ELECTRICAL MODEL OF A SOLAR CAR SYSTEM USING SIMULINK

Submitted to

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Declaration

We hereby declare that this thesis titled “*Electrical model of a solar car system using SIMULINK*” and the work presented in it and submitted to the Department of Electrical and Electronics Engineering of BRAC University is an outcome of our own work and effort. Any information from other sources have been acknowledged in the reference section. It was not submitted anywhere else for any other publication.

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Abstract

A feasible alternative source of renewable energy is solar power technology. Considering the crucial hindrances in developing and implementing the system solar powered car, the necessity of a simulation tools comes in front. For this reason a simulation tool having the options to model and analyze the characteristics of different electronic and mechanical components i.e. a solar panel, a battery and a DC motor should have been developed. Moreover, it is capable of combining different components with control algorithms to examine and evaluate the performance of the whole system in different ambient conditions.

In this paper, the demonstration to develop a dynamic model of a solar car in SIMULINK is explained including the approaches to develop the model of different components from scratch and how to use it to test and verify the behavior of them. SIMULINK is a graphical programing language tool for modeling and simulation highly integrated with MATLAB which makes the mathematical operations and plotting the graphs easiest ever. The dynamicity of the model offers the user to change the parameters of every components and environment to fit their purpose. The scope of the article extends to combination of all components of the solar car to test overall system at diverse car velocity for any single day of the year.

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1. INTRODUCTION

The unsustainable nature of fossil fuel and its horrendous effect on our environment create concerns to find an environment friendly alternative energy source as dependency on fossil fuel is increasing exponentially. Quest of finding environment friendly energy source show us the alternatives of all fuel types and energy carriers types renewable energy sources like sun, wind, tides, hydropower and biomass which are safe, clean and different from fossil fuel. All renewable energy sources are effective but solar energy is the most sustainable as our sun will provide this solar energy for another billion year. Photovoltaic cell efficiency increases every year as new ideas with new technology keeps improving every year and production of photovoltaic panels is now most than ever before, doubling its production in every two years. Now it is the fastest growing alternative energy source of all renewable energy sources. So, considering improvement in solar energy technology, growth, efficiency and effectiveness we should implement this technology as this is environment friendly and also sustainable.

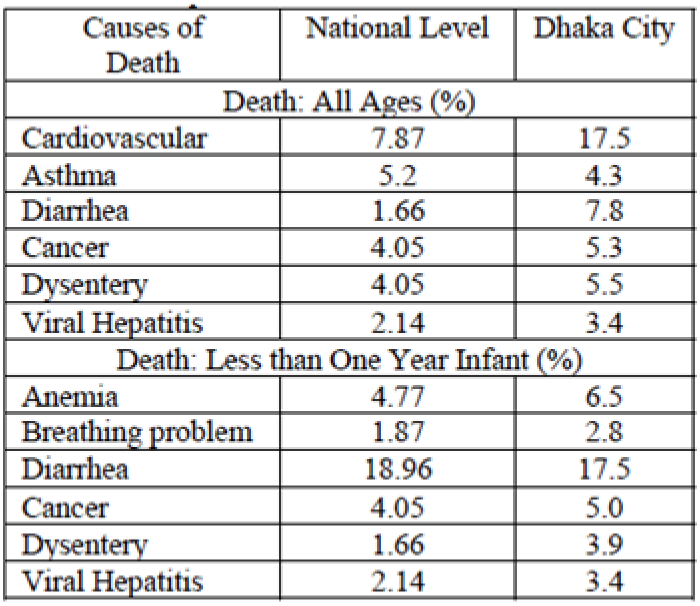
In last few years, lots of researches have been conducted and increasing attention has been spent towards the applications of solar energy to car. Various solar car have been built and tested. In spite of a significant technological effort and some spectacular outcomes, several limitations, such as low power density, energetic drawbacks, weight, fuel savings and cost, cause pure solar cars to be still far from practical feasibility. So the necessity tells us that we need such a tool or system that can evaluate overall performance of a solar car in different conditions. Therefore we would develop a dynamic model of solar car to validate the characteristics of different components of the car along with the capability of evaluating its overall performance in a user friendly simulation environment of SIMULINK.

1.1. MOTIVATION

1.1.1. POLLUTION:

Pollution has become the first enemy of the mankind. The whole world is now more afraid of pollution rather than nuclear blast. It is an issue that troubles us economically, physically and every day of our lives.

Our main focus is on vehicle industry which causes air pollution, the major sources of pollution and health hazards. Dhaka has been rated as one of the most polluted cities of the world. Bangladesh Atomic Energy Commission reports that automobiles in Dhaka emit 100 kg lead, 3.5 tons SPM, 1.5 tons SO2, 14 tons HC and 60 tons CO in every day. Immediate effect of smoke inhalation from vehicle which is driven by fuels causes headache, vertigo, burning sensation of the eyes, sneezing, nausea, tiredness, cough etc. It is long term effect may cause asthma and bronchitis. Lead affects the circulatory, nervous and reproductive systems as well as affects kidney and liver including liver cancer or cirrhosis. Carbon monoxide hampers the growth and mental development of an expected baby. Nitrogen oxides cause bronchitis and pneumonia.



Causes of Death	National Level	Dhaka City
Death: All Ages (%)		
Cardiovascular	7.87	17.5
Asthma	5.2	4.3
Diarrhea	1.66	7.8
Cancer	4.05	5.3
Dysentery	4.05	5.5
Viral Hepatitis	2.14	3.4
Death: Less than One Year Infant (%)		
Anemia	4.77	6.5
Breathing problem	1.87	2.8
Diarrhea	18.96	17.5
Cancer	4.05	5.0
Dysentery	1.66	3.9
Viral Hepatitis	2.14	3.4

Table 1.1.1: The death rate for pollution

1.1.2. SCARCITY AND PRICE OF FOSSIL FUEL:

Humans have depended on fossil fuels as their primary source of energy since the eighteenth century. Since world population increasing exponentially ever, the supplies of these fossil fuels have diminished. The fossil fuel of greatest concern, likely the first to become scarcer, is petroleum. The price of gasoline at the pump is the most obvious indicator.

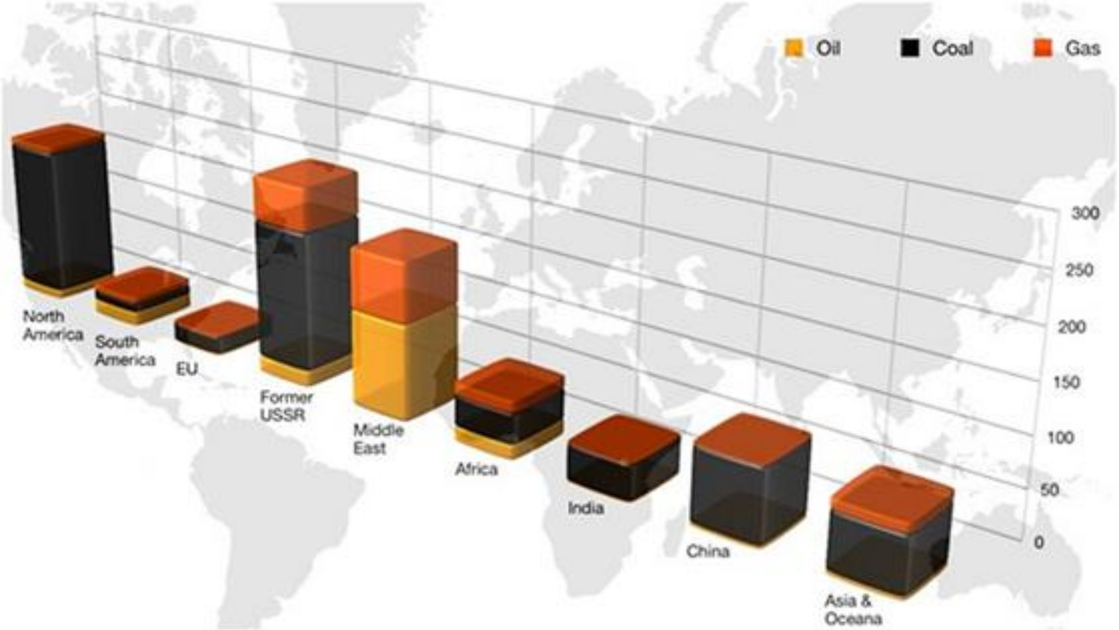


Figure 1.1.1: Scare Of Fossil Fuel Sources

Also, the coming scarcity of fossil fuels causes the prices of oil and natural gas are approximately four times what they were in 1999 and the existing fuels prices are continuously raising.

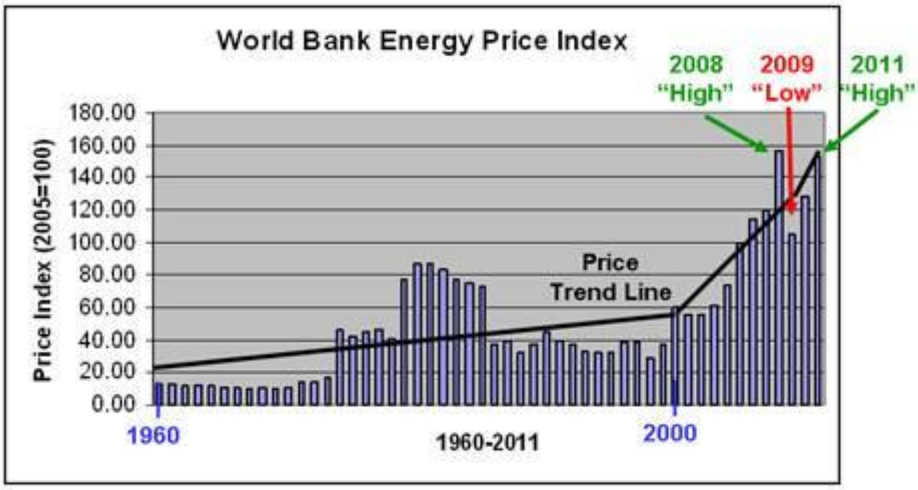


Figure 1.1.2: Price trend of fossil fuel

So it’s urgent to think an alternative method of transport like solar energy as solar car is great idea for cars because it is effective and cost free. It would be wonderful to have a car that you have to do nothing for its fuel or giving extra money. Solar powered cars are one kind of electrical car that has solar panel on its outside and it would harness energy from the sun via solar panels. Solar panels will pass electricity to the battery and charge it then passes the electrical energy to motor which give the car driving force by converting electrical energy to mechanical energy. They are noiseless and pollution-free with no rotating parts and need minimum maintenance. So we should look forward for a car that is safe, environment friendly, noiseless and make our everyday life whole lot easy.

1.1.3. EXPERIMENT COST & LACK OF A GOOD SIMULATION TOOL

Though a lots of experiments and research is going on throughout the world on solar vehicle, the experiments are very costly and time consuming. They have to collect the panel, build an electric car and batteries and test them on Road at different speed and get to a decision that the car should be lighter or any other problems like this. Here comes the necessity of a good simulation tool. There is no good simulation tool to evaluate the overall performance of the vehicle. We want to develop a model of complete solar car so that people can use it to validate their proposed car would work or not in their physical and environmental parameters.

1.2. PROJECT OBJECTIVE

The main objective of this project is to model a solar car to help future researchers or any interested individuals to verify the performance of the solar car by simulating. We would like to model the car in SIMULINK which has high integration with MATLAB, the most powerful mathematical tools ever.

The car consists of three fundamental components, a panel, a battery and a DC motor. We would design dynamic model of every component so that user can fit the model to their interest. Ambient condition generator tool will be developed to give the environmental parameters of the day. The DC motor drives the complete car, so the power drawn by it depends on the weight, speed etc. of the car. So a power calculation tool would be better to build than a simple DC motor. We would like to develop the tool also. To increase the battery life a charge controller is needed to prevent over discharge and overcharge. We will model a simple charge controller with dynamic threshold inputs.

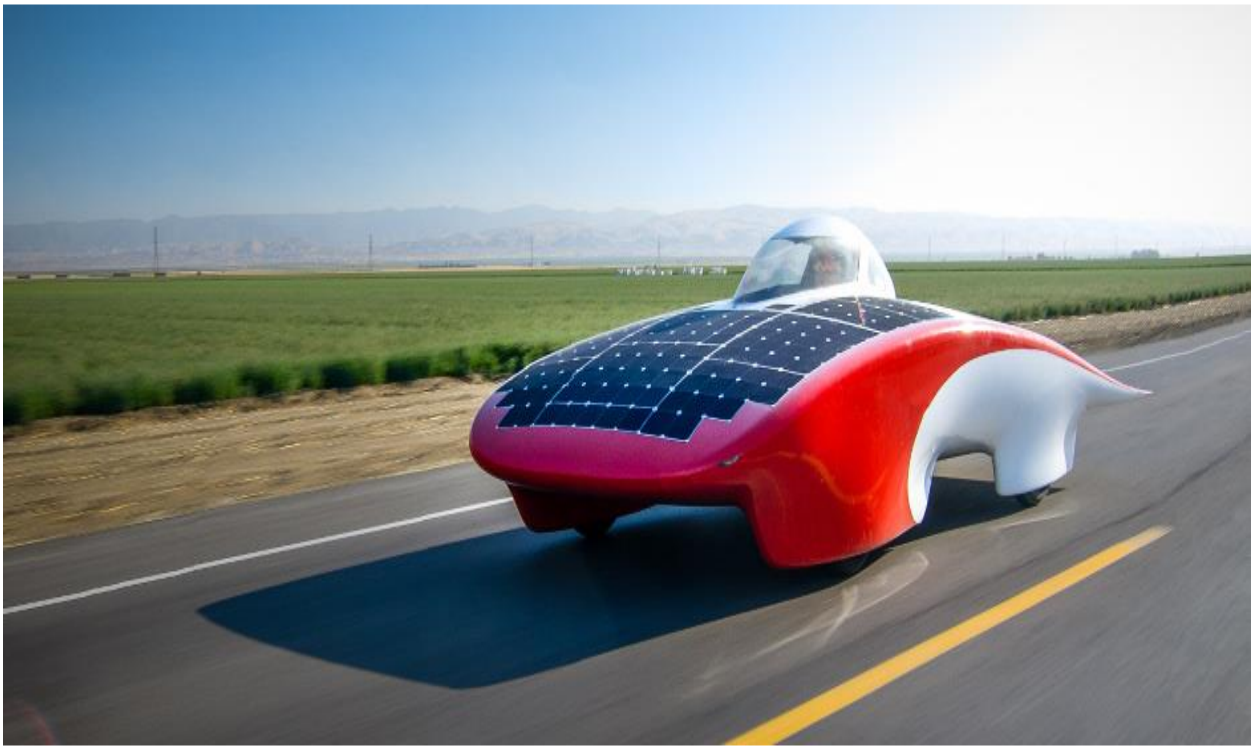


Figure 1.2: A Solar Car

1.3. PROJECT OVERVIEW

Figure 1.3 shows the fundamental parts of solar car which we are going to model and implement is SIMULINK. The main four parts are PV Module, Battery, DC motor and charge controller.

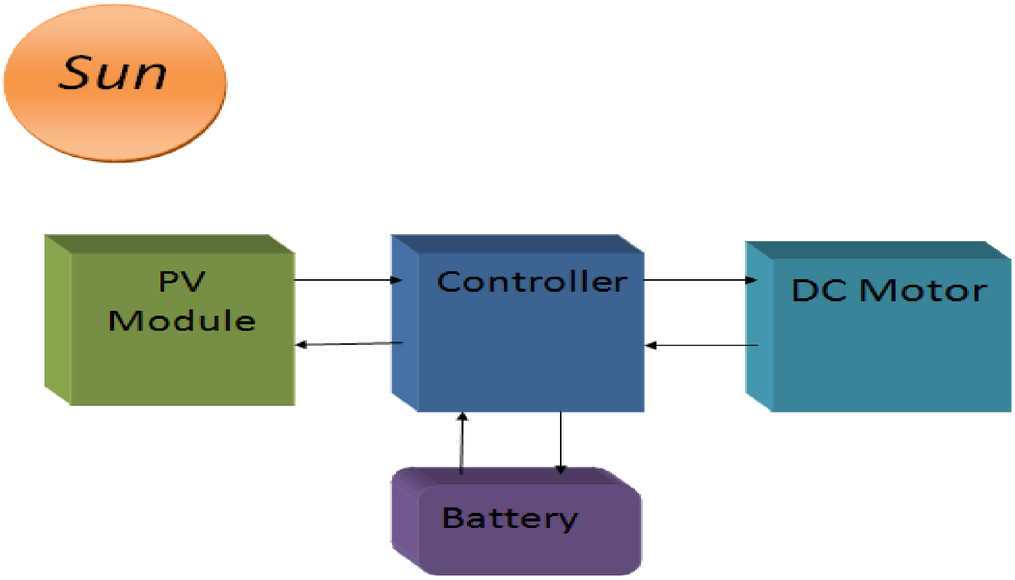


Figure 1.3. The block diagram of the project

1.3.1. SOLAR PANEL

Solar cars are powered by the sun's energy. Solar panels are the most important part of a solar car since they are solely responsible for collecting the sun's energy. We will model the panel and observe different characteristics of it.

1.3.2. BATTERY

The solar panels will collect energy from the sun and convert it into usable electrical energy, which in turn will be stored in the lead acid batteries to be supplied to the motor when necessary.

1.3.3. DC MOTOR

The motor drives the car by converting electrical energy to mechanical energy. A power calculation tool that calculates the power drawn out by the car can represent the DC motor. A DC motor will be designed in this way.

1.3.4. CHARGE CONTROLLER

A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharging. The basic functions of a controller are quite simple. Charge controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery over discharge. So, it is an essential part of nearly all power systems that charge batteries.

1.4. SCOPE OF THE PROJECT

The scope of the project involves a solar powered car model in SIMULINK software, where we can simulate the total solar car system to check the systems overall performance and have idea build a better real solar car according to our simulated data. Solar car simulation model involves solar panel model, battery model, motor model and charge controller model integrated together making the total system work like a solar car. This simulation model will monitor the current flow from the panel to battery, battery’s change in the state of charge according to current and how much power delivered from battery to motor which give the car driving force. This will in turn help calculate the battery capacity and solar panel wattage required to travel the desired maximum round trip of certain distance in certain time. With help of user friendly SIMULINK software we design panel, battery, motor and charge controller simulation model which integrated model represent a solar car system.

2. SOLAR PANEL

This chapter deals with solar cells, modules and their equivalent electric circuits. The I-V (current vs. voltage) and P-V (power vs. voltage) characteristics are plotted and discussed after modeling the module with Simulink. The changes of I-V and P-V curves over changing temperature and irradiance is also observed in the project by simulating the photovoltaic module in SIMULINK.

2.1. SOLAR CELLS

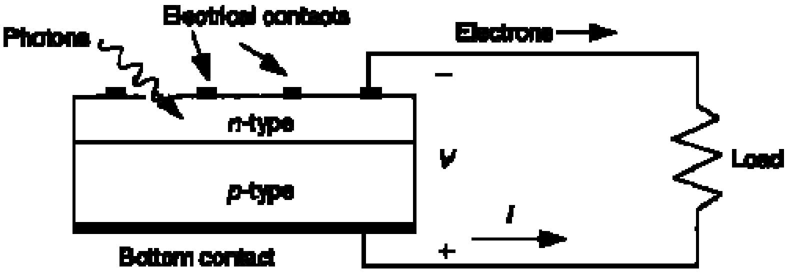


Figure-2.1: Photovoltaic cell exposed to sun light

Solar cells are made of silicon usually, which are specially treated to form an electric field. The backside is positively doped with boron and the negative side doped with phosphorus is exposed towards the sun. When photons of sunlight hits the solar cell, electrons are displaced from the atoms in the semiconductor material, creating electron-hole pairs. If electrical conductors are then attached to the positive and negative sides (Figure-2), an electrical circuit is formed and the moving electrons create electric current I_{ph} (photocurrent).The greater the intensity of sunlight, the greater is the flow of electricity.

