Abstract: This paper presents the implementation of Solar Highways across India by computing solar radiation with respect to latitude of Indian major cities and by using Photovoltaic (MPPT) systems which is consist of a generalized photovoltaic model, MPPT Algorithm, DC-DC converter and Battery if we consider battery as a load, by using Matlab software, which can be representative of Insolation, PV module and array, MPPT algorithms and Battery for easy use on simulation platform. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. Computing Solar radiation with respect to latitude of Indian major cities and taking the effect of solar intensity and cell temperature, the characteristics of PV model are simulated with MPPT Algorithm and the characteristics of batteries are simulated to install the MPPT System. This system can be used for implementation of solar highways across India.

keywords: Battery, DC-DC Converter, Insolation, Matlab, Maximum Power Point, Photovoltaic Model.

I. INTRODUCTION

One of the major concerns in the power sector is the day-to-day increasing power demand but the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming. Solar power has two big advantages over fossil fuels. The first is in the fact that it is renewable; it is never going to run out. The second is its effect on the environment; solar energy is completely non-polluting.

The Solar Highway System is the generation of power through the solar panels which could be install parallel with highways and storing it in a storage system. The plan behind in solar highway system is to build up charging stations for electric vehicles on highways and this stored form of energy can be used in these charging stations which would be helpful in charging of hybrid and electric cars that pass through the highways. Doing this would increase the usage of electric cars for even longer runs. It would boost the usage of electric vehicles and hence the consumption of fuel would be decreased. This produced energy could also be used to light up the highway at nights and for traffic operations of the Highway systems through solar photovoltaic panels that can save a lot of electricity being used.

Solar radiation calculation of Indian major cities with respect to latitude of those cities and solar declination angle on hourly basis of day to day is one of the main considerations for implementing solar highways. PV System has Solar panel which is consisting of N number of Photovoltaic cells is the fundamental energy conversion component of photovoltaic (PV) systems. Its conversion efficiency depends on many extrinsic factors, such as insolation levels, temperature, and load condition. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. MPPT systems tracks maximum power point from PV panel in order to generate PWM signal for DC-DC converter which is installed between source and load for efficient usage of power. The number of battery models are available, but taking characteristics of battery models also one of the main considerations for installation of MPPT Systems.

Recently, a number of powerful electronics simulation software package have become popular in the design and development of power electronics applications. However, the Sim Power System tool in Matlab offers wind turbine models but no PV model to integrate with current electronics simulation technology. Thus, it is difficult to simulate and analyze in the generic modeling of PV power system. This motivates me to develop and simulate a generalized model for PV cell, module, and array with MPPT Algorithms and battery models using Matlab.

II. SOLAR INSOLATION CALCULATION

A. Sun's Declination Angle:

Sun's declination angle d, is the angular distance of a sun's rays north (or south) of the equator. It is the angle between a line extending from the centre of the sun to the centre of the earth and the projection of this line upon the earth's equatorial plane. The declination is positive when the sun's rays are north of the equator and negative when they are south of the equator. At the time of the winter solstice, the sun's rays are 23.5 degrees south of the earth's equator \( (d = -23.5^\circ) \) for north). At the time of the summer
solstice, the sun's rays are 23.5 degrees north of the earth's equator (d = -23.5° for south). At the equinoxes, the sun's declination is zero.

The declination angle throughout the year can be well approximated by a sine function [1]

\[ d = \sin^{-1}[0.4\sin\left(\frac{360}{365}(n - 82)\right)] \]  

Where n is the day of the year.

