# VISVESVARAYA TECHNOLOGICAL UNIVERSITY
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**Project Report**

on

**"Design and Analysis of Solar-Wind fed Battery Charger for Electric Vehicles using MATLAB/SIMULINK"**

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

**BACHELOR OF ENGINEERING**

in

**ELECTRONICS & COMMUNICATION ENGINEERING**


Submitted by

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**Approved by All India Council for Technical Education, New Delhi.**


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# CERTIFICATE

This is to certify that, the VIII Semester Project work titled **"Design and Analysis of Solar-Wind fed Battery Charger for Electric Vehicles using MATLAB/SIMULINK"** is carried out by **Akash K.B [4MU18EC001]**, **Indra Kumar R [4MU18EC009]**, **Sindhura Y.N [4MU18EC030]** and **Sukrutha R [4MU18EC031]**, bonafide students of **Mysuru Royal Institute of Technology, Mandya**, in partial fulfillment for the award of the Degree of Bachelor of Engineering in the Department of Electronics & Communication Engineering, of the Visvesvaraya Technological University, Belagavi, during the year 2021-2022. The project report has been approved as it satisfies the academic requirements with respect to the project work prescribed for the Bachelor of Engineering Degree.

| Signature of Guide | Signature of HOD | Signature of Principal |
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| (Prof. Mohammed Ali) | (Prof. Jyothi M.P) | (Dr. Abhinandhan K S) |

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# DECLARATION

We Akash K.B, Indra Kumar R, Sindhura Y.N and Sukrutha R students of VIII semester Bachelor of Engineering in Electronics and Communication Engineering, MRIT, Mandya, hereby declare that, this dissertation work titled "Design and Analysis of Solar-Wind fed Battery Charger for Electric Vehicles using MATLAB/SIMULINK" has been carried out independently under the guidance of **Prof. Mohammed Ali**, Assistant Professor, Department Of Electronics and Communication Engineering, MRIT, Mandya in partial fulfillment of the requirements for the award of the degree in Bachelor of Engineering in Electronics and Communication Engineering, affiliated to Visvesvaraya Technological University (VTU), Belagavi during the Academic year 2021-2022.

We further declare that, this project has not been submitted with this dissertation either in part or full to any other university or institution for the award of other degree or any fellowship.

**Place: Mandya**

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ABSTRACT

Now a days, Electric vehicles (EV) are more popular and there is a need to increase the number of Charging station for Electric Vehicles. The raise in the price of oil & Pollution issues has increased the interest on the development of Electric vehicles. In general Electric vehicles uses a battery that is charged from an external power supply, but Solar Photo voltaic (PV) modules can be used to charge a battery by means of absorbing radiation from the sun and converting it into electrical power. Also, wind power is one of the fastest growing renewable energy technologies, where Wind is used to produce electricity using the kinetic energy created by motion.

In the present work the Solar & Wind energy based charging mechanism is used to generate the power for charging the battery packs of Electric vehicles. The renewable charging station consists of both the solar photo voltaic modules & a Wind generator. To transverse the ultimate power in the solar panel, an additional MPPT algorithm is used. Among different MPPT Algorithms, Perturb & Observe (P&O) techniques are used.

The DC-DC Converter is used to reduce the DC voltage produced from the solar PV panel. Three phase rectifier is used to convert an AC power output of wind to DC power. The proposed system is modeled, designed and its results are validated using MATLAB/Simulink.

**KEYWORDS:** Electrical vehicles [EV], Photo voltaic [PV], Solar & wind energy based charging mechanism [SWCM], Maximum power point tracker [MPPT], Perturb & Observe [P&O]

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# Chapter 1

# Introduction

At present, energy crisis is a vital unsolvable problem. The consumption and extraction cost of fossil fuels such as gasolene and diesel are very high. The most important downside is global warming caused by the burning of fossil fuels, where large amount of greenhouse gases is emitted that causes pollution. In prospect, there will be no fuel left for usage because of the rise in demand for gasolene and diesel. So, it is wise to adapt to electric vehicles rather than traditional IC engine vehicles. Solar-wind power technology is an efficient and feasible alternative source of renewable energy. Solar energy from the sun is stored in a battery and is employed to run a vehicle.

Renewable energy sources are the most widely studied electric power sources like wind turbine and PV cells which are the most popular renewable sources. The PV model gains a great attention in the last decades as it has not a moving part and produces less pollution to environment. The output characteristic of PV array depends on parameters radiation intensity and temperature. An increase in radiation intensity can cause increasing in the generated power in the maximum power point of PV module. The PV cells operate with maximum output power and tracks the maximum available output power of PV array and make PV system more efficient.

A solar cell is the building block of a PV panel. It is developed by connecting many solar cell in series and parallel. DC-DC Converter Based on MPPT, It is essentially used to achieve a regular DC voltage from DC source which may be the output of a rectifier or a battery or a solar cell and is fed to DC-DC converter. Popular MPPT algorithm includes P & O method, Incremental conductance method, Ripple correlation technique. Among these P & O method gives good result for all types of turbines. The P & O method is most used in MPPT because of its simple technique and it requires only few parameters. It perturbs the terminal voltage of PV array and compares the generated output power of PV with the last cycle of perturbation.

Various EV charging stations and simulation models has been analysed in and most of the literature deals with solar PV only. In some literature only wind energy is used to generate the power for recharging the EV and some EV charging station has hybrid (wind and other power sources) energy sources and ideal simulation model is used to study the performance of the system . In this work, renewable energy (solar and wind) based recharging station has been designed. Moreover, the utilization of renewable charging station make green environment. The simulations are carried out in MATLAB/Simulink Software.

**What is Energy?**

The term 'Energy' refers to the capacity or ability to do work. Kinetic energy, electrical energy, thermal energy, potential energy, chemical energy, nuclear energy, and other types of energy exist. All sources of energy are related to motion. Kinetic Energy, for example, is connected with any moving object or body.

Energy, according to the principle of conservation of energy, or the fundamental rule of thermodynamics, cannot be generated or destroyed, but can only be transformed from one form to another.

There are two primary sources of energy: Conventional sources of energy and Non-Conventional sources of energy. Conventional Sources of energy- The sources of energy that are in use for long periods of time by humans and once finished cannot be replaced quickly are called conventional sources of energy. For example Coal, petroleum, etc. Non-Conventional Sources of energy- The sources of energy that are continuously replenished in nature and are widely available. They are called non-conventional because till now they are not used extensively in our daily life. These sources of energy also do not cause pollution. For example Solar energy from the sun, wind energy from the winds, tidal energy, Bio-gas, and so on.

**Non-Conventional Sources of Energy**

The Sun is the ultimate source of energy on our planet and all other examples that are mentioned above are obtained either directly or indirectly from the sun. For example, the wind energy that we obtain from the winds and the winds are produced by the unequal heating of two different regions of the surface of the earth. Thus, we can use these sources of energy till our earth receives light from the sun, which is there for the next millions of years. This is also the reason why non-conventional sources of energy are also called renewable sources of energy as every day these energies are getting renewed in nature.

Non-conventional sources of energy, often known as renewable sources of energy, are energy sources that are continually renewed by natural processes. Non-conventional energy sources are not quickly depleted and may be created at a consistent pace for repeated usage. Tidal, Wind, Solar, Nuclear, Biomass, and other natural resources geothermal energy, are referred to as "non-conventional resources." Because they are pollution-free, we can use them to generate clean energy with minimal waste. Furthermore, these energy sources are less expensive and do not contaminate the environment or natural surroundings. They are also known as renewable energy sources since they may be created or created through natural processes at a rate greater than or equal to the rate at which they are used.

**Types of non conventional energy sources:**

1. **Tidal energy**: It is the energy possessed by the rise and fall of water during high and low tides. The tidal energy can be processed to electricity by building dams across the narrow openings of the sea.

2. **Wind Energy**:The energy obtained from the wind is called wind energy. The wind contains kinetic energy which can used to harness energy by converting it to mechanical energy by the use of windmill. Although, wind energy has been used by us for a long time, it was used in propelling the sails of the ship in the ancient times.

3. **Solar Energy**:The sun is the biggest source of energy that we have, it's radiating very high energy constantly for very long time and will continue to do so. The energy we obtain from the sun is called solar energy.

4. **Geo-thermal Energy**: It is the heat energy possessed by the rocks inside the earth. The places where the rocks inside the hot is very hot are called hotspot.

5. **Biodmass Energy**: The waste and the dead remains of living animals , plants is called bio-mass. They contain carbon compounds. The chemical energy stored in them is called bio-mass energy.

6. **Nuclear Energy**: It is the energy produce when one heavy nucleus splits into two light nuclei or two light nuclei fuses to one heavy nucleus producing enormous amount energy in form of heat and light.

Among these types of Non-conventional energy sources we are using Solar and Wind Energy.

## 1.1 Objectives

The objectives to be achieved are:

- Analysis of PV array.
- Design and analysis of MPPT algorithm.
- Design and analysis of Buck converter.
- Design and analysis of Wind System.
- Analysis of Rectifier
- Modeling of Solar-Wind fed Battery Charger using MATLAB/Simulink.

## 1.2 Methodology

The block diagram of Solar-wind fed Battery charger for Electric vehicles is as shown in fig.(1.1)

A Photo voltaic array is a linked collection of PV modules. Each PV module is made up of multiple inter connected PV cells. The cell converts Solar energy into DC electricity. PV cells operates via the PV effect which describes how certain material can converts sun lights into electricity. They absorb some pf the energy of the sun and cause current flow between to oppositely charged layers.

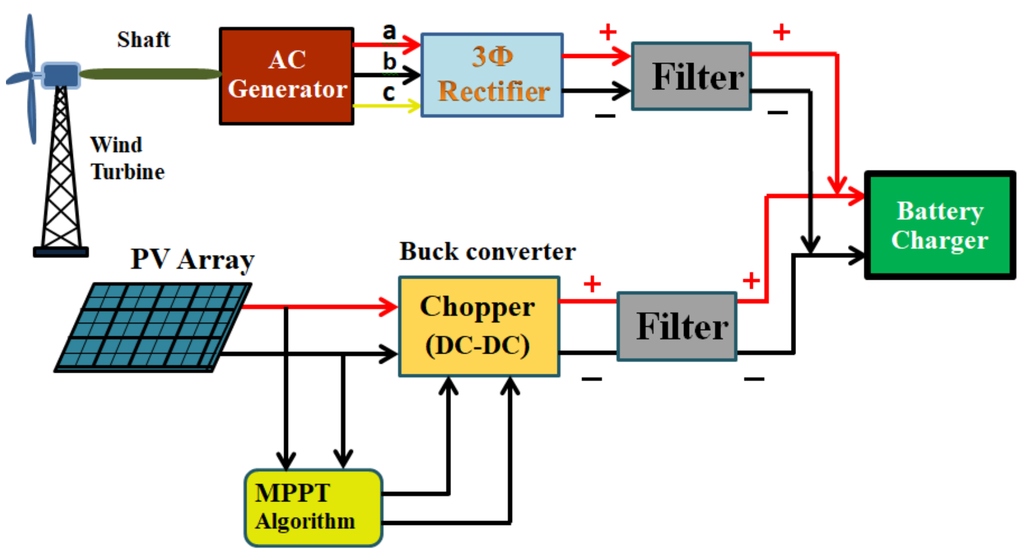



Figure 1.1: General block diagram

MPPT algorithms are necessary in PV applications Because the MPPT of a solar panel varies with the irradiance & Temperature, the use of MPPT algorithm is required in order to obtain the maximum power from PV array. Among all the algorithms P & O are most common as they have the advantage of an easy implementation.

