International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0315
e ISSN: 2584-2854
Volume: 02
Issue: 07 July 2024
Page No: 2149-2156

PV Module with MPPT and Boost Converter to Charge a 60W Battery

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Abstract

In order to charge an E-Cart battery, this article explores the crucial field of solar energy usage. The paper's main proposal validates the modified MPPT approach using simulation and experimental data, demonstrating how effective they are in increasing efficiency for battery charging applications. The solution provides a modified model of MPPT technique to achieve maximum efficiency with a simplified model. In order to acquire a greater voltage than input, a boost converter is used. Notwithstanding, the report acknowledges the difficulties in maximizing solar cell efficiency and discusses prospective avenues for future research as well as developing technology.

Keywords: *Battery charger, Fill factor (FF); Maximum Power Point Tracking (MPPT) algorithm; Photovoltaic (PV).*

1. Introduction

Energy is essential, but the concerns associated with our existing dependence on fossil fuels to generate energy include increased prices, security risks, and environmental damage. The rise of renewable energy, especially solar power with PV systems, offers advantages like low maintenance and high efficiency. PV system converts abundant solar energy into electricity with no moving parts, minimal maintenance, silicon substitution, scalability, energy conservation, modularity, ease of installation, and the ability for decentralized power generation. The technique to achieve maximum light energy observation has been a special need always. Although many algorithms are available but hunt of the best technique is always continued.

2. Background

The solar cell is made up of silicon materials such as silicon, polycrystalline thin films and single crystalline thin film [1]. In actual cell behaves like a current source with internal resistances. The voltage generated by the solar cell is of 0.5 V to 0.8 V, depends on technology of cell [2]. This voltage and current are low enough to be used. To increase the amount of voltage and current respectively, 36 or 72 cells can be connected in parallel and series to form modules [3]. Connecting many in both parallel and serial fashion creates solar arrays, also known as PV panels. The solar insolation, cell temperature, and output voltage of the PV cell module all affect its output characteristics. PV systems applications need system modeling and simulation since the diode's V-I and V-P properties are also nonlinear. For a solar panel, there are several MPPT algorithms that may be used to achieve maximum power production. Operating it continuously at full power point is important. Temperature and solar radiation have a significant impact on PV properties [4].

3. Modelling of Solar Cell

The physical characteristics of the solar cell provide the basis for a mathematical model of a double diode [5]. The development of an equation

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for the V-I curve parameters is constrained, nevertheless, by the implicit and nonlinear structure of the model. As a result, the modeling in this study takes into account the single diode model. A single diode equivalent circuit is used to numerically describe a solar cell or module [6]. The following factors are taken into account while determining a photovoltaic cell's characteristics: Environmental factors, such as temperature T and irradiance Internal parameters: electron charge q, ideality constant A, Boltzmann constant k and energy band-gap Electrical parameters: open circuit voltage, short circuit current, and series resistance Rs and shunt resistance Rsh. The single cell current is defined by the following equation.

$$I = Ipv - Io[e^{\frac{qVT}{AkTc}} - 1] \qquad (1)$$

The single cell current equation for a known temperature Tc and known solar irradiation level Sc represents the solar current [7]. The fluctuating ambient temperature Ta impacts both the cell output voltage and the cell photocurrent [8]. The temperature coefficients CTV and CTI for cell output voltage and cell photocurrent, respectively, express these impacts in the model as follows:

$$CTV = 1+\beta T\ (Ta-Tb)\ , CTI = 1 + \gamma t/Sc(Tb-Tc) \qquad (2)$$

Where Ta represents the outside temperature at the time of the cell test, and βT and γt, respectively, are the cell's values. Using this, the cell's updated model for a different ambient temperature Tb is obtained [9]. As the correction factors for variations in cell output voltage Vc and photocurrent Iph, respectively, the change in the operating temperature and the change in the photocurrent resulting from variation in the solar irradiation level may be represented as CSV and CSI:

$$CSV = 1+ \beta T\alpha s\ (Sb - Sc),\ CSI = 1+1/Sc(Sb - Sc) \qquad (3)$$

Where Sc is the reference solar irradiance level during the cell testing and Sb is new level and obtained using

$$\Delta_{TC} = 1 + \alpha_s(S_b - S_c) \qquad (4)$$

For the solar cells used, the constant, which denotes the slope of the change in the α_scell operating temperature owing to a change in the solar irradiation level, is equal to 0.2 [10,11]. The new values of the VCb is cell output voltage and photocurrent Iphb are determined for the new temperature Tb and solar irradiation Sb using the correction factors CTV, CTI, CSV, and CSI as follows:

