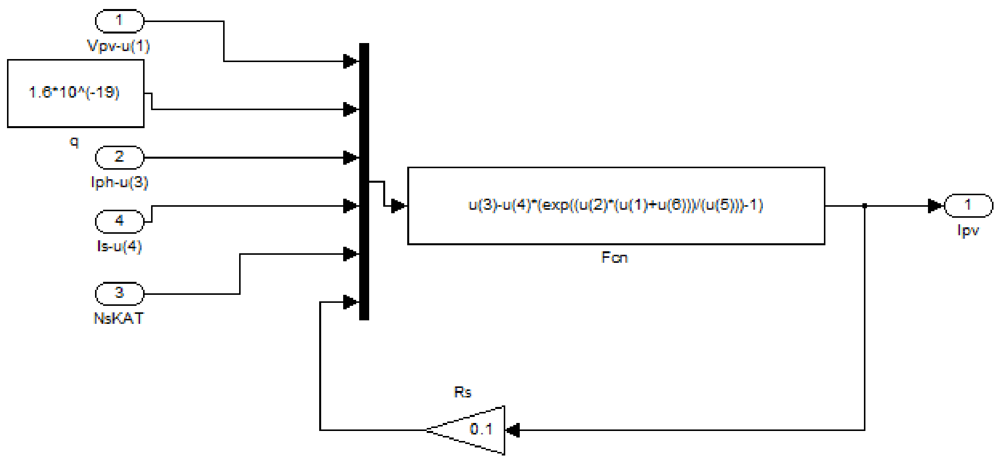


Figure 4.7: Module Output Current

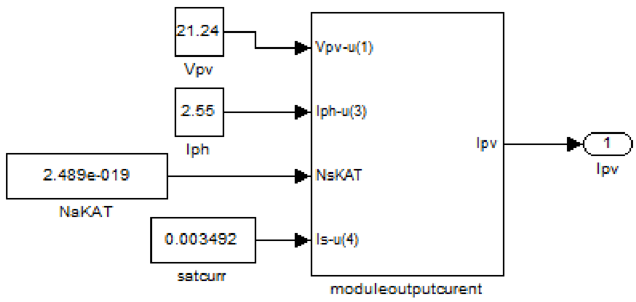


Figure 4.8: Subsystem of Module Output Current

- Total number of cells in parallel (N_p) = 1

All above blocks are now interconnected as shown below:

e. Interconnection

The Simulink model can be used for getting the I-V and P-V output characteristics of PV Module with the input of Solar irradiation, temperature as environment input and PN junction voltage as material input.[1]

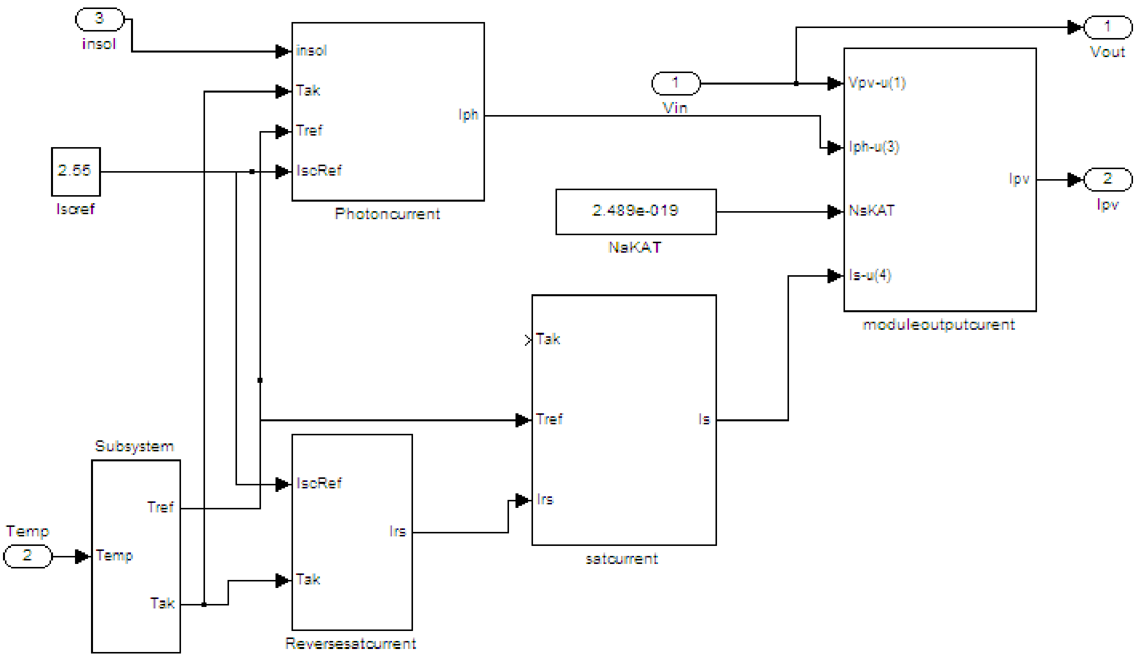


Figure 4.9: Interconnection

4.1 Circuit Oriented Model

The Circuit model of the given PV Module is shown in figure.In the equivalent circuit of PV cell the voltage available across the PV cell is nothing but the PN junction voltage of 0.6V.

The Open circuit voltage of PV Module is $\frac{21.24V}{36cells} = 0.594$ V.

The I-V and P-V Characteristics are as shown below:[5]

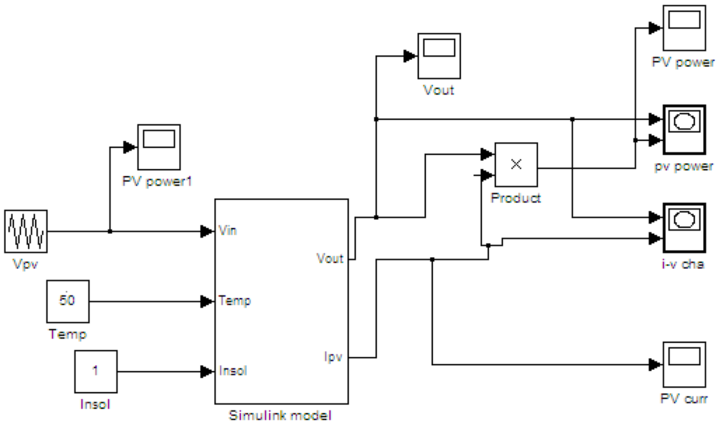


Figure 4.10: PV Module Simulink Model

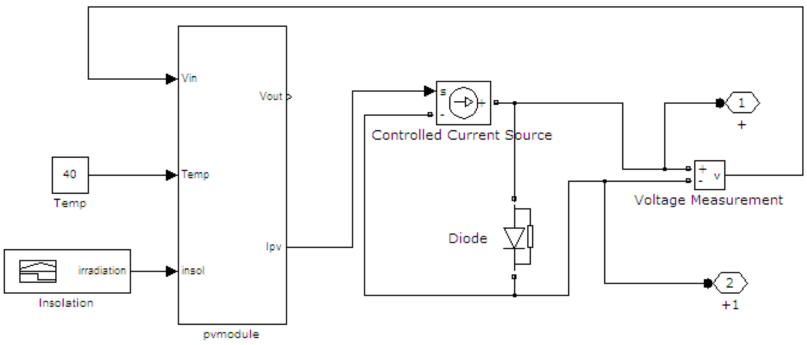


Figure 4.11: Detailed Circuit Module

4.2 Result

It can be seen that the PV current $I_{ph}$is a function of the Solar irradiation and is the only energy conversion process in which light energy is converted to electrical energy. The equations indicate that PV voltage is a function of the junction voltage of diode, The physical equations governing the PV Module (also applicable to PV cell) is elaborately presented with numerical values of module saturation current at various temperatures.

Hence, this circuit model presents the relationship between module parameters and

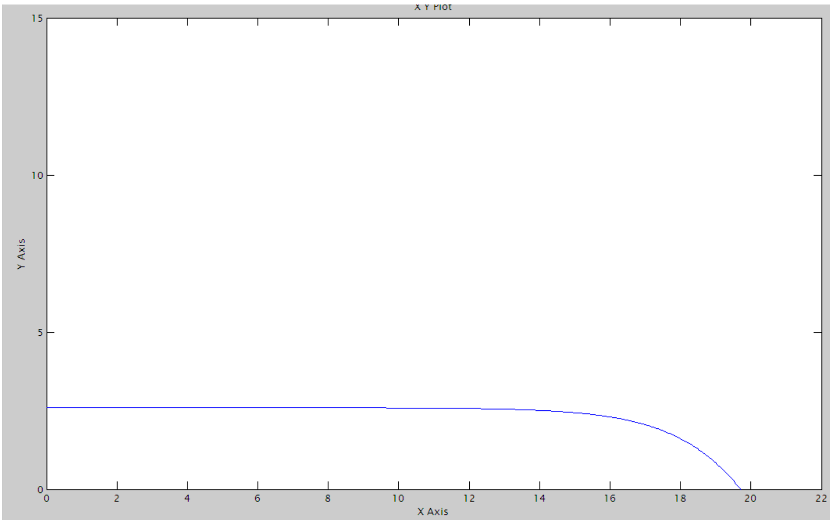


Figure 4.12: I-V Characteristics

circuit performance.
The I-V and P-V Characteristics under constant irradiance with varying temperature are presented respectively. When the operating temperature increases, the current output increases marginally but the voltage output decreases drastically, which result in net reduction in power output with a rise in temperature.