DC-DC converter play and important role in solar power systems. They step down the output voltage of a PV array for a given set of conditions. After this filter is use to get pure DC.

Similarly, since its connected to a parallel combination with wind power system, The same voltage has to be obtained from Wind turbine also.

There is a maximum power at the output of the wind turbine. If wind and solar power generation system would like to capture the maximum wind energy, wind turbine speed must be adjusted in real time based on changes in wind speed. According to the principle of electric wind generator, we know that when the input mechanical power is greater than the output electrical power.

A wind turbine turns wind energy into Rotational mechanical energy using aerodynamic force from the rotor blades. When wind flows across the blade,the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, through a shaft and a series of gates that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

AC generator is a device that is used to produce electrical power by converting the Rotational mechanical energy into Electric energy(AC). But here required DC supply for charging the battery, so rectifier is used and it converts AC-DC. After the Rectifier a filter is used to get a pure DC. Pure DC is given to Battery charging station to charge a Electric Vehicles.

# Chapter 2

# Literature Review

The literature review presents the concept about the Solar-Wind fed Battery charger for Electric Vehicles.

## 2.1 Technical Journal and Conference Papers

[1] Shakti Singh, Prachi Chauhan, Nirbhow Jap Singh, "Feasibility of Grid-connected Solar-wind Hybrid System with Electric Vehicle Charging Station", 2021, This paper presents a grid-connected solar-wind hybrid system to supply the electrical load for an EV charging station is incorporated in the system. The proposed system is designed by considering the cost of the purchased energy, which is sold to the utility grid, while the power exchange is ensured between the utility grid and other components of the system. It is determined that a cost-effective and reliable system can be designed by the proper management of renewable power generation and load demands. The proposed system may be helpful in reducing the reliance on the over-burdened grid, particularly in developing countries. The proposed system will be helpful in promoting renewable energy sources in smart grid and can reduce the dependence of a small community on the grid.

[2] Amirhossein Jahanfar, M. Tariq Iqbal, "Design and dynamic simulation of a wind turbine powered electric vehicle charging system",2021,These days, electric vehicles (EVs) are popular, and there is a need to increase the number of charging stations for EVs. Newfoundland has considerable potential for wind energy to charge EVs. The design of such a system and its dynamics are described, and simulation results are provided in this paper. In this research, a charging station for electric vehicles is designed, and the simulation result is provided. The initial installation cost seems a bit high, so this project might not be economical, but it is quite practical and environmentally friendly. The system consists of a 10 kW wind turbine, an 8.5 kW bidirectional inverter, a battery bank to store energy while the vehicle is on the road.

[3] P Jyothi, P Saketh, Ch Vignesh, V S Kirthika Devi, "Renewable energy powered DC charging system for electric vehicle",2020, In this paper, a renewable based DC charging

system is introduced which integrates power from sun, wind and battery energy storage system (BESS) to provide an uninterruptible power supply for the load. Variable irradiance and wind speeds are considered for this study. Incremental conductance method with boost converter and hill climb method with buck converter are implemented in solar and wind respectively to maximize the system efficiency. Modelling and validation of proposed system is done using MATLAB/Simulink platform.

Simulation model for charging of electric vehicle through energy generated from solar and wind integrated system with storage system is presented in this paper. Incremental conductance method which controls boost converter and P&O technique which controls buck converter are used to extract maximum power. Variable irradiance and different wind speeds are given as input parameters for the system. Bidirectional converter is used which provides suitable path for charging and discharging of the storage system with the help of controller.

[4] Osama Elbaksawi, "Design of Photovoltaic System Using Buck-Boost Converter based on MPPT with PID Controller",2019, Different models of the PV system containing many techniques of DC-DC converter are applied in this paper such as, buck converter, boost converter and buck-boost converter which are inserted to be close the power between PV array and load by varying its duty cycle, it is named maximum power point tracking(MPPT).

Converter and MPPT system based on incremental conductance algorithm conclude that the MPPT controller deliver maximum power possible by using proposed model and give adjustment duty cycle of the DC-DC converter at any change in the irradiance. In This paper the performance of different models for PV system using MATLAB/Simulink are implemented. The maximum power is obtained using proposed model method. It is observed that the characteristics obtained based on this method is closest to the theoretical and simulations. Also from this proposed model, maximum values of voltage, maximum value of current and maximum value of power are developed.

[5] C. Chellaswamy, V. Nagaraju, R. Muthammal, "Solar and Wind Energy Based Charging Station for Electric Vehicles",2018, This paper describes the solar and wind energy based charging mechanism (SWCM) to generate the power for charging the battery packs of electric vehicles (EV). The renewable charging station consists of both the solar photo voltaic (PV) modules and a wind generator. The SWCM immensely reduce the require-

ment of fossil fuels to generate electricity which results in greatly reduced CO2 and CO related emissions. The simulation model has been developed in MATLAB- Simulink for the proposed SWCM. The I-V and P-V characteristics of the solar panel have been studied under various irradiance levels and different parameters of wind turbine has been studied under two different loading (1 kW and 3 kW) conditions. The obtained results show that the proposed renewable charging mechanism is suitable for EV charging thus creating pollution free environment.

A simulation model has been developed using MATLAB-Simulink and the performance of solar and wind energy has been studied. Various parameters of the solar module have been verified under different irradiation level. The SG has been studied under different loading condition. Finally, the hourly load of EV versus generated electricity has been analyzed. From the output generated by the hybrid system, we strongly say that the proposed SWCM provides enough power for recharging the electric vehicle and the time taken for charging can be avoided by battery swapping method. At last, we are concluding that this approach reduces the pollution and increase the usage of EVs as a result creating pollution free environment.

[6] Nirmala. M, Malarvizhi. K, Thenmozhi. G, "Solar PV based Electric Vehicle",2018, The aspect of the locomotive trade is being restructured by concerns over oil deliveries, international guidelines and fuel rates. Consequently the vehicle technology should be adaptive to these concerns. The projected paper describes solar PV powered Electric Vehicle,that solves the key downside of fuel and pollution. It is an initiative in implementing eco-friendly transportation in the world to build a green environment. An effectiveness of the proposed system have been modeled and its results, verified in MATLAB/SIMULINK.

The paper deliberates about operation of the BLDC motor in closed loop control in accord with the change in solar irradiance condition and change in set speed of an electric vehicle.

[7] Prakhar Sharma, Pankaj Kumar, Himanshu Sharma, Nitai Pal, "Closed loop controlled boost converter using a pid controller for solar wind power system installation",2018, The proposed work deals with the close loop boost converter with PID controller, which is used to attain a stabilized voltage despite of parameter changes and load disturbances. Designed system will help to analyze the better stable output voltage with efficient sys-

tem having minimum fluctuation.

The proposed system presents the modeling of a step up converter topology for solar or wind energy system installations. Based on the simulation responses in MATLAB, steady state error appears in the open loop system is resolved using the closed loop PID control technique. PID controller has small hardware and less cost. Simulation results realize improved constant output voltage with tracking of reference voltage by Trial and Error method tuning technique of PID control. Moreover, discussed system topology can also be effectively utilized in the fuzzy logic controller scheme.

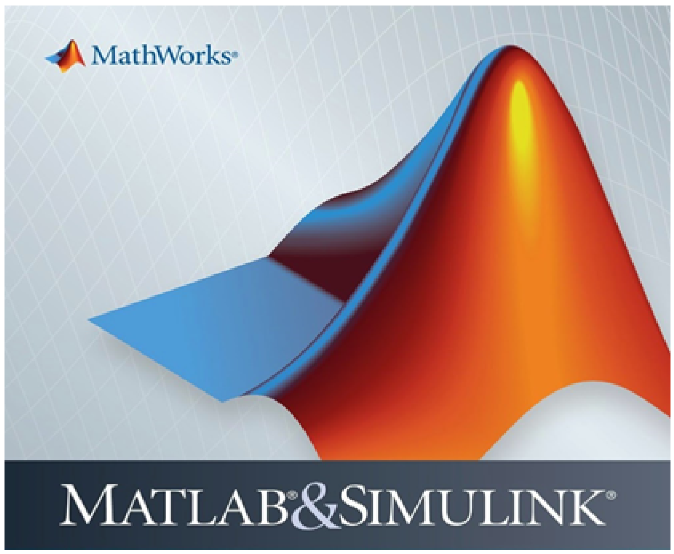
[8] A. Bharathi Sankar, R. Seyezhai, "Simulation and Implementation of Solar Powered Electric Vehicle",2016, This paper discusses about the application of solar energy to power up the vehicle. The basic principle of solar based electric vehicle is to use energy that is stored in a battery to drive the motor and it moves the vehicle in forward or reverse direction.This paper focuses on the design, simulation and implementation of the various components, namely: solar panel, charge controller, battery, DC-DC boost converter, DC-AC power converter (inverter circuit) and BLDC motor for the vehicle application. All these components are modeled in MATLAB / SIMULINK.

The importance of utilization of solar power in electric vehicle application is discussed in this paper. The proposed electric vehicle will be fuel efficient, reduce the pollution and provide noiseless operation. The drive range of the proposed electric vehicle powered by solar is improved compared with the conventional one. Selection of BLDC drive for the vehicle provides high efficiency, high operating life, torque/speed characteristics, high output power to size ratio and noiseless operation. The design of DC-DC boost converter is investigated and the input and output voltage ripple is reduced which is verified experimentally.

# Chapter 3

# Software specification

MATLAB was invented by mathematician and computer programmer cleve moler in 1970. An abbreviation of matrix laboratory is a programming language and numeric computing environment developed by mathworks.




MATLAB allows matrix manipulations, plotting of functions and data implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. Latest version of MATLAB is 2021a (R2021a), it offers hundreds of new and updated features and functions in MATLAB and Simulink.

MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C, C++, Java, and FORTRAN; analyze data; develop algorithms; and create models and applications.

It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods.

## Features of MATLAB

Following are the basic features of MATLAB

- It is a high-level language for numerical computation, visualization and application development.
- It also provides an interactive environment for iterative exploration, design and problem solving.
- It provides vast library of mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration and solving ordinary differential equations.
- It provides built-in graphics for visualizing data and tools for creating custom plots.
- MATLAB's programming interface gives development tools for improving code quality maintainability and maximizing performance.
- It provides tools for building applications with custom graphical interfaces.
- It provides functions for integrating MATLAB based algorithms with external applications and languages such as C, Java, .NET and Microsoft Excel.