B. Insolation Calculation:
Solar Insolation can be calculated by [1][16]

\[ I = H \cos \theta_h \]  

Where I = Solar Insolation, H = 1000 W/m² (= Clear day solar Insolation on a surface perpendicular to incoming solar radiation). This value actually varies greatly due to atmospheric variables. \( \theta_h \) = Zenith Angle (Zenith Angle is the angle from the zenith (point directly overhead to the sun’s position in the sky)) The zenith angle is dependent upon latitude, solar declination angle and time of the day.

\[ \theta_h = \cos^{-1}(\sin l \sin d + \cos l \cos d \cos h) \]  

Where l = Latitude, h = Hour Angle (Angle of radiation due to time of day) = 15° x (Time -12) Time is given as the hour of the day from midnight, d = Solar declination Angle.

III. MPPT SYSTEM
Tracking the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part of a PV system. Maximum power point tracking technique is used to improve the efficiency of the solar panel. It tracks maximum power point from PV panel in order to generate PWM signal for DC-DC converter which is installed between source and load for efficient usage of power. As such, many MPP tracking (MPPT) methods available. The methods vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity, and in other respects. In fact, so many methods is available that it has become difficult to adequately determine which method, newly proposed or existing, is most appropriate for a given PV system.

Due to nonlinear characteristics of PV Panel, Photovoltaic (PV) systems have three big problems, namely [2]:

- The efficiency of PV power generation is very low, especially under low radiation states.
- The amount of electric power generated by solar arrays is always changing with weather conditions, i.e. temperature and irradiation.
- Important problem consideration in achieving high efficiency in PV power generation system is to match the PV source and load impedance properly for any weather conditions to get maximum power generation.

According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thévenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. The configuration diagram of the photovoltaic generating system for the maximum power point tracking controller [3] is as shown in Figure.

![Fig. 1: Maximum Power Point Tracking Controller](image_url)

It is composed of the PV module to convert solar energy into the electrical energy and the dc-dc converter for step-up or step down depends upon load requirements. In the PV module, a voltage and current are measured and the power is calculated and the MPPT control is performed about the solar radiation change. By using reference voltage outputted from the MPPT control, the DC-DC converter is controlled through PWM.

A. Mathematical Model of PV Cells:

1) Solar Cell Model: A general mathematical description of I-V output characteristics for a PV cell has been studied for over the past four decades. Such an equivalent circuit-based model is mainly used for the MPPT technologies [5][6][7][8][9]. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, is shown in Fig.2 [5][6].

![Fig. 2: Solar Cell Model](image_url)

The voltage-current characteristic equation of a solar cell is given as [5][6]
Where \( I_{ph} \) is a light-generated current or photocurrent, \( I_{Sh} \) is the shunt leakage current, \( I_S \) is the cell saturation of dark current, \( q (=1.6 \times 10^{-19} \text{ C}) \) is an electron charge, \( k (=1.38 \times 10^{-23} \text{ J/K}) \) is a Boltzmann’s constant, \( T \) is the cell's working temperature, \( A \) is an ideal factor, \( R_{Sh} \) is a Shunt resistance, and \( R_s \) series resistance of solar cell.

The photocurrent mainly depends on the solar insolation and cell’s working temperature, which is described as[5][6].

\[
I_{ph} = [I_{SC} + K_I (T - T_{Ref})] H \tag{6}
\]

Where \( I_{SC} \) is the cells short-circuit current, \( K_I \) is the cells short-circuit current temperature coefficient, \( T_{Ref} \) is the cell’s reference temperature, and \( H \) is the solar insolation in mW/cm\(^2\).

On the other hand, the cell’s saturation current varies with the cell temperature, which is described as[5][6].

\[
I_S = I_{RS} \left( \frac{T}{T_{Ref}} \right)^3 \exp \left[ qE_G (T - T_{Ref})/(T_{Ref} T k A) \right] \tag{7}
\]

Where \( I_{RS} \) is the cell’s reverse saturation current at a reference temperature and standard solar radiation. \( E_G \) is the bang-gap energy of the semiconductor used in the cell and \( A \) is the ideal factor, dependent on PV technology [6][8].

The temperature dependence of the energy gap of the semiconductor is given by [5][6]

\[
E_G = E_G (0) - \alpha T^2 / (T + \beta) \tag{8}
\]

Where \( \alpha \) and \( \beta \) are material constants.