2.1.1. SOLAR CELL MODEL

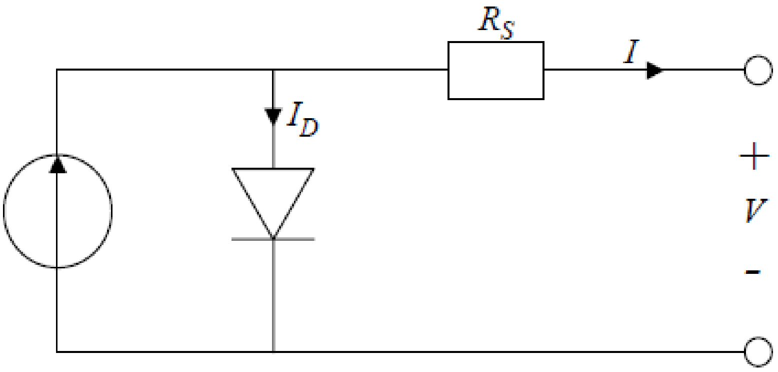


Figure-2.1.1: Equivalent Electric circuit of single solar cell

When there is no sunlight, the solar cell is not an active device; it works as a diode. If it is connected to an external supply it generates a current I_D, called diode current or dark current.

That is why the electric circuit model of solar cell is like figure-3, which contains a current source I_{ph}, a diode and a series resistance representing the internal resistance of a cell R_s. The net current I is therefore the difference between I_{ph} and I_D.

$$I = I_{ph} - I_D = I_{ph} - I_0\left(e^{\frac{q(V+IR_S)}{mkT_c}} - 1\right)$$

$where,$

$m = Idealizing\ factor$

$k = Boltzmann's\ gas\ constant$

$T_c = absolute\ temperature\ of\ the\ cell$

$q = electronic\ charge$

$V = voltage\ imposed\ across\ the\ cell$

$I_0 = Dark\ saturation\ current$

2.1.2. I-V CHARACTERISTICS

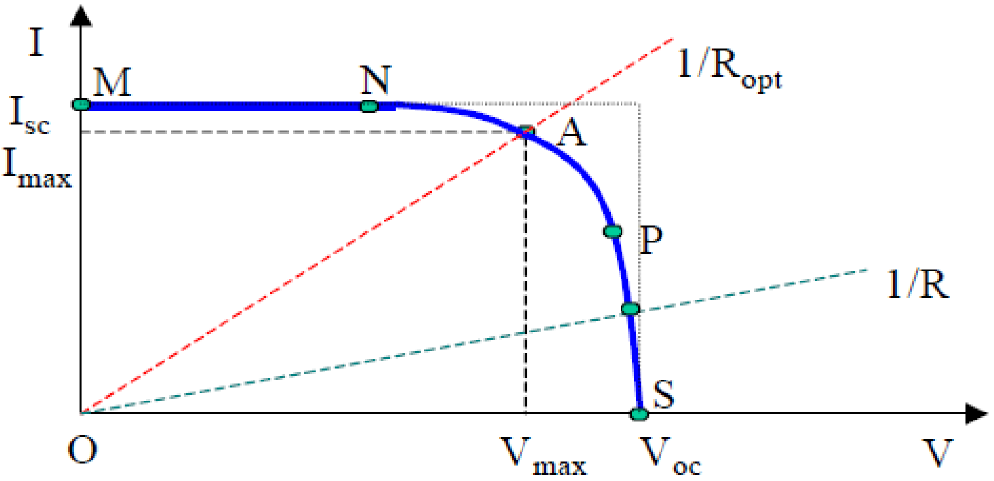


Figure 2.1.2: IV characteristic of a solar cell

If the terminals of the cell are connected to a resistance *R*, the operating point is determined by the intersection of the *IV* characteristic of the solar cell with the straight line of slope 1/R (figure-4).

2.1.3. SOLAR CELL PARAMETERS

A solar cell has the following fundamental parameters:-

a) **Short circuit current:** $I_{ph} = I_{sc}$. It is the greatest value of the current generated by a cell under short circuit conditions i.e. V = 0.

b) **Open circuit voltage:** It corresponds to voltage of cell at night, when generated current I = 0. Mathematically,

$$V_{oc} = V_t ln\left(\frac{I_{ph}}{I_0}\right), \qquad where\ V_t = \frac{mkT_c}{q}$$

c) **Maximum Power Point:** It is the point of IV curve (figure-4) where maximum power is dissipated.

d) **Maximum efficiency:** It is the ratio between maximum power and incident light power.

$$\eta = \frac{P_{max}}{P_{in}}$$

e) **Fill Factor:** It is the ratio between maximum power and the product of I_{sc} and V_{oc}.

$$FF = \frac{P_{max}}{V_{oc}I_{sc}}$$

2.2. MODULE MODEL

Cells are grouped into module. A PV module consists of N_{PM} parallel branches each having N_{SM} solar cells in series (figure-5).

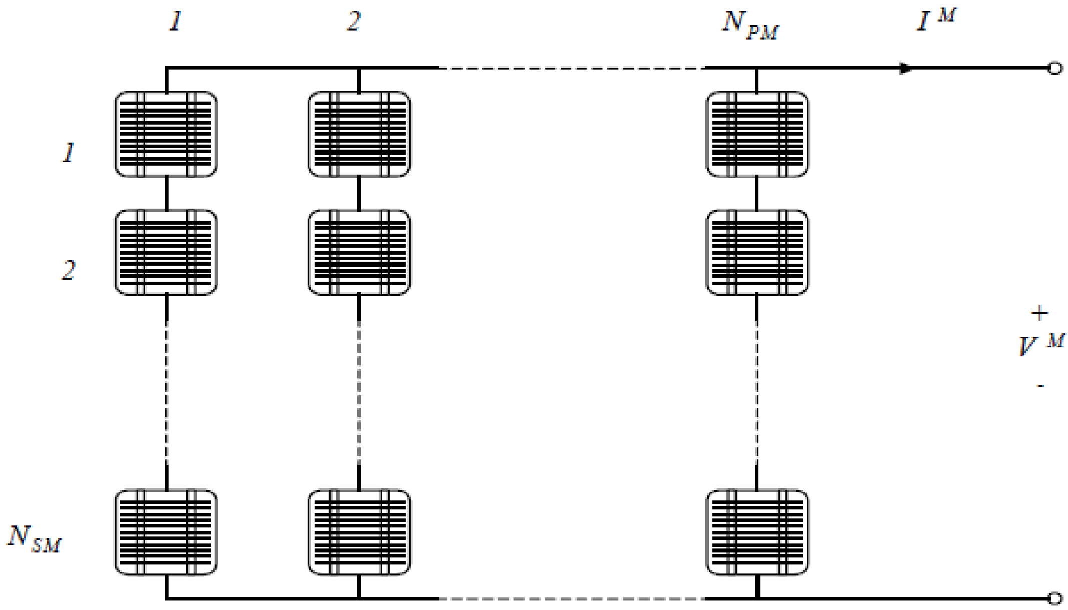


Figure-2.2: PV module

A model of this PV module can be obtained by replacing each cell by equivalent circuit of figure-3. Then the modules current I_M can be expressed as-

$$I_M = I_{SC}^M \left[1 - \exp\left(\frac{V^M - V_{OC}^M + R_S^M . I^M}{N_{SM} V_t^C} \right) \right]$$

$here,$

$'M' superscript\ represents\ the\ module$

$'C' superscript\ represents\ a\ cell$

$I_{SC}^M = Module's\ short\ circuit\ current = N_{PM} I_{SC}^C$

$V_{OC}^M = Module's\ open\ circuit\ voltage = N_{SM} I_{OC}^C$

$R_S^M = Equivalent\ series\ resistance\ of\ module = \frac{N_{SM}}{N_{PM}} R_S^C$

$V_M = Load\ voltage$

2.2.1. ALGORITHM FOR THE COMPUTATION OF I_M

Step-1: Manufacturer's catalogue provides the following information under standard condition.

- $Maximum\ power\ of\ the\ module, P^M_{max,0}$
- $Short\ circuit\ current\ of\ the\ module, I^M_{SC,0}$
- $Open\ circuit\ voltage\ of\ the\ module, V^M_{OC,0}$
- $Number\ of\ cells\ in\ series, N_{SM}$
- $Number\ of\ cells\ in\ parallel, N_{PM}$

Step-2: Calculation of cell's data as below-

- $Maximum\ power\ of\ a\ cell, P^C_{max,0} = \dfrac{P^M_{max,0}}{N_{SM}N_{PM}}$
- $Short\ circuit\ current\ of\ a\ cell, I^C_{SC,0} = \dfrac{I^M_{SC,0}}{N_{PM}}$
- $Open\ circuit\ voltage\ of\ a\ cell, V^C_{OC,0} = \dfrac{V^M_{OC,0}}{N_{SM}}$
- $Thermel\ voltage\ of\ acell, V^C_{t,0} = \dfrac{mkT^C}{q}$
- $V_{OC,0} = \dfrac{V^C_{OC,0}}{V^C_{t,0}}$
- $FF_0 = \dfrac{P^C_{max,0}}{V^C_{OC,0}I^C_{SC,0}}$
- $FF = \dfrac{\left(V_{OC,0} - \ln\left(V_{OC,0} + 0.72\right)\right)}{\left(V_{OC,0} + 1\right)}$
- $r_s = 1 - \dfrac{FF}{FF_0}$
- $Series\ resistence\ of\ the\ cell, R^C_S = r_s \dfrac{V^C_{OC,0}}{I^C_{SC,0}}$

Step-3: Now, the parameters should be determined under operating conditions module voltage, V^M, ambient temperature, T_a and irradiance G_a.

- $C_1 = \dfrac{I^C_{SC,0}}{G_{a,0}}$
- $I^C_{SC} = C_1 G_a$
- $T^C = T_a C_2 G_a$

- $V_{OC}^{C} = V_{OC,0}^{C} + C_3(T^C - T_0^C)$
- $V_t^C = \dfrac{mk(274 + T^C)}{q}$

Step-4: Now the module current under the operating condition is determined using the equation below-

$$I_M = I_{SC}^{M}\left[1 - \exp\left(\frac{V^M - V_{OC}^{M} + R_S^M . I^M}{N_{SM}V_t^C}\right)\right]$$

2.2.2. FLOWCHART OF THE ALGORITHM

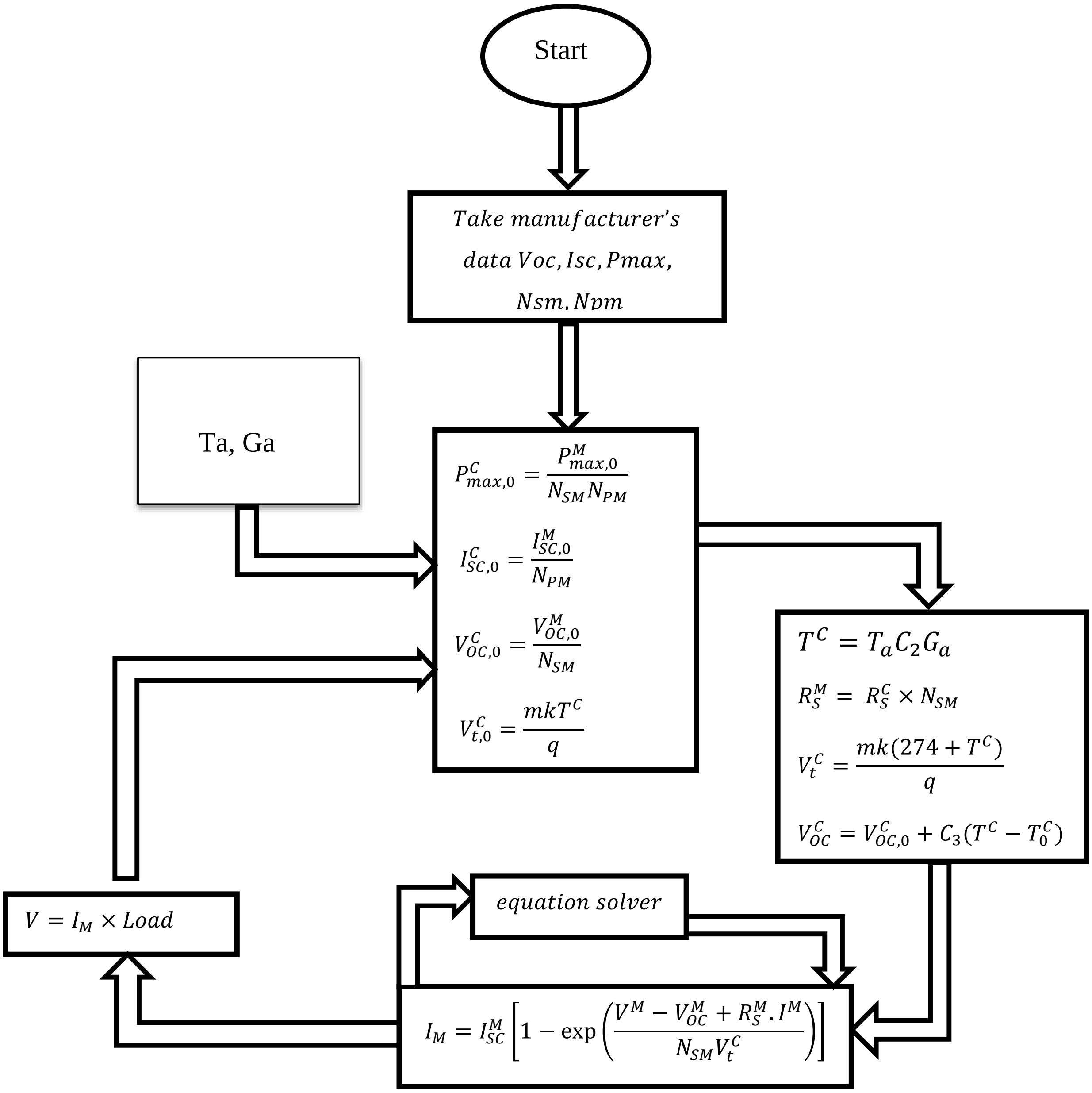


Figure 2.2.2. Solar module model Flowchart

2.3. SIMULINK MODEL OF SOLAR PANEL

The algorithm of the previous section is implemented in SIMULINK’s graphical programing language by executing each step in sequence. The system is packaged with some input and output ports.

2.3.1. MASK DIAGRAM

The system is masked with some input and output pins along with a parameter dialogue box where user can specify the manufacturer’s data of the panel of the user’s interest.

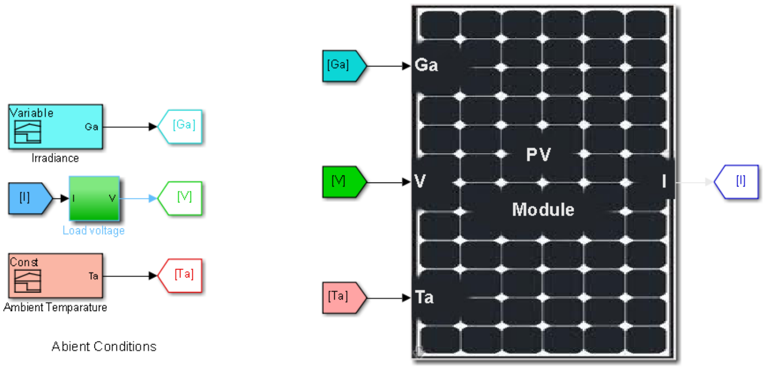
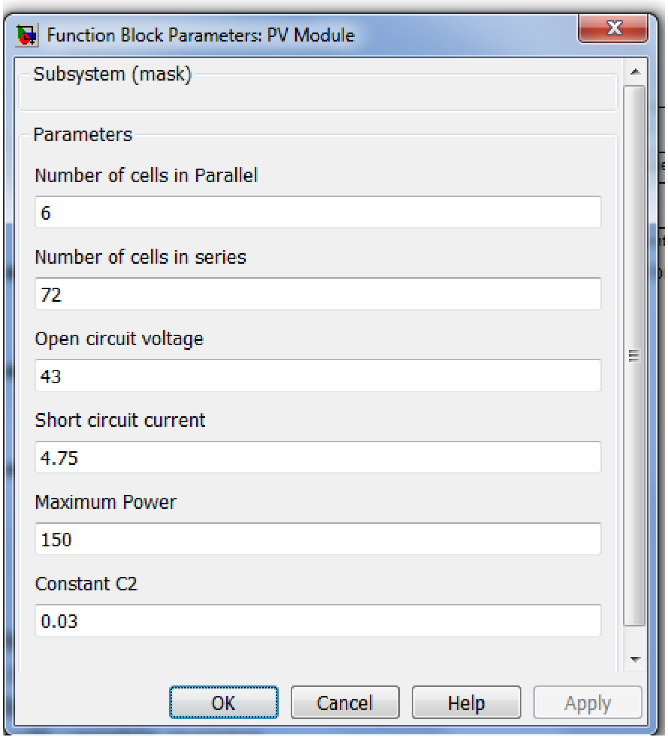


Figure 2.3.1: Masked PV module in Simulink

The signal builder block can generate ambient condition i.e. the temperature and irradiance. The voltage at the terminal of the panel is shown as input because the output current depends on the potential difference between two points. We have given the following parameter values to the module, and simulate using these values. After that we got I-V and P-V curves under different operating conditions. The conditions are created by the signal generator blocks shown in the figure.



Number of cells in Parallel: 6

Number of cells in series: 72

Open circuit voltage: 43

Short circuit current: 4.75

Maximum Power: 150

Constant C2: 0.03

Figure 2.3.2: The mask parameters of PV module

2.3.2. SYSTEM UNDER THE MASK

The following figure is the model of a solar panel in Simulink basic block diagram. The blocks with f(u) is the user defined function block which performs mathematical operations on input and gives out the result. The algebraic Constraint block is used to solve a nonlinear equation.