## Uses of MATLAB

MATLAB is widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including

- Signal Processing and Communications
- Image and Video Processing
- Control Systems
- Test and Measurement
- Computational Finance
- Computational Biology

Simulink is a block diagram environment for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB®, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

## Key features of Simulink

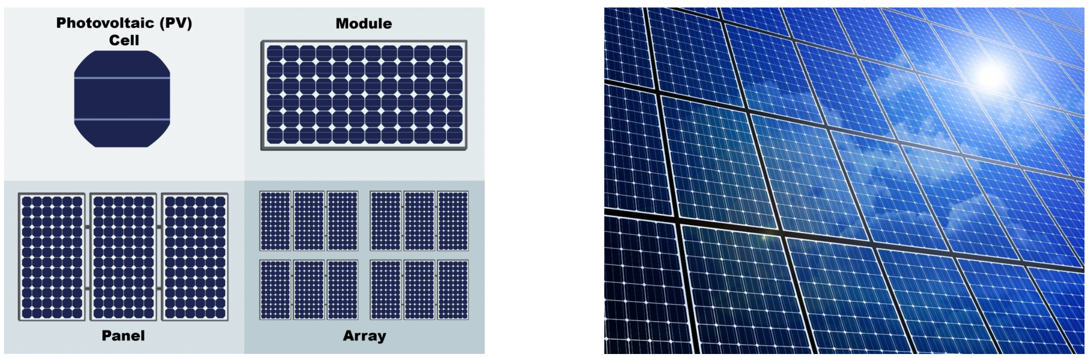
- Graphical editor for building and managing hierarchical block diagrams.
- Libraries of predefined blocks for modeling continuous-time and discrete-time systems.
- Simulation engine with fixed-step and variable-step ODE solvers.
- Scopes and data displays for viewing simulation results.
- Project and data management tools for managing model files and data.
- Model analysis tools for refining model architecture and increasing simulation speed.
- MATLAB Function block for importing MATLAB algorithms into models.
- Legacy Code Tool for importing C and C++ code into models.

# Chapter 4

# Solar cell and MPPT

## 4.1 Introduction to Solar cell (PV array)

A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels. The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). The Solar cell diagram is as shown in fig.(4.1a) and fig.(4.1b).




(a) (b)

Figure 4.1: Solar Panels

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light.

Solar cell is a current source, the electronic characteristic of which can be represented by an equivalent circuit as shown in fig.(4.2).

An ideal solar cell equivalent circuit consists of a current source $I_L$ and a diode. But in practice there are two extra resistances, one in series $R_s$ and the other in parallel $R_{sh}$. The series resistance is because of the fact that a solar cell is not a perfect conductor and represents the ohmic loss. The parallel resistance is caused by the recombination of electron-hole pair or leakage current from one terminal to the other due to poor insulation at edges.

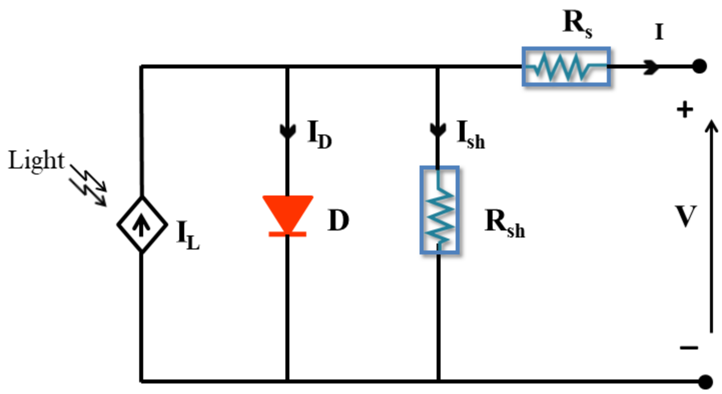



Figure 4.2: Equivalent circuit diagram of Solar cell

From the equivalent circuit diagram,

$I_L – I_d – I_{sh} = I$

Where,

IL = Current produced by the solar cell

Id = Diode current

Ish = Shunt or leakage current

I = Load current

The two limiting parameters used to characterise the output of solar cells for given irradiance, operating temperature and area are:

1 **Short circuit current**($I_{sc}$) - The maximum current, at zero voltage. Ideally, if V = 0, $I_{sc}$ = $I_L$. Note that $I_{sc}$ is directly proportional to the available sunlight.

2 **Open circuit voltage**($V_{oc}$) - The maximum voltage, at zero current. The value of $V_{oc}$ increases logarithmically with increased sunlight. This characteristic makes solar cells ideally suited to battery charging.

Note that at I = 0,

$$V_{OC} = \frac{nkT}{q} ln\left(\frac{I_L}{I_O} + l\right) \tag{4.1}$$

**Typical representation of an I-V Characteristics of Solar cells:**

The fig.(4.3) shows the current-voltage (I - V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a single solar cell or panel is the

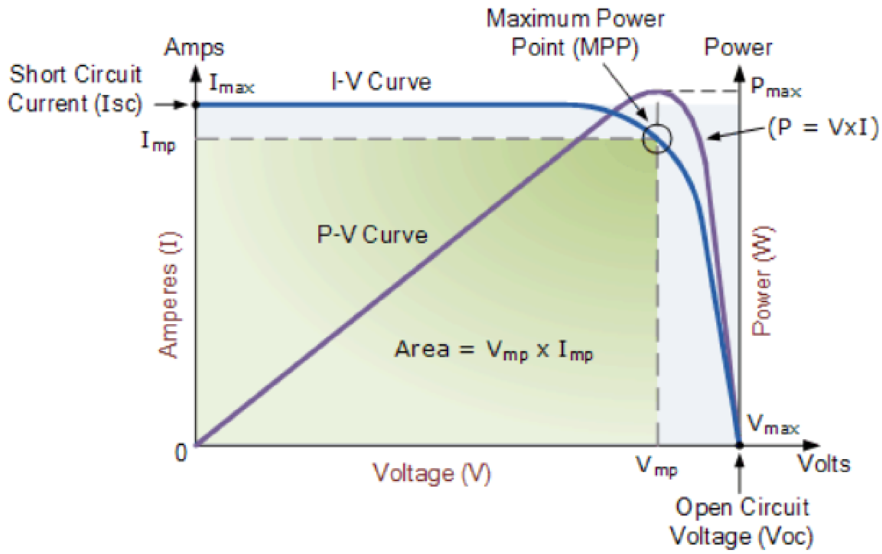



Figure 4.3: I-V Characteristics of Solar cells

product of its output current and voltage (I $\times$ V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

**Applications of Solar energy:**

- Electricity generation through photo voltaic cells
- Solar thermal power generation
- Solar energy is harnessed to pump water in remote areas.
- Solar cookers
- Solar cars, Solar buses and even satellite are also seen to operate with the help of solar energy.
- It is also use in the field of remote lighting system areas.
- It also use in portable power supplies.
- Its may be use in the field of emergency power.

## 4.2 Chopper

DC-DC converter is a converter which converts the DC voltage level of the input source into another DC voltage level. The DC-DC conversion can be done directly or can be done using alternative way. The alternative way is to invert DC input into AC and rectified back into DC after stepping up or stepping down the AC voltage using step-up or step-down transformer. A buck converter steps down the applied DC input voltage level directly.

There are mainly two types of chopper Step-up and Step-down chopper. This classification is based on the average DC output voltage of chopper. However, on the basis of quadrant operation, a chopper may be classified into five different types: Class-A, Class-B, Class-C, Class-D and Class-E chopper.

**Step-up Chopper** : It is a kind of chopper in which the average DC output voltage is more than the source voltage. In this chopper, power flows from load to source and load contains a source of emf and should be inductive.

**Step-down Chopper** : A chopper whose average DC output voltage is less than the source voltage is called step-down chopper. Power flows is always from source to load in this chopper.

**Class-A chopper** : can only operate in first quadrant. This means that, the load current and load voltage is always positive. Load current always flows from source to load and hence we can say that power is always transferred from source to load. Step-down chopper is an example of Class-A chopper.

**Class-B chopper** : The operation of Class-B chopper is confined in second quadrant. What does this mean? This means, though output voltage of chopper will be positive but the load current will be negative. Negative load current means, io flows from load to source. Thus, the power will always be transferred from load to source in this type of chopper. Step-up chopper is a Class-B chopper.

**Class-C chopper** : It can operate in both the first as well as second quadrant. During the first quadrant operation, it acts a step-down chopper while in second quadrant it behaves as step-up chopper. Basically, Class-C is obtained by parallelly connecting Class-A & Class-B chopper. This type of chopper is also known as Two Quadrant Class-A chopper. Refer the figure shown above for better understanding.

**Class-D chopper** : It can operate in first and fourth quadrant. In this chopper, the direction of load current doesn't reverse rather the average DC output voltage (Vo) may reverse. For in-depth understanding of how the polarity of output voltage reverses, kindly read Class-D chopper. Power can either be transferred from source to load or load to source. This chopper is also known as Two Quadrant Class-B chopper.

**Class-E chopper** : It is a universal chopper and can operate in all the four quadrants. Four choppers and four diodes are required to make the circuit of Class-E chopper. The necessary condition for this chopper is that load must be inductive. To obtain operation of this chopper in third and fourth quadrant, polarity of load emf is reversed. Kindly read Class-E chopper for full concept of this chopper and its operation.

### 4.2.1 Buck Converter:

DC-DC converters are also known as Choppers. Here we will have a look at the Step Down Chopper or Buck converter which reduces the input DC voltage to a specified DC output voltage.

**Basic Topology of Buck Converter :**

**The basic buck converter** consists of a controlled switch, a diode, capacitor and controlled driving circuitry. The switch controls the flow of input power into output by turning ON and OFF periodically. The time for which the switch is ON during the whole period is known as Duty cycle.

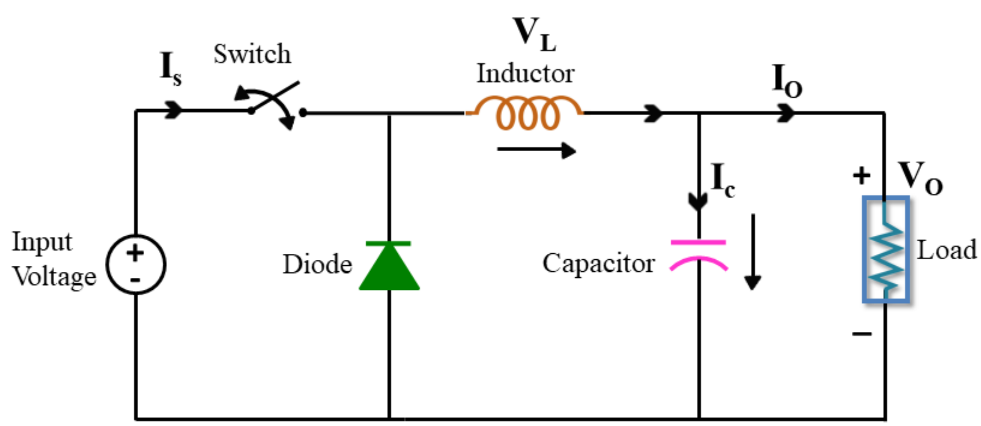



Figure 4.4: Block diagram of Buck converter

The input voltage source is connected to a controllable solid state device which operates as a switch. The solid state device can be a Power MOSFET or IGBT. Thyristors are not used generally for DC-DC converters because to turn off a Thyristor in a DC-DC circuit requires another commutation which involves using another Thyristor, whereas Power MOSFET and IGBT can be turned off by simply having the voltage between the GATE and SOURCE terminals of a Power MOSFET.