The shunt resistance \( R_{Sh} \) inversely related with shunt leakage current to the ground. In general, the PV efficiency is insensitive to variation in \( R_{Sh} \) and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. Usually the value of \( R_{Sh} \) is very large and that of \( R_s \) is very small, hence they may be neglected to simplify the analysis. The simplified model of PV solar cell with suitable complexity is shown in Fig.4 [5][6] and can be expressed as equation [6][9].

\[
l = I_{ph} - I_S \left[ \exp \left( q(V) / kT A \right) - 1 \right] \tag{9}
\]

2) **Solar Module and Array Model**: Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series-parallel configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The equivalent circuit for the solar module arranged in NP parallel and NS series is shown in Fig.5[5][6].

The terminal equation for the current and voltage of the array becomes as follows [5][6]

\[
l = N_P I_{ph} - N_P I_S \left[ \exp \left( q(V) / (kT A) \right) - 1 \right] - (N_P V / N_S) + \frac{1R_S}{R_{Sh}} \tag{10}
\]

In fact, the PV efficiency is sensitive to small change in \( R_S \) but insensitive to variation in \( R_{Sh} \). For a PV module or array, the series resistance becomes apparently important and the shunt down resistance approaches infinity which is assumed to be open. In most commercial PV products, PV cells are generally connected in series configuration to form a PV module in order to obtain adequate working voltage. PV modules are then arranged in series-parallel structure to achieve desired power output. An appropriate equivalent circuit for all PV cell, module, and array is generalized and expressed in Fig.6 [5][6].
The mathematical equation of generalized model can be described as [5][6]

\[ I = N_p I_{ph} - N_p I_s \exp \left( \frac{q(V - I_R S)}{N_p kTA} - 1 \right) \]  \hspace{1cm} (11)

The most simplified model [5][7][8] of generalized PV module is depicted in Fig. 7 [5][6].

The equivalent circuit is described on the following equation [6]

\[ I = N_p I_{ph} - N_p I_s \exp \left( \frac{q(V)}{N_p k TA} - 1 \right) \]  \hspace{1cm} (12)

**B. MPPT Algorithms:**

The choice of the algorithm depends on the time complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity, and in other aspects. Here we chose Perturb and Observe algorithm for analysis and simulation on installation of Photovoltaic system. Because it is the true MPPT Algorithm, it applies for analog as well as digital and low implementation complexity.

1) **Perturb and Observe Algorithm:** The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in new power is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If new power is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed.

Figure shows the plot of module output power versus module voltage for a solar panel at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points. As shown in the figure above, the point A is on the left hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of new power becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP. The flowchart for the P&O algorithm [2] is shown in Fig.9.

**C. DC-DC Converter:**

DC-DC converter (DC Chopper) can be used as switching mode regulators to convert a dc voltage, normally unregulated, to a regulated dc output voltage. The regulation is normally achieved by pulse width modulation at a fixed frequency and switching device is normally a power BJT, MOSFET or 2GBT.

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. The efficiency of switch-mode dc–dc converters is widely discussed in [10]. Most switching-mode power supplies are well designed to function with high efficiency.

Among all the topologies available, both Cuk and buck–boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage[3]. Although the buck–boost configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power
components, and poor transient response, make it less efficient.

On the other hand, the Cuk converter has low switching losses and the highest efficiency among nonisolated dc–dc converters. It can also provide a better output–current characteristic due to the inductor on the output stage. Thus, the Cuk configuration is a proper converter to be employed in designing the MPPT.