$$V_{Cb} = C_{TV}C_{SV}V_C I_{phb} = C_{TI}C_{SI}I_{ph} \qquad (5)$$

The reference cell output voltage (Vc) and reference cell photocurrent (Iph) are the respective values.The following is the voltage-current characteristic equation for a solar cell:

$$I = I_{ph} - I_o\left[e^{\left(\frac{q(V+IR_s)}{kT_bA}\right)} - 1\right] - \frac{V+IR_s}{R_{sh}} \qquad (6)$$

The photocurrent depends on solar insolation and temperature of cell, which can be described as

$$I_{ph} = [I_{sc} + K_I(T_b - T_c)]\lambda \qquad (7)$$

Where KI is the short circuit current temperature of the cell and λ is solar irradiation in kW/m2. The saturation current of cell varies with the cell temperature as under:

$$I_O = I_o\left(\frac{T_b}{T_c}\right)^3 e^{[\ qE_G(\frac{1}{T_b} - \frac{1}{T_c})/kA]} \qquad (8)$$

Where EG stands for the semiconductor's energy band gap in the cell. An perfect photovoltaic cell has zero loss and zero leakage to ground, or Rs = 0 and Rsh = 0. Further the equation can be reduced to

$$I = I_{ph} - I_o\left[e^{\left(\frac{qV}{kT_bA}\right)} - 1\right] \qquad (9)$$

The analogous circuit for the solar modules set up

e ISSN: 2584-2854
Volume: 02
Issue: 07 July 2024
Page No: 2149-2156

in Ns series and Np parallel. The following is the terminal equation for the array's current:

$$I = N_p I_{ph} - N_p I_o \left[e^{\left(\frac{q\left(\frac{V}{N_S} + I\frac{R_S}{N_P}\right)}{kT_b A} \right)} - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (10)$$

While the efficiency is unaffected by variations in Rsh, it is sensitive to slight changes in Rs. The PV module mathematical model may be expanded as follows:

$$I = N_p I_{ph} - N_p I_o \left[e^{\left(\frac{qV}{N_S k T_b A} \right)} - 1 \right] \quad (11)$$

In the event that the module consists of Np parallel cell connections, the photovoltaic and saturation currents may be stated as: Iph, module = Iph *N, Io, and module = Io* Np