The second switch used is a diode. The switch and the diode are connected to a low-pass LC filter which is appropriately designed to reduce the current and voltage ripples. The load is a purely resistive load. The input voltage is constant and the current through load is also constant. The load can be seen as current source.

The controlled switch is turned on and off by using Pulse Width Modulation(PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. This leads to a complicated design for the low-pass LC filter which would be required to handle a large range of frequencies.

Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

The Buck converter has two modes of operation. The first mode is when the switch is on and conducting.

Mode 1 : Switch is ON, Diode is OFF The voltage across the capacitance in steady state is

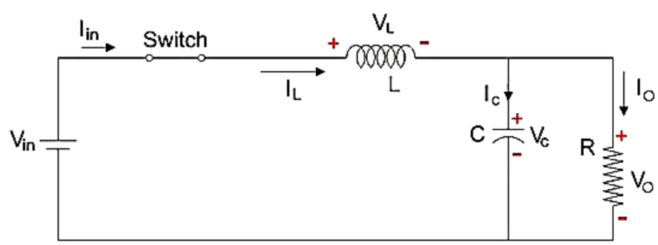



Figure 4.5: ON State

equal to the output voltage.

Let us say the switch is on for a time $T_{ON}$ and is off for a time $T_{OFF}$. We define the time period,T,as

T = $T_{ON} + T_{OFF}$

and the switching frequency,

$f_{switching} = \frac{1}{T}$

Let us now define another term, the duty cycle,

$D = \frac{C}{T}$

Let us analyse the Buck converter in steady state operation for this modeusing KVL.

$$\therefore V_{in} = V_L + V_O \tag{4.2}$$

$$\therefore V_L = L\frac{di_L}{dt} \tag{4.3}$$

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_{in} - V_O}{L} \tag{4.4}$$

Since the switch is closed for a time $T_{ON}$ = DT we can say that Δt = DT.

$$(\Delta i_L)_{closed} = \left(\frac{V_{in} - V_O}{L}\right) DT \tag{4.5}$$

While performing the analysis of the Buck converter, we have to keep in mind that

- The inductor current is continuous and, this is made possible by selecting an appropriate value of L.
- The inductor current in steady state rises from a value with a positive slope to a maximum value during the ON state and then drops back down to the initial value witha negative slope. Therefore the net change of the inductor current over anyone complete cycle is zero.

Mode 2 : Switch is OFF, Diode is ON

Here, the energy stored in the inductor is released and is ultimately dissipated in the load resistance, and this helps to maintain the flow of current through the load. But for analysis we keep the original conventions to analyse the circuit using KVL.

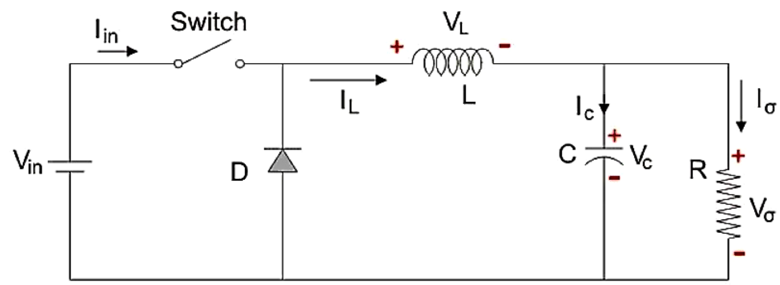



Figure 4.6: OFF State

Let us now analyse the Buck converter in steady state operation for Mode II using KVL.

$$\therefore V_L + V_O = 0 \tag{4.6}$$

$$\therefore V_L = L\frac{di_L}{dt} = -v_0 \tag{4.7}$$

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_{in} - V_O}{L} \tag{4.8}$$

Since the switch is open for a time

$T_{OFF} = T - T_{ON} = T - DT = (1-D)T$

we can say that, $\Delta t = (1-D)T$.

$$(\Delta i_L)_{open} = \left(\frac{-V_O}{L}\right)(1-D)T \tag{4.9}$$

It is already established that the net change of the inductor current over anyone complete cycle is zero.

$$\therefore (\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0 \tag{4.10}$$

$$\left(\frac{V_{in}-V_O}{L}\right)DT+\left(\frac{-V_O}{L}\right)(1-D)T=0 \tag{4.11}$$

$$D=\frac{V_O}{V_{in}} \tag{4.12}$$

A circuit of a Buck converter and its waveforms is shown below.

The inductance, L, is 20mH and the C is 100µF, and the resistive load is 5 Ω. The switching frequency is 1kHz.The input voltage is 100V DC, and the duty cycle is 0.5.

**Applications of Buck converter :**

- Point of Load Converters - Used to drive high current loads efficiently. Usually used in PCs and Motherboards.
- Battery Chargers - FOr mobile phones, laptops and power banks.
- Solar chargers.
- To drive BLDC motors.

## 4.3 Maximum power point tracking(MPPT)

Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load.

To extract the maximum power, it is necessary to implement an MPPT algorithm that dynamically adjusts the extraction of the power. Convergence speed is one of the most important features among all different MPPT algorithms. Any improvement in the rise time of MPPT improves the reliability of the system and increases the power extraction and efficiency of the whole system.

Different MPPT techniques have been proposed in the literature such as the Perturbation and observation (P&O) technique, the incremental conductance (IncCond) technique, ripple correlation technique, short circuit current (SCC) technique, and open circuit voltage (OCV) technique.

These techniques vary in complexity, cost, speed of convergence, sensors required, hardware implementation, and effectiveness.

Due to the various MPPT methods, different research in PV systems has presented a comparative analysis of MPPT techniques. Indeed, some papers present comparative study among only few methods and others present a comparison of several MPPT methods, based on simulations, under the energy production point of view. The MPPT techniques are evaluated considering different irradiation and tempreature variation and calculation of the energy supplied by the complete PV array.

## 4.4 Pulse width modulation (PWM)

Pulse Width Modulation(PWM) is a digital technology that uses the amount of power delivered to a device that can be changed. It generates analogue signals by using a digital source. A PWM signal is basically a square wave which is switched between on and off state. The duty cycle and frequency of a PWM signal determine its behaviour.

Pulse Width Modulation (PWM) is a technique which takes a constant steady state DC voltage and produces a train of fixed amplitude ON/OFF pulses whose average DC value is determined by the width or duration of the pulses given by the duty cycle. The current is determined by the impedance of the load being supplied.

PWM solar charge controllers are electronic devices used in solar energy systems to protect the battery. These devices connect the solar panels to the battery to prevent it from overcharging and over-discharging.

## 4.5 P & O Algorithm

Perturb and observe algorithm is simple and does not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature and is easy to implement with analogue and digital circuits. It perturbs the operating point of the system causing the PV array terminal voltage to fluctuate around the MPP voltage even if the solar irradiance and the cell temperature are constants.

Moreover, it is the most widely used and workhorse MPPT algorithm because of its balance between performance and simplicity. However, it suffers from the lack of speed and adaptability which is necessary for tracking the fast transients under varying environmental conditions. It is simple and straightforward technique but degraded performance is achieved due to the trade-off between accuracy and speed upon selecting the step size. fig.(4.7) shows the P&O Flow chart.

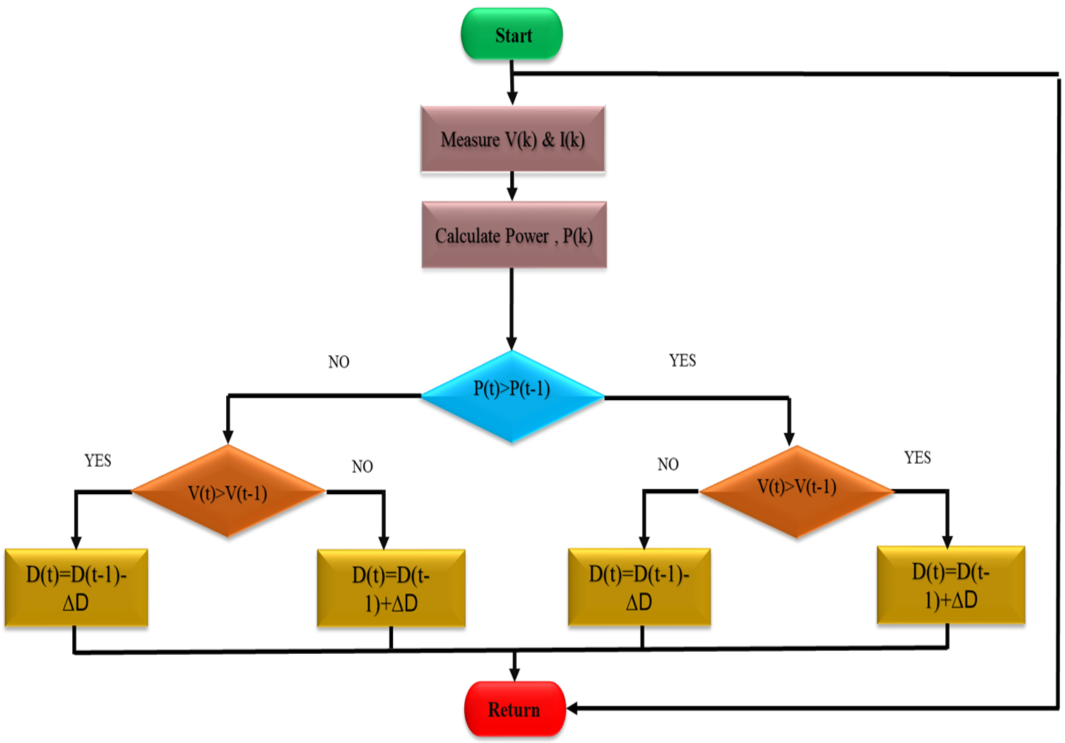



Figure 4.7: Flow chart of P & O

Chapter 5

# Wind system

## 5.1 Introduction to Wind turbine

The terms wind energy, or wind power, describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

So how do wind turbines make electricity? Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

Smaller wind turbines are used for applications such as battery charging for auxiliary power for boats or caravans, and to power traffic warning signs. Larger turbines can contribute to a domestic power supply while selling unused power back to the utility supplier via the electrical grid.

The Wind turbine diagram are shown in fig.(5.1).