Figs. 10, 11 and 12 shows a Cuk converter and its operating modes [3], which is used as the power stage interface between the PV module and the load. The Cuk converter has two modes of operation. The first mode of operation is when the switch is closed (ON), and it is conducting as a short circuit. In this mode, the capacitor releases energy to the output. The equations for the switch conduction mode are as follows [3]

\[ V_{L1} = V_g \]  
\[ V_{L2} = -V_1 - V_2 \]  
\[ i_{c1} = i_2 \]  
\[ i_{c2} = i_2 - V_2 / R \]

On the second operating mode when the switch is open (OFF), the diode is forward-biased and conducting energy to the output. Capacitor C1 is charging from the input. The equations for this mode of operation are as follows

\[ V_{L1} = V_g - V_1 \]  
\[ V_{L2} = -V_2 \]  
\[ i_{c1} = i_1 \]  
\[ i_{c2} = i_2 - V_2 / R \]

The principles of Cuk converter operating conditions state that the average values of the periodic inductor voltage and capacitor current waveforms are zero when the converter operates in steady state.

1) Design of Cuk Converter:

The Design of Cuk converter follows [11].
Average output voltage:

\[ V_o = -kV_i / 1-k \]  

(21)

Where \( k \) is duty cycle, \( V_i \) is input voltage, \( V_o \) is average output voltage.

Average input current:

\[ I_i = kI_0 / 1-k \]  

(22)

Where \( I_i \) is average input current, \( I_0 \) is output current

Peak to Peak ripple current of Inductor L1:

\[ \Delta i_1 = V_g f/L_1 \]  

(23)

Where \( f \) is switching frequency.

Peak to Peak ripple voltage of capacitor C1:

\[ \Delta V_1 = I_i (1-k)/C_1 f \]  

(24)

Peak to Peak ripple current of Inductor L2:

\[ \Delta i_2 = kV_g f/L_2 f \]  

(25)

Peak to Peak ripple voltage of capacitor C2:

\[ \Delta V_2 = kV_g / 8C_2 L_2 f^2 \]  

(26)

D. Modelling of Batteries

Battery is a device that converts chemical energy to electrical energy for discharging and this process get reverse while charging of the battery. If we consider Battery as a load of the Photovoltaic system, then we need to model and simulate the battery characteristics. If we install a Solar Highways, the modelling and simulation of batteries is of utmost importance for transportation systems such as hybrid and electric vehicles.

Typically the major issues in generating an appropriate and feasible battery models are due to complex inter-related battery electrical parameters, which need to be considered together for accuracy in modelling. The challenge is associated with obtaining a not too complex battery model but yet which depicts the battery terminal voltage and the internal resistance which are a function of several inter-related variables such as the Battery State of Charge (SOC) [12].

1) State of Charge (SOC): The parameter that indicates the amount of charge present in a battery is the State of Charge (SOC). State of charge of a battery is its available capacity expressed as a percentage of its rated capacity. Knowing the amount of energy in a battery compared with the energy it had when it was new gives the user an indication of how much longer the battery will continue to perform before it requires recharging. The main factors that influence the capacity (SOC) of a battery are [12]: Internal resistance, Discharge type, Discharge mode and rate of discharge/charge.

2) State of Charge (SOC): There are numerous techniques available by which a battery can be modelled. Few of them are [12][13][14][15]. Simple battery model, simple Thevenin model (Linear and nonlinear), Battery model for predicting I-V Characteristics, Runtime based model, Fourth order dynamic model, adaptive battery model and Over-current battery model.

3) Simply Battery Model

![Simple Battery Model](Fig13: Simple Battery Model)

This model consists of an ideal battery with open-circuit voltage \( E_0 \) and a constant internal resistance \( ESR \) (from Fig(13)[13]). The terminal voltage is given by \( V_0 \) which can be obtained from open-circuit measurement and \( ESR \) can be obtained from both open-circuit measurements and one extra measurement with load connected at the terminal when the battery is fully charged [13]. This model has several drawbacks. This model does not take into account the varying internal resistance because of varying state of charge, electrolyte concentration and sulphate formation. In this model, the energy drawn out of the battery is assumed to be limitless or where the SOC is of little importance. This clearly indicates that it is most approximate model and it cannot be used for battery monitoring in Hybrid Electric Vehicles (HEV).