From the result it concluded :

a. Maximum Power P_m = 60W

b. Maximum voltage V_m = 17.1V

c. Current at max.power I_m = 3.5A

d. Open circuit voltage V_{oc} = 21.06V

e. Short ckt.current I_{sc} = 3.74A

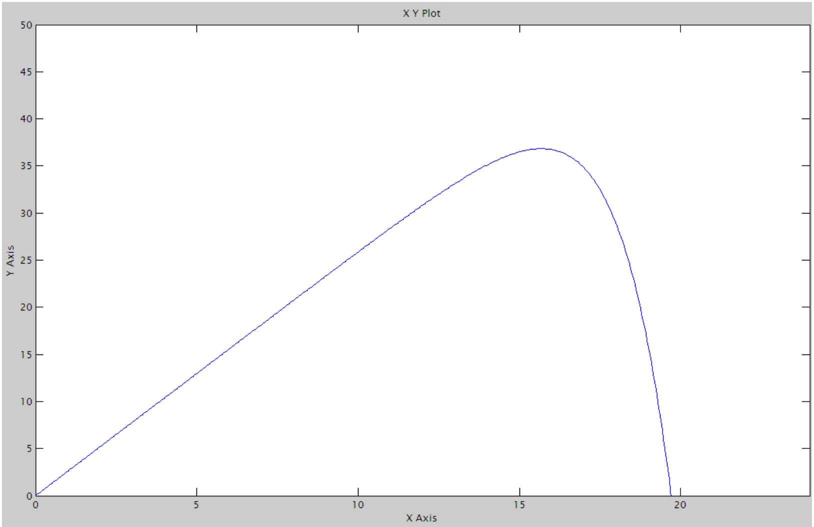


Figure 4.13: P-V Characteristics

4.3 Design of DC-DC Converter

With the variation of irradiation and temperature, the power output of PV Module is varies continuously. The Maximum Power Point Tracking (MPPT) algorithm is used for extracting the maximum power from the Solar PV Module and transferring that power to the load. A DC-DC converter (step up/ step down),as shown if figure below serves the purpose of transferring maximum power from the PV Module to the load and acts as an interface between the load and the module.[3]

By changing the duty cycle of the PWM control signal, the load impedance as seen by the source varies and matches the point of the peak power with the source so as to transfer the maximum power.The PV Modules are always used with DC to DC converters to get the maximum power point operation. The types of converters used are buck, boost and buck-boost. For battery charging applications buck-boost configuration is preferred where as boost converters are used for grid connected applications. DC-DC boost converters are used often in PV systems to step up the low module voltage to higher load voltages. Hence, DC-DC boost converter is used for the design of MPPT controller.

4.3.1 Design of Dc-Dc Boost Converter

The boost converter configuration shown in fig.consists of DC input voltage source V_s, boost inductor L, controlled switch S, diode D, filter capacitor C, and load resistance R.

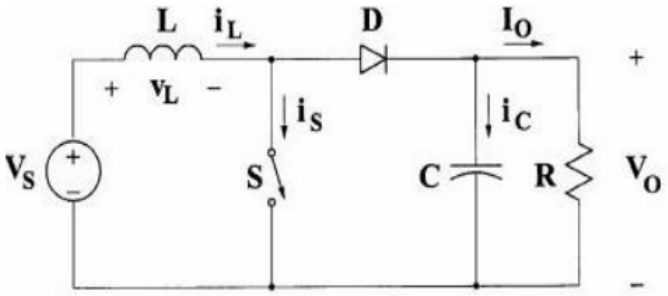


Figure 4.14: Configuration of DC to DC Boost Converter

If the switch operates with a duty ratio D, the DC voltage gain of the boost converter is given by

$$M_v = V_0/V_s = 1/(1 \text{ - D})$$

where

V_s= is input voltage

V_0 =is output voltage

D = the duty cycle of a pulse width modulation (PWM) signal used to control the MOSFET on and off states.

The boost converter operates in the continuous conduction mode for inductor$L > L_b$ where,

$$L_b\text{=}(1 - D^2) \text{ *D *R/(2 *f)}$$

The current supplied to the output RC circuit is discontinuous. Thus, a larger filter capacitor is required to limit he output voltage ripple.
The minimum value of filter capacitor hat provides the output DC current to the load when the diode D is off is given by $C_{min.}$
The minimum value of the filter capacitance results in the ripple voltage Vc is given by