Figure 5.1: Wind turbines

### 5.1.1 Types

There is different structure of wind Turbine which are classified at two types,

1 Horizontal Axis Wind Turbine(HAWT)

2 Vertical Axis Wind Turbine (VAWT).

[1] Horizontal Axis Wind Turbine: HAWTs are used widely because they tap more wind energy (from only one direction), so make them more economical than VAWT. The main components of HAWT are blades, Nacelle, and foundation tower.

[2] Vertical Axis Wind Turbine: although HAWTs are more economical, VAWTs are more portable and take less space to install. These kinds of wind turbines tap wind energy from any direction. VAWT is usually used at stand-alone systems to supply individual households with electricity, heat, and even pumping water. Varies designs of VAWTs are available, like Straight-bladed Darrius VAWT.

The HAWT and VAWT diagrams are shown in fig.(5.2).

(a) Horizantal turbine

(b) Vertical turbine

Figure 5.2: Turbine types

**Typical wind energy conversion systems**:
On the basis, there are two categories of wind turbines,

1. Fixed speed wind turbine
2. Variable speed wind turbine

Until the mid-1990s, most of the installed wind turbines were fixed speed ones, based on squirrel cage induction machines directly connected to the grid, and the generation was always done at the constant speed. Today, most of the installed wind turbines are variable speed ones, which are based on three typical electrical systems, 1- permanent magnet synchronous generators (PMSGs), 2- squirrel cage Induction generator (SCIG) 3- doubly-fed induction generator (DFIG).

### 5.1.2 Permanent magnet synchronous generator

A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature.

Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines and hydro turbines into electrical power for the grid. Some designs of Wind turbines also use this generator type.

### 5.1.3 Wind turbine parts and functions

The below fig.(5.3) shows the inside of the wind turbine

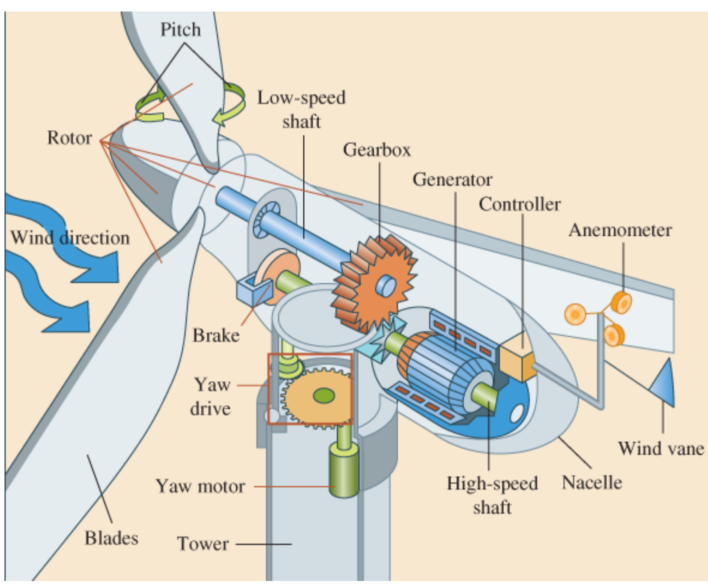



Figure 5.3: The inside of a wind turbine

### • Generator

The wind turbine generator converts mechanical energy to electrical energy. Wind turbine generators are a bit unusual, compared to other generating units you ordinarily find attached to the electrical grid. One reason is that the generator has to work with a power source (the wind turbine rotor) which supplies very fluctuating mechanical power (torque).

### • Rotor

The rotor is the rotating part of a turbine; it consists of (mostly) three blades and the central part that the blades are attached to, the hub. A turbine does not necessarily have to have three blades; it can have two, four, or another number of blades. But the three-blade rotor has the best efficiency and other advantages.

### • Hub

A rotor hub is used to connect a shaft and rotor blade of the wind turbine. The hub includes blade bearings, bolts, internals & a pitch system. These are designed with cast iron, welded sheet steel & forged steel. These are available in two types like Hinge-less hub & Teetering hub.

### • Gear box

In wind turbines, a gearbox is used to change high toque power with low-speed which is received from a rotor blade to low torque power with high speed. This power is used for the generator. The gearbox is connected in between the generator and main shaft.

### • Shaft

The shaft in a motor is a cylindrical component that extrudes out from the motor and its housing. The purpose of the shaft is to convert energy from the motor into the end use application. Precision pins and shafts operate as a function of speed vs torque.

## 5.2 Three phase rectifier

Rectifier is a device that converts Ac voltage into DC voltage. rectifier uses diode and thyristor, to convert AC supply voltage into DC voltage. A 3 Phase rectifier is a device which rectifies the input AC voltage with the use of 3 phase transformer and 3 diodes which are connected to each of the three phases of transformer secondary winding. Three-phase rectifiers are used for various low-power and high-power applications like UPS systems, VFDs, cycloconverters, AC voltage regulators, etc.

### 5.2.1 Significance of 3 Phase Rectifier

A single phase rectifier also rectifies i.e. converts AC supply to DC supply but uses only single phase of transformer secondary coil for the conversion. And the diodes are connected to the secondary winding of single phase transformer.

The drawback of this arrangement is high ripple factor. In case of half wave rectifier the ripple factor is 1.21 and in case of full wave rectifier the ripple factor is 0.482. In both the cases the value of ripple factor cannot be neglected. While in case of half wave rectifier the value is quite large but in full wave rectifier too the value of rectifier is significantly large.

Thus, in such types of arrangement we need smoothing circuit in order to remove these ripples. These ripples are the AC components in the DC voltage. This is called pulsating DC voltage. If this pulsating DC voltage is used in several applications it lead to poor performance of the device. Thus, the Smoothing circuit is used, filter works as a smoothing circuit for rectifier system.

## 5.3 Filter

A filter circuit is one which removes the ac component present in the rectified output and allows the dc componrnt to reach the load.

### Why do we need filter?

The ripple in the signal denotes the presence of some AC component. This ac component has to be completely removed in order to get pure dc output. So, we need a circuit that smoothens the rectified output into a pure dc signal.

The following fig.(5.4) shows the functionality of a filter circuit.

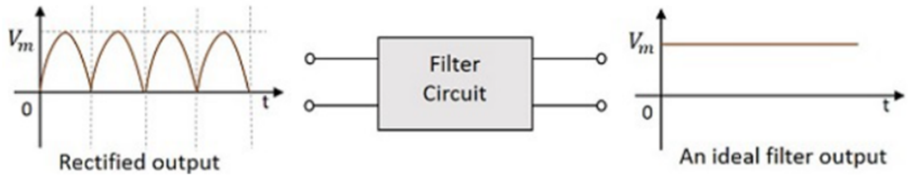



Figure 5.4: Functionality of Filter

## Chapter 6

# Design and Modeling

## 6.1 Solar system

### 6.1.1 Analysis of PV array

The PV array is shown in fig.(6.1). The basic component of PV system is known as Solar cell . Solar panel is a combination of solar cell ,connected in series and parallel to generate a usable voltage and current respectively. Here the PV consist with two inputs i.e, irradiance of 1000 w/m2 and temperature of 25°C. The values irradiance and temperature can be varied. To get a required current and power the number of series string=1 and number of parallel string=1 is set. To get more power and current the string can be increased. m is the measurement port.

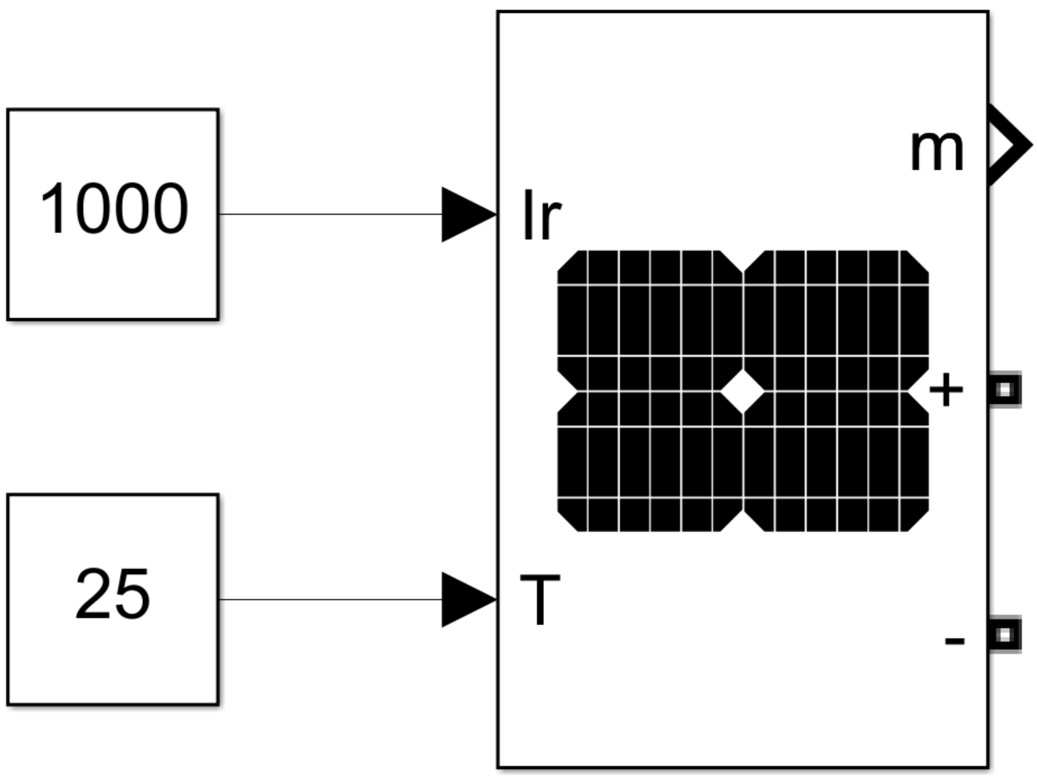



Figure 6.1: PV array

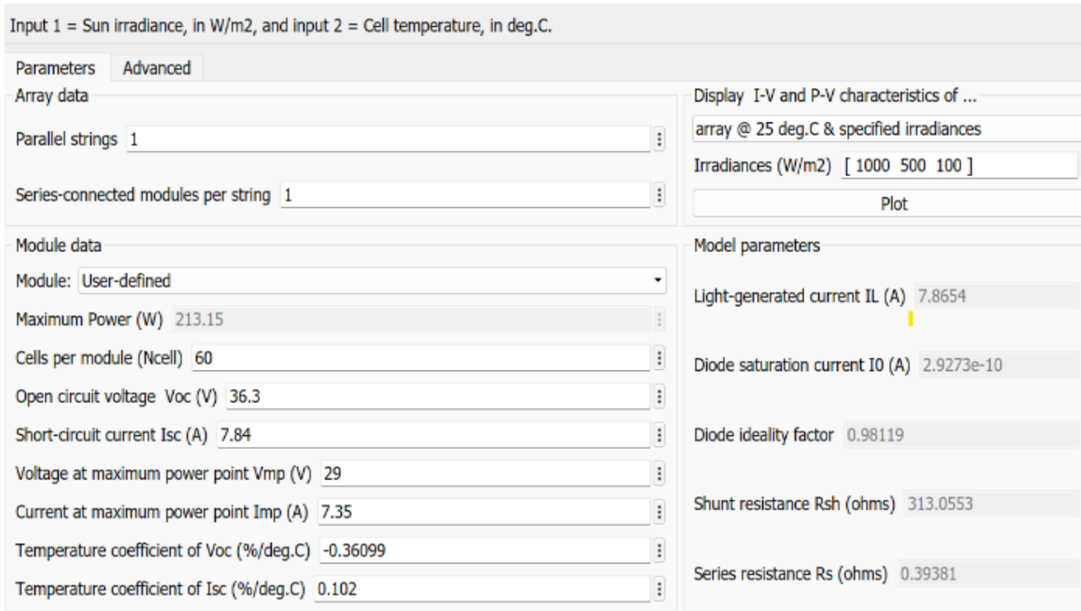



Figure 6.2: Specification of PV array

### 6.1.2 Modeling of buck converter

Buck converter is modeled with the help of MATLAB/SIMULINK. Simulink model for Buck converter is as shown in fig.(6.3). A buck converter is a step down dc to dc converter .It uses a power semiconductor device as a switch to turn on and off of the supply to the load. The switching action can be implemented by using MOSFET. To get a regulated dc output LC filter is used with the value of L = 0.7726 mH and C = 369.79 μF.