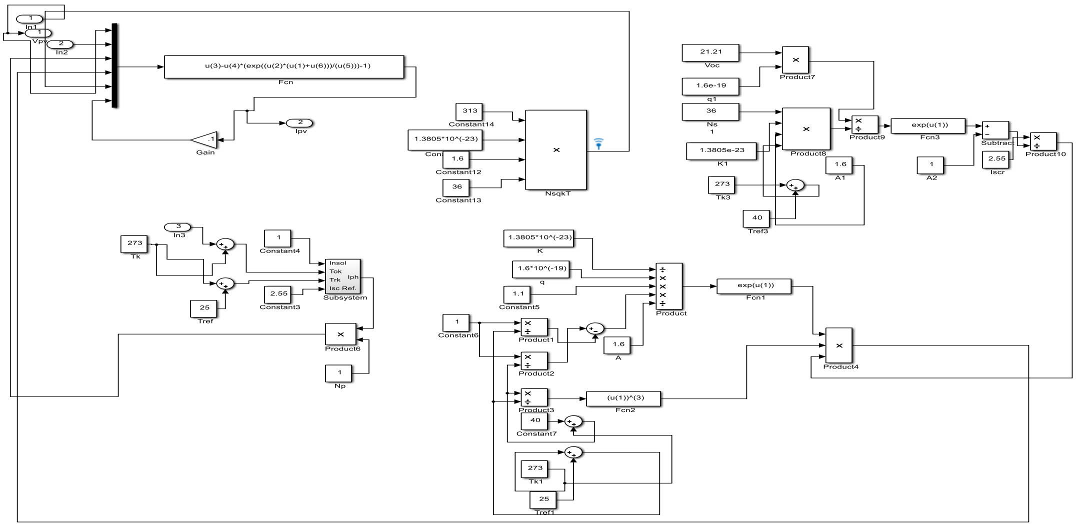

Figure 1 PV Module Cell Model

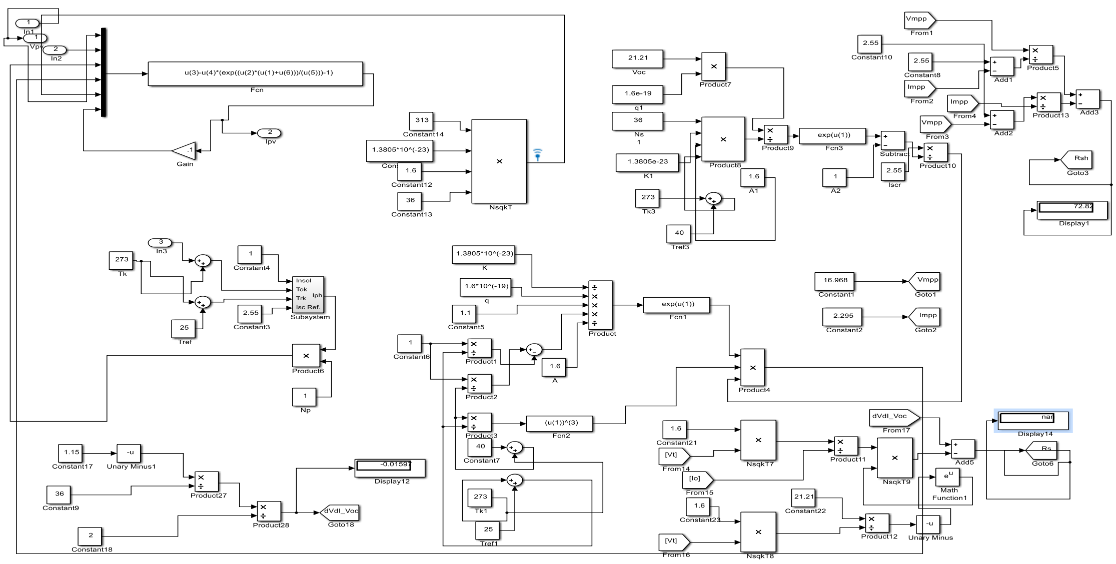

Figure 2 Simulation for The Extraction of Internal Parameters

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The value of internal resistances can be calculated by simplified explicit method. “Slope” and “iteration” are the other methods. The explicit method is strongly influenced by the variations of both temperature and irradiance. Fig.1 & Fig.2 The slope method keeps its performances regardless of variations. Therefore, in this thesis this method is preferred to calculate Rs [12,13].