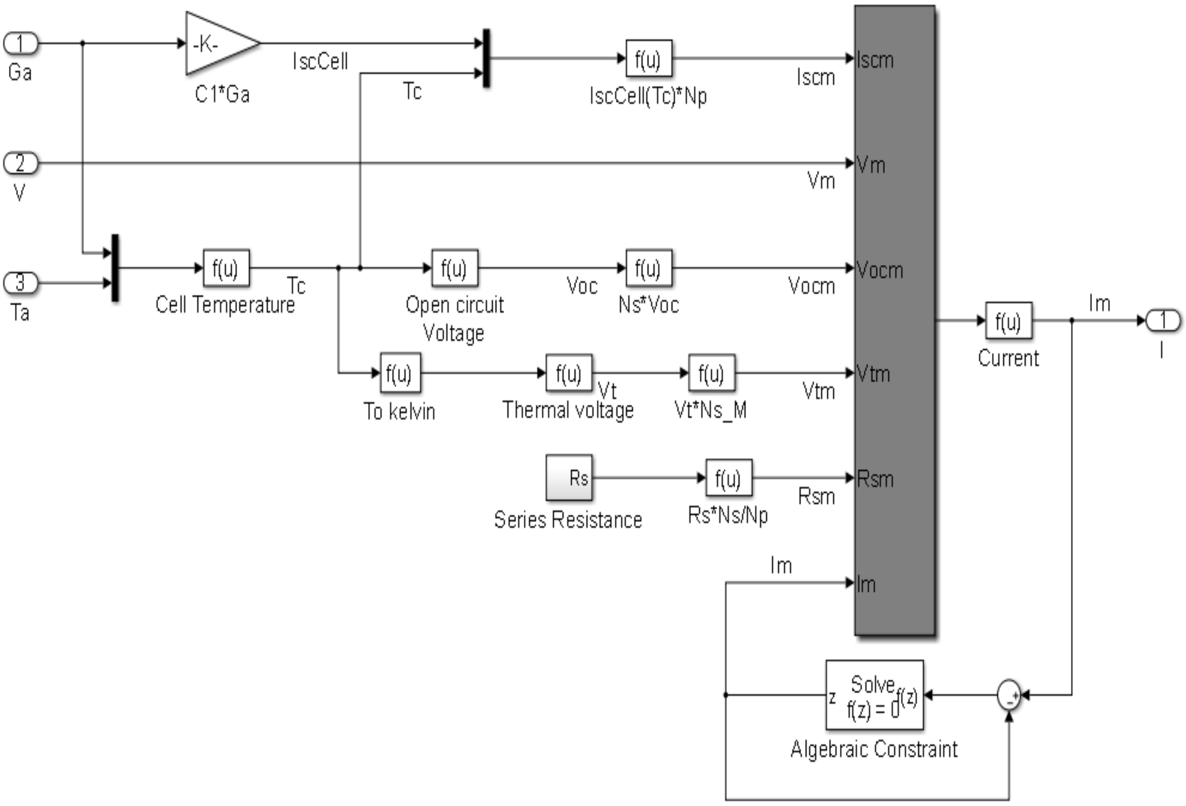


Figure 2.3.3: PV module SIMULINK block diagram

2.4. TESTING THE MODEL

The model has been run under different ambient condition by changing temperature and irradiance as the input to the model. A variable load is connected to observe the I-V and P-V characteristics of the panel. When we vary the temperature, the irradiance is kept constant and vice versa.

2.4.1. EFFECTS OF CHANGING IRRADIANCE

As the irradiance increases short circuit current also increases along with the open circuit voltage. Because of both increasing of V and I, the Pmax is also increases according the irradiance.

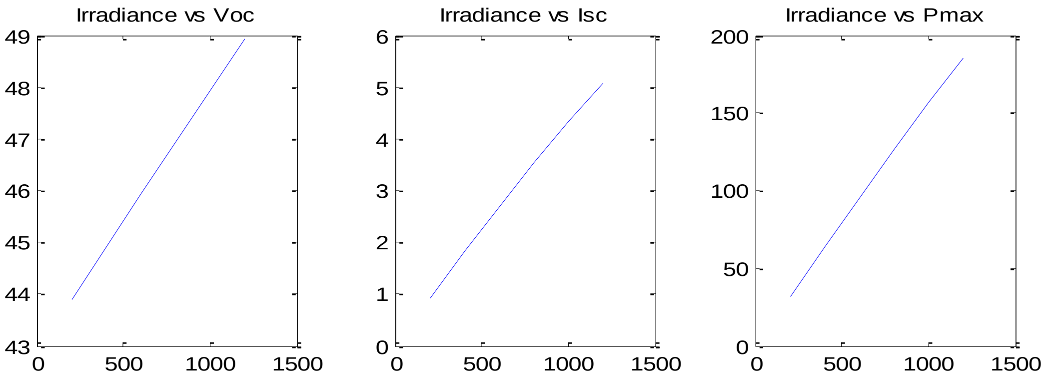


Figure 2.4.1: effect of changing irradiance

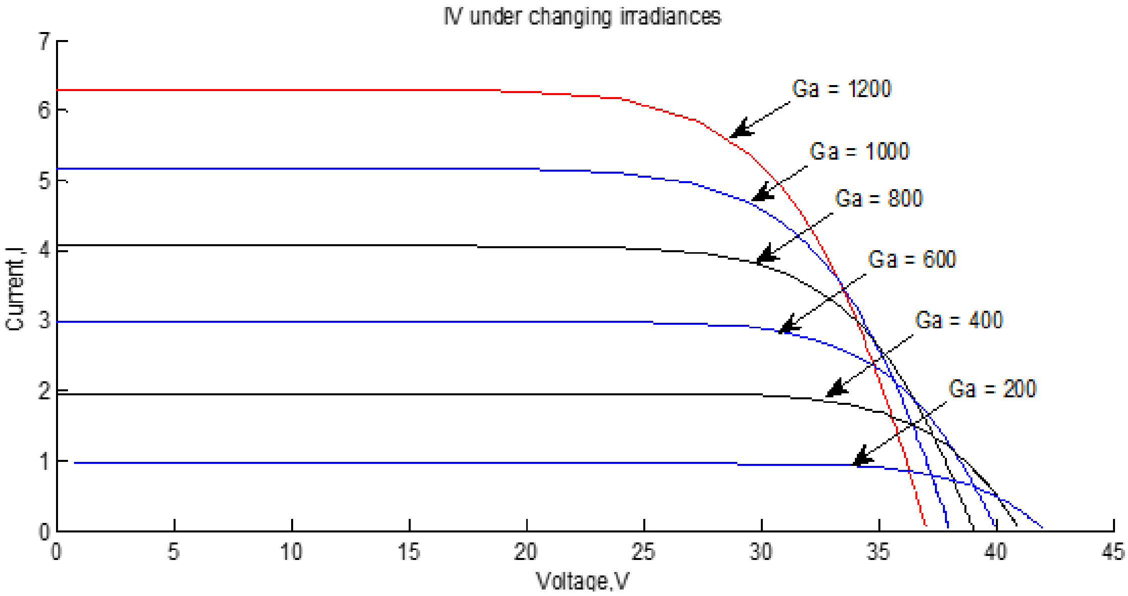


Figure 2.4.2: I-V characteristic under changing irradiance

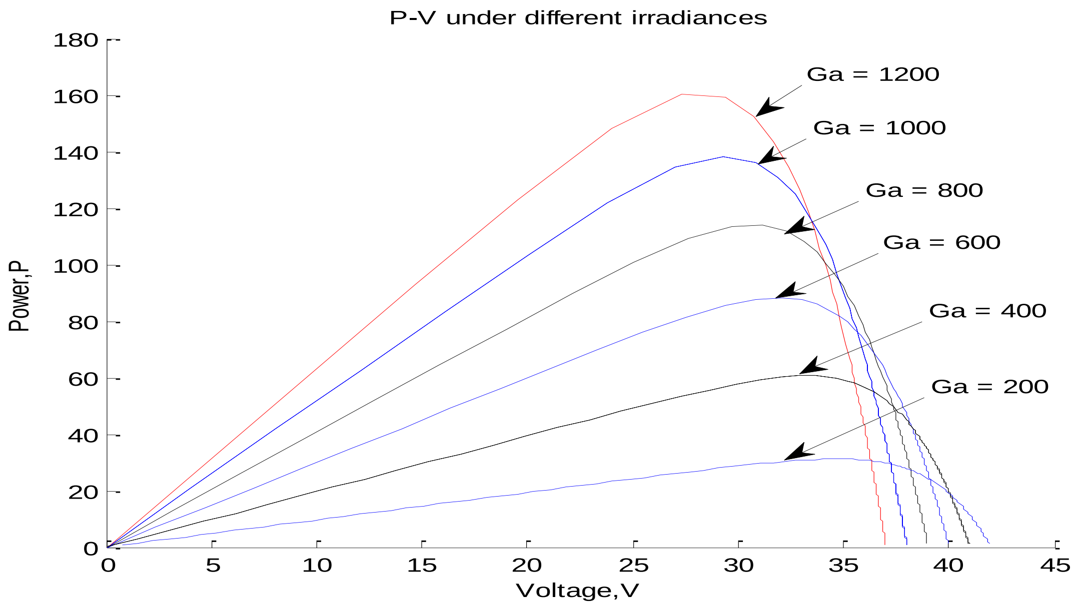


Figure 2.4.3: P-V characteristic under changing irradiance

2.4.2. EFFECTS OF CHANGING TEMPERATURE

The simulation is run under the condition of variable temperature and constant irradiance. The open circuit voltage falls as temperature increases, but the short circuit current is less in high temperature. The maximum power point is also inversely proportional to the temperature.

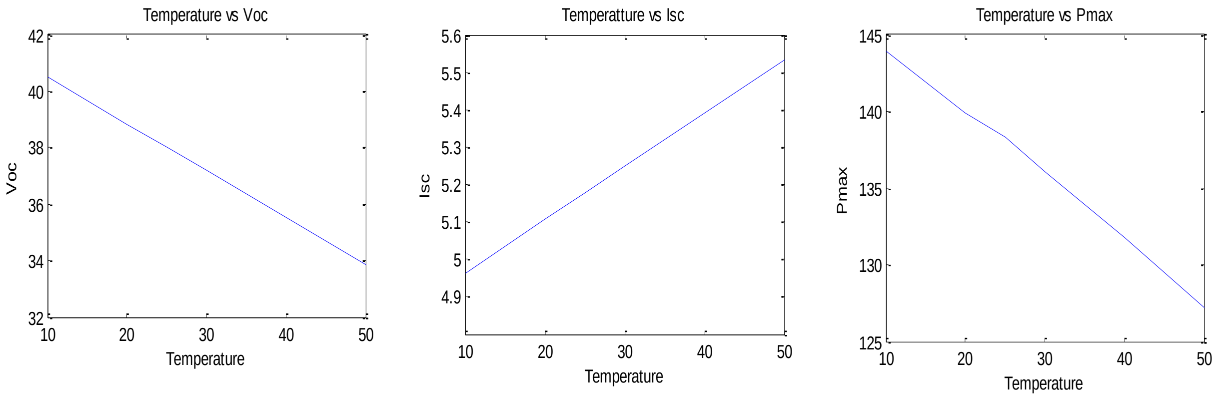


Figure 2.4.4: effect of changing Temperature

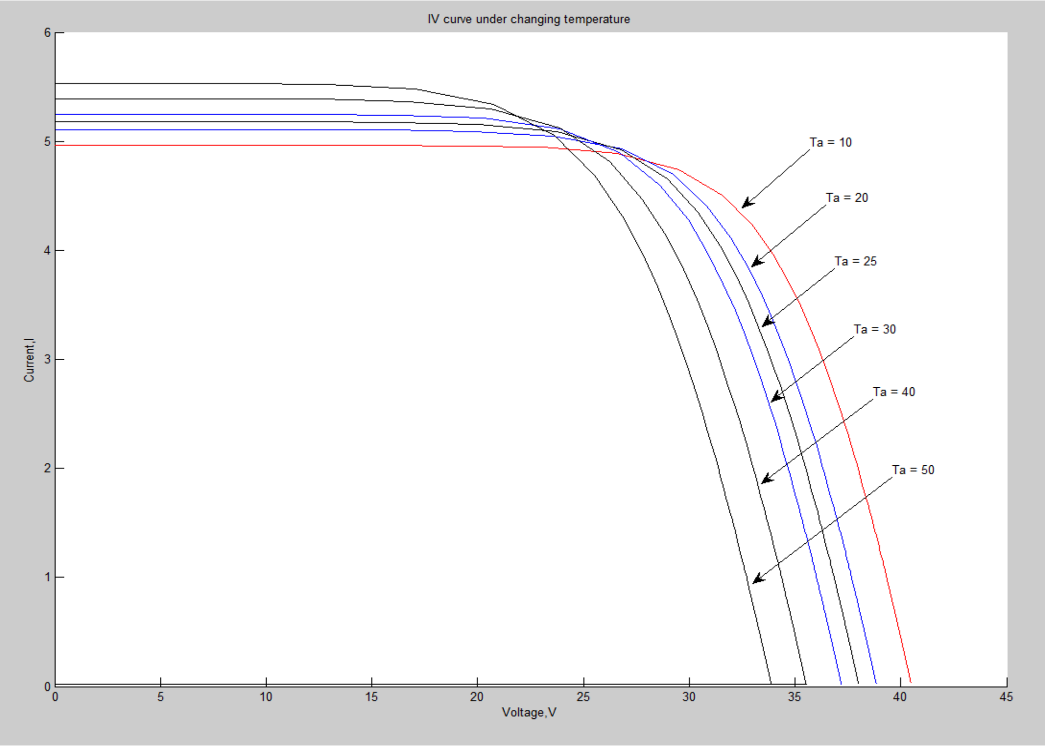


Figure 2.4.5: I-V characteristic under changing temperature

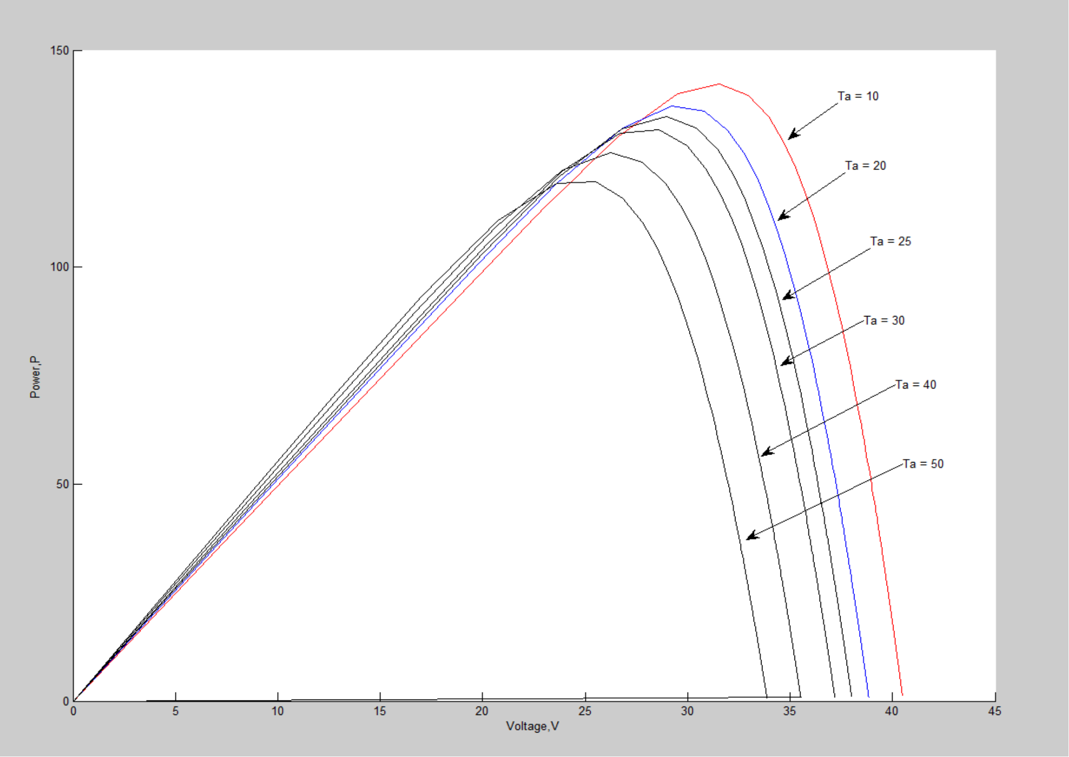


Figure 2.4.6: P-V characteristic under changing temperature

From the I-V curve we observe that the curve looks in perfect shape as expected by satisfying the given open circuit voltage, short circuit current etc. conditions. So our simulation is verified.

3. BATTERY

A battery is a device that converts chemical energy into electrical energy and vice versa. Usually it has two terminals – Positive Cathode and Negative Anode. During potential changing (charging or discharging) the system depends upon the chemical reaction of electrolyte (liquid or paste solution). Basically, electrolyte allows the ions to flow between the two terminals (cathode and anode) or the battery active materials which allows current to flow out of the battery to perform required work.

The uses of battery are knows no bound. For any electronic devices that needs high energy storage capacity (electric vehicle, electric generator or IPS etc.) or for any device that needs low energy output (portable devices like cell phone, laptop etc.), battery is used for either to storage energy or to act as a power supply. Along with technological improvement the storage capacity, size, life time is improving also the new uses of batteries are also emerging day by day.

For our solar car we are using battery for a media to store energy to have continuous output. In order to do that we need specific specification of battery to perform our task successfully which needs clear understanding of its parameters as well as its nature of behavior. In this chapter we will try to show the precise purpose and how we are expecting the battery to be executed through our simulated data.

3.1. TYPES OF BATTERIES

On the basis of charging capability batteries can be of two types:-

1. Primary
2. Secondary

3.1.1. PRIMARY BATTERY

Primary batteries are non-rechargeable batteries used for one time purpose and then discarded. There are many kinds of primary batteries like -

- Alkaline battery
- Aluminum-air battery
- Aluminum ion battery

- Bunsen Cell
- Dry cell
- Zinc-air battery
- Lithium battery etc.

3.1.2. SECONDARY BATTERY

Secondary batteries are the batteries which are rechargeable unlike primary batteries. Some kinds of secondary batteries are -

- Flow battery
- Fuel Cell
- Molten Salt battery
- Nickel-Cadmium battery
- Potassium ion battery
- Lithium ion battery
- Lead Acid Cell battery

As our solar car stands on the solar energy and we are going to use this renewable energy as a means of fuel, we need a battery which is rechargeable. So, basically we are using Secondary batteries.

Consumption of rechargeable batteries are increasing day by day as the field of multipurpose electronic means are developing to meet the every possible needs of the people. Thus we can say that the fields of rechargeable Secondary batteries are vast and different kinds of purpose require different kinds of Secondary battery.

Some of the primary and secondary battery's structure and their uses are being described. Also our required rechargeable battery is explained in brief and why are using it.

3.2. PRIMARY BATTERIES

3.2.1. ALKALINE BATTERY

Basic activity happens in Alkaline batteries is the reaction between zinc and manganese dioxide where zinc power acts as an Anode and manganese dioxide acts a cathode. Alkaline battery has '**alkaline**' electrolyte of potassium hydroxide unlike other battery systems where other active materials are used for electrodes.

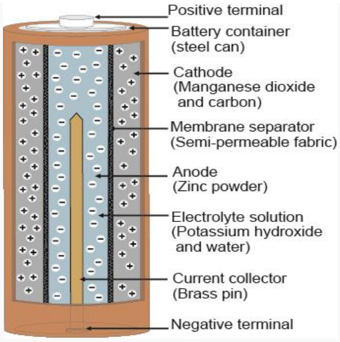


Fig 3.2.1: Alkaline battery

3.2.2. DRY CELL

The basic difference of a Dry Cell is it uses paste electrolyte unlike other battery systems. Its paste electrolyte actually helps to flow current as it has enough moisture and the main benefit of a Dry Cell is its non-spilling behavior as it has no liquid electrolyte which actually make suitable for portable equipment.