$$C_{min} = (\mathrm{D} * V_0) \ / \ (\ \mathrm{R} * \mathrm{F} * V_r).$$

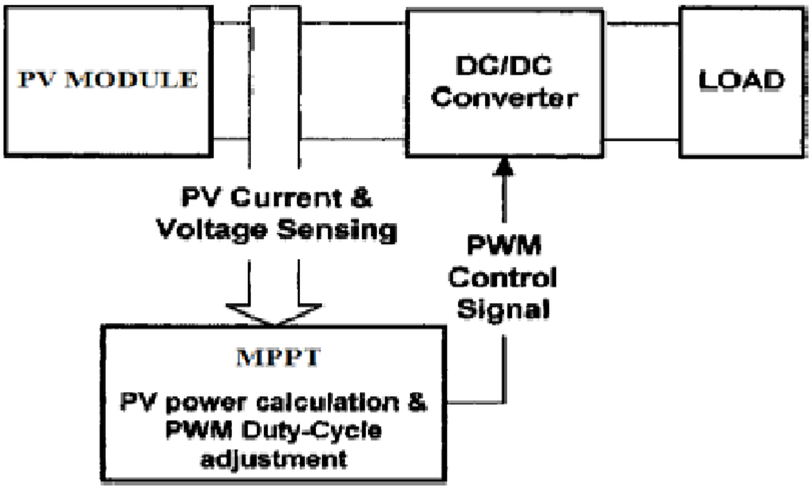


Figure 4.15: DC DC converter for operation at the MPP

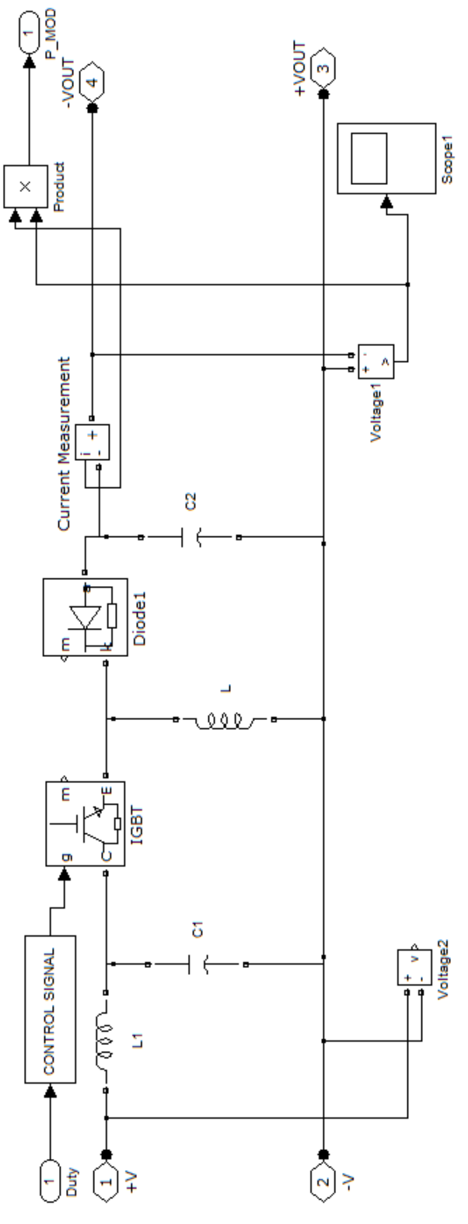


Figure 4.16: Boost converter circuit with DC supply

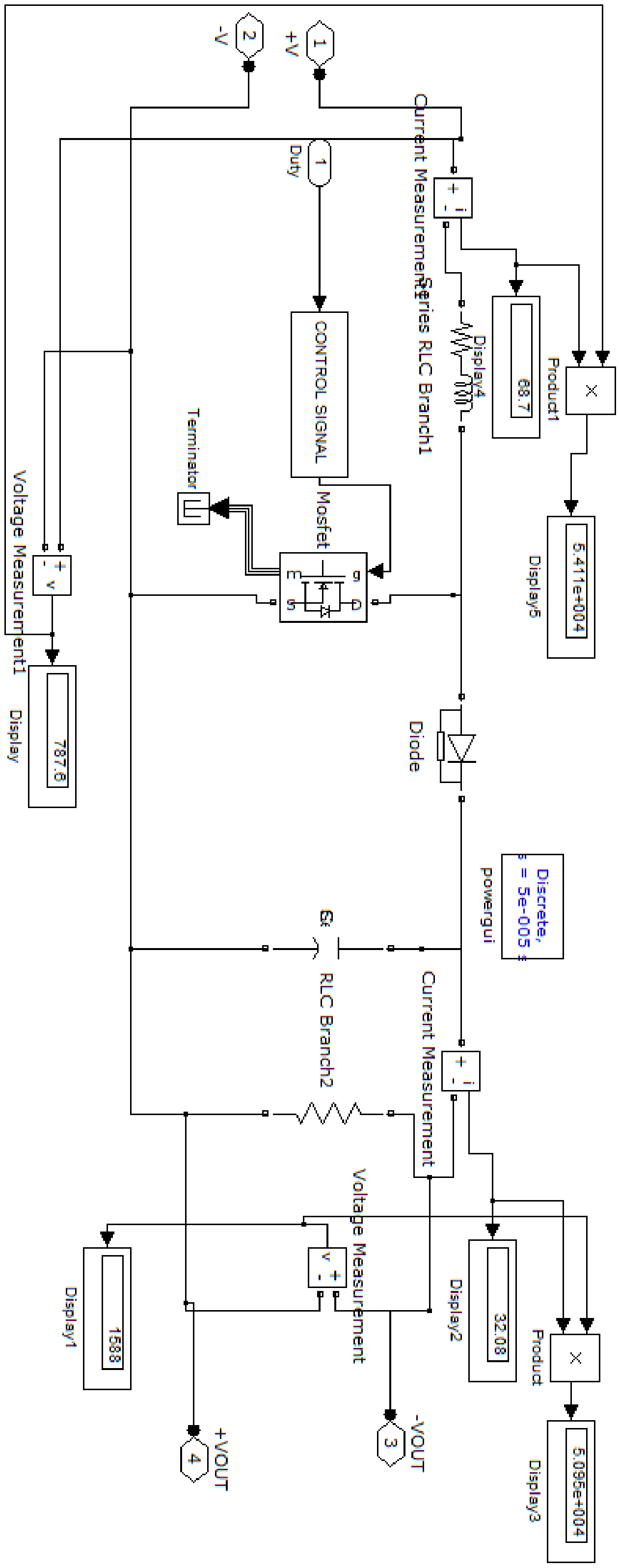


Figure 4.17: Boost converter circuit with PV input

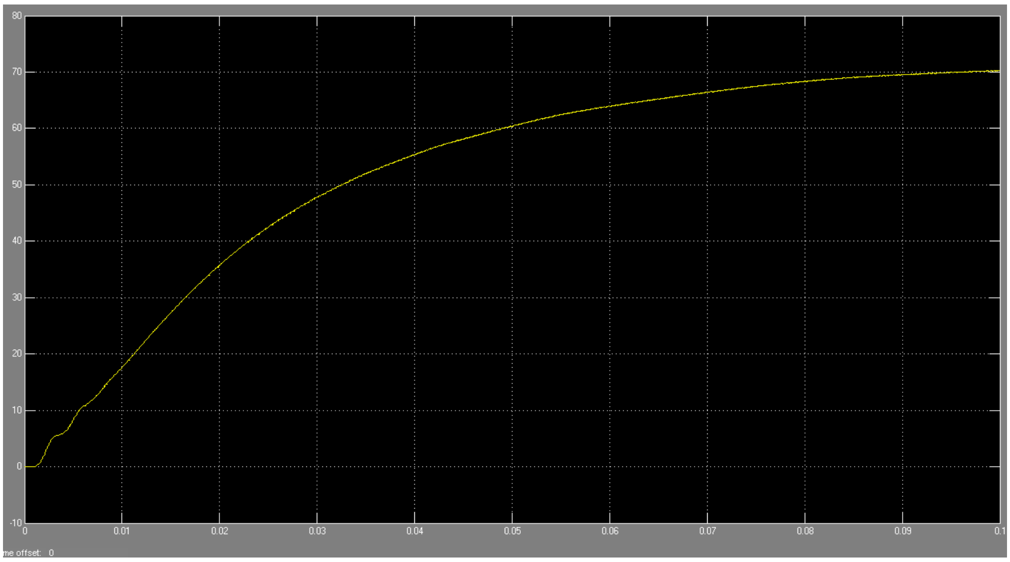


Figure 4.18: Output voltage of boost converter circuit

4.4 MPPT Control Algorithm

Many MPPT techniques have been proposed in the examples are the Perturb and Observe (P and O), Incremental Conductance (IC), Fuzzy Logic Method. The P and O algorithm is very popular and simple. So it is taken for the design.

The power graph for P and O algorithm is shown in Fig. In P and O algorithm a slight perturbation ($\Delta D = 0.01$) is introduced in the system. This perturbation causes the power of the solar module to change. If the power increases due to the perturbation, then the perturbation is continued (D + ΔD) in that direction . After the peak power is reached, the power at the next instant decreases and hence after that the perturbation reverses (D - ΔD)

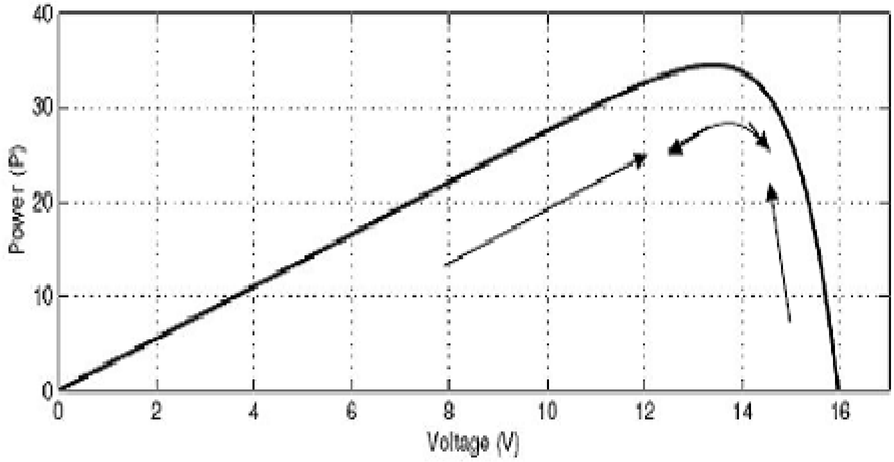


Figure 4.19: Power graph for P and O algorithm

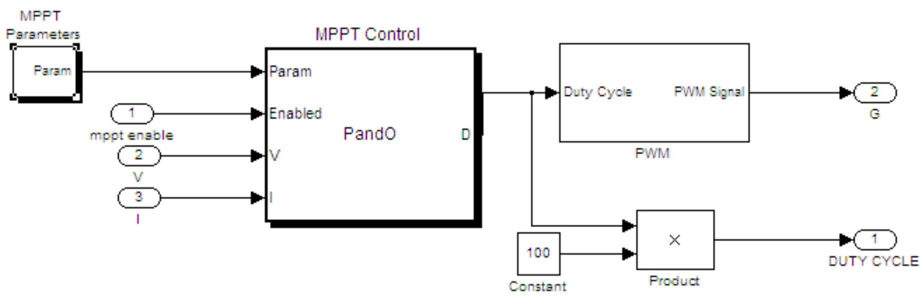


Figure 4.20: MPPT system block diagram

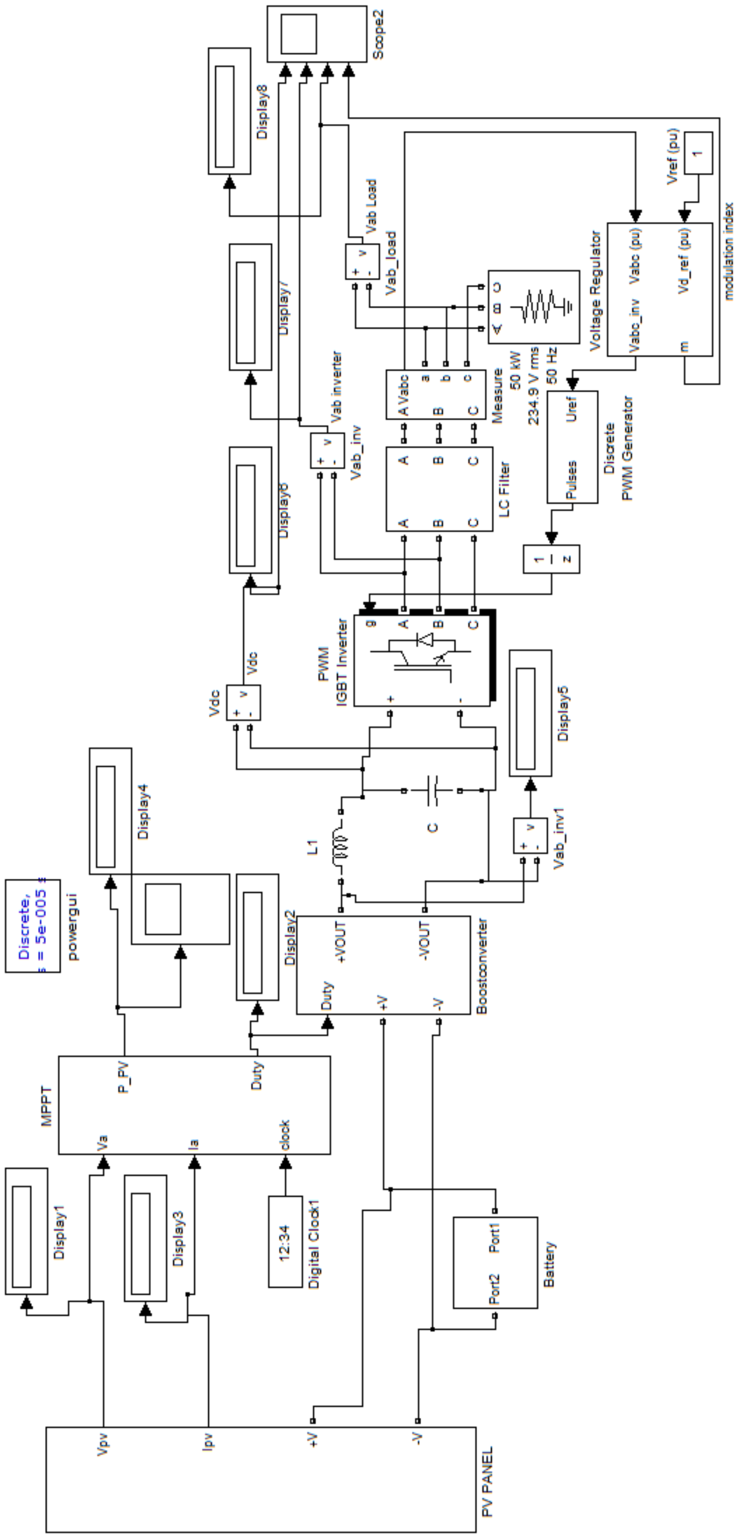


Figure 4.21: MPPT with PV panel and Boost converter

Chapter 5

Software Simulation of Battery Model

A simple, fast, and effective equivalent circuit model structure for lead-acid batteries was implemented to facilitate the battery model part of the system model.
In this simulation, initially the battery is discharged at a constant current of 10A. The battery is then recharged at a constant 10A back to the initial state of charge. A simple thermal model is used to model the battery temperature.
It is assumed that cooling is primarily via convection, and that heating is primarily from the battery internal resistance. A standard 12V lead-acid battery can be modeled by connecting six copies of the 2V battery cell block in series.

5.1 Battery Model Structure

A physical system lead-acid battery model was created. The battery model was designed to accept inputs for current and ambient temperature, as shown in Fig 5.1. The outputs were voltage, SOC and electrolyte temperature.[11]

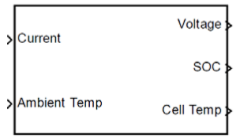


Figure 5.1: Battery Model

A diagram of the overall battery model structure is shown in Fig.5.2, which contains three major parts: an Equivalent circuit model, Thermal model, and a Charge and Capacity model.

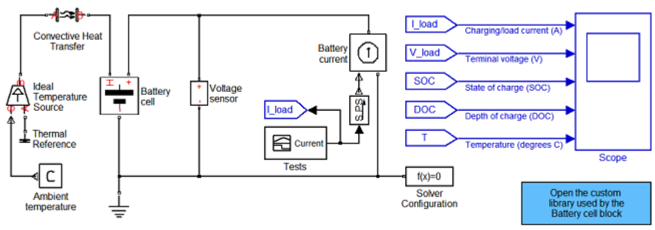


Figure 5.2: Overall lead acid Battery model structure

5.1.1 The Major part of Battery model structure:

- **Equivalent circuit model:** The equivalent circuit depends on the battery current and several nonlinear circuit elements. A simple nonlinear equivalent circuit is shown in figure 5.3.