4) Simple Thevenin Model: In [13], the battery is modelled as a simple Thevenin circuit comprising of a Thevenin voltage and a Thevenin resistance. The open-circuit voltage of the battery is represented by the Thevenin voltage and the internal resistance of the battery is represented by the Thevenin resistance. The circuit of this model is shown in Fig.14.

![Simple Thevenin Model](Fig14: Simple Thevenin Model)

In the model shown in Fig.14, The terminal voltage (\( V_{terminal} \)) of the battery is represented by the equation

\[ V_{terminal} = V_{OC} - I_{batt} * R_i \]

(27)

Where, \( V_{terminal} \) is the terminal voltage across the battery. \( V_{OC} \) is the open-circuit voltage, \( I_{batt} \) is the battery current. \( R_i \) is the internal resistance of the battery.

However these parameters are not constant but they
depend on the depth of discharge. Depth of discharge is defined as the extent of discharge of the battery. It is given by the ratio of charge taken out from the battery to the total charge present in the battery before discharge. This ratio is between 0 and 1 and is denoted by the symbol Q. In equation number 27, the $V_{OC}$ and $R_i$ are not constants and vary during the course of discharge. Their variation during the course of discharge is dependent on the depth of discharge (Q) either linearly or non-linearly [13]. Hence, we get two different models based on the relationship between $V_{OC}$ and $R_i$ with depth of discharge (Q). They are discussed as follows,

**Linear Dependence:**

In this model, $V_{OC}$ and $R_i$ vary linearly with the depth of discharge (Q). The relationship is given as[14]

$$V_{OC} = a_0 + b_0 Q$$  \hspace{1cm} (28)

$$R_i = a_1 + b_1 Q$$  \hspace{1cm} (29)

Where, Q is the depth of discharge defined as $q/q_{\text{max}}$, q represents the amount of charge withdrawn from the battery. It is calculated as $q = I_{\text{batt}} * t$. Where $I_{\text{batt}}$ is the battery current in amps and t is the time in hours. $q_{\text{max}}$ is the maximum amount of charge stored in the battery. It is equal to the rated capacity of the battery in Amps.

The parameters $a_0$, $a_1$, $b_0$, $b_1$ are the co-efficient of the linear relation and they are evaluated through actual experiment on the battery [14]. The terminal voltage of the battery was monitored continuously and at regular time intervals the open-circuit voltage was also measured. The internal resistance ($R_i$) of the battery is given as[14]

$$R_i = (V_{OC} - V_{\text{terminal}})/ I_{\text{batt}}$$  \hspace{1cm} (30)

Where $R_i$ represents the internal resistance of the battery, $V_{OC}$ represents the open-circuit voltage, $V_{\text{terminal}}$ represents the terminal voltage of the battery, $I_{\text{batt}}$ represents the battery current.

In [14], the graphs of $V_{OC}$ and $R_i$ on a time scale are plotted using the experimental values and a regression algorithm (as in [14]) was applied to obtain the mathematical relation. From the mathematical relation, the values of the parameters in equations 28 and 29 were evaluated to be

$a_0 = 12.62$, $a_1 = -1.93$, $b_0 = 2.74$, $a_4 = -3.27$, $a_5 = 2.03$, $a_6 = -0.48$

$b_0 = 0.23$, $b_1 = -0.1$, $b_2 = 0.37$, $b_3 = 0.88$, $b_4 = 0.62$, $b_5 = 0.15$

Once these equations were known, it was possible to predict the performance under a constant load. Using equations 31 and 32, the current and amount of discharge were calculated. Using the following equations, the battery efficiency and maximum power were also calculated [14].