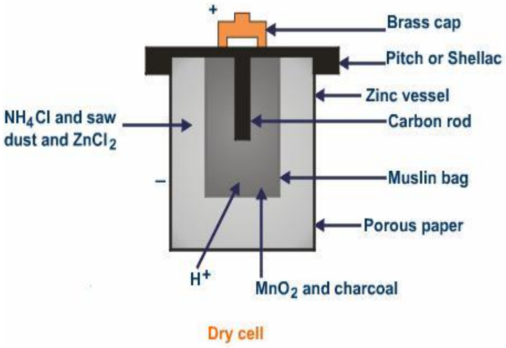


Fig 3.2.2: Dry Cell

3.2.3. ZINC-AIR BATTERY

In Zinc-air batteries the active materials are in contact with air where the system is powered by Zinc oxide contacting with oxygen from the air. The electrolyte is zinc water solution and this battery have high energy density and relatively cheap. `

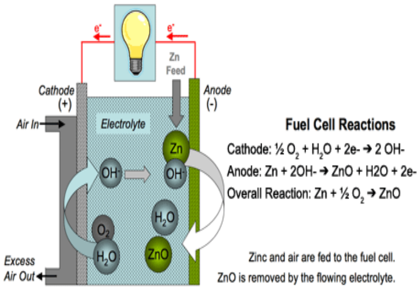


Fig 3.2.3: Zinc-air battery

3.2.4. LITHIUM BATTERY

In Lithium batteries the active materials are made of lithium metal. Here mixture of $SOCl_2$ and LiAlCl4 acts as an electrolyte as well as cathode lithium metal acts as an anode. This battery has high charge density and high cost per unit. This battery is used for portable electronic devices.

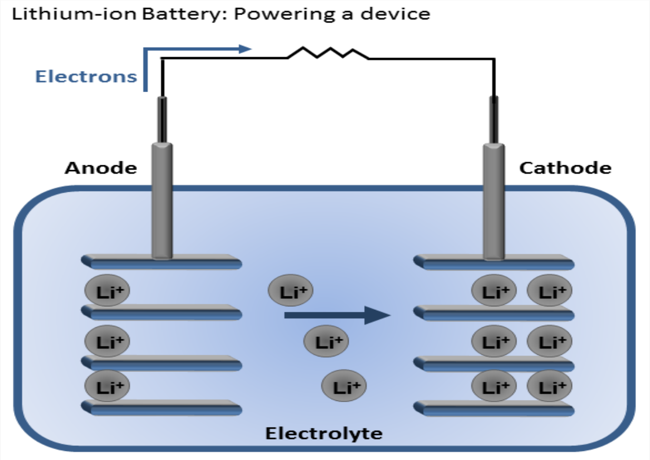


Fig 3.2.4: Lithium battery

3.3. SECONDARY BATTERIES

3.3.1. FLOW BATTERY

The basic system of Flow battery has two separate electrolytes for anode and cathode and they are being separated by an ion-exchange membrane. The ion-exchange membrane confirms the flow of current in the system. Separated by the membrane both of the liquids circulate in their own respective space.

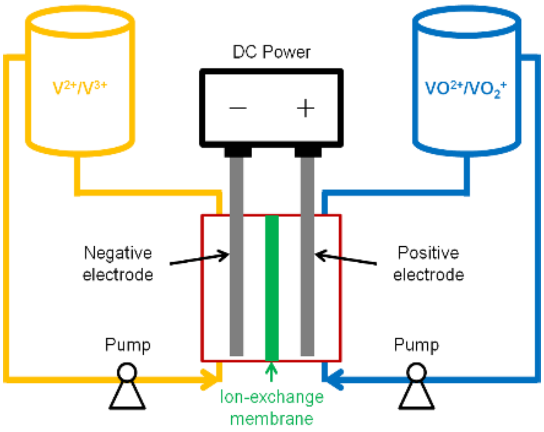


Fig 3.3.1: Flow battery

3.3.2. FUEL CELL

Unlike other batteries Fuel Cell does not have any built in media through which it can produce required energy rather it is a device that converts chemical or fuel energy into electrical energy. Natural Hydrogen gas is the most common fuel but for greater efficiency hydrocarbons are also being used. From the anode side Hydrogen fuel are inserted and natural air are being inserted form the cathode side. Excess fuel from the anode side and excess water are being pushed out form the system. This system requires constant source of fuel.

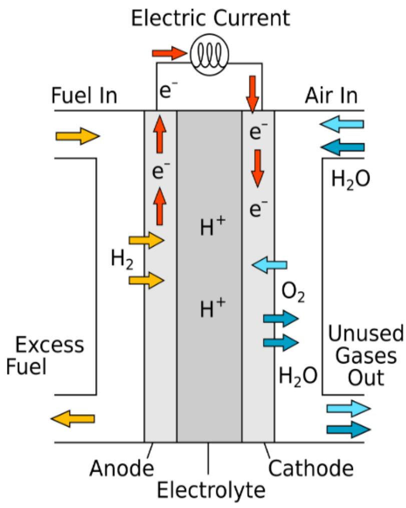


Fig 3.3.2: Fuel Cell

3.3.3. LITHIUM-ION BATTERY

The basic principal of a lithium-ion battery is the circulation of lithium ion from negative active material to positive active material during charging. This is the most commonly used rechargeable battery for portable electronic devices for its high energy density, no memory effect and low loss of charge when not in use.

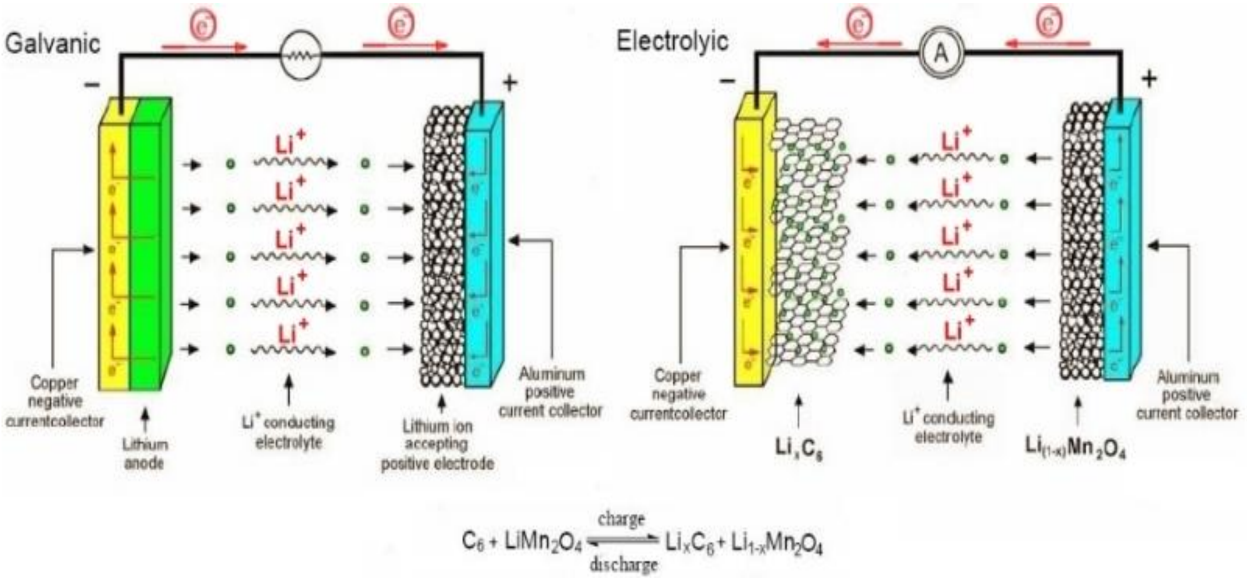


Fig 3.3.3: Lithium-ion battery

3.3.4. LEAD ACID CELL BATTERY

Lead acid cell battery is the oldest type of rechargeable battery which was invented by French scientist Gaston Plante´ in 1859.The basic structure of lead acid cell battery is consists of two active materials (anode and cathode) separated by a separator and the whole system is submerged in electrolyte which is basically sulfuric acid (H_2SO_4) and water solution ($H_2 O$). If an electrical load is connected between the active materials, during discharge sulfate ions bond to the plates while the sulfuric acid leaves the electrolyte.

Although it has low energy to weight and low energy to volume ratio it is able to supply high surge current. For this reason we have used lead acid cell battery for our solar car.

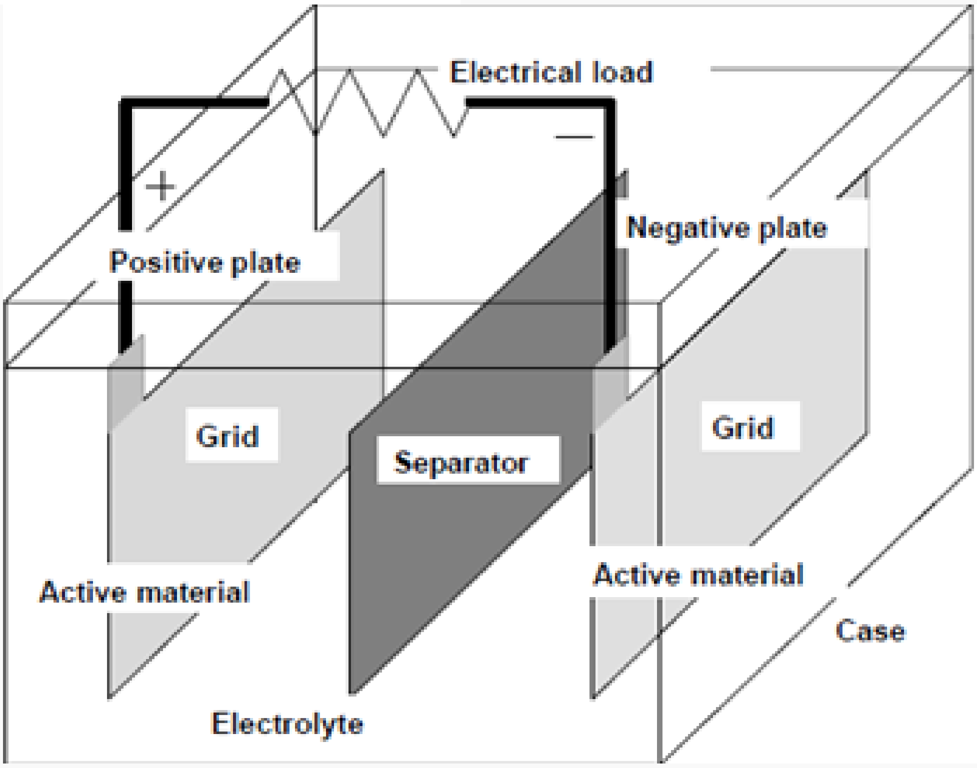


Fig 3.3.4: Lead Acid Cell battery

3.4. BATTERY PARAMETERS

• **State of Charge (SOC) (%)** –

SOC is an expression of the present battery capacity as a percentage of maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time. It can also be explained as –

$$\mathrm{SOC} = \frac{\text{Available capacity}}{\text{Nominal capacity}}$$

• **Depth of Discharge (DOD) (%) –**

The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. DOD is actually the opposite of SOC.

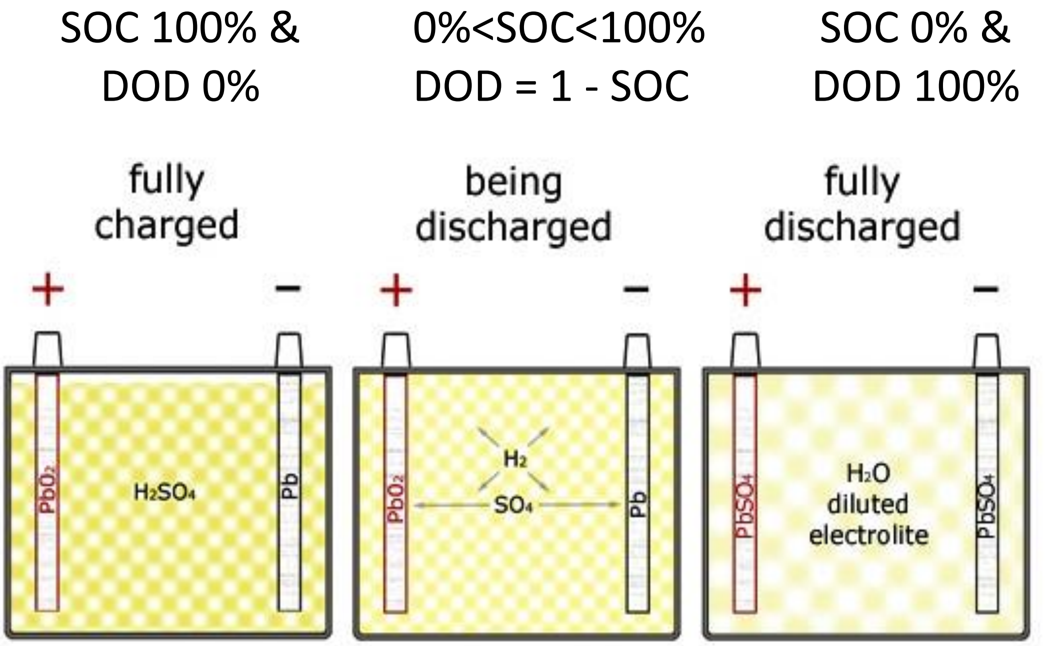


Fig 3.4: Charging and discharging (SOC Vs DOD)

• **Terminal Voltage (Vt) –**

The voltage between the battery terminals with load applied. Terminal voltage varies with SOC and discharge/charge current.

• **Open-circuit voltage (Voc) –**

The voltage between the battery terminals with no load applied. The open-circuit voltage depends on the battery state of charge, increasing with state of charge.

• **Internal Resistance (Rs)–**

The resistance within the battery, generally different for charging and discharging, also depends on the battery state of charge. As internal resistance increases, the battery efficiency decreases and thermal stability is reduced as more of the charging energy is converted into heat.

• **Nominal Voltage (V) –**

The reported or reference voltage of the battery, also sometimes thought of as the "normal" voltage of the battery.

• **Cut-off Voltage –**

The minimum allowable voltage of the battery is known as Cut-off-Voltage. It is this voltage that generally defines the "empty" state of the battery.

• **Capacity or Nominal Capacity (Ah for a specific C-rate) –**

The coulometric capacity or the amount of matter transform capacity during an electrolysis reaction, the total Amp-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. Capacity is calculated by multiplying the discharge current (in Amps) by the discharge time (in hours) and decreases with increasing C-rate.

• **Energy or Nominal Energy (Wh (for a specific C-rate)) –**

Nominal capacity is basically the "energy capacity" of the battery, the total Watt-hours available when the battery is discharged from 100 percent state-of-charge to the cut-off voltage. Energy is calculated by multiplying the discharge power (in Watts) by the discharge time (in hours). Like capacity, energy decreases with increasing C-rate

• **Energy Density (Wh/L) –**

The nominal battery energy per unit volume, sometimes referred to as the volumetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery size required to achieve a given electric range.

3.5. TYPES OF BATTERY MODEL

There are various types of battery model and process to calculate their parameters varies accordingly. Thus, it is high time to select an appropiate battery model from these models need clear understanding to calculate their parameters and we need to find a simple way to avoid difficulties. Some battery models are explained below –

3.5.1. SIMPLE BATTERY MODEL

A Simple battery model consists of a source voltage (Fig: Vsource) which series with the internal resistence(Rs) and finally terminal voltage of the battery(Vo).

In this model the two parameters Rs and Vout where Vout can measured through open circuit voltage and the internal resistence can be measured from open circuit votage as well as from fully charged battery with load connected.

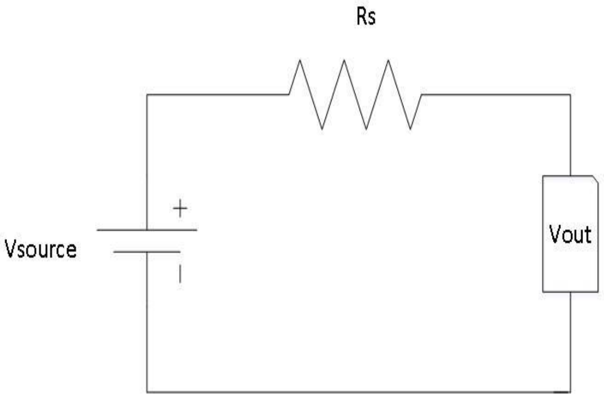


Fig 3.5: Simple battery model

3.5.2. THEVENIN BATTERY MODEL

Thevenin battery model is a commonly used battery model which consists of a no-load ideal source voltage (Fig: Voc) which series with the battery internal resistance Rs along with capacitace Co over resistance Ro and finally the terminal voltage (Fig: Vt).

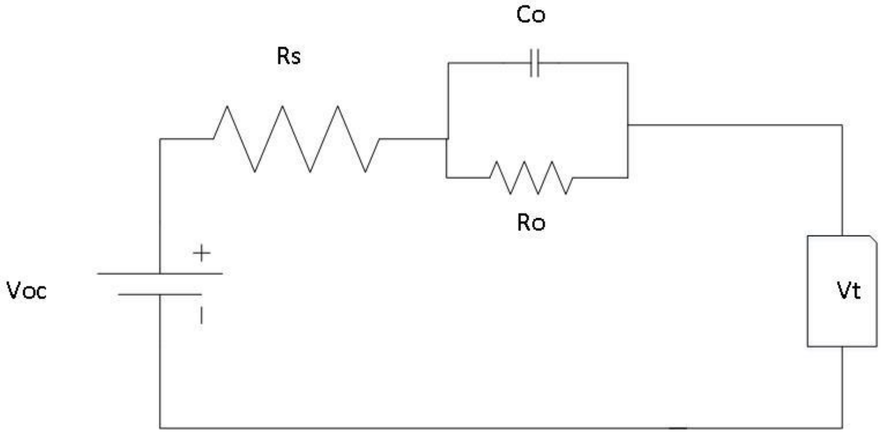


Fig 3.5.2: Thevenin battery model

Here, Capacitane Co is nothing but the capacitance between electrolyte and active materials and resistane Ro is the battery overvoltage due the contact resistance of active materials to electrolyte.

If Ick flows through the whole circuit then and the voltage across the Co or Ro is Vo then –

Vt = Voc - (Ick*Rs +Vo)

3.5.3. RANDLE’S BATTERY MODEL

This model consists of a source voltage (Fig: Vsource) which series with the internal resistance Ri along with the capacitance Cs over Rs where Cs and Rs are the transient effect due to the ion shifting for different concentration the current densities of the active materials. Finally the Capacitance C is to store the overall charge and R represents a self-discharging resistance.