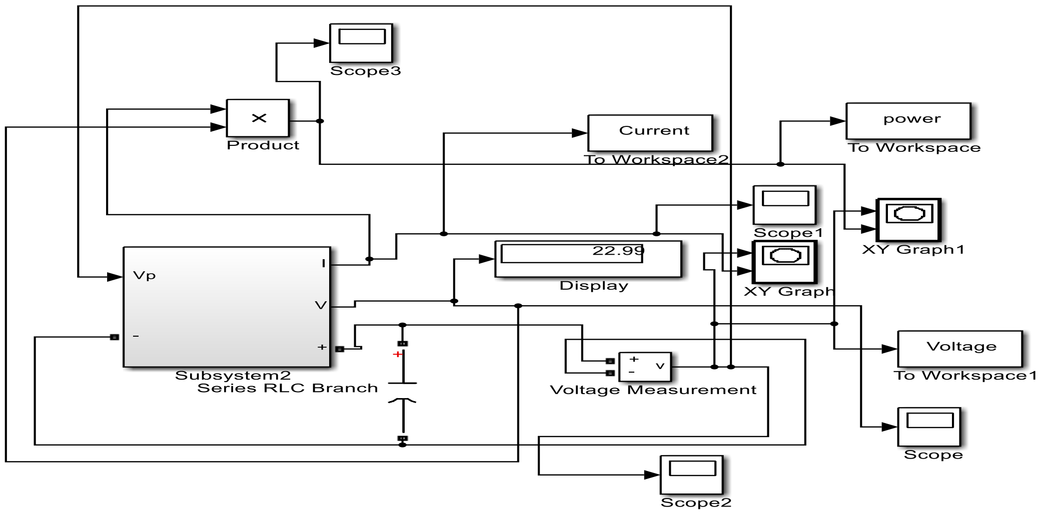

Figure 3 Simulation of PV Module of 36 Cell Connected in Series

4. Control Schemes and Design

This approach tracks the operating point electrically by varying the load to maximize the power. Using different MPPT methods using the perturb and observe approach, a perturbation is introduced while the panel is in operation. Panel voltage is compared by altering the duty cycle of the converter [14]. Fig.3 The voltage is increased or decreased using the fundamental method with a defined step. When oscillating around the MPP, the magnitude of the deviation is determined by the step size. While a larger step will aid in reaching MPP, a smaller step will aid in reducing oscillation, impede tracking faster, and increase power loss when it oscillates [15,16]. The controller employs an incremental conductance technique, which monitors minor changes in PV array voltage and current, to assess the effect of a voltage shift [17]. By utilizing the incremental conductance (dI/dV) of the solar array, this method determines the sign of the change in power with respect to voltage (dP/dV). The incremental conductance method determines the maximum power point by comparing the incremental conductance (ΔI /ΔV) to the array conductance (I / V) [18]. If these two are equivalent (I / V = ΔI /ΔV), the output voltage is the MPP voltage. The controller maintains this voltage at this level until the radiation shifts and the process is repeated. Through the use of a sweep waveform for the PV array current in the current sweep approach, the I-V characteristic of the PV array is monitored and updated at predefined intervals [19]. The "open voltage method" or "constant voltage" MPPT technique quickly cuts off the power supply to the load in order to measure the open-circuit voltage with zero current [20].

5. A Novel Technique for MPPT

In this technique, a new methodology is proposed in which few assumptions are taken therefore few higher order of values which have small impact can be removed because for a small wattage value this has negligible significance and the stability is not affected. However, the power tracking here is the lesser wattage is possible but the improvement can be done with intervention of higher powers of the equations Fig.4 & Fig.5. Considering one diode model:

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e ISSN: 2584-2854
Volume: 02
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Page No: 2149-2156

$$I = N_p I_{ph} - N_p I_o \left[e^{\left(\frac{q\left(\frac{V}{N_s} + I\frac{R_s}{N_p}\right)}{k T_b A} \right)} - 1 \right] - \frac{V+IR_s}{R_{sh}} \quad (12)$$

Neglecting higher powers as their values are negligible,

$$I = I_{ph} - I_0 \left\{ 1 + \left(\frac{q(V+IR_s)}{N_s AkT} \right) - 1 \right\} - \frac{V+IR_s}{R_{sh}} \quad (13)$$

$$I = I_{ph} - I_0 \left\{ \left(\frac{qV}{N_s AkT} + \frac{q\, IR_s}{N_s AkT} \right) \right\} - \frac{V+IR_s}{R_{sh}} \quad (14)$$

Rearranging the terms and considering constant terms equal to some coefficients, the equation can be rewritten as follows

$$I = \frac{I_{ph}}{K_1} - \frac{VK_2}{K_1}$$

Where,

$$K_1 = \left(1 + \frac{I_0 R_s q}{kTN_s} + \frac{R_s}{R_{sh}} \right) \text{ and } K_2 = \left(\frac{I_0 q}{kTN_s} + \frac{1}{R_{sh}} \right) \quad (15)$$