  The equivalent circuit empirically approximates the behavior seen at the battery terminals. The structure consists of two main parts: a main branch which approximates the battery dynamics under most conditions, and a parasitic branch which accounts for the battery behavior at the end of a charge.

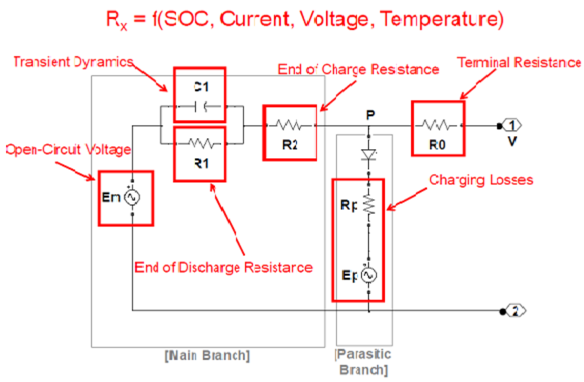


Figure 5.3: Equivalent circuit

The Battery equivalent circuit represents one cell of the battery. The output voltage was multiplied by six, the number of series cells, to model a 12 volt automotive battery. Fig. shows the electrical circuit diagram containing elements that were used to create the battery circuit equations.
The emf varied with temperature and state of charge (SOC).

$$E_m = E_{mo} - K_E * (273 + \theta) * (1 - SOC) \tag{5.1}$$

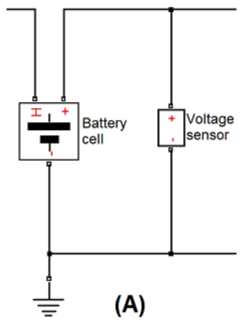


Figure 5.4: Equivalent circuit in MATLAB

- **Parasitic branch current:** This block implements the Parasitic Branch which consists of three components (Diode, Parasitic Branch resistance (R_p) and DC voltage source).

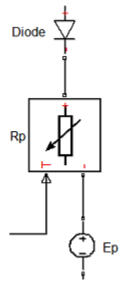


Figure 5.5: Parasitic branch current block

- **Thermal Model(Ambient and Electrolyte Temperatures):** The Ambient temperature block in Figure 5.6 tracked ambient temperature, which is consists of four components.

   a. PS constant (ambient temperature)

   b. Thermal reference

   c. Ideal temperature source

   d. Convective heat transfer

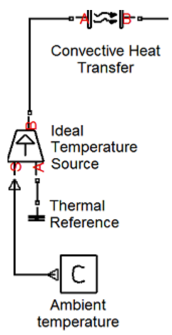


Figure 5.6: Thermal model

- **A Charge and Capacity model:** The Charge and Capacity block in Figure 5.7 tracked the battery capacity, State of charge, and Depth of charge.
  A Charge and Capacity model contains of Ssome blocks which are Controlled current source ,Simulink-PS converter , Signal builder.[11]

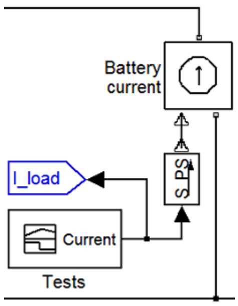


Figure 5.7: A Charge and Capacity model

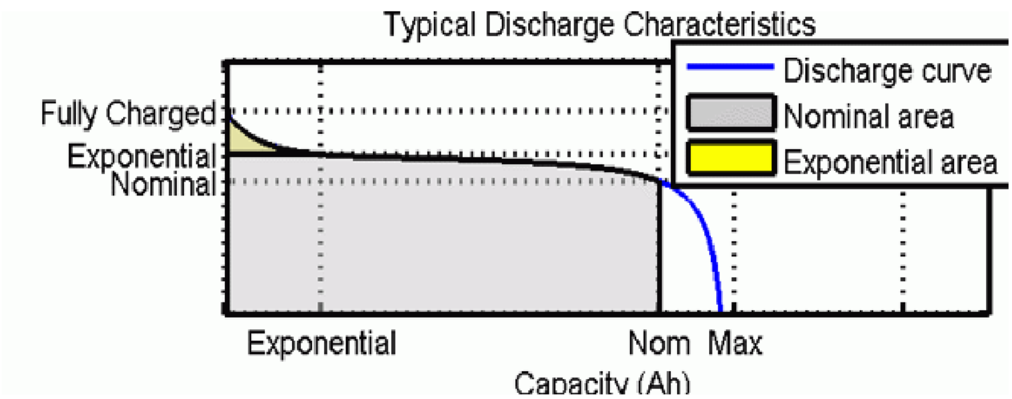


Figure 5.8: Battery Charging and Discharging

5.1.2 State of Charge and Depth of Charge

State of charge measured the fraction of charge remaining in the battery. Depth of charge measured the fraction of usable charge remaining, given the average discharge current.

Larger discharge currents caused the batterys charge to expire more prematurely, thus DOC was always less than or equal to SOC.

$$SOC = 1 - [Q_c/C(Q, \theta)] \tag{5.2}$$

$$DOC = 1 - [Q_c/C(I_{avg}, \theta)] \tag{5.3}$$

5.2 Battery Simulink

The batteries should be as completely charged as possible before discharge tests begin. To simplify, the battery modeling in charging and discharging state, the initial values of the SOC and DOC are equal to 20 % and the final values of the SOC and DOC are equal to 80 %

Battery was discharged under 10A current load and then charged under 10A constant current as it is shown in figure.cell terminal voltage at the first point of discharged process equal to 2.15V (i.e. the battery terminal voltage = 12.9V), SOC = 80 % , DOC = 80 % and when the load placed, the cell voltage, SOC and DOC becomes decreased until it reached 1.95V (i.e. the battery terminal voltage = 11.7V), 12 %, zero % (respectively),

when the battery become charged all parameter increased until cell terminal voltage reached to 2.25V (i.e. the battery terminal voltage = 13.5V) and both SOC and DOC reached to 85%.