Here, the transient effects Cs and Rs are resposible for the - change of Soc while C and R are function of Soc. Thus accurate estimation of Soc requires carefull estimaton of time constants. If the voltage across the transients (Cs and Rs) is Vcs and the voltage across C or R is Vf and the current across the resistor Ri is Ii then –

$$Vcs = \frac{\mathrm{IiRs - Vcs}}{\mathrm{CsRs}}$$

$$\mathrm{Vf} = \frac{\mathrm{IiR{-}Vf}}{\mathrm{CR}}$$

$$Vf = \frac{\mathrm{Ii}}{\mathrm{C}}$$

$$Vo = \mathrm{Vcs} + \mathrm{Vf} + \mathrm{IiRi}$$

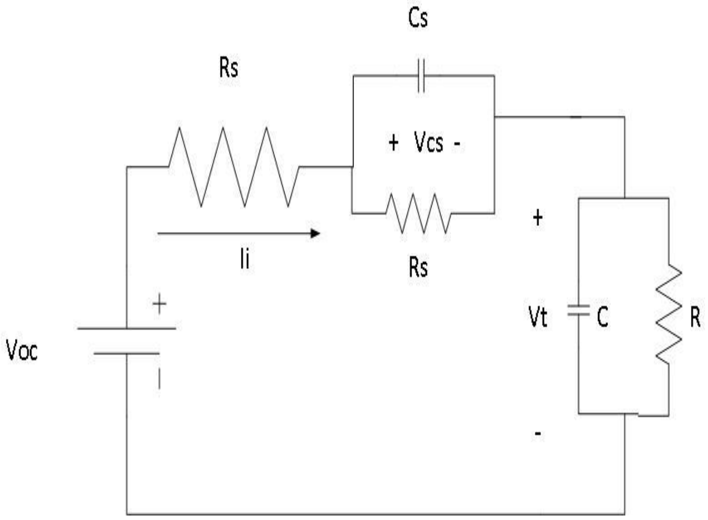


Fig 3.5.3: Randle’s battery

3.5.4. COPPETI BATTERY MODEL

Here, C represents as the storage capacitor which stores the overall charge the battery that finally sends the charge to the battery's terminal point. This Capacitor series with the polarization capacitor Cp and the battery's internal resistor R. The whole circuit current is I actually opposite to the polarization current. Hence, we take two assumptions –

If Vout < nV [V is contant]

By taking time contant –

Vout = n {Vc(t) +Vcp(t)}[Vc is the votage across C and Vcp is the voltage across Cp or R]

$$\frac{\mathrm{d}}{\mathrm{d}t}\,\mathrm{Vc} = \frac{-\mathrm{I(t)}}{\mathrm{C(t)}}$$

And if Vout > nV then –

Vout = n {Vc(t) + R(t)*I(t)}

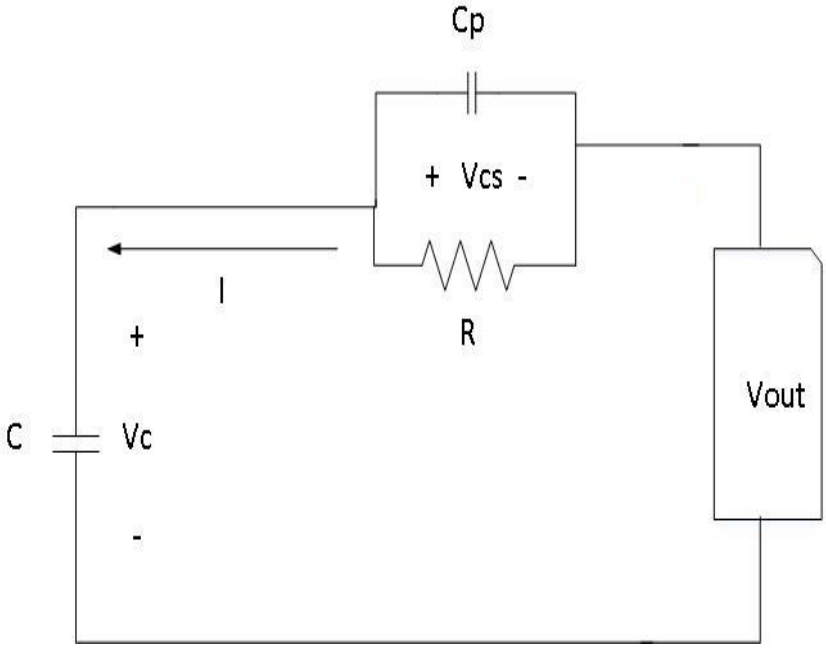


Fig 3.5.4: Copetti battery

3.6. PROPOSED BATTERY MODEL

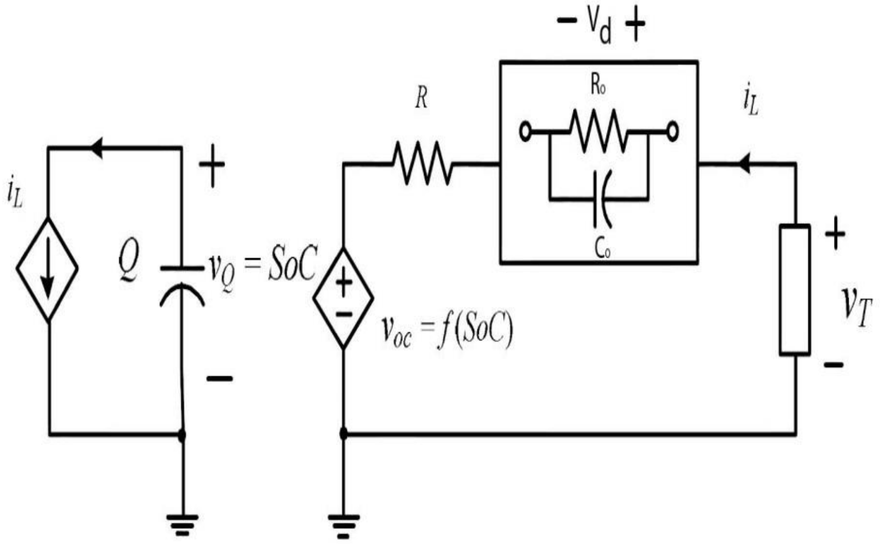


Fig 3.6: Proposed battery model

Our proposed battery model is basically thevenin model considering the voltage across the parallel components a constant voltage Vd. Here we are following the perspective of simple battery model by considering all the parameters as constant, function of SOC(State Of Charge). Here –

Voc = f(SOC) = b_1 SOC + b_0

P = Vt*I

Vt = Voc - Vd - IL*R

I = $\frac{(Voc- Vd)-\sqrt{(Voc-Vd)^2- 4RP}}{2R}$

Vd = x_1 SOC + x_0

Rs= y_1 SOC + y_0

The parameters which are function of SOC (VOC, Vd, Rs) will be extracted later on from the experimental values and then injected in the battery model for verification purpose.

3.7. FINDING BATTERY PARAMETERS

For different SOC we will figure out the values of Voc, Vd, and Rs to achieve the function of them as a leniar function of SOC. The difference between the Open circuit voltage(Voc) and the terminal voltagee (Vt) is the internal loss of the circuit, thus in different SOC by changing the load we find scttered Voc – Vt and its fitted values by line regression against I (circuit current) curve's slope is the internal resistance (Rs). From these extracted Voc ,Vt and Rs of specific SOC we can easily calcute Vd (capacitive voltage). In different SOC , Voc – Vt vs I curve along with internal resistance (Rs) and capacitive votage(Vd) are shown below –

SOC 90%

Voc - Vt **(V)**	I **(A)**		Voc - Vt **(V)**	I **(A)**
12.33	0		12.16	4.45
12.25	1.51		12.15	5.01
12.24	2.12		12.14	5.52
12.22	2.42		12.13	6
12.2	3.06		12.11	6.51
12.2	3.55		12.09	7.61
12.18	3.99		12.10	7.96
12.16	4.45		12.08	7.98

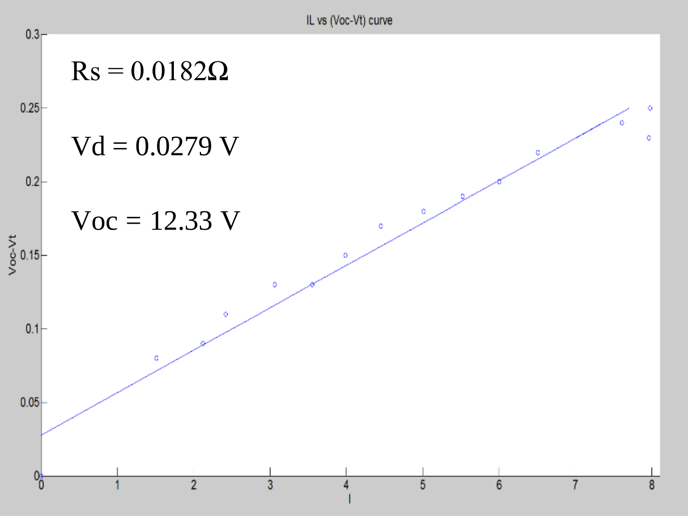


Fig 3.7.1: Voc –

SOC 70%

Voc-Vt **(V)**	I(**A**)		Voc-Vt **(V)**	I(**A**)
12.05	1.55		11.88	4.99
11.99	2		11.87	5.55
11.96	2.52		11.86	6
11.94	3.06		11.85	6.48
11.92	3.50		11.83	7.61
11.91	4		11.81	7.95
11.90	4.50		11.82	8
11.88	4.99		11.80	1.55

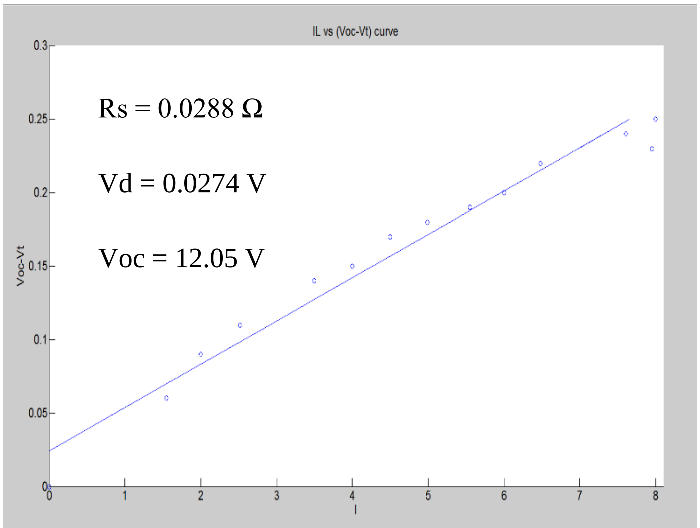


Fig 3.7.2: Voc – Vt vs

SOC 55%

Voc-Vt (**V**)	I(**A**)		Voc-Vt (**V**)	I(**A**)
11.83	0		11.63	4.54
11.75	1.55		11.61	5.06
11.72	2.01		11.59	5.5
11.69	2.55		11.58	5.98
11.68	2.98		11.56	6.5
11.66	3.47		11.55	7.08
11.64	4		11.53	7.53
11.63	4.54		11.52	7.94

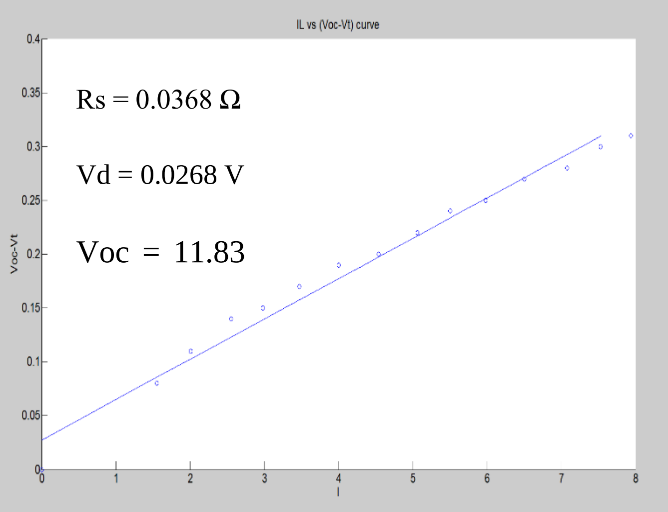


Fig 3.7.3: Voc – Vt

From this three sets of data we derived the following equations,

Voc = 1.4667 * SOC + 11.0233

Vd = 0.086 * SOC – 0.011

Rs = -0.0531 *SOC + 0.066

3.8. APPROACHES TO MODEL THE BATTERY

3.8.1. ALGORITHM

Sept one

Collect the value of the battery capacity and initial Sate of charge (SOC)

Step two

Calculate the functions of SOC which are Voc, Vd, Rs and the equations are –

$Voc = 1.4667 * SOC + 11.0233$
$Vd = 0.086 * SOC – 0.011$
$Rs = -0.0531 *SOC + 0.066$

Step three

Calculate the battery current based on the power required and the parameters of the previous step as the following equation –

$$I = \frac{Voc - Vd - \sqrt{(Voc - Vd)^2 - 4RP}}{2R}$$

Step four

Calculate the Ampere hour loss from the equation –

$AHL = I_L*t/V_t$

Step five

Calculate the total charge drawn out from the battery during discharge form the equation

$Q_{dis} = AHL + I_L * t$

Step six

Calculate new SOC by subtracting the old SOC from the Q_{dis}.

SOC = Old SOC – Q_{dis}

And check if the SOC is less than 25% if not then execute step two again. If SOC is less than 25% disconnect the load and stop.

3.8.2. FLOWCHART WITH BLOCK DIAGRAMS

The steps of the previous section is shown in a flowchart in the following figure.

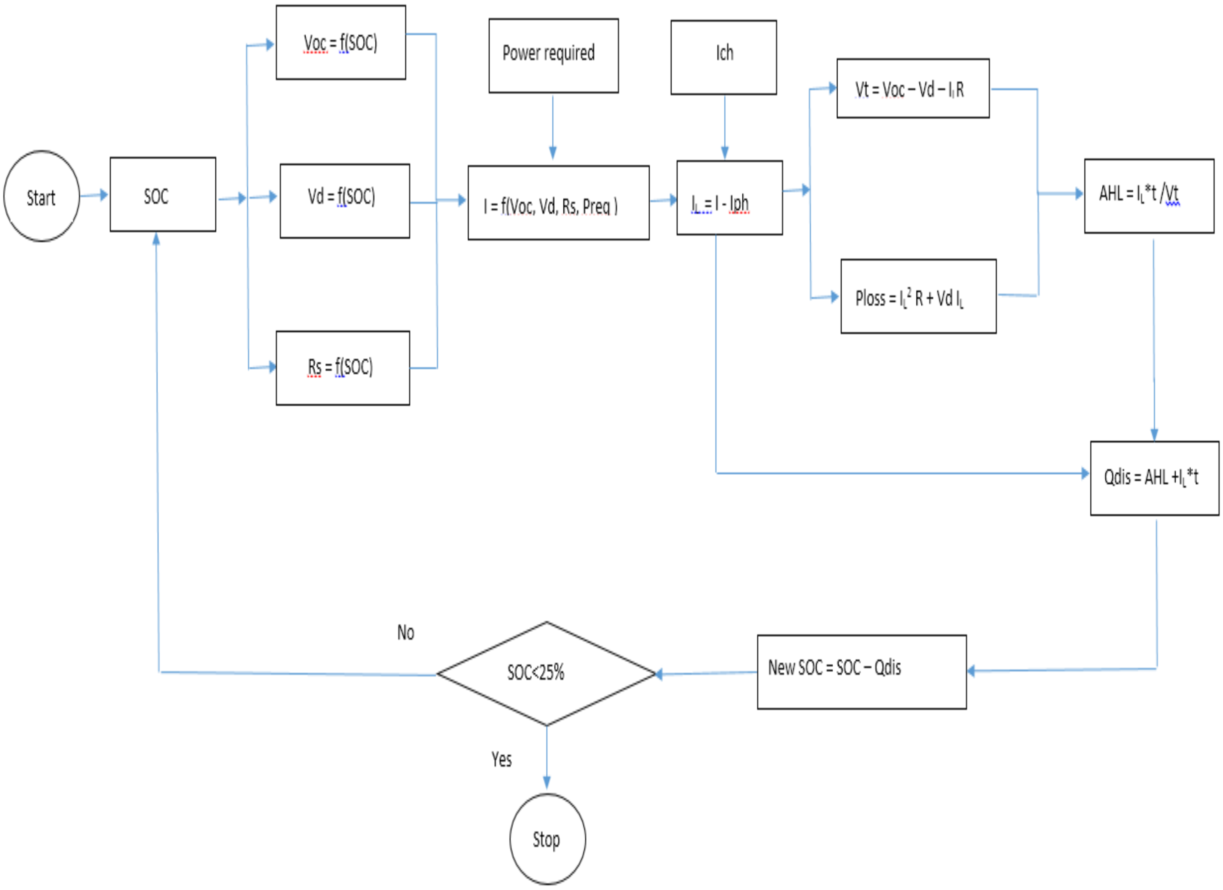


Fig 3.8.2: Battery model flowchart

3.9. SIMULINK MODEL OF THE BATTERY

The model is implemented in SIMULINK, using fundamental and subsystem blocks. The total model is then masked in a single subsystem with some mask parameters.

3.9.1. MASK DIAGRAM

The mask diagram of the battery along with the required power generator, and charging current supplier is shown in Figure 3.9.1. The block takes Power required and charging current as input and gives the terminal voltage, load current and current SOC as output. This outputs can be transferred to Matlab workspace to plot and analyze.

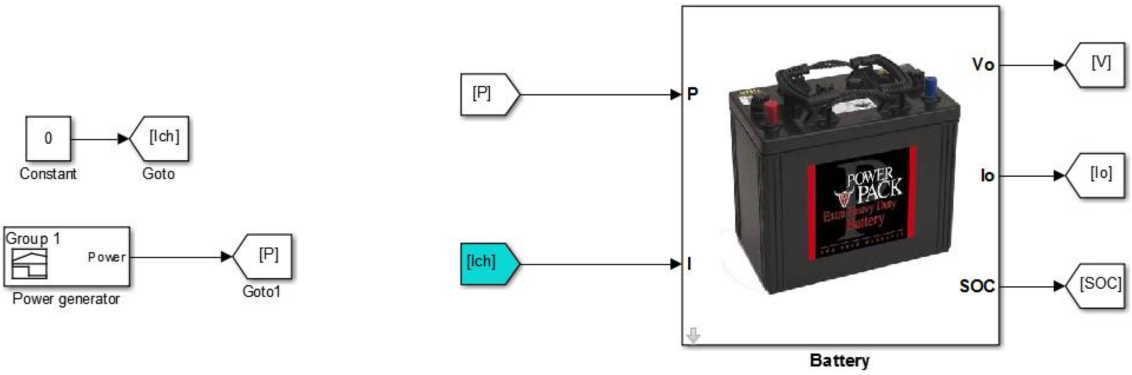
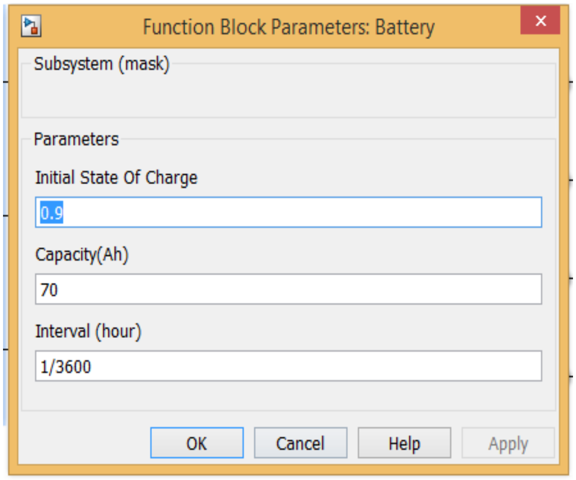


Figure 3.9.1. Mask diagram of the battery

The mask parameter of figure 3.9.2 takes three inputs. Initial state of charge of the battery before running the simulation, capacity of the battery, and the interval. Interval is a measure of time as user's choice that how after how much interval user wants to sample the data. 1/3600 means the users wants to get the SOC, Vt and I from the block at every second. It takes a lot of time to simulate a data set of the whole day. If user wants he can increase the simulation speed by sampling the data at higher interval.


Function Block Parameters: Battery

Subsystem (mask)

Parameters

Initial State Of Charge: 0.9

Capacity(Ah): 70

Interval (hour): 1/3600

Figure 3.9.2. Mask parameters

3.9.2. LOOKING UNDER THE MASK

The simulation block is designed in accordance to the flowchart for understanding purpose. Vo, Io and SOC is the output of the system which goes to charge controller as well as to the MATLAB workspace to analyze the data.