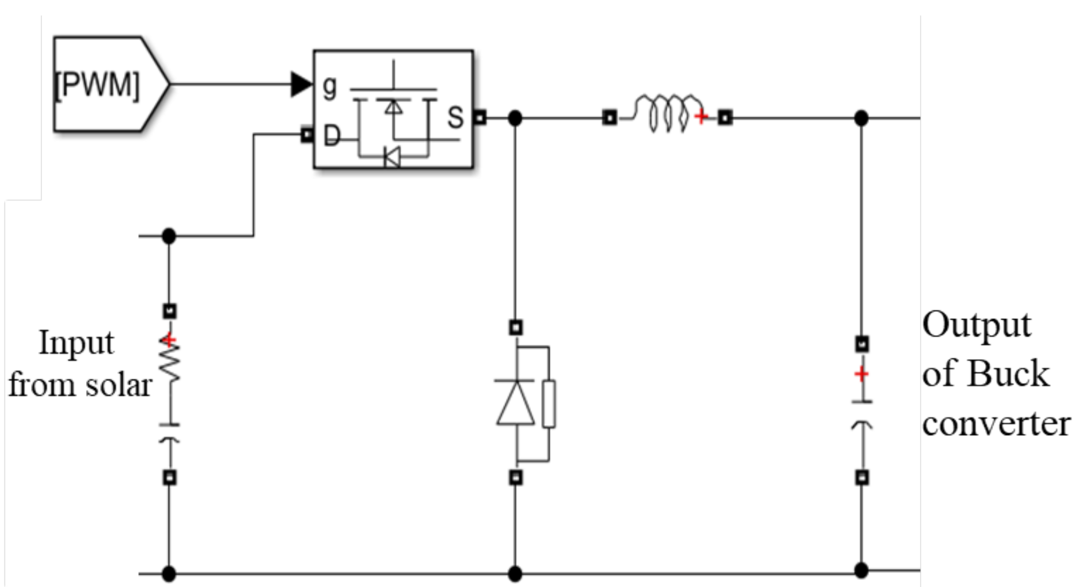



Figure 6.3: Design of buck converter

**Design:**

Solar rated power = 213 watts, $f_s = 5k$

In PV voltage to chopper = $V_{in}$ = 28 - 36 Volts

Output of chopper = input of Battery = V = 12 Volts

Current ripple = 10%

Voltage ripple = 1%

$\therefore output current = \frac{Rated power}{V_o} = \frac{213}{12}$ = 17.75 Amps.

So current ripple, ΔI = 10% of o/p current= 10% of 17.75 = 1.775 Amps

Voltage ripple ΔV = 1% of $V_o$ = 1% of 12 = 0.12 Volts

Hence inductance L,

$$L = \frac{V_o(V_{in} - V_o)}{f_s * \Delta I * V_{in}} \tag{6.1}$$

$\therefore L = \frac{12(28-12)}{5k*1.775*28}$ = 0.7726 mH

$$C = \frac{\Delta I}{8 * f_s * \Delta V} \tag{6.2}$$

$\therefore C = \frac{1.775}{8*5k*0.12}$ = 369.79 µF

### 6.1.3 Modeling of Solar system

Solar system is modelled with the help of MATLAB/Simulink. Simulink model for solar system is as shown in fig.(6.4). The circuit is operated with input irradiance = 1000 and temperature = 25°C. Both values effect the performance of pv array. To reduce the dc voltage from the pv array buck converter is designed. It consist of semiconductor switch as MOSFET. Here we use L and C filter to get pure dc. The values of L = 772.64 mH and C= 369.79 µF. Then it connected to a load i.e, Battery of capacity 12 Volts, 100 Amps/hrs with SOC of 90%.

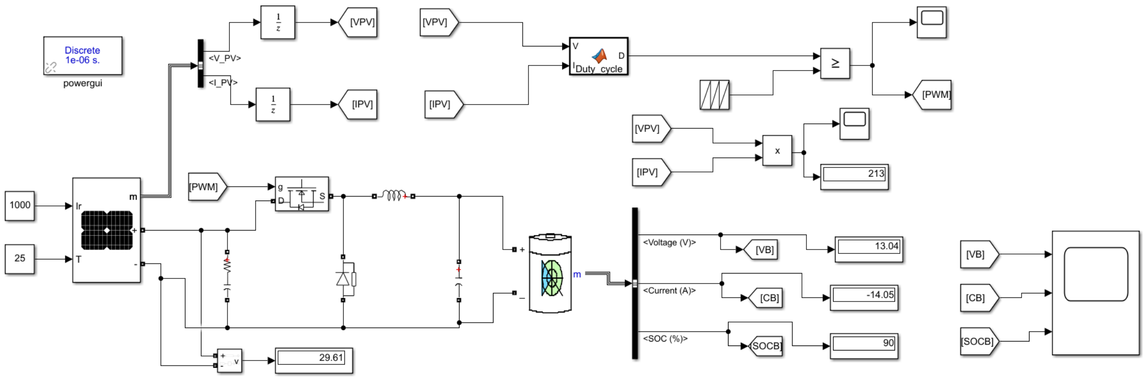



Figure 6.4: Simulink model of solar system

## 6.2 Wind system

### 6.2.1 Modeling of 3 Phase Rectifier

The design of 3$\phi$ rectifier with the help of MATLAB/SIMULINK is as shown in fig.(6.5). It consist with 6 diodes. each single phase consist with the pair of diodes. Diode d1, d3, d2, d4 forms a bridge rectifier between B and C phases similarly diodes d3, d5, d4, d6 forms a bridge between A and B phases. To get a pure dc L and C filter is used with the value of L = 1 mH and C = 200 μF.

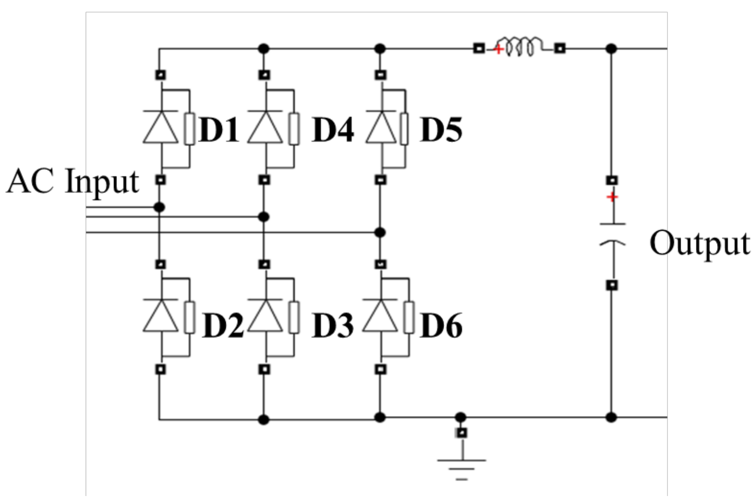



Figure 6.5: Simulink model of 3 Phase Rectifier

### 6.2.2 Modeling of Wind system

Wind system is modelled with the help of MATLAB/SIMULINK. Simulink model for wind system is as shown in fig.(6.6). The turbine consist with the input pitch angle = 2 and wind speed = 100.To get a more current these values can be varied. The output torque is given to the PMSG(permanent magnet synchronous generator) which converts mechanical power to electrical power i.e, 3$\phi$ AC. To convert 3$\phi$ ac to dc 3$\phi$ rectifier is designed. Then its connected to the load battery.

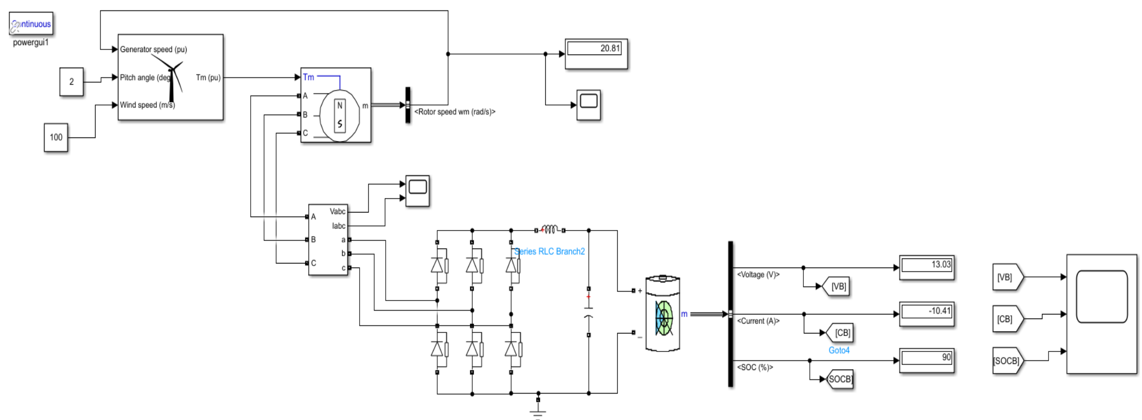



Figure 6.6: Simulink model of wind system

## 6.3 Modeling of Solar-Wind system

Solar-wind system is modelled with the help of MATLAB/SIMULINK. The model of proposed system is as shown in fig.(6.7). The solar subsystem is parallely connected with the wind subsystem. Then it given to the load battery. Both solar and wind system are designed for same voltage. Which finally results in total voltage of 12 Volts and total current of 24 Ampere.