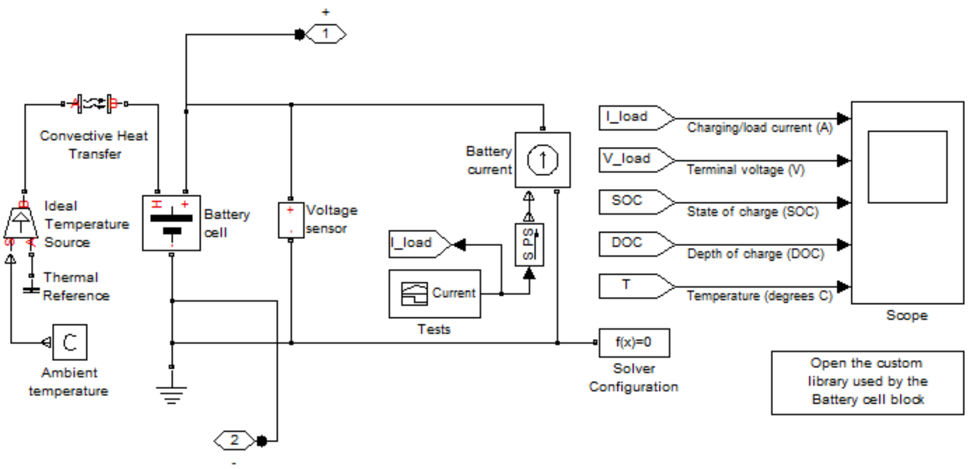


Figure 5.9: Battery simulink model

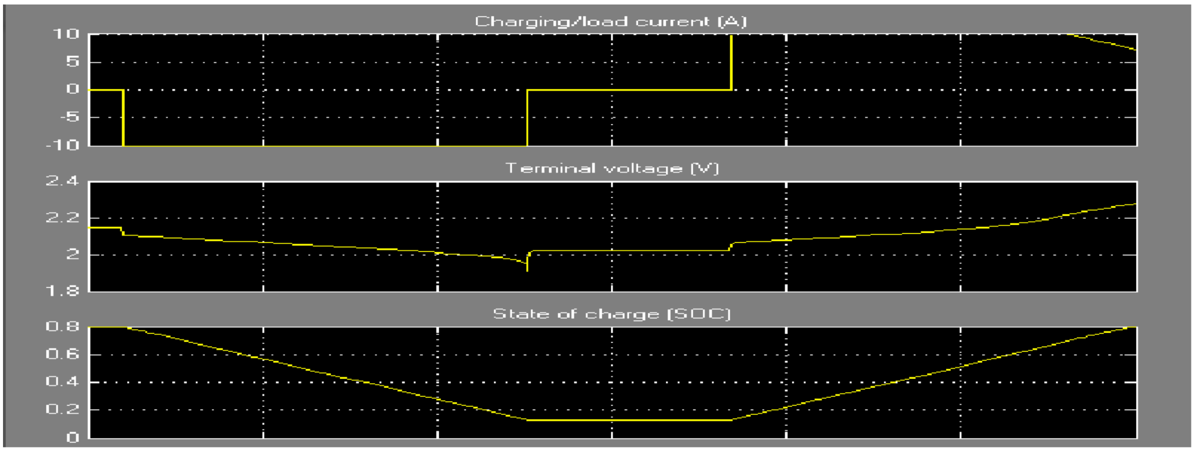


Figure 5.10: Waveform of charging current,Terminal voltage,State of Charge

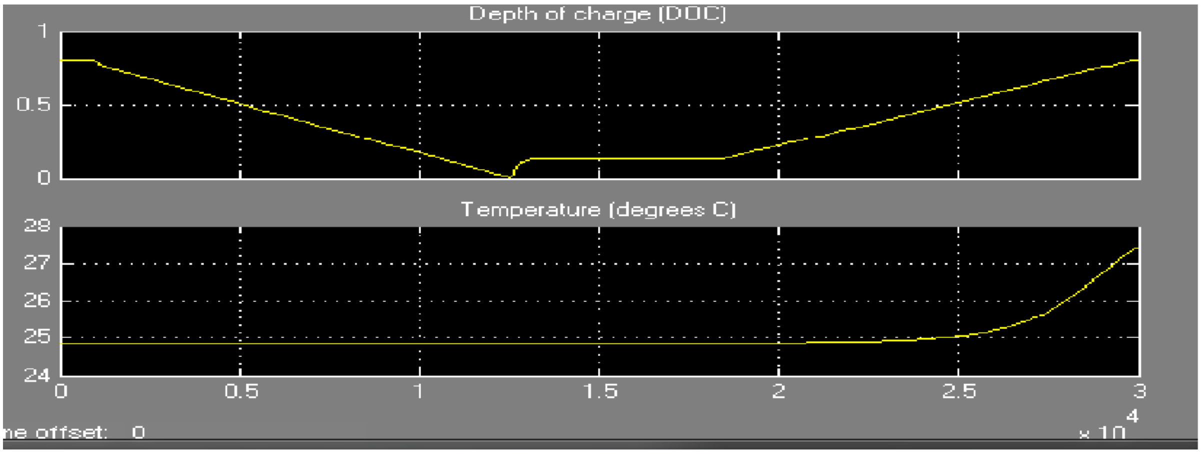


Figure 5.11: Waveform of DOC,Temperature

5.3 Result Of Solar Photovoltaic Module

Input	Output
Insolation(G)=$(G/1000)1kW/meter^2 = 1$	Photon current (I_{ph})= 2.575 A
Absolute temperature(T) = 313 K	Rev.Sat.Current (I_{rs}) = $2.377 * 10^{(} - 6)$A
Reference Temperature (T_{ref})= 298 K	Saturation Current (I_o) = $9.92 * 10^{(} - 6)$ A
Short circuit current (Isc_{ref})= 2.55 A	Photovoltaic voltage (V_{pv}) = 787.6 V
No. of cells in series (N_s)= 36	Photovoltaic current (I_{pv}) = 94.23 A
No. of cells in parallel (N_p)=1	Photovoltaic output power(P_{pv}) = 50.09kW
Open circuit voltage (V_{oc})= 21.24 V	
S.C. temp.coeficient(K_i) = 0.0017A/K	
Ideality factor(A) = 1.6	
Band gap energy(E_{go}) = 1.1ev	

Table I: Result of Solar Photovoltaic Module

Chapter 6

Wind Energy Conversion System

6.1 Wind Turbine

Wind turbines convert the kinetic energy present in the wind into mechanical energy by means of producing torque.
Since the energy contained by the wind is in the form of kinetic energy, its magnitude depends on the air density and the wind velocity.
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 owing air mass per unit time.[7]

6.1.1 Power Content of the Wind

The amount of power transferred to a wind turbine is directly proportional to the area swept out by the rotor, to the density of the air, and the cube of the wind speed.[7]

a. The power P in the wind is given by

$$P = 0.5 * C_p * \rho * A * V^3 \tag{6.1}$$

Where C_p= Turbine power coefficient

ρ=Air density(kg/m^3)

A= Rotor swept area(m^2)

D=Rotor blade diameter(m)

v= Mean wind speed(m/s)

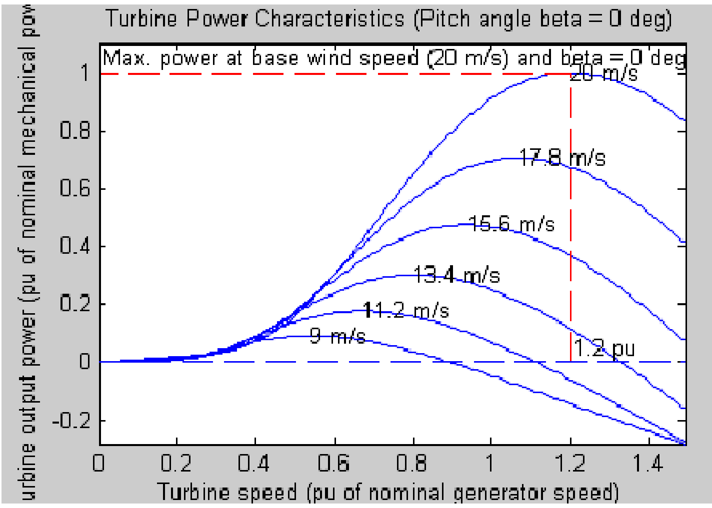


Figure 6.1: Turbine Power Characteristics

6.2 Wind Turbine Induction Generator (Phasor Type)

The Wind turbine and the induction generator (WTIG) and their icon representation in Simulink are shown on figure 6.3.

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 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.[10]

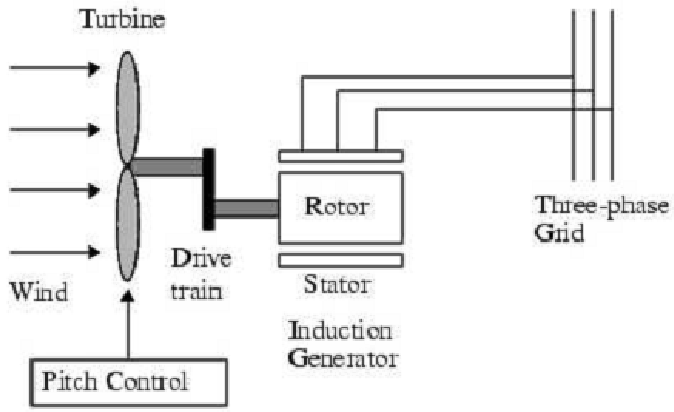


Figure 6.2: Wind Turbine Induction Generator (Phasor Type)

Figure 6.3: Wind turbine blockset

6.3 Wind Turbine Doubly-fed Induction Generator (Phasor Type)

The Wind turbine and the doubly-fed induction generator (WTDFIG) and their icon representation in Simulink are shown in the figure.6.5

The AC/DC/AC converter is divided into two components: the rotor-side converter C_{rotor} and the grid-side converter C_{grid}. C_{rotor} and C_{grid} are Voltage-Source Converters that use forced-commutated power electronic devices (IGBT) to synthesize an AC voltage from a DC voltage source.

A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L is used to connect C_{grid} to the grid. The three-phase rotor winding is connected to C_{rotor} by slip rings and brushes and the three-phase stator winding is directly connected to the grid.

The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings.

The control system generates the pitch angle command and the voltage command signals V_r and V_{gc} for C_{rotor} and C_{grid} respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals. [8]

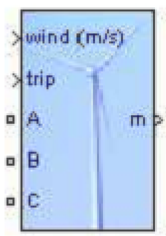


Figure 6.4: Wind turbine blockset

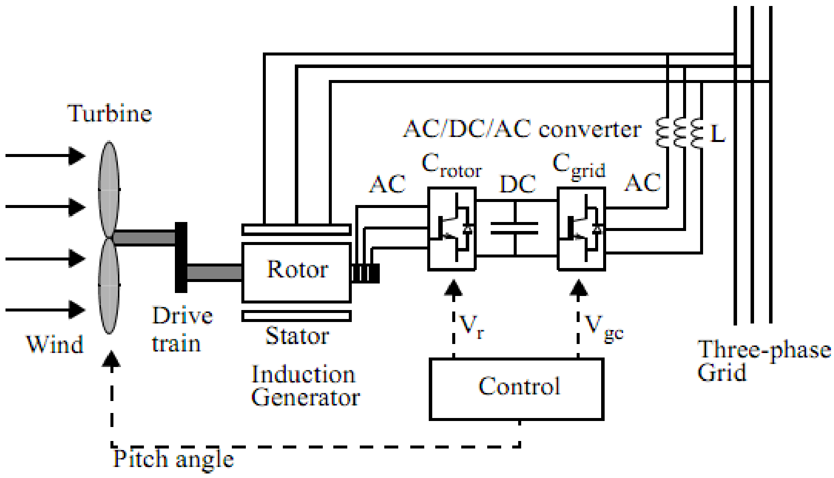


Figure 6.5: Wind turbine and Doubly fed induction generator

6.4 Doubly-Fed Induction Generator (DFIG) Driven by a Wind Turbine model

As shown in the figure 6.6 below a 50 kW wind farm is connected to a 25kV distribution system exports power to a 120 kV grid through a 30 km .

Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter modeled by voltage sources.

The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. 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. Here,wind turbines using a doubly-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 50 kw and voltage of 219.65 V.

This voltage level of 219.65 V is stepped up to a voltage level of 25 kV. This 25 kV voltage level is further stepped up to 120kV. The resultant circuit diagram of wind driven doubly fed induction generator is simulated using MATLAB/SIMULINK and shown in figure.