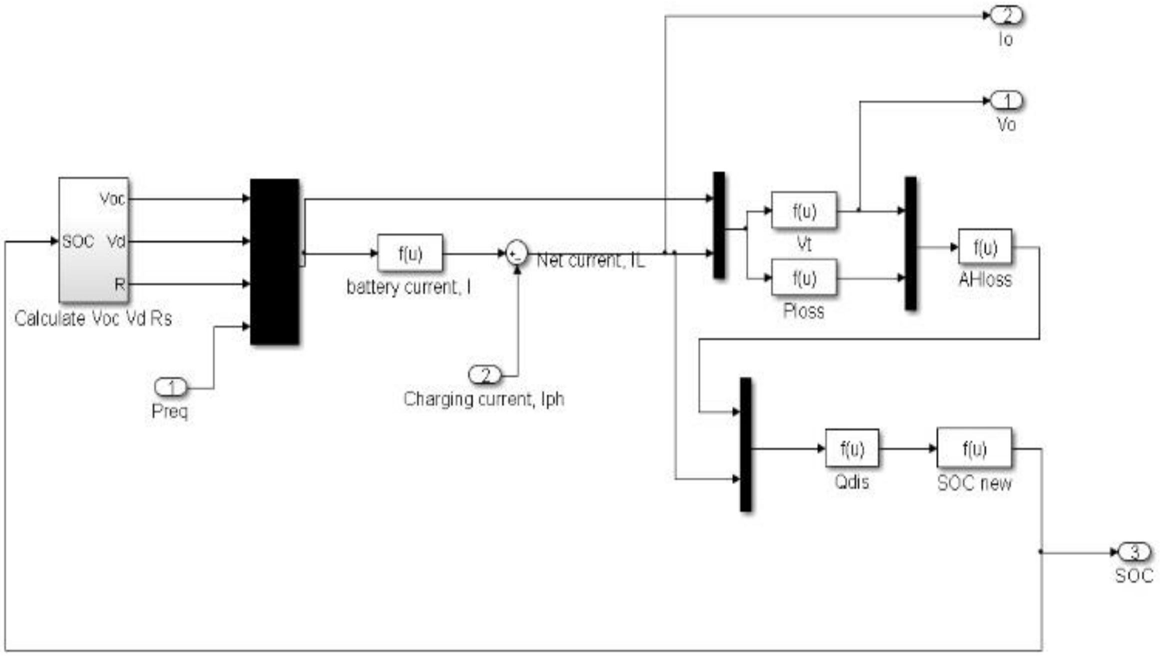


Fig 3.9.2: Simulink model of the battery

3.10. TESTING THE MODEL

In section 3.7 we plotted some experimental values of the battery. Now we run the simulation with the equal amount of load to observe the same graph and compare to verify our model.

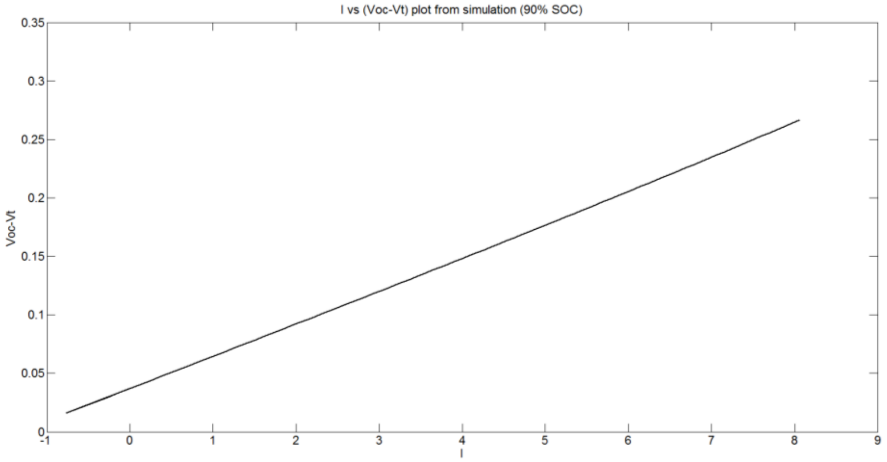


Figure 3.10.1. I vs (Voc-Vt) plot (90% SOC)

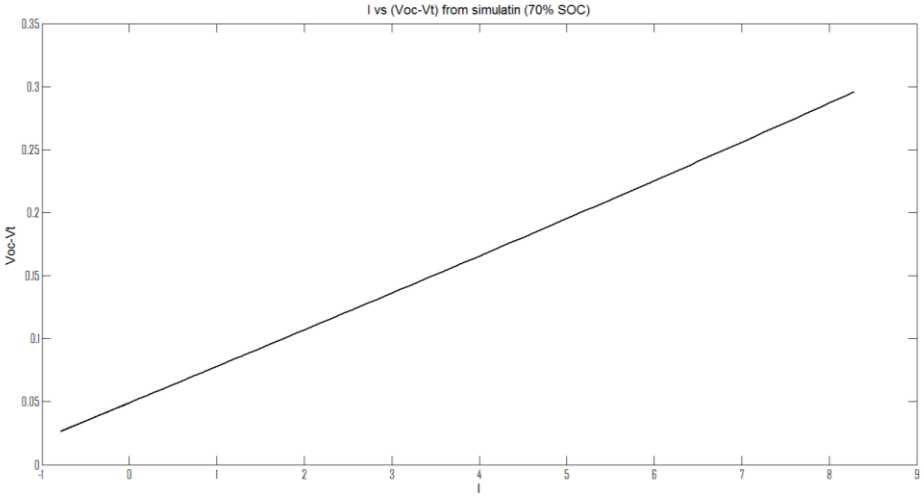


Figure 3.10.1. I vs (Voc-Vt) plot (70 % SOC)

This two plots almost matches with the experimental curves. So we can come to a decision that our model and implementation is correct and the error is tolerable.

The battery would be connected with a controller to avoid over charge and over discharge. The battery can be charged from panel or from power grid with an adapter. When there is no sunlight the controller gives charge to the battery from national grid and when there is enough current in the panel the controller switches back to panel.

4. DC MOTOR

Motor is an electrical machine that converts electrical energy into mechanical energy. Motor works through the interaction between a motor's magnetic field and winding currents to produce rotary force that convert electricity into motion.

In electrical vehicle or solar car we normally use DC motor. Motor in an electrical vehicle requires

- Quick starts and stops rate
- Quick acceleration or deceleration
- High torque low speed hill climbing
- Low torque high speed cruising
- Wide speed range of operation

We had to make right selection of DC motor which fulfills all of the requirements of an electrical vehicle from self-exited dc motor which has two types

- Shunt exited
- Series exited

4.1. MOTOR SELECTION:

Motor converts the electrical energy into mechanical energy and help the car to get the driving force to run or get speed on the road. Battery gives the electrical energy to motor and we have to choose motor specification according to power supply to battery to motor. As we have five batteries in series, each have 12V voltage rating so total supply of the motor is 60V and we had to choose motor which have the voltage rating around 60V. From many types of motors we preferred DC series excitation motor brushed for our solar car project. The reasons for choosing this are

- **Simplicity** of its circuit and operation.
- **Generation of torque** directly from DC power supply to the motor
- Easier control of **speed** and **direction of rotation**

Figure : DC series excitation motor of our solar car project

4.1.1. MOTOR SPECIFICATIONS

- Type: DC series excitation motor (brushed)
- Company: Hong Kong Dong Hui Motor Industrial Co.,Ltd.
- Rated Power: 1 kW
- Rated Current: 28 A
- Rated Voltage: 60 V
- Insulation class: E
- Rotation per minute: 630rpm

4.1.2. ELEMENTARY CIRCUIT OF DC SERIES MOTOR

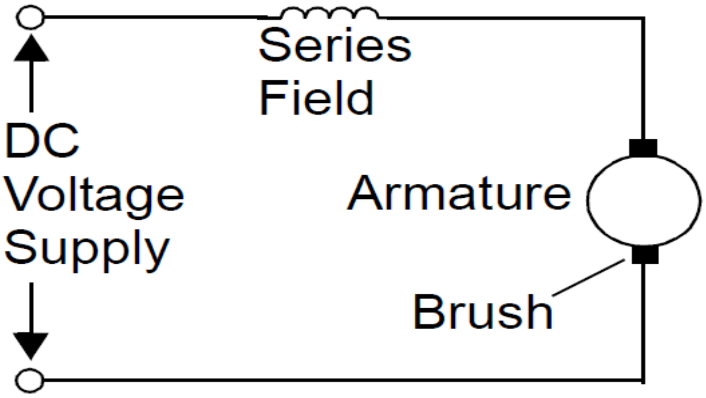


Figure 4.1.2: Elementary circuit of DC Series Motor

In the DC series motor permanent magnet is replaced by another coil winding called the armature winding. It generates a magnetic field when current flows through.

In the **figure 4.1.2** armature and field windings are in series with DC voltage to be applied. The greater the DC applied voltage the greater the rotational speed.

4.2. DC MOTOR MECHANISM

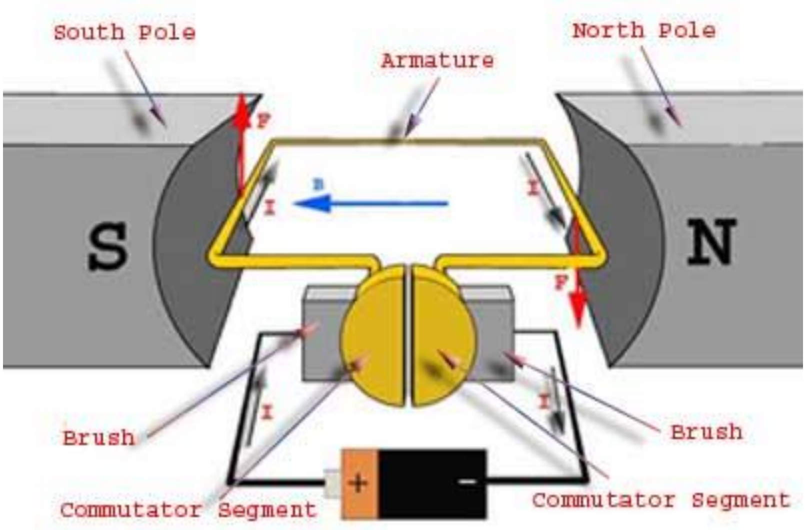


Figure 4.2: Basic operation of DC Series Motor

In the **figure 4.2** basic construction of a dc motor contains a current carrying armature which is connected to the supply end through commutator segments and brushes and placed within the north south poles of an electro-magnet.

When electric current passes through magnetic field, the magnetic force produces torque and this toque causes DC motor to turn. Here electric current supply through commutator. The electrical energy in the rotor and armature is converted to mechanical energy at the motor shaft.

4.3. SPEED CONTROL

We know that speed of the motor is proportional to the EMF and torque of the motor is proportional to current. The speed of dc motor can be controlled by either by armature control or by field control.

4.3.1. ARMATURE CONTROL OF DC SERIES MOTOR

Speed adjustment of dc series motor by armature control may be done by any one of the methods that follow

- **Armature resistance control method:** Here the controlling resistance is connected directly in series with the supply to the motor. The power loss in the control resistance of dc series motor can be neglected because this control method is utilized for a large portion of time for reducing the speed under light load condition. This method of speed control is most economical for constant torque.

- **Shunted armature control:** Here rheostat shunting the armature and a rheostat in series with the armature combination is used to speed control. Power loss in this method is huge and it is not economical.

- **Armature terminal voltage control:** Here the speed control of dc series motor can be accomplished by supplying the power to the motor from a separate variable voltage supply.

4.3.2. FIELD CONTROL OF DC SERIES MOTOR

The speed of dc motor can be controlled by this method by any one of the following ways

- **Field diverter method:** Here this method uses a diverter. The field flux can be reduced by shunting a portion of motor current around the series field. Lesser the diverter resistance less is the field current, less flux therefore more speed. This method gives speed above normal and the method is used in electric drives in which speed should rise sharply.

- **Field voltage control:** This method requires a variable voltage supply for the field circuit which is separated from the main power supply to which the armature is connected. Such a variable supply can be obtained by an electronic rectifier.

In our solar car system we achieved speed control by varying of a potentiometer to vary the voltage applied at the motors windings. This electrical system of speed control had to be translated to a mechanical system of acceleration via the use of a foot pedal system seen in conventional cars. Therefore the potentiometer was integrated into a foot pedal accelerator that makes use of a pressure lever and springs to control the magnitude of the potentiometer.

When we press the pedal down; potentiometer terns on and resistance increases cause voltage at the terminal to increase also. It causes the shaft of the motor to rotate faster and car to accelerate.

Similarly when we ease the pedal; potentiometer act in the reverse direction cause resistance and voltage at the terminal to decrease. Then car starts to slow down.

4.4. POWER CALCULATION OF MOTOR

Power needed to drive a car can be determined by combining the force that acting on the car causes it to move at car speed at which this driving force must be sustained. Drive force that moves the vehicle generated by drive torque which acts wheel of the car to move it. At the design stage it's easier to frame the calculation around this drive force rather than the drive torque. Thus the calculations in this section start by determining the size of this drive force, and given a set of speed at which the vehicle should move, the drive power is found.

The total drive force that has to act on the vehicle to make it move (or keep it moving) can be estimated by adding together individual force components that arise from different physical effects. These are

- The rolling resistance force
- Aerodynamic drag force
- Force of acceleration

4.4.1. THE ROLLING RESISTANCE FORCE

Force that resists the motion when a vehicle rolls on a surface is called rolling resistance force. Wheel diameter, speed, load on the wheels etc. also contribute in the rolling resistance force. For example vehicle has more rolling resistance in sand surface than in concrete surface. The rolling resistance force can be expressed as,

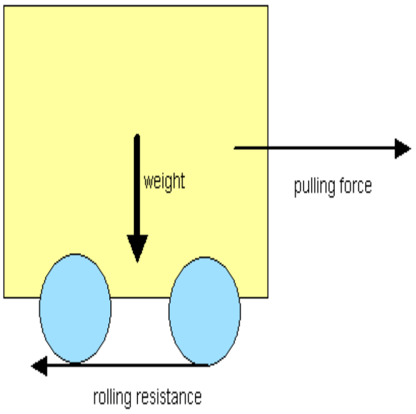


Figure 4.4.1: Rolling resistance force

$$F_{ROLLING} = \mu_R * W \text{-------------------------} \quad (4.4.1)$$

Here,

W= the weight of the car.

μ_R= the coefficient of rolling resistance.

μ_R is a constant that depends on the type of tires of the vehicle and the surface on which it will roll. Thicker tires with wider treads, although good for adhesion, however produce more rolling resistance.

To conserve power solar cars need to use thinner tires. Also harder surfaces offer lower rolling resistance force than softer ones. Some standard values are shown as follows:

μ_R	Description
0.0003 to 0.0004	Pure rolling resistance Railroad steel wheel on steel rail
0.0010 to 0.0024	Railroad steel wheel on steel rail. Passenger rail car about 0.0020
0.001 to 0.0015	Hardened steel ball bearings on steel
0.0022 to 0.005	Production bicycle tires at 120 psi (8.3 bar) and 50 km/h (31 mph), measured on rollers
0.0045 to 0.008	Large truck (Semi) tires
0.010 to 0.015	Ordinary car tires on concrete
0.0385 to 0.073	Stage coach (19th century) on dirt road. Soft snow on road for worst case.
0.3	Ordinary car tires on sand

Table 4.4.1: Coefficient Of Rolling Resistance μ_R of different wheels/surface

4.4.2. AERODYNAMIC DRAG FORCE

The force that prevent the vehicle from moving through air is called aerodynamic drag force. The aerodynamic drag force can be expressed as,

F_{DRAG} = (1/2)*Cd*Across*ρ*(V^2) ---------------------------- **(4.4.2)**

Here,

Cd = the coefficient of drag of the vehicle, Across is it’s frontal area in square feet.

ρ = a constant that accounts for the air mass density

V = the vehicle’s speed.

To minimize drag for any given Cd, the coefficient of drag, and across, its frontal area must be minimized.

The drag force becomes increasingly noticeable at speeds of above 40 km/h due to it being proportional to the square of the speed. Because batteries provide only 1% as much power per weight as gasoline, optimizing for either high-speed or long-range performance goals, requires that one keeps this critical performance factor foremost in mind.

4.4.3. FORCE OF ACCELERATION

The force of acceleration should be only accounted for when the car is accelerating and is given by newton's 2nd law of motion

$F_{ACCELERATION} = m*a$-------------------------------- **(4.4.3)**

Where m is the mass of the car and a is the acceleration

4.4.4. TOTAL FORCE

From equations 4.4.1, 4.4.2, 4.4.3 we can find the total at driving force

$F_T = F_{ROLLING} + F_{DRAG} + F_{ACCELERATION}$

$$= \mu_R * W + \frac{1}{2} * C_d * A_{cross} * \rho * V^2 + m * a \text{------------------------------- } \mathbf{(4.4.4)}$$

Weight, *W*= mg	500 kg * 9.81 ms-2 = 4905 N
Top speed, *VMAX*	60 km/h = 16.7 ms-1
Coefficient of rolling resistance, μ_R	0.01
Coefficient of drag, C_D	.35
Frontal area, A_{cross}	1m*1.1m
Mass density of air, ρ	1.2 kgm-3

Table 4.4.4. Parameters for calculation of motor power

When the car runs at constant speed, there is no acceleration, so the equation of the total force becomes

$F_T = F_{ROLLING} + F_{DRAG}$

$= \mu_R * W + \frac{1}{2} * C_d * A_{cross} * \rho * V^2$ …… **(4.4.5)**

At the design stage the following necessary assumptions of what the most probable values of the above parameters might be was made as given below in the Table.