$$V_{OC} = a_0 + a_1 Q + a_2 Q^2 + a_3 Q^3 + a_4 Q^4 + a_5 Q^5$$  \hspace{1cm} (31)

$$R_i = b_0 + b_1 Q + b_2 Q^2 + b_3 Q^3 + b_4 Q^4 + b_5 Q^5$$  \hspace{1cm} (32)

Where, Q is the depth of discharge defined as $q/q_{\text{max}}$, q represents the amount of charge withdrawn from the battery. It is calculated as $q = I_{\text{batt}} * t$. Where $I_{\text{batt}}$ is the battery current in amps and t is the time in hours. $q_{\text{max}}$ is the maximum amount of charge stored in the battery. It is equal to the rated capacity of the battery in Amphrs.

The parameters $a_0$, $a_1$, $a_2$, $a_3$, $a_4$, $a_5$ and $b_0$, $b_1$, $b_2$, $b_3$, $b_4$, $b_5$ are the co-efficient of the relation and they are evaluated through actual experiment on the battery[14]. The terminal voltage of the battery was monitored continuously and at regular time intervals the open-circuit voltage was also measured. The internal resistance ($R_i$) of the battery is given as[14]

$$R_i = (V_{OC} - V_{\text{terminal}})/ I_{\text{batt}}$$  \hspace{1cm} (33)

Where $R_i$ represents the internal resistance of the battery, $V_{OC}$ represents the open-circuit voltage, $V_{\text{terminal}}$ represents the terminal voltage of the battery. $I_{\text{batt}}$ represents the battery current.

In [14], the graphs of $V_{OC}$ and $R_i$ on a time scale are plotted using the experimental values and a regression algorithm (as in [14]) was applied to obtain the mathematical relation. From the mathematical relation, the values of the parameters in equations 31 and 32 were evaluated to be

$a_0 = 12.62$, $a_1 = -1.93$, $a_2 = 2.74$, $a_3 = -3.27$, $a_4 = 2.03$, $a_5 = -0.48$

$b_0 = 0.23$, $b_1 = -0.1$, $b_2 = 0.37$, $b_3 = 0.88$, $b_4 = 0.62$, $b_5 = 0.15$

Once these equations were known, it was possible to predict the performance under a constant load. Using equations 31 and 32, the current and amount of discharge were calculated. Using the following equations, the battery efficiency and maximum power were also calculated [14].

$$\eta = V_{\text{terminal}}/V_{OC} = (V_{OC} - R_i * I_{\text{batt}})/V_{OC}$$  \hspace{1cm} (34)

$$P_{\text{max}} = V_{OC}^2/4R_i$$  \hspace{1cm} (35)

**IV. IMPLEMENTATION AND SIMULATION OF MODEL**

Incoming solar radiation is calculated using Matlab according to the equation (1), (2) and (3) with respect to latitude of Indian major cities. Fig.15 shows insolation Vs hours in a day,(21/22 of Dec.) at declination angle -23.5° in winter solstice and Fig.16 shows insolation Vs hours in a day(21/22 of Jun.) at declination angle 23.5° in summer solstice.
A generalized PV model is also built using Matlab according to equation (5), (6), (7), (8) and (12). To illustrate and verify the nonlinear \( I-V \) and \( P-V \) output characteristics of PV module, model is simulated for different solar insolation and temperature and shown in Figs.17,18,19,20,21 and 22. The specifications of the solar module used for simulation is given in Table 1. The nonlinear nature of PV cell is apparent as shown in the Fig.17 and 18, i.e., the output current and power of PV cell depend on the cell’s terminal operating voltage and temperature, and solar insolation as well. The figures also shows that with increase of working temperature, the short-circuit current of the PV cell increases, whereas the maximum power output decreases. In as much as the increase in the output current is much less than the decrease in the voltage, the net power decreases at high temperatures. On the other hand, with increase of solar insolation, the short-circuit current of the PV module increases, and the maximum power output increases as well. The reason is the open-circuit voltage is logarithmically dependent on the solar irradiance, yet the short-circuit current is directly proportional to the radiant intensity. The developed model is simulated for different solar insolation level without MPPT Perturb and Observe algorithm as shown in Fig.23 and 25. The developed model is simulated for different solar insolation level with MPPT Perturb and Observe algorithm as shown in Fig.24 and 26.