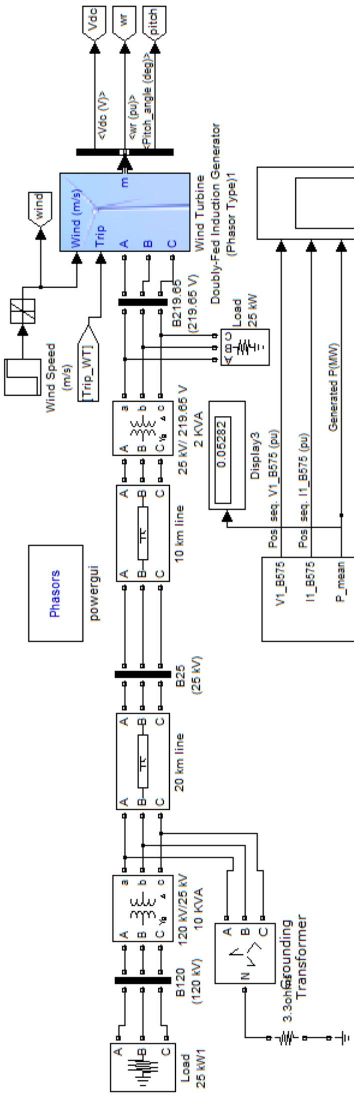


Figure 6.6: Matlab simulink model of wind turbine with DFIG

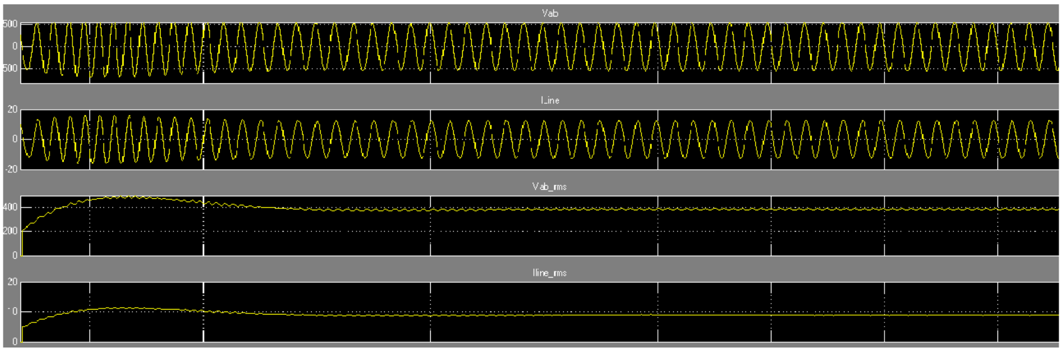


Figure 6.7: Waveform of RMS voltage and current

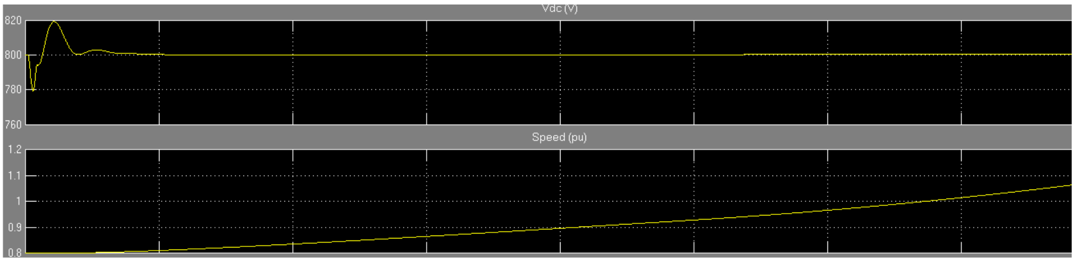


Figure 6.8: Waveform of Rotor speed and voltage

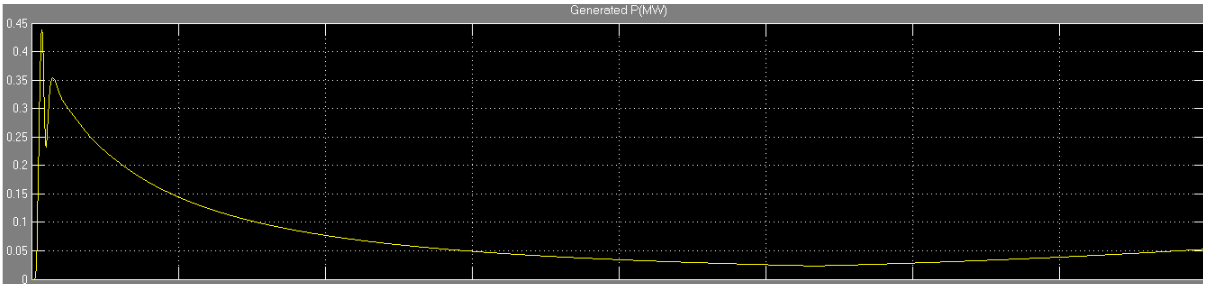


Figure 6.9: Waveform of Active power generated

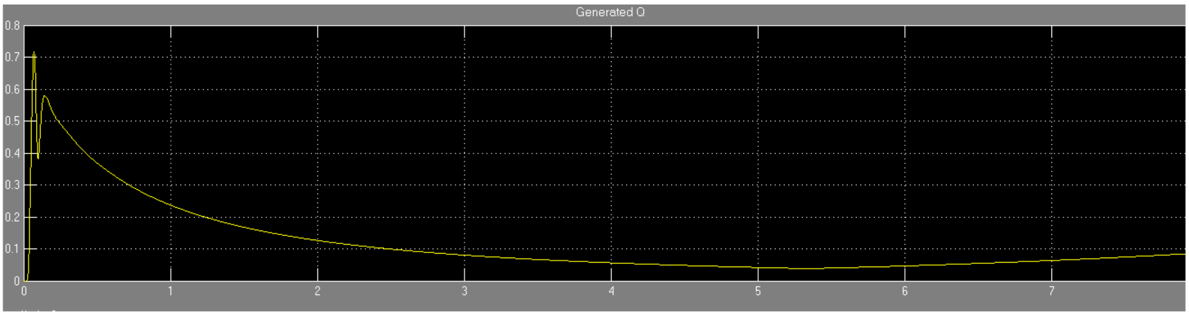


Figure 6.10: Waveform of Reactive power generated

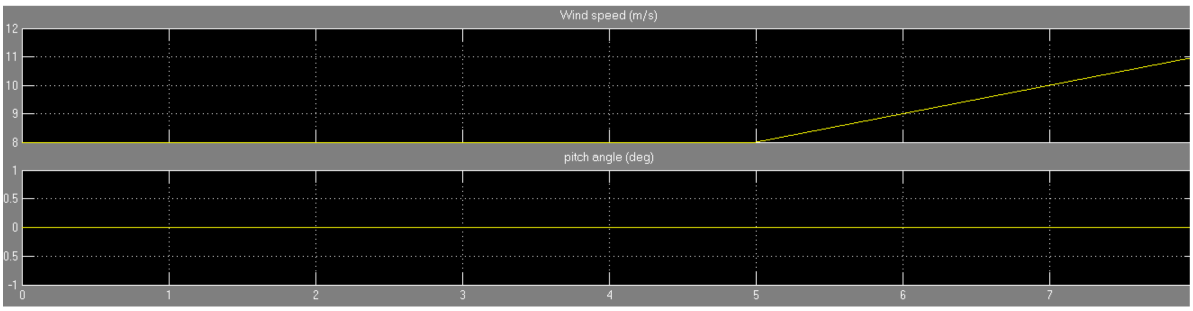


Figure 6.11: Waveform of Wind speed and Pitch angle

6.5 Hybrid Solar-Wind Power System

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.
Hybrid Solar-Wind applications are implemented in the field, where all-year energy is to be consumed without any chance for an interrupt.Photovoltaic Solar Panels and small Wind turbines depend on climate and weather conditions. Therefore, neither Solar nor Wind power is sufficient alone.
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 through 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.
This configuration is fit for Stand-alone Hybrid Power System used in remote area. 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 Doubly fed induction generator (DFIG) and PV array. The two energy sources are connected in parallel to a common dc bus line through their individual dc-dc converters. The load may be dc connected to the dc bus line or may include a PWM voltage source inverter to convert the dc power into ac at 50 Hz.
cite8 Each source has its individual control. The output of the hybrid generating system goes to the dc bus line to feed the isolating dc load or to the inverter, which converts the dc into ac. 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, through a discharge diode. A battery discharge diode is to prevent the battery from being charged when the charger is

opened after a full charge.[11]

Proposed hybrid system is as shown below :

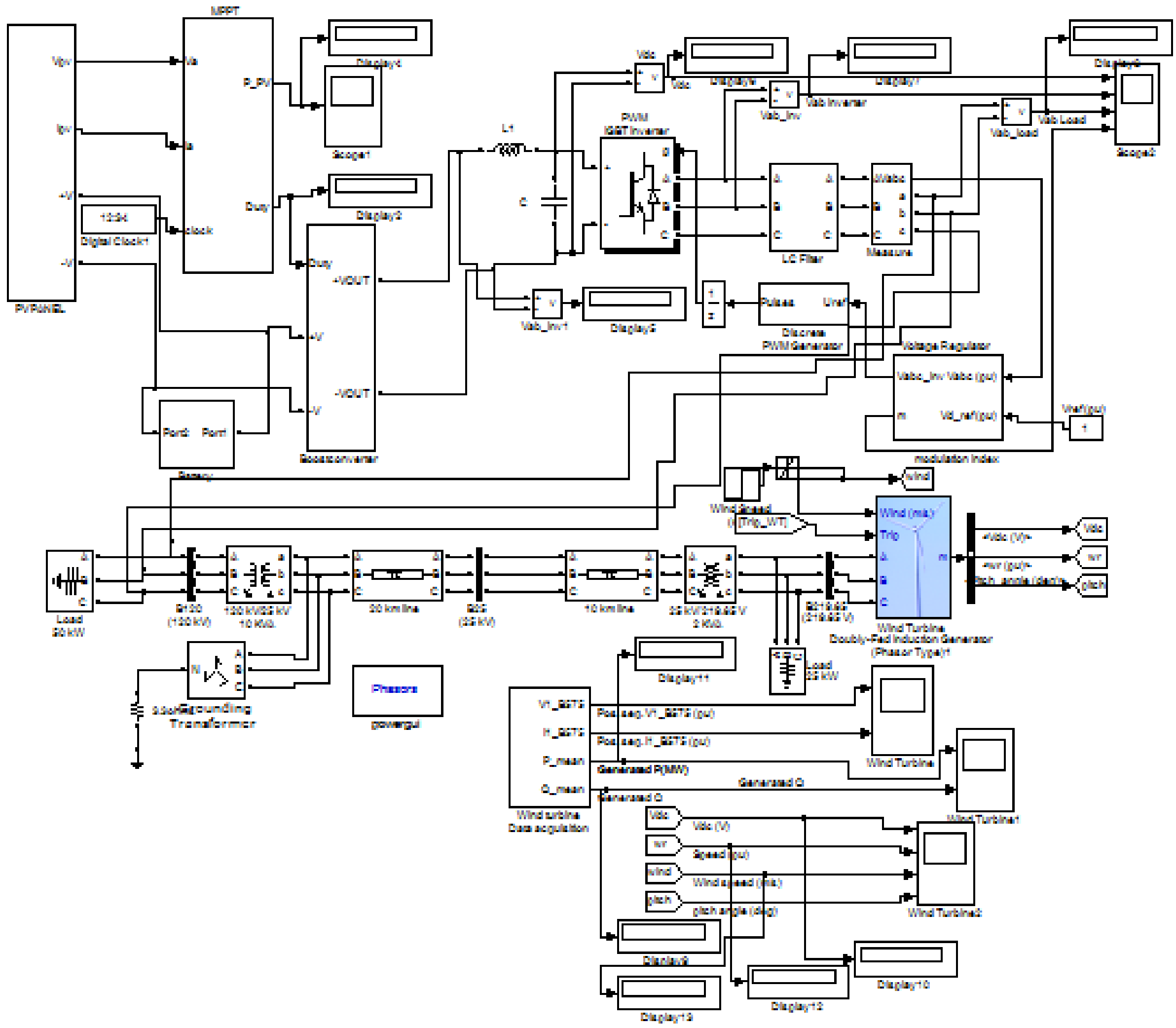


Figure 6.12: Solar-Wind Hybrid System

Chapter 7

Optimization Technique

Initially first for the Ahmedabad location,Solar insolation and Wind speed is obtained from NASA meterological department Sites.