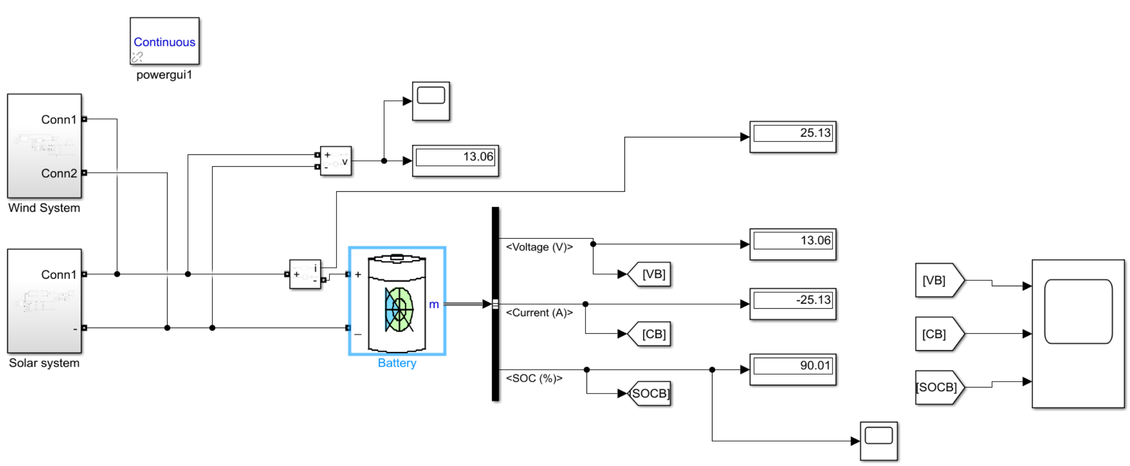


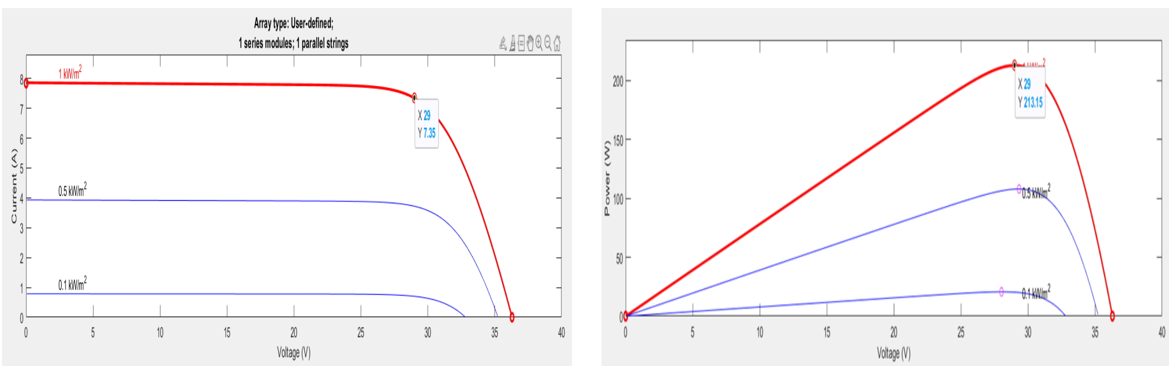

Figure 6.7: Simulink model for proposed Solar and Wind

# Chapter 7

# Simulation and Results

## 7.1 Solar system

The I-V output characteristics of PV module with varying irradiation and varying temperature as shown in fig.(7.1a) and the P-V output characteristics of PV module with varying irradiation and varying temperature are shown in fig.(7.1b). When the irradiation increases, the current output increases and the voltage output also increases. This result in net increases in output power with increase in irradiation and varying temperature.




(a) I-V Characteristics

(b) P-V characteristics

Figure 7.1: The characteristics of PV panel

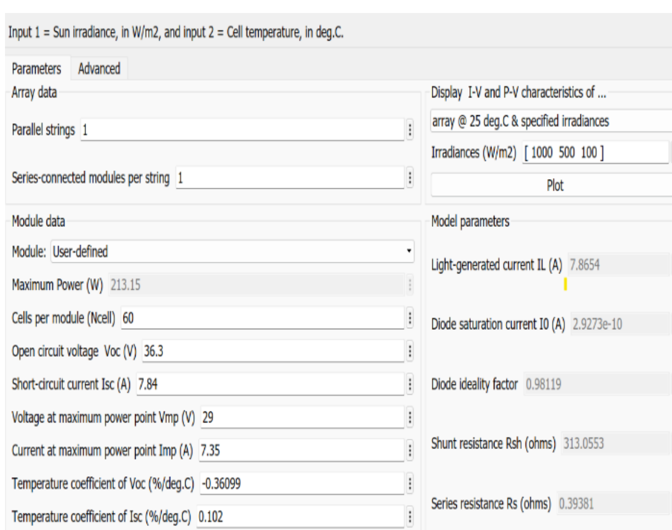



Figure 7.2: Specification of PV array

Solar system modelling is shown in fig.(6.4) which produces Voltage $\approx$ 13 Volts and Current $\approx$ 14 Ampere and SOC of 90% and it produces the power has 214 Watts. The waveform analysis is shown in fig.(7.3) and fig.(7.4).

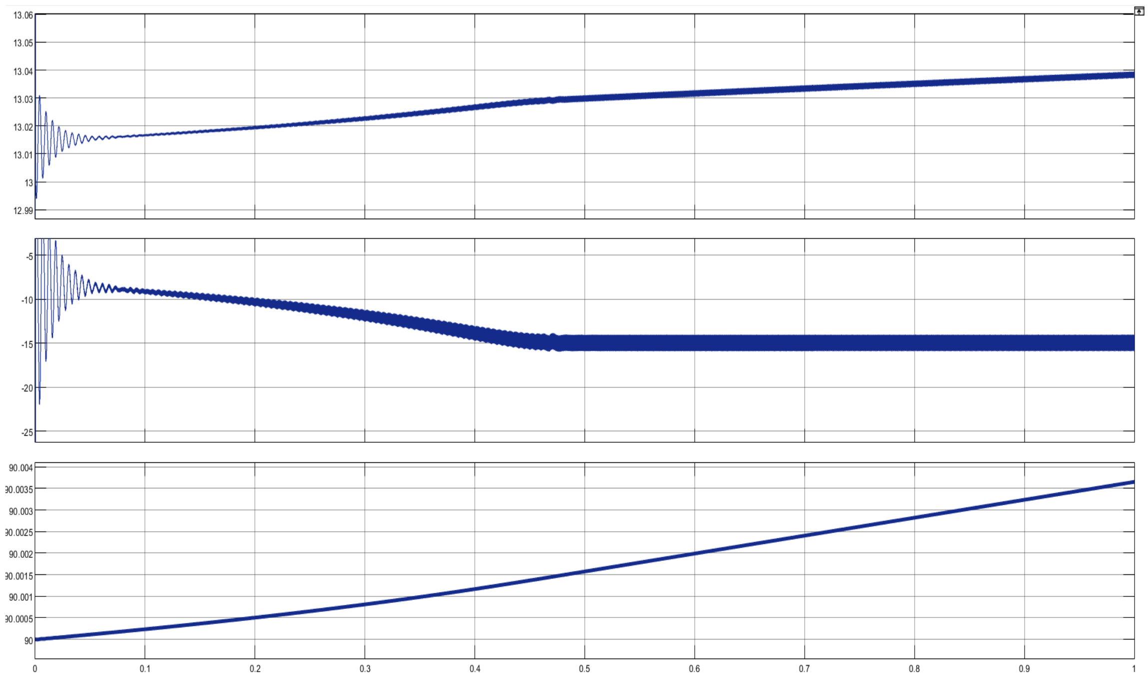



Figure 7.3: Solar voltage, current and SOC response

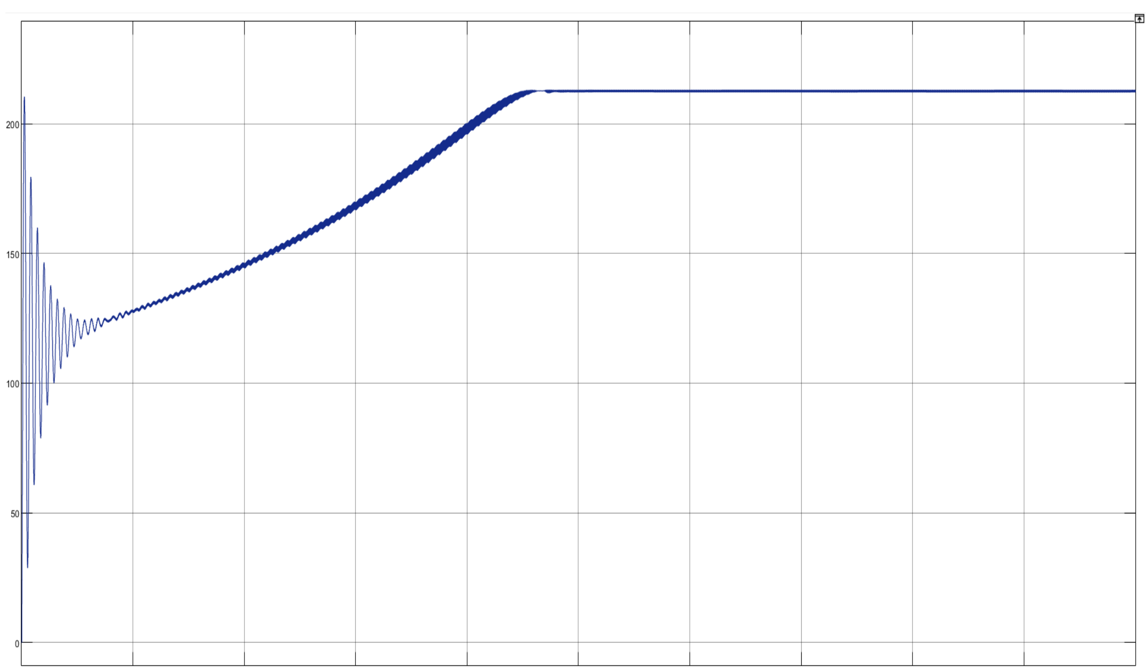



Figure 7.4: Solar output power response

## 7.2 Wind system

The characteristics of turbine output power vs turbine angular speed curve of wind turbine is shown in fig.(7.5) . The maximum power at the base wind speed is (p.u. of nominal mechanical power)=0.73. Base wind speed = 12 m/s. Pitch angle beta to display wind turbine power characteristics (deg) = 0 deg .