The power needed to be supplied by the motor in order to provide the current speed and acceleration will therefore be,

W = mg

Here,

m = Mass of the car

g = gravitational constant

$v = at$

$P_T = F_T * v$

$= \mu_R * m * g * a * t + \frac{1}{2} * C_d * A_{cross} * \rho * a^3 * t^3 + m * a^2 * t$…… **(4.4.6)**

And at constant velocity,

$P_T = \mu_R * m * g * a * t + \frac{1}{2} * C_d * A_{cross} * \rho * a^3 * t^3$ …………………**(4.4.7)**

4.5. APPROACHES TO MODEL POWER BLOCK

4.5.1. ALGORITHMS TO FIND POWER AT DIFFERENT SPEED

Step 1:

Get the required parameters of the car

- Mass of the car, m
- Frontal area of the car, A_{CROSS}
- Air density, ρ
- Rolling resistance coefficient, μ_R
- Drag coefficient of the vehicle. C_D

Step 2:

- Maximum velocity of the car, V_{max}
- Time to reach maximum velocity, t_{max}
- Velocities in which the car runs, v
- Time ranges of the velocities, t

Step 3:

- Acceleration, $a = V_{max}/t_{max}$
- Distance covered at different speed, s = v*t
- Rise time at different speed, tr = v/a
- Fall time at different speed, t_f = tr/2
- Constant velocity time, $t_c = t - t_r - t_f$

Step 4:

- Get the current time, ti
- If ti is in the rise time range, Power = $\mu_R * m * g * a * t + \frac{1}{2} * C_d * A_{cross} * \rho * a^3 * t^3 + m * a^2 * t$
- If ti is in the constant velocity time, tc, Power = $\mu_R * m * g * a * t + \frac{1}{2} * C_d * A_{cross} * \rho * a^3 * t^3$
- If ti is in the fall time range, Power = 0

4.5.2. FLOWCHART OF POWER CALCULATION

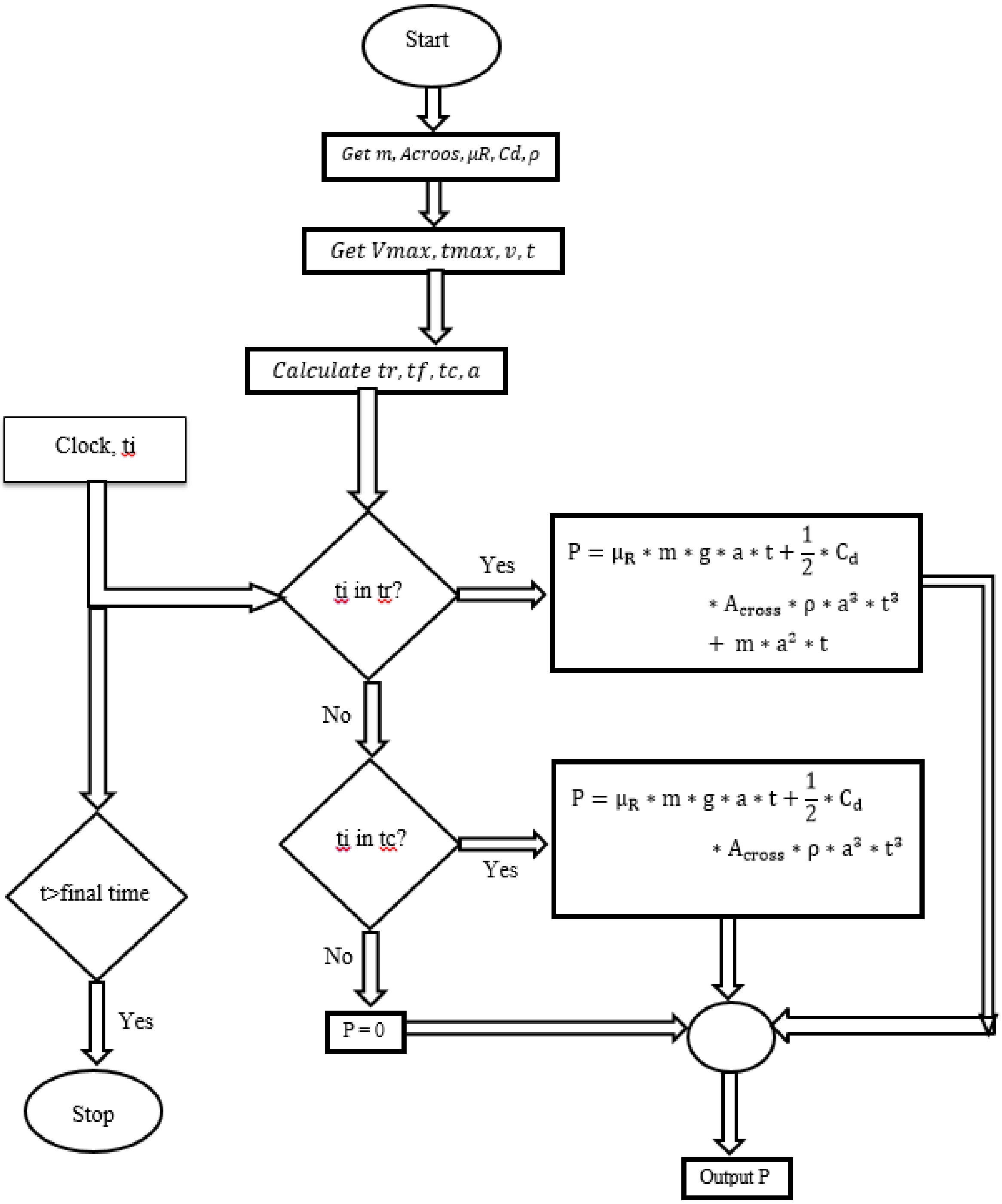
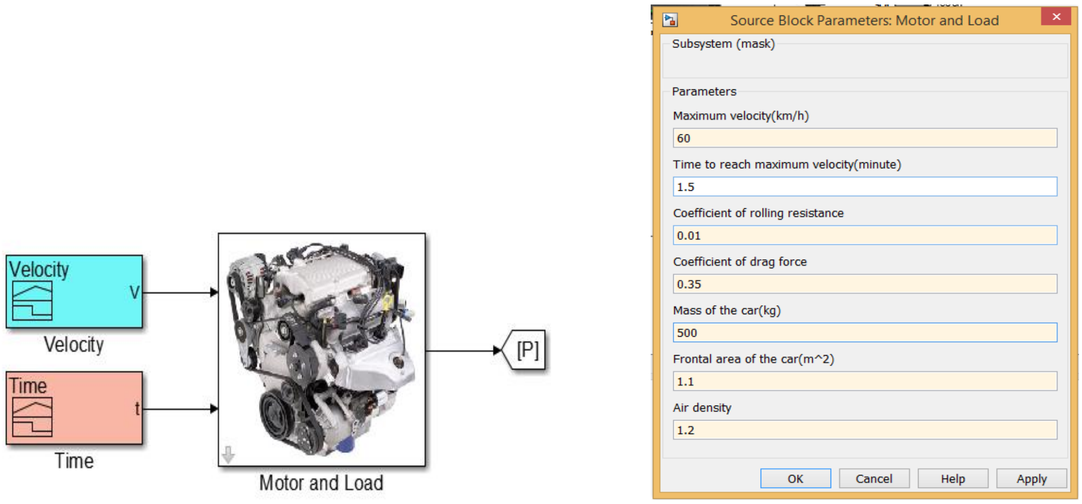


Figure 4.5.2: Flowchart of power calculation

4.5.3. SIMULINK MASK DIAGRAM AND OUTPUT



Source Block Parameters: Motor and Load

Subsystem (mask)

Parameters

Maximum velocity(km/h): 60

Time to reach maximum velocity(minute): 1.5

Coefficient of rolling resistance: 0.01

Coefficient of drag force: 0.35

Mass of the car(kg): 500

Frontal area of the car(m^2): 1.1

Air density: 1.2

Figure 4.5.3 Mask diagram and parameters

The signal builders can be used to give different velocity at different time. The parameters is passed to a MATLAB program to calculate the power. The program is given in the appendix.

4.5.4. ANALYZING THE LOAD

We run the block by giving the following speed and time

v = [10 20 30 40 50 40 30 20 10]

t = [0.18 0.09 0.06 0.045 0.036 0.045 0.06 0.09 0.18]

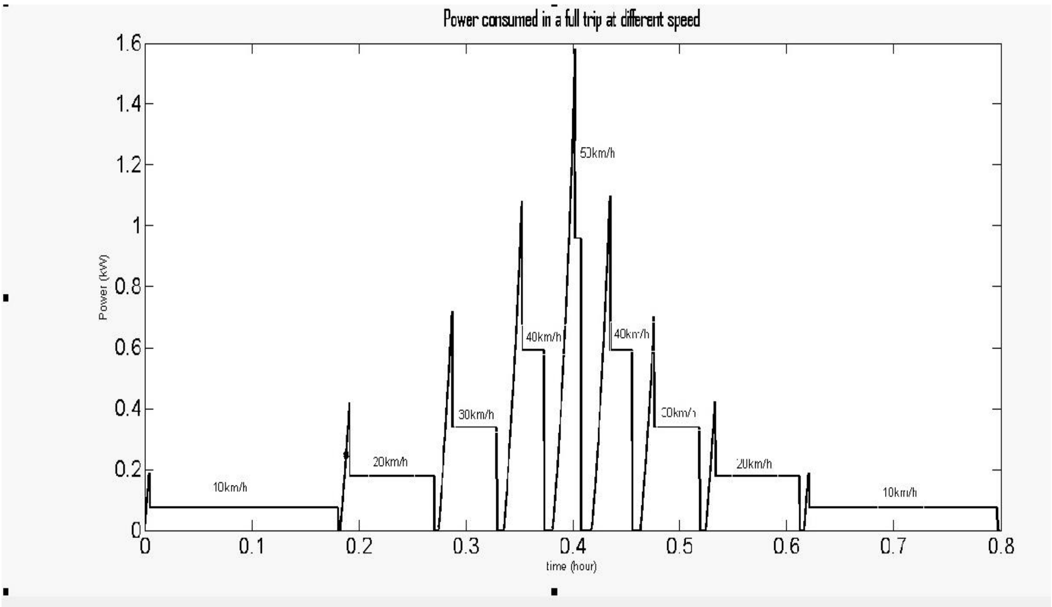


Figure 4.5.4. The power output for the tested values

In the figure 4.5.4 we can see that at the start of the trip there was no velocity, so power needed by the motor was zero. As we increased the speed, motor was started to need more power. Figure shows motor needs more power supplied to him as car gained more speed by time. At highest speed motor needed highest power. As the speed slow down, motor needs lesser power to supply to him.

5. CHARGE CONTROLLER

The purpose of a charge controller is to keep batteries observed and safe for long time from over charging and over discharging. Inside it, a microcontroller is programmed to detect the voltages at the battery terminal and/or the PV panel terminals and accordingly determine what charging current battery needs to be supplied. Most charge controllers also have an indicator light or audible alarm to alert the system user/operator to the load disconnects condition. There are some important functions of battery charge controllers and system controls-

Prevent Battery Overcharge: to limit the energy supplied to the battery by the PV array when the battery becomes fully charged.

Prevent Battery Over discharge: to disconnect the battery from electrical loads when the battery reaches low state of charge.

Provide Load Control Functions: to automatically connect and disconnect an electrical load at a specified time.

5.1. CHARGE CONTROLLER SET POINTS

To make healthy battery life the charge controller must ensure the battery remains within the range of 100% to 20% of state of charge. A set of terminal voltage is found that corresponds to the 100% and 20% state of charge at a particular charging/discharging current based on a corresponding set of controller set points can be determined.

The charge controller would then protect the battery from over-charge if the battery voltage goes beyond its upper set point by disconnecting the solar panel charger from battery. It would protect the battery from over-discharge if the battery voltage goes beyond its lower set point by disconnecting the load from the battery.

5.1.1. HIGH VOLTAGE DISCONNECTS (HVD)

The maximum voltage that the charge controller can allow the battery to reach to avoid over-charging of the battery is called high voltage disconnects. When the controller senses that the battery reaches this voltage regulation set point, the controller will discontinue battery by disconnecting the PV array from the battery.

5.1.2. ARRAY RECONNECT VOLTAGE (ARV)

The battery starts loosing charge when the PV array is disconnected from charging. The greater the charging and discharging rates the faster the battery voltage will decrease. When the battery voltage decreases to a predefined voltage, the solar panel is reconnected to the battery for charging. The voltage at which the module is reconnected is defined as the array reconnects voltage (ARV) set point.

5.1.3. VOLTAGE REGULATION HYSTERESIS (VRH)

VRH is essential since it tells us the effectiveness of the battery recharging procedure as determined by the chosen HVD and the ARV set points. VRH is too wide, it means that the PV array is remaining disconnected for too long periods of time, effectively lowering the module energy utilization and also making it difficult and slow to bring the battery to full charge. Also, allowing the battery to discharge for long period of time causes loss of active materials inside due to sulphation. If the hysteresis is too small, the module will cycle on and off too rapidly, adding to increased switching noise. Also the greater the number of times the battery charging/discharging cycle used the greater the harm to its health. Most controllers have hysteresis values between 0.4 and 1.4 V for a nominal 12 V system.

5.1.4. LOW VOLTAGE DISCONNECTS (LVD)

If battery voltage drops too low, due to prolonged bad weather or if certain non-essential loads are discharging the battery well beyond 20% state of charge then the controller needs to disconnect from the battery from the load to prevent further discharge. The voltage at which this is to be done is the controllers Low Voltage Load Disconnect (LVD) Set Point.

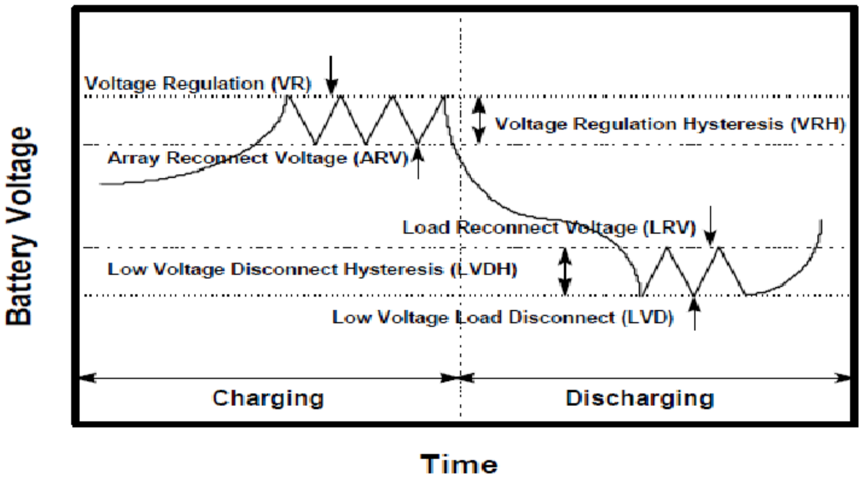


Figure 5.1: Charge controller set points

5.1.5. LOAD RECONNECT VOLTAGE (LRV)

When the PV array charges the battery up to a certain state of charge the load can be safely reconnected. The corresponding voltage that defines this safe point is the load reconnects voltage set point. LRV should be 0.5 V higher than the load-disconnect set point. Typically LVD set points used in small PV systems are between 12.5 volts and 13.0 V for most nominal 12 V lead-acid batteries. If the LRV set point is selected too low, the load may be reconnected before the battery has been charged.

5.1.6. LOW VOLTAGE LOAD DISCONNECTS HYSTERESIS (LVLH):

The voltage difference between the low voltage disconnect set point and the load reconnect voltage is called the low voltage disconnect hysteresis (LVLH). This also works as an indication of the effectiveness of our Low voltage set points, LVD and LRV. If the low voltage disconnect hysteresis is too small, the load may cycle on and off rapidly at low battery state of charge possibly damaging the load or controller, and extending the time it required to charge the battery fully. If the low voltage disconnect hysteresis is too large the load may remain off for extended periods until the array fully recharges the battery.

5.2. CHARGE CONTROLLER IN SIMULINK

For simulation purpose we developed a simple model of charge controller. The operation of this controller is simplified only to prevent overcharge and over discharge.

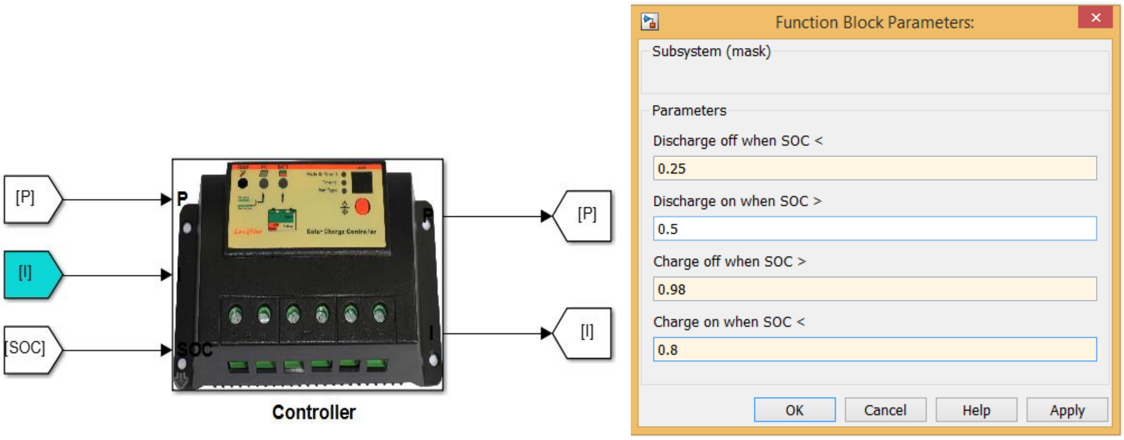
5.2.1. BASIC OPERATIONS

Connecting the panel: When the SOC of the battery is 100%, the panel should be disconnected to prevent overcharge and after a certain level of SOC, the panel should be connected again.

Connecting the Motor: When the SOC of the battery goes below a certain level the Motor is disconnected, but the charging is going on. After reaching a feasible level of SOC the Motor is again connected to the battery.

5.2.2. MASK DIAGRAM OF THE CONTROLLER

The controller takes SOC of the battery, current of the panel and power required from the motor. Depending on the mask parameters and SOC, current of the panel, and the required power goes to the output.



Discharge off when SOC < 0.25

Discharge on when SOC > 0.5

Charge off when SOC > 0.98

Charge on when SOC < 0.8

Figure 5.2.2. The mask diagram and parameters of Controller

SOC	Pout	Iout
SOC<0.25	0	Iin
SOC>0.5	Pin	--
SOC>0.98	Pin	0
SOC<0.8	--	Iin

Table 5.2.2. Input output relationships of controller

5.2.3. LOOKING UNDER THE MASK

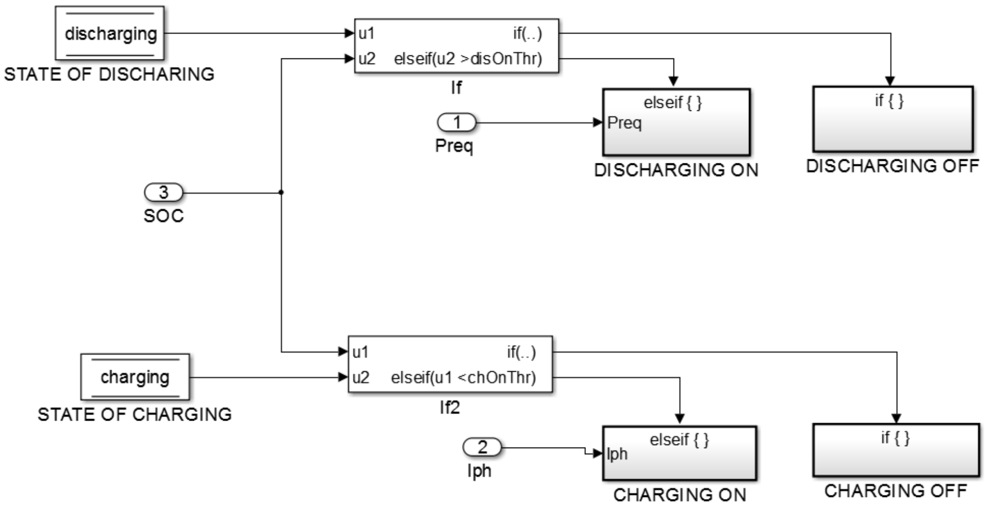


Figure 5.2.3. The Simulink block diagram of simple charge controller

6. THE COMPLETE SOLAR CAR

Now we are going to combine the panel, the battery, DC motor and the charge controller to evaluate the overall performance of the car.