Components used for Solar-Wind Hybrid Power System:

Wind Turbine: 50KW, Solar PV panel: 50KW, Converter:50KW, Battery: of 12V and 200Ah.

a. Solar Insolation and Wind Speed for Ahmedabad location[4]

Month	Daily Solar Radiation($kWh/m^2/day$)	Clearness index	Wind Speed (m/s)
January	6.15	4.2	3.53
February	6.49	4.2	3.58
March	6.49	4.1	3.72
April	6.06	4.0	4.18
May	5.42	3.9	4.82
June	5.29	4.1	5.12
July	3.77	2.9	4.38
August	3.76	2.7	3.69
September	4.88	3.6	3.49
October	6.01	4.1	2.71
November	6.33	4.2	2.68
December	5.80	4.0	3.03

Table I: Solar Radiation and Wind Speed data column chart

7.1 Calculation for System Sizing of Solar Wind Hybrid Power System

7.1.1 Power Generated by Wind turbine:

Wind turbine captures kinetic energy from wind and converts into electricity. Basic equation for energy recovery form the wind is as follows.

$$P = 0.5 * C_p * \rho * A * V^3 * u_c \tag{7.1}$$

Where C_p= Turbine power coefficient

ρ=Air density (kg/m^3)

A= Rotor swept area(m^2)

D= Rotor blade diameter(m)

v= Mean wind speed(m/s)

7.1.2 Power Generated by Photovoltaic Panel:

Determine daily load requirement and calculate the size of the photovoltaic array.

$$PV arraysize = \frac{TP}{SH} \tag{7.2}$$

where

TP= Total Power Requirement

SH= Sunshine Hours

7.1.3 Required Battery and Inverter Size:

$$BatteryBankSize = \frac{5 * TP}{BatteryVoltage} \tag{7.3}$$

where

TP=Total Power Required

For stand-alone system inverter size that is almost equals to PV array size.

7.1.4 Steps for Sizing Calculation of Stand-alone PV / Wind Hybrid Power System

a. Determine daily load requirement in kW and kWh.Multiply daily load by a fudge factor of 1.5. This accounts the system efficiencies, including wire and interconnection losses as well as the efficiency of the battery charging and discharging cycles.

b. Determine daily sunshine hours and decide battery voltage

c. Calculate power generated by Wind turbine using average daily wind speed and rotor diameter using above equation

d. Calculate total power required by PV panel by subtracting power generated by wind turbine from daily load required.

e. Determine PV array size

f. Determine battery bank size

g. Determine inverter size that is almost equals to PV array size.[13]

7.1.5 Calculated data for the load of 10 kWh/Day

To calculate the sizing data for load requirement of 10 kWh/day the calculation has been done as per given procedure. The results are shown in table III. The input data required for calculation is shown in table II.

	March-June	July-October	November-Feb.
Load Requirement	10 kWh/day	10 kWh/day	10 kWh/day
Total Sunshine Hours(SH)	10 Hours/day	8 Hours/day	7 Hours/day
Battery voltage	48 V	48 V	48 V
Wind Speed	4.046 m/s	4.995 m/s	3.205 m/s
Wind Turbine rotor Diameter	2.8 m	2.8 m	2.8 m

Table II: Data Required for Calculation for 100 kWh/day

	March-June	July-Oct.	Nov.-Feb.
Actually Load Req.	15000 Wh/day	15000 Wh/day	15000 Wh/day
Power gen.by wind turbine	513.61 Wh/day	966.41 Wh/day	255.29 Wh/day
Power req.by PV panel	14486.38 Wh/day	14033.58 Wh/day	14744.70 Wh/day
Required Array size	1448.63 Watt	1754.198 Watt	2106.386 Watt
Battery bank size	1508.99 Ah	1461.83 Ah	1535.906 Ah

Table III: Calculation of Sizing and Power Generation

7.1.6 Calculated data for the load of 100 kWh/Day

To calculate the sizing data for load requirement of 100 kWh/day the calculation has been done as per given procedure. The results are shown in table III. The input data required for calculation is shown in table IV.

	March-June	July-Oct.	Nov.-Feb.
Load Req.	100 KWh/day	100 KWh/day	100 KWh/day
Total Sunshine Hours(SH)	10 Hours/day	8 Hours/day	7 Hours/day
Battery voltage	96 V	96 V	96 V
Wind Speed	4.046 m/sec	4.995 m/sec	3.205 m/sec
Wind Turbine rotor Diameter	8 m	8 m	8 m

Table IV: Data Required for Calculation for 100 kWh/day

	March-June	July-Oct.	Nov.-Feb.
Actually Load Req.	150000 Wh/day	150000 Wh/day	150000 Wh/day
Power gen.by wind turbine	4192.73 Wh/day	7889.08 Wh/day	2084.03 Wh/day
Power req. by PV panel	145807.27 Wh/day	142110.92 Wh/day	147915.97 Wh/day
Required Array size	14580.72 Watt	17763.86 Watt	21130.85 Watt
Battery bank size	7594.12 Ah	7401.61 Ah	7703.95 Ah

Table V: Calculation of Sizing and Power Generation

7.2 Calculation for Cost of Electricity

To calculate Cost of electricity, Capital cost and life time of equipment should be known.

Normally 50 kW PV panel generates 200 units per day and 50 kW wind turbine generates 150 units per day.

Calculation steps.

a. Decide components, its Capital cost, life time of each equipment.

b. Calculate cost per year of each equipment by dividing capital cost of that equipment to the life time of that equipment.

c. Calculate electricity generation over year.

d. Cost of electricity is the summation of cost per year of all equipment divided by electricity generation over year.[12]

For this calculation we will consider three plant size i.e. 1kWh/day, 10 kWh/day,100 kWh/day.

7.2.1 Case-I Solar Power System

We will consider 1st 50 kW PV panel, 50 kW Inverter, battery of 200Ah.

As 50 kw PV panel generates 200 units per day so this system should be used for loading condition of 200 kWh/day.

Equipment	Rating	Cost(INR)	Lifetime(Years)
PV	50 kW	120000000	20
Battery	200 Ah	20000	3
Inverter	50 kW	1000000	20

Table VI: Equipment details

Calculation:

Total Capital Cost = Cost of PV panel + Cost of Battery + Cost of Inverter

= 120000000 + 20000 + 1000000

= 13020000

$$CostPeryear = \frac{CostofPVPanel}{LifetimeofPVPanel} + \frac{CostofBattery}{LifetimeofBattery} + \frac{CostofInverter}{LifetimeofInverter} \tag{7.4}$$

$= \frac{12000000}{20} + \frac{20000}{3} + \frac{1000000}{20}$

=656666.66

Total Cost per year = Cost per year + Op. and Maintenance cost + Discount rate

= 656666.66 + 65666.66 +65666.66

= 788000

In above equation Operation and maintenance cost and discount cost is 10 % of cost per year.

$$Costofenergy = \frac{TotalCostperyear}{Generationperyear} \tag{7.5}$$

$$= \frac{788000}{200 * 365} \tag{7.6}$$

$$= 11 \text{ Rs/kWh}$$

Now, considering the different plant size i.e. 1 kWh/day, 10 kWh/day, 100 kWh/day. Same calculation can be done.

Calculation of Standalone Solar PV Power System					
	Unit Sizing	1 KWh/Day	10 KWh/day	100 KWh/day	
PV Panel	50	37.5	375	2500	KW
Battery	1	2	15	130	Quantity
Inverter	50	2.5	25	250	KW
Cost of PV Panel	12000000	9000000	90000000	600000000	Rs
Cost of Battery	20000	40000	300000	2600000	Rs
Cost of Inverter	1000000	50000	500000	5000000	Rs
Capital Cost	13020000	9090000	90800000	607600000	Rs
Life Time of PV Panel	20	20	20	20	Years
Life Time of Battery	3	3	3	3	Years
Life Time of Inverter	20	20	20	20	Years
Electricity produced by PV	200	100	1000	10000	kWh/day
Total Electricity Production Over a Year	73000	36500	365000	3650000	kWh/day
Cost per year	656666.66	465833.33	4625000	35116666.66	Rs/Year
Operation and maintence	65666.66	46583.33	462500	3511666.66	Rs/Year
Discount Rate	65666.66	46583.33	462500	3511666.66	Rs/Year
Total Cost	788000	5550000	5550000	42140000	Rs/Year
Cost of Electricity	11	16	15	12	Rs/KWh

Figure 7.1: Solar Power System : Calculation result for different loading

7.2.2 Case-II Wind Power System

We will consider 1st 50 kW Wind turbine, Battery of 200Ah.

As 50 kW Wind turbine generates 150 units per day so this system should be used for loading condition of 150 kWh/day.