To achieve maximum power equating this equation equals to zero

$$V_{max} = \frac{I_{ph}}{2K_2}, \; I_{max} = \frac{I_{ph}}{2K_1} \quad (16)$$

Substituting these values in power equation

$$P_{max} = \frac{I_{ph}^2}{4K_1K_2} \quad (17)$$

6. Implementation of Proposed MPPT

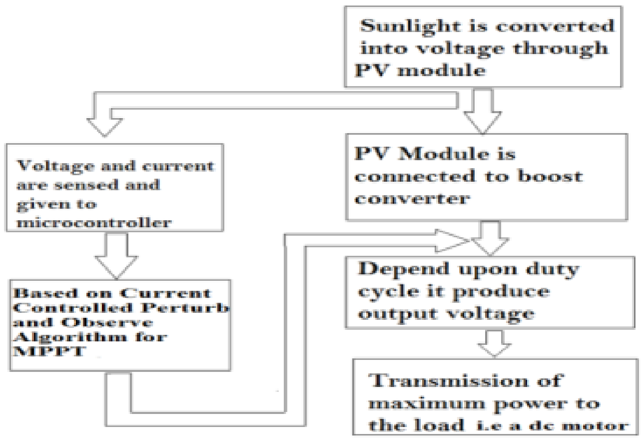

Figure 4 Block Diagram to Achieve of MPPT with The Solar Module

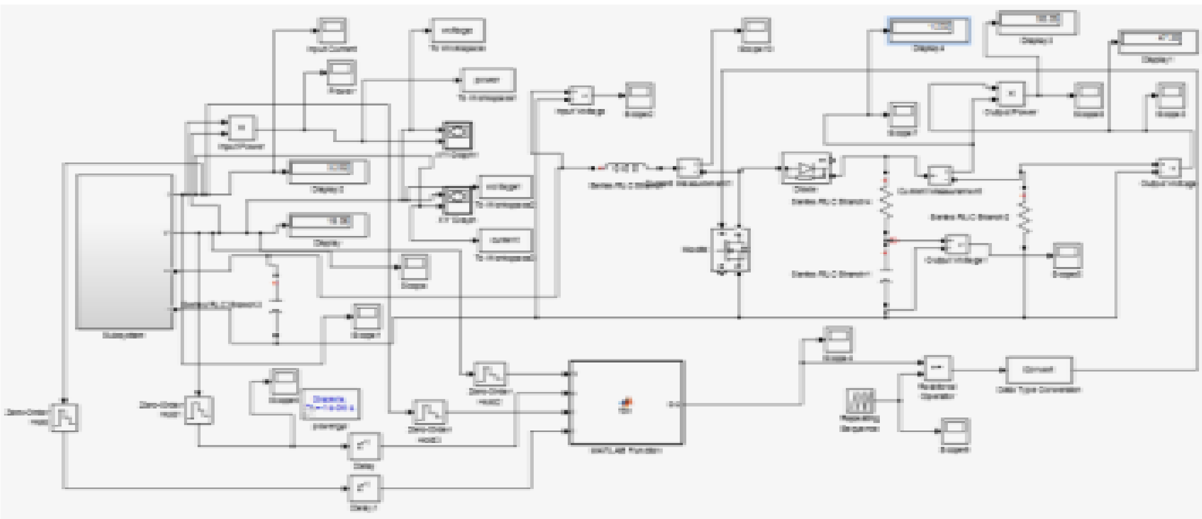

Figure 5 Simulation Model of System for 60 W

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https://doi.org/10.47392/IRJAEM.2024.0315

e ISSN: 2584-2854
Volume: 02
Issue: 07 July 2024
Page No: 2149-2156

7. Results

The different graphs shown here are calibrated on different points of the system with MATLAB plot. Fig.6 shows that initially the short circuit current of PV cell remains constant and after that current gradually move towards zero with increment in voltage. A power and voltage graph that progressively rises to its maximum and then declines are seen in Fig.7. The slope of the increment and decay are different because of impact of the series and parallel resistance of the circuit.

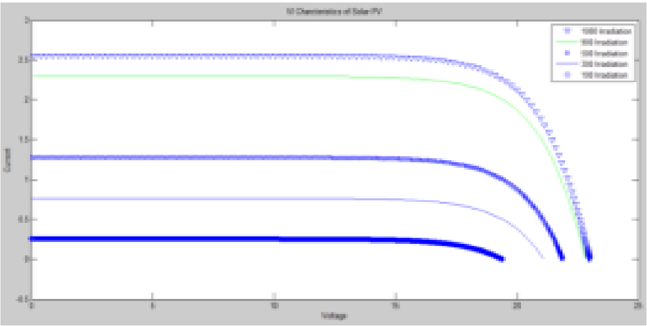


Figure 6 **VI Characteristics at Different Solar Irradiation**

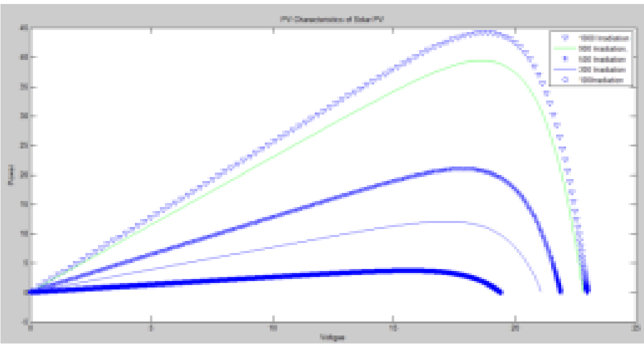


Figure 7 **PV Characteristics at Different Solar**