Battery model is also built using Matlab according to the equation (28), (29) and (30) for linear model and equation (31), (32) and (33) for nonlinear model. To illustrate and verify the linear and nonlinear characteristics, the model is simulated and Fig.27 shows terminal voltage Vs time in hours for Thevenin linear model and Fig.28 shows Thevenin nonlinear model. These results show there is significant discrepancy between the linear model and the non-linear model with polynomial fit. For this type of battery, the resistance does not increase with amount of discharge for the entire test.

Table I. Specification of the Simulated PV Module

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power((P_{MP}))</td>
<td>87.89 W</td>
</tr>
<tr>
<td>Voltage at peak power((V_{MP}))</td>
<td>13 V</td>
</tr>
<tr>
<td>Current at peak power((I_{MP}))</td>
<td>6.761 A</td>
</tr>
<tr>
<td>Short circuit current((I_{SC}))</td>
<td>7.51 A</td>
</tr>
<tr>
<td>Open circuit voltage((V_{OC}))</td>
<td>17 V</td>
</tr>
<tr>
<td>Temperature co-efficient of short circuit voltage((K_t))</td>
<td>0.00023 A/K</td>
</tr>
</tbody>
</table>
Fig.17: V-I Output Characteristics of PV Panel at T=28°C and H=100mw/Sq.Cm

Fig.18: V-P Output Characteristics of PV Panel at T=28°C and H=100mw/Sq.Cm

Fig.19: V-I Output Characteristics of PV Panel with Different Insolation

Fig.20: V-P Output Characteristics of PV Panel with Different Insolation
Fig. 21: V-I Output Characteristics of PV Panel with Different Temperature

Fig. 22: V-P Output Characteristics of PV Panel with Different Temperature

Fig. 23: V-P Output Characteristics of PV Panel without MPPT P&O Algorithm at T=28°C and H=100 mw/sq.cm

Fig. 24: V-P Output Characteristics of PV Panel with MPPT P&O Algorithm at T=28°C and H=100 mw/sq.cm
Fig. 25: V-P Output Characteristics of PV Panel without MPPT P&O Algorithm for Various Insolations at T=28°C

Fig. 26: V-P Output Characteristics of PV Panel with MPPT P&O Algorithm for Various Insolations at T=28°C

Fig. 27: Terminal Voltage vs Times in Hours for Thevenin Linear Battery Model

Fig. 28: Terminal Voltage vs Times for Thevenin Non-Linear Battery Model
V. CONCLUSION

Solar radiations are calculated with respect to latitude of the Indian major cities. This is one of the main analysis we have to do before the installation of Solar highways. And also a generalized PV module has been developed and verified with available module. The proposed PV model takes solar radiation intensity and cell temperature as input and outputs the I-V and P-V characteristics under various conditions. Such a generalized PV model is easy to be used for the implementation on Matlab modeling and simulation platform. We used this PV model for simulation with MPPT P&O algorithm and can be used for the analysis in the field of solar photovoltaic conversion system and MPPT systems. The proposed MPPT systems are well-designed system including a proper converter and selecting an efficient and proven algorithm; the implementation of MPPT is simple and can be easily constructed to achieve an acceptable efficiency level of the PV modules. And this proposed control system is capable of tracking the PV array maximum power and thus improves the efficiency of the PV system and reduces low power loss and system cost. The proposed battery models characteristics are verified and used in the industry. The use of the proposed model of the battery allows a better understanding of the battery behaviour when used in conjunction with Electric Vehicle or Battery Energy Storage System.

VI. REFERENCES


[18] http://www.esrl.noaa.gov/gmd/grad/solcalc/solareqn s.PDF