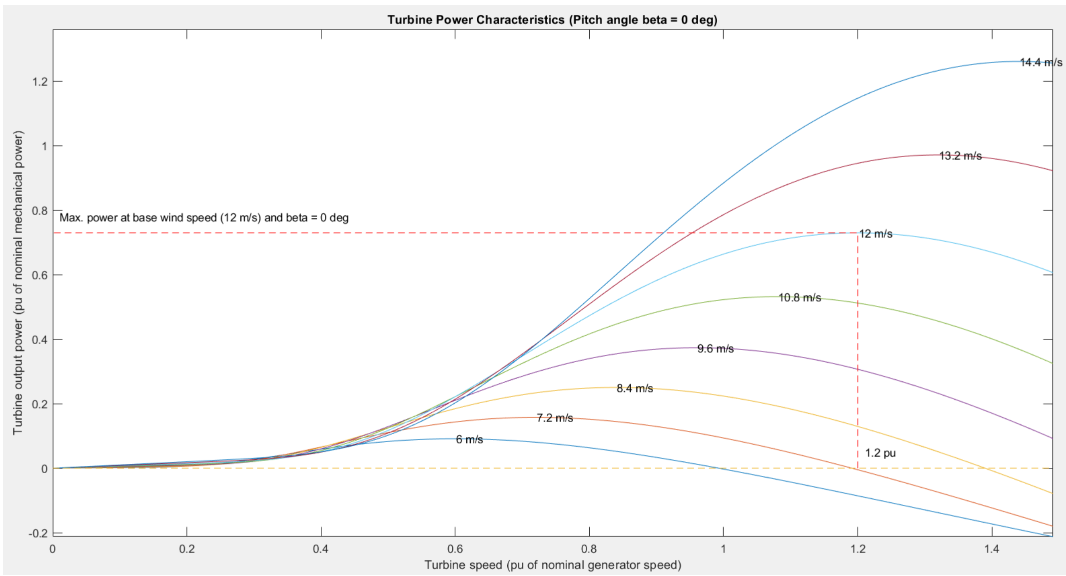
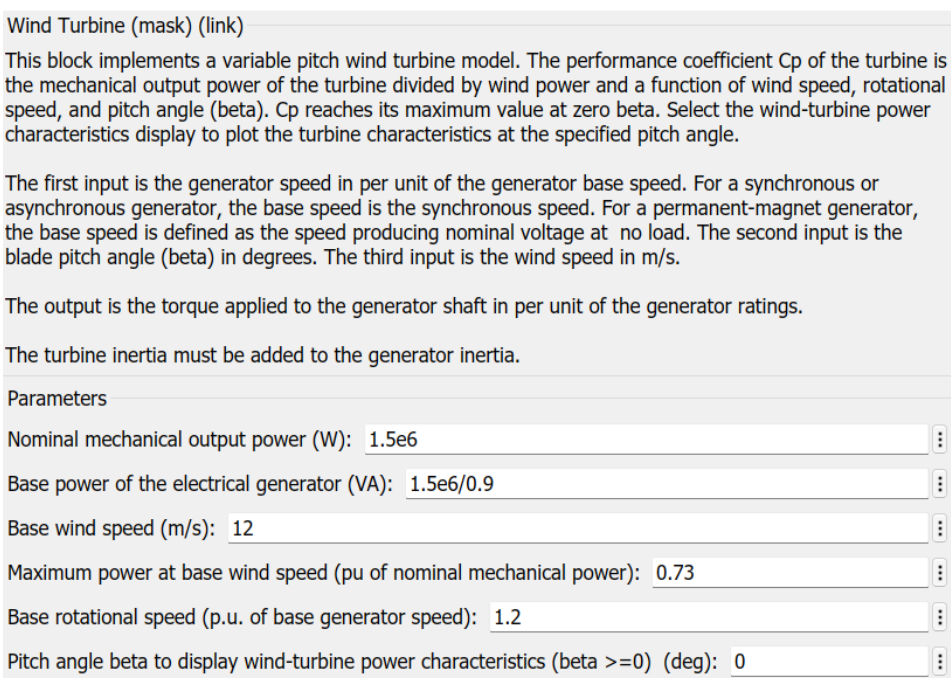



Figure 7.5: The characteristics of power vs angular speed curve of wind turbine



Wind Turbine (mask) (link)

This block implements a variable pitch wind turbine model. The performance coefficient Cp of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). Cp reaches its maximum value at zero beta. Select the wind-turbine power characteristics display to plot the turbine characteristics at the specified pitch angle.

The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (beta) in degrees. The third input is the wind speed in m/s.

The output is the torque applied to the generator shaft in per unit of the generator ratings.

The turbine inertia must be added to the generator inertia.

Parameters

Nominal mechanical output power (W): 1.5e6

Base power of the electrical generator (VA): 1.5e6/0.9

Base wind speed (m/s): 12

Maximum power at base wind speed (pu of nominal mechanical power): 0.73

Base rotational speed (p.u. of base generator speed): 1.2

Pitch angle beta to display wind-turbine power characteristics (beta >=0) (deg): 0

Figure 7.6: Specification of Wind turbine

The wind system modeling is shown in fig.(6.6). It produces the wind voltage $\approx$ 13 Volts and wind current $\approx$ 10 Ampere and SOC OF 90%. The waveform analysis is shown in fig.(7.7).

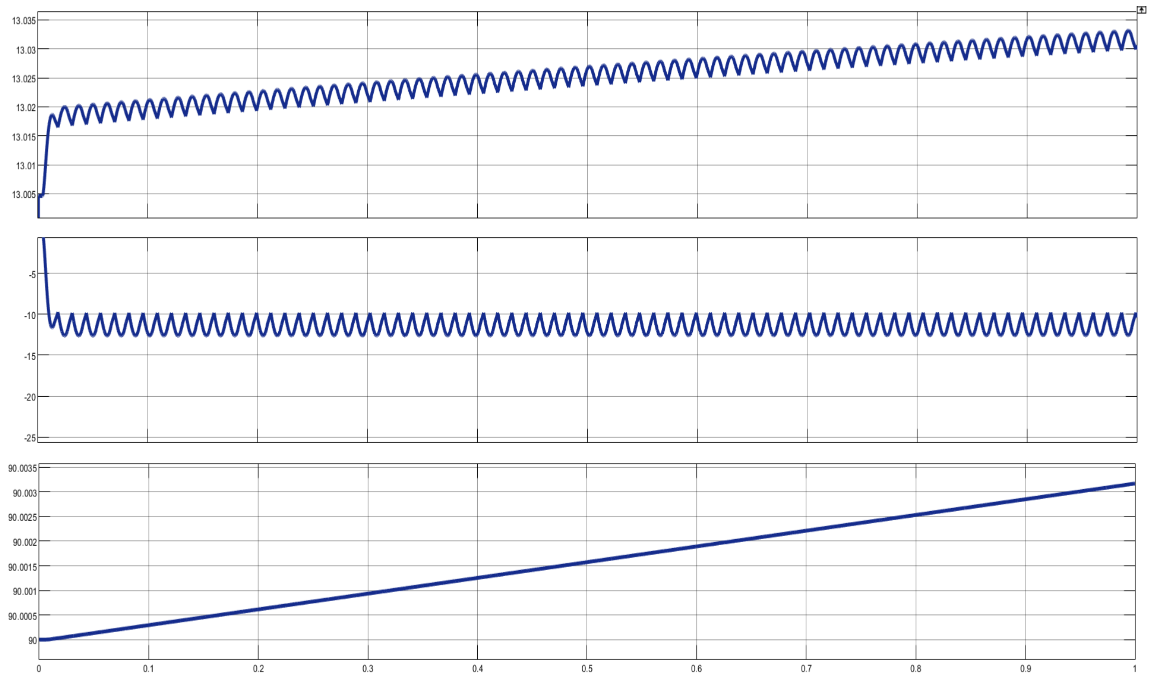



Figure 7.7: Wind voltage, current and SOC response

## 7.3 Solar and Wind system

The solar – wind modeling is shown in fig.(6.7). That produces the combined solar and wind voltage of 13 Volts. For both system the voltage is remained same. The total current becomes increases because the solar and wind subsystem is parallely connected. In parallel connection the current is added. Total current $\approx$ 25 Ampere. The State of Charge is 90%. The waveform analysis is shown in fig.(7.8).

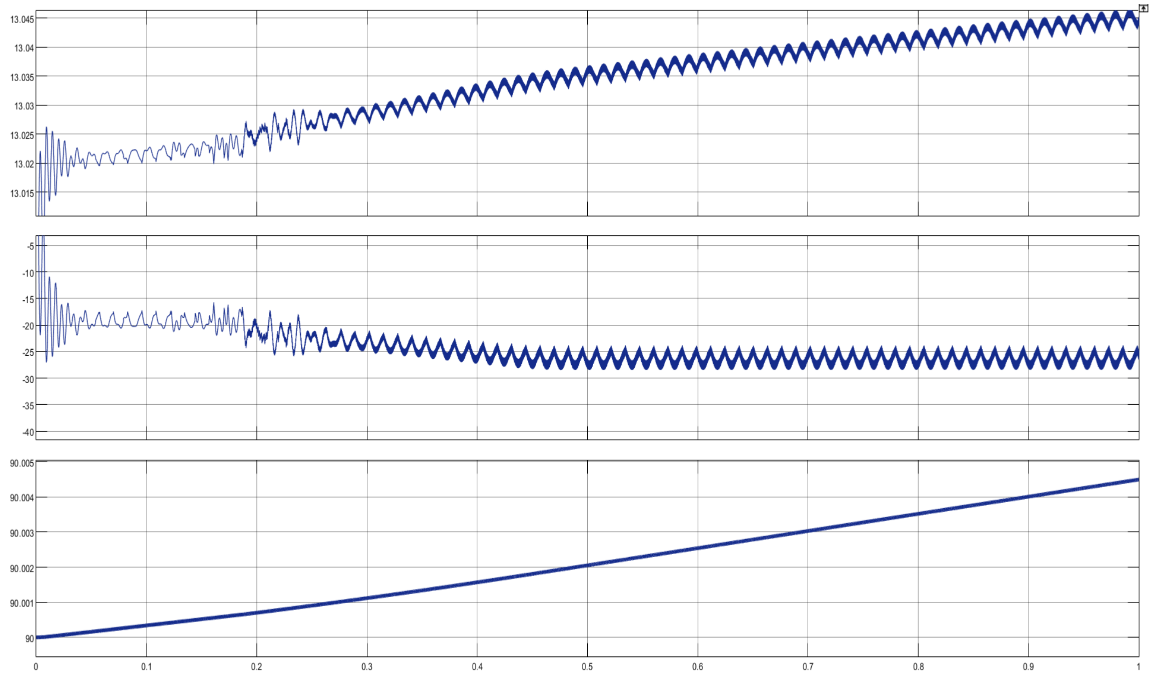



Figure 7.8: Solar and Wind voltage, current and SOC response

## Chapter 8

# Conclusion

The objective of the work carried is the integration of wind turbine system & solar photo voltaic's system to demonstrate the efficiency, reliability, and maximum power generation of a hybrid power system, Which is further utilized to charge the battery of an electrical vehicle. In fact, the effects of the simulation actually demonstrate the efficiency of the planned hybrid power system, in order to generate maximum power for moist summer weather in various countries trying to use renewable energy.The Solar system, Buck converter, MPPT algorithm, Wind system, Rectifier has been successfully designed using MATLAB/SIMULINK. Wind and PV are the primary power sources of the system, and the battery is used as a backup and long term storage unit. To satisfy the charging requirement of EV's the natural source Solar radiation and Wind speed frequency is set. It is achieved to obtain the complete output of solar system of 12 Volts with the current of 14 Ampere. Also, the complete output of wind system will be 12 Volts with current of 10 Ampere. The Solar PV subsystem and Wind energy converting subsystem are connected in parallel which results in final output voltage of 12 Volts and the final current of 24 Ampere.

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