6.1. COMBINING THE COMPONETS

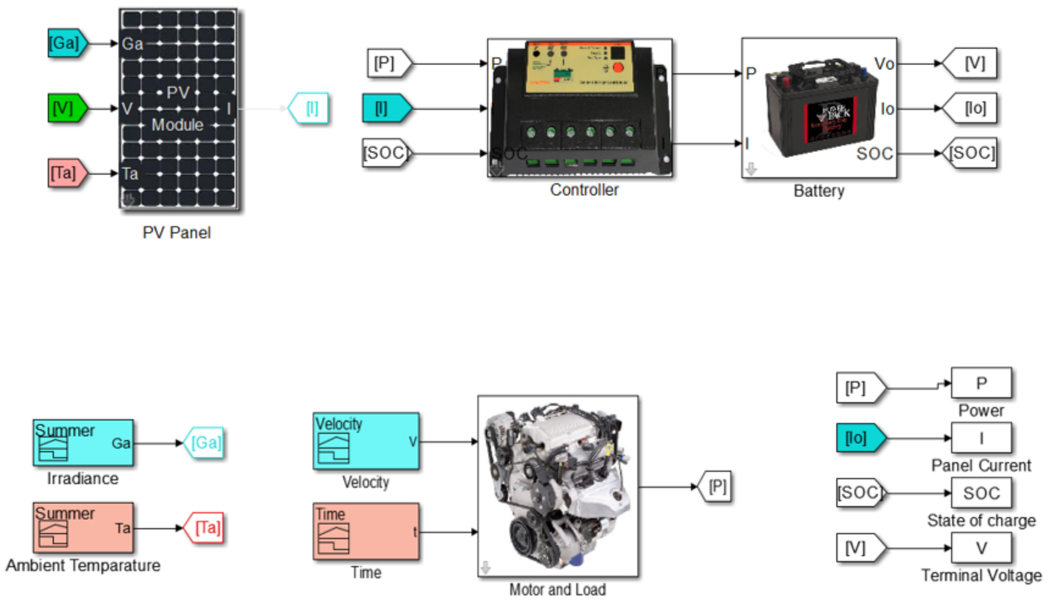


Figure 6.1. The complete car combining all individual components

The output of the panel is connected to the battery through the charge controller. The motor is also connected to the battery via the controller. The outputs of the battery is send to the workspace to plot and analyze the data. The car can be run at different ambient condition at varying speed at different time stamps. There are only one panel and one battery, but the car of our experiment requires 5 batteries. That is why we can divide the data by five to see the output curves.

6.2. EVALUATING OVERALL PERFORMANCE

We would run the program for a full day in summer, the car goes from home to office and stays under sun for eight hours, and then the car gets back home again. We will observe the change of SOC and terminal voltage of the battery throughout the day. The initial SOC is 75%.

6.2.1. AT SUMMER CONITION

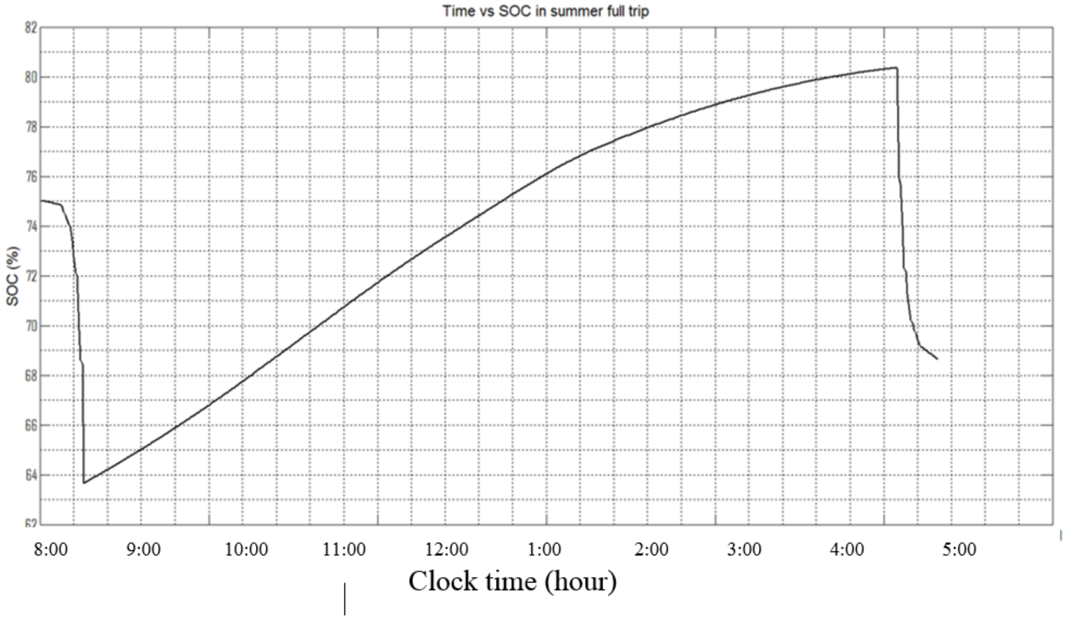


Figure 6.2.1. Time vs SOC in summer day

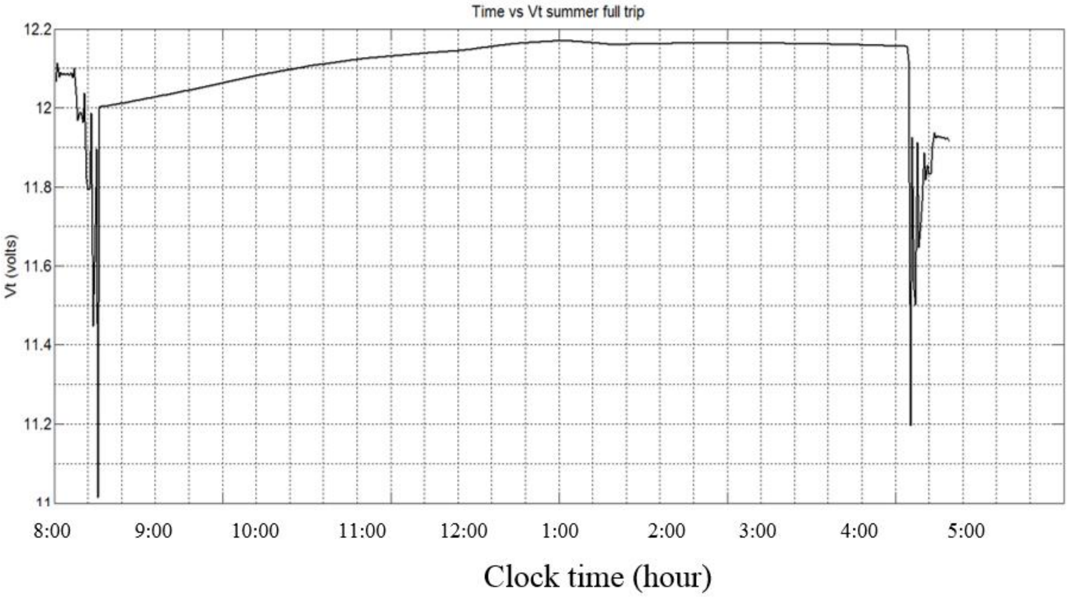


Figure 6.2.2. Time vs Vt in summer day

6.2.2. AT WINTER CONDITION

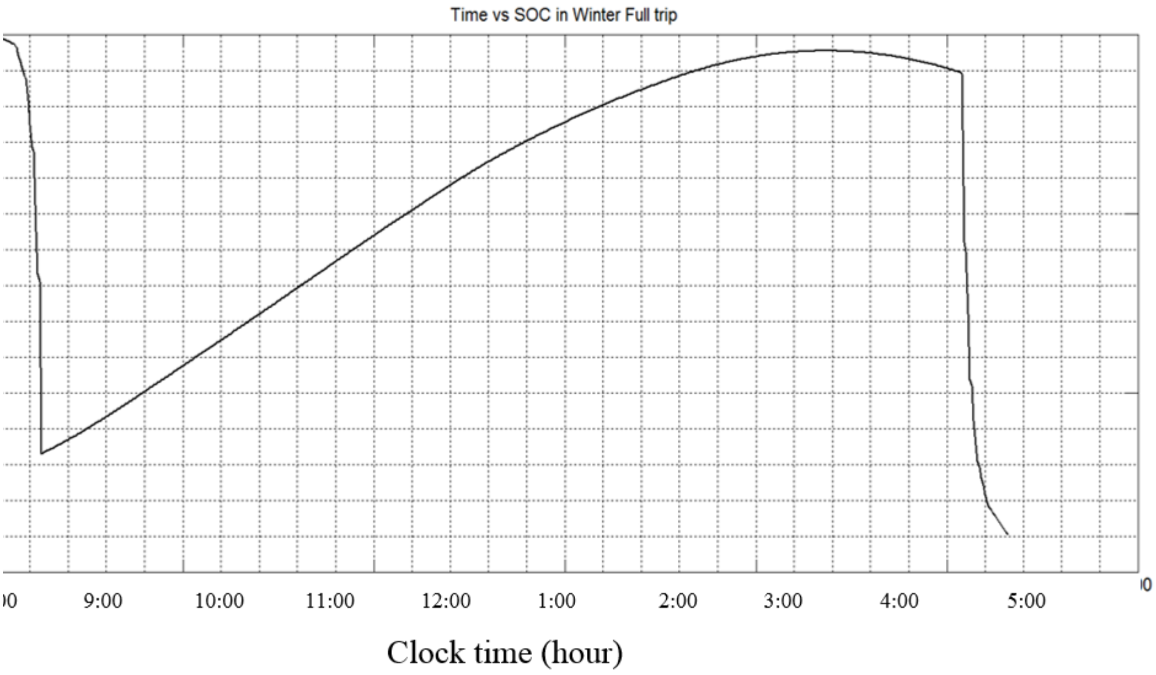


Figure 6.2.3. Time vs SOC in winter day

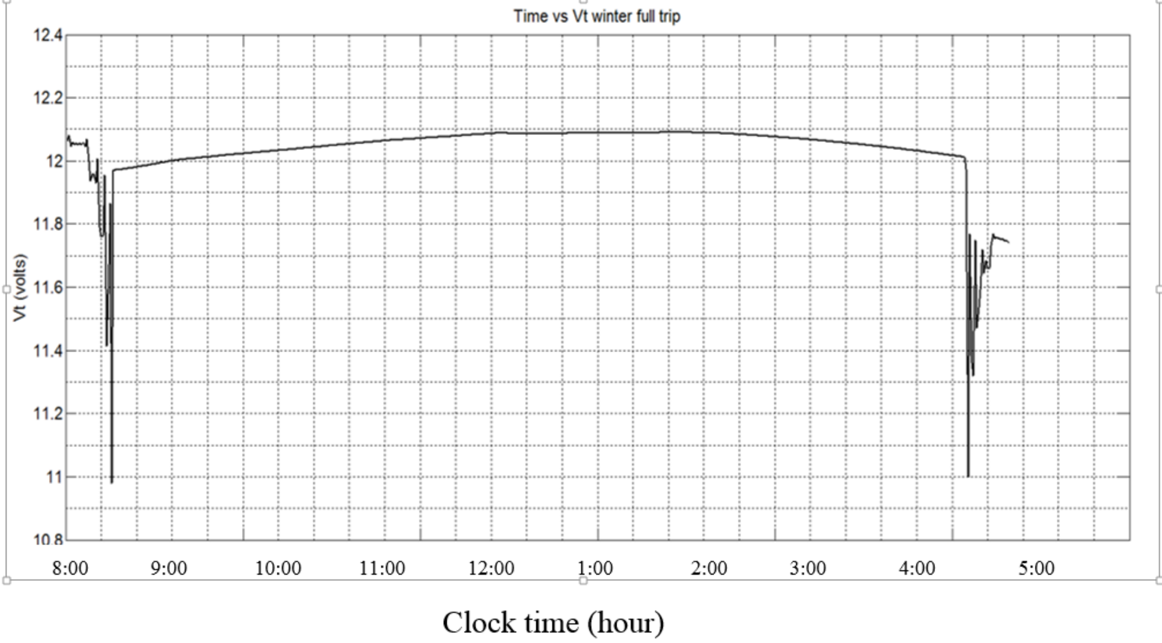


Figure 6.2.4. Time vs Vt in winter day

6.2.3. WITHOUT SUNLIGHT

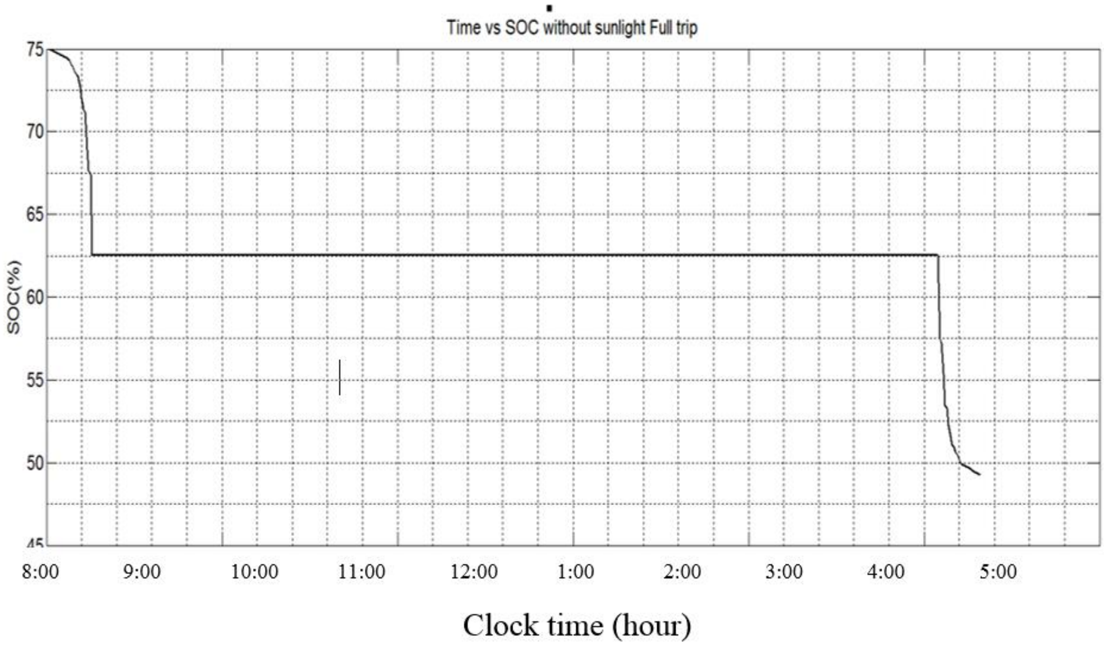


Figure 6.2.5. Time vs SOC in without sunlight

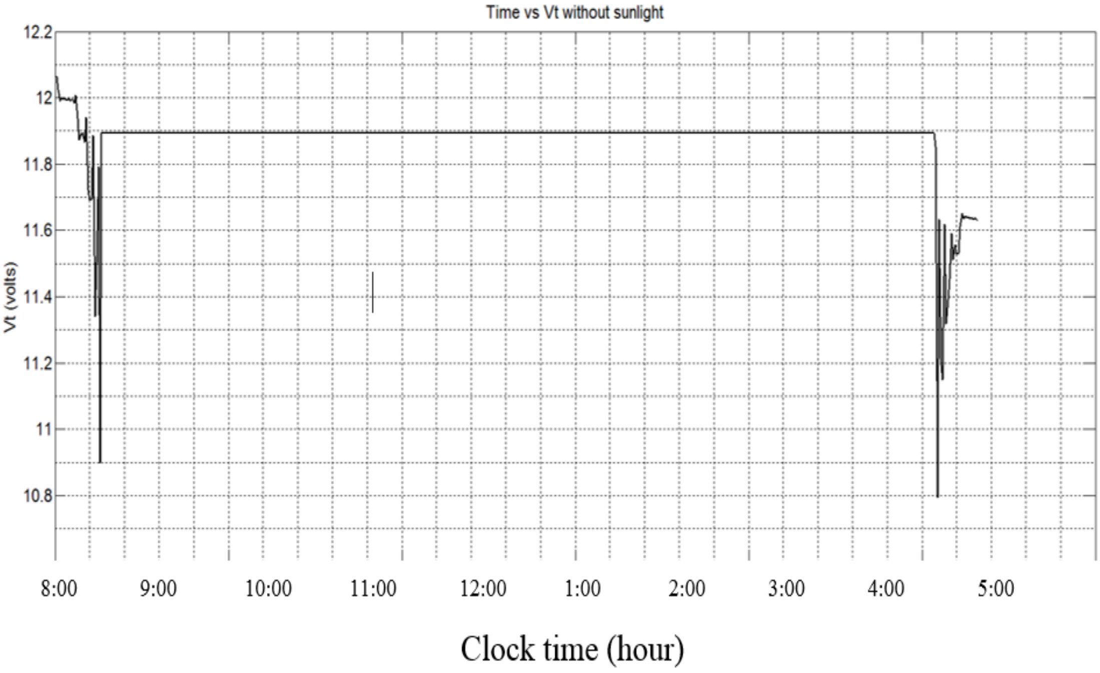


Figure 6.2.6. Time vs Vt in without sunlight

7. CONCLUTION AND FUTURE ASPECTS

Facing the ongoing energy crisis of the world, it is important that we harvest all the energy available to us and implementing them such a way that will bring us in taking a step ahead towards doing so. Solar energy more specifically solar cars would be an amazing advancement in future car technology because it is infinite, efficient, cheap and of course eco-friendly. It also makes good sense to develop a green car technology that car manufactures will be able to save energy without cutting down on the luxuries that they provide to their customers.

Since we develop a dynamic model of a solar car, we hope that it will help to examine the technical aspects of the solar car technology. This model provides a clear understanding about the temperature effects on the model as well as we come to know the charging/discharging rate (SOC) changes the capacity and all other functions of it are very much related with it. Also it will be used for research work and educational purpose.

In future we will try to research on the C-rate or deep cycle of the battery through this model to figure out the battery’s longevity which will be very much helpful for the user.

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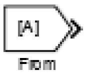
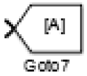
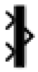
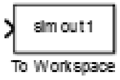
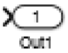
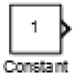
- Online- http://ww1.microchip.com/downloads/en/appnotes/00905a.pdf

APPENDIX

SIMULINK BLOCKS IDENTITY

	Take data from Goto block
	Send data to From block
	Signal builder
	Mux
	Product block
	Send data to workspace
	Amplifier
	Input port
	Output port
	Constant
	Summation block
	User defined Function

MATLAB PROGRAM FOR LOAD

```
function [Power] = powerCal(t,v, vmax, tmax,m,A,Crr,Cd,Ad,g)

time = t;
vmax = 60*1000/3600;
tmax = 1.5*60;
a = vmax/tmax;
s = v.*t*1000;
t = t.*3660;
ts(1) = 0;
for i=2:length(t)+1
    ts(i)=ts(i-1)+t(i-1);
end
v = v.*1000/3600;

numOfStamp = length(t);

tr = v/a;
tf = tr/2;

tc = t-tr-tf;

 for i=1:numOfStamp
     for t = floor(ts(i))+1:floor(ts(i+1))

         if t<ts(i)+tr(i)

             P(t) = m*a^2*(t-ts(i)) + m*g*Crr*a*(t-ts(i)) +
0.5*Cd*A*Ad*a^3*(t-ts(i))^3;
         elseif t<ts(i+1)-tf(i)
             P(t) =  m*g*Crr*v(i) + 0.5*Cd*A*Ad*v(i)^3;
         else
             P(t) = 0;
         end

     end
 end

 Power = timeseries(P','Name','Power');
```