Equipment	Rating	Cost(INR)	Lifetime(Years)
Wind turbine	50 kW	8750000	15
Battery	200 Ah	20000	3

Table VII: Equipment details

Calculation:

Total Capital Cost = Cost of Wind turbine + Cost of Battery

= 8750000 + 20000

= 8770000

$$CostPeryear = \frac{CostofWindturbine}{LifetimeofWindturbine} + \frac{CostofBattery}{LifetimeofBattery} \tag{7.7}$$

$$= \frac{8750000}{15} + \frac{20000}{3} \tag{7.8}$$

= 590000

Total Cost per year = Cost per year + Op. and Maintenance cost + Discount rate

= 590000 + 59000 + 59000

= 708000

In above equation Operation and Maintenance Cost and Discount Cost is 10 % of Cost per year.

$$Costofenergy = \frac{TotalCostperyear}{Generationperyear} \tag{7.9}$$

$$= \frac{708000}{150 * 365} \tag{7.10}$$

$$= 13 \text{ Rs/kWh}$$

Now, considering the different plant size i.e. 1 kWh/day, 10 kWh/day, 100 kWh/day. Same calculation can be done

Calculation of Standalone Wind PV Power System					
	Unit Sizing	**1 KWh/Day**	**10 KWh/day**	**100 KWh/day**	
Wind Turbine	50	37.5	375	2500	KW
Battery	1	2	15	130	Quantity
Cost of Wind turbine	8750000	6562500	65625000	437500000	Rs
Cost of Battery	20000	40000	300000	2600000	Rs
Capital Cost	8770000	6602500	65925000	440100000	Rs
Life Time of Wind Turbine	15	15	15	15	Years
Life Time of Battery	3	3	3	3	Years
Electricity produced by Wind	150	75	900	7500	kWh/day
Total Electricity Production Over a Year	54750	27375	328500	2737500	kWh/day
Cost per year	590000	450833.33	4475000	30033333.33	Rs/Year
Operation and maintence	59000	45083.33	447500	3003333.33	Rs/Year
Discount Rate	59000	45083.33	447500	3003333.33	Rs/Year
Total Cost	70800	541000	5370000	36040000	Rs/Year
Cost of Electricity	13	19	16	13	Rs/KWh

Figure 7.2: Wind Power System : Calculation result for different loading

7.2.3 Case-III Solar-Wind Hybrid Power System

We will consider 1st 50 kW PV panel, 50 kW Wind turbine, 50 kW Inverter, Battery of 200Ah. As 50 kW PV panel generates 200 units per day and 50 kW wind turbine generates 150 units per day so this system should be used for loading condition of 350 kWh/day.

Equipment	Rating	Cost(INR)	Lifetime(Years)
PV	50 kW	120000000	20
Wind turbine	50 kW	8750000	15
Battery	200 Ah	20000	3
Inverter	50 kW	1000000	20

Table VIII: Equipment details

Calculation:

Total Capital Cost = Cost of PV panel + Cost of Wind turbine + Cost of Battery

+ Cost of Inverter

= 120000000 + 8750000 + 20000 + 1000000

= 21770000

$$\text{Cost Per year} = \frac{Cost of PV panel}{Lifetime of PV panel} + \frac{Cost of Wind turbine}{Lifetime of Wind turbine} + \frac{Cost of Battery}{Lifetime of Battery} + \frac{Cost of Inverter}{Lifetime of Inverter}$$

$$= \frac{12000000}{20} + \frac{8750000}{15} + \frac{20000}{3} + \frac{1000000}{20}$$

$$= 1140000$$

Total cost per year = Cost per year + Op. and Maintenance Cost + Discount rate

= 1140000 + 114000 +114000

= 1338000

In above equation Operation and Maintenance Cost and Discount cost is 10% of Cost per year.

$$Costofenergy = \frac{TotalCostperyear}{Generationperyear} \tag{7.11}$$

$$= \frac{1338000}{350 * 365} \tag{7.12}$$

$$= 10 \text{ Rs/kWh}$$

Now, considering the different plant size i.e. 1 kWh/day, 10 kWh/day, 100 kWh/day. Same calculation can be done.

Calculation of Hybrid Solar-Wind Power System					
	Unit Sizing	1 KWh/Day	10 KWh/day	100 KWh/day	
PV Panel	50	37.5	375	2500	KW
Battery	1	2	15	130	Quantity
Inverter	50	2.5	25	250	KW
Wind Turbine	50	37.5	375	2500	KW
Cost of PV Panel	12000000	9000000	90000000	600000000	Rs
Cost of Battery	20000	40000	300000	2600000	Rs
Cost of Inverter	1000000	50000	500000	5000000	Rs
Cost of Wind turbine	8750000	6562500	65625000	437500000	Rs
Capital Cost	21770000	15652500	156425000	1045100000	Rs
Life Time of PV Panel	20	20	20	20	Years
Life Time of Battery	3	3	3	3	Years
Life Time of Inverter	20	20	20	20	Years
Life Time of Wind Turbine	15	15	15	15	Years
Electricity produced by PV	200	100	1000	10000	kWh/day
Electricity produced by Wind	150	75	900	7500	KWh/day
Total Electricity Production Over a Year	127750	63875	876000	6387500	kWh/day
Cost per year	1140000	903333.33	9000000	60283333.33	Rs/Year
Operation and maintence	114000	90333.33	900000	6028333.33	Rs/Year
Discount Rate	114000	90333.33	900000	6028333.33	Rs/Year
Total Cost	1338000	1084000	10800000	72340000	Rs/Year
Cost of Electricity	10	17	13	11	Rs/KWh

Figure 7.3: Solar-Wind Hybrid Power System : Calculation result for different loading

7.3 Comparison

Comparison for Unit Sizing that is PV panel of 50 kW, Wind turbine of 50 kW, Battery of 200 Ah and Inverter of 50 kW between Solar Power System,Wind Power System, and Hybrid Power System. Hybrid Power System initially costs high but it generates more electricity and it also least cost of electricity than Solar Power System.

	Solar PV System	Wind Power System	Hybrid System
Plant size	200 kWh/day	150 kWh/day	350 kWh/day
Initial capital	13020000 INR	8770000 INR	21770000 INR
Electricity gen.over year	73000 kWh	590000 kWh	127750 kWh
Cost of Energy	11 Rs/kWh	13 Rs/kWh	10 Rs/kWh

Table IX: Comparison between Solar PV System,Wind Power System and Hybrid Power System

For plant size of 1 kWh/day , it can be suggest that for lower plant size Solar Power Plant is more economical that Hybrid Power System.

	Solar PV System	Wind Power System	Hybrid System
Initial capital	9090000 INR	6602500 INR	15652500 INR
Electricity gen.over year	36500 kWh	27375 kWh	63875 kWh
Cost of Energy	16 Rs/kWh	19 Rs/kWh	17 Rs/kWh

Table X: Comparison between Solar PV System,Wind Power System and Hybrid Power System for 1 kWh/day

For plant size of 10 kWh/day, it can be suggested that Hybrid Power System is more economical.

	Solar PV System	Wind Power System	Hybrid System
Initial capital	90800000 INR	65925000 INR	156425000 INR
Electricity gen.over year	365000 kWh	328500 kWh	876000 kWh
Cost of Energy	15 Rs/kWh	16 Rs/kWh	13 Rs/kWh

Table XI: Comparison between Solar PV System,Wind Power System and Hybrid Power System for 10 kWh/day

For plant size of 100 kWh/day , it can be suggested that Hybrid Power System is more economical.

	Solar PV System	Wind Power System	Hybrid System
Initial capital	607600000 INR	440100000 INR	1045100000 INR
Electricity gen.over year	3650000 kWh	2737500 kWh	6387500 kWh
Cost of Energy	12 Rs/kWh	13 Rs/kWh	11 Rs/kWh

Table XII: Comparison between Solar PV System,Wind Power System and Hybrid Power System for 100 kWh/day

Chapter 8

Conclusion and Future work

8.1 Conclusion

From the simulation results of Solar PV panel.it can be concluded that the PV current $I_{ph}$is a function of the Solar irradiation and is the only energy conversion process in which light energy is converted to electrical energy.
Also it indicate that PV voltage is a function of the junction voltage of diode.
From the I-V and P-V characteristics,it shows that under constant irradiance with varying temperature,When the operating temperature increases, the current output increases marginally but the voltage output decreases drastically, which result in net reduction in power output with a rise in temperature

From the simulation of Doubly-Fed Induction Generator (DFIG) Driven by a Wind Turbine model model,it can be concluded that wind turbines using a doubly-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 50 kw and voltage of 219.65 V. This voltage level of 219.65 V is stepped up to a voltage level of 25 kV. This 25 kV voltage level is further stepped up to 120kV.

Input	Output
Insolation(G)=$(G/1000)1kW/meter^2 = 1$	Photon current (I_{ph})= 2.575 A
Absolute temperature(T) = 313 K	Rev.Sat.Current (I_{rs}) = $2.377 * 10^(-6)$A
Reference Temperature (T_{ref})= 298 K	Saturation Current (I_o) = $9.92 * 10^(-6)$ A
Short circuit current (Isc_{ref})= 2.55 A	Photovoltaic voltage (V_{pv}) = 787.6 V
No. of cells in series (N_s)= 36	Photovoltaic current (I_{pv}) = 94.23 A
No. of cells in parallel (N_p)=1	Photovoltaic output power(P_{pv}) = 50.09kW
Open circuit voltage (V_{oc})= 21.24 V	
S.C. temp.coeficient(K_i) = 0.0017A/K	
Ideality factor(A) = 1.6	
Band gap energy(E_{go}) = 1.1ev	

Table I: Result of Solar Photovoltaic Module

From the Cost Optimization techniques implemented in this work.it can be concluded that

- Hybrid Power System Initially cost high but it generate more electricity with least Cost of Energy.
- For lower Plant Size it can be suggested that Solar Power Plant is more economical but for higher plant size, Hybrid System is more economical as compare to Stand-alone Solar and Wind Power System.
- Also ,proved that as loading condition increases per day, the Cost per unit reduce.

8.2 Future work

- To Optimize the cost,different optimization techniques will be used,such as Particle Swarm Optimization,Hybrid Genetic Algorithm
- Use of Supercapacitor in place of Battery for excess electricity storage

Appendix A

Implementation of MPPT Algorithm in MATLAB

The Perturb and Observe algorithm that extract the Maximum Power Point in matlab is shown below

```
function D = PO(V,I,T)
persistent P2 P1 dP d dd n;
if isempty(V)
V=20;
end
if isempty(I)
I=0;
end
if isempty(P2)
P2=0;
end
if isempty(P1)
P1=0;
end
```

AppendixA

```
if isempty(dP)
dP=0;
end
if isempty(d)
d=1;
end
if isempty(dd)
dd=0;
end
if isempty(n)
n=1;
end

    if (T > n*0.02)
n = n + 1;
P1=P2;
P2=V*I;
dP=P2-P1;
if (dd==0)
if dP>1
dd=0.01;
d=d+dd;
else
if dP<-1
dd=-0.01;
d=d+dd;
else
dd=0;
end
```

Appendix A

```
end
else
if ((dP<1)||(dP>-1))
dd=0;
d=d+dd;
else
if ((dP/dd)>0)
dd=0.01;
d=d+dd;
else
dd=-0.01;
d=d+dd;
end
end
end
end
D=d/(d+1);
if D<0.1
D=0.1;
d=D/(1-D);
else
if D>0.9
D=0.9;
d=D/(1-D);
else
end
end
end
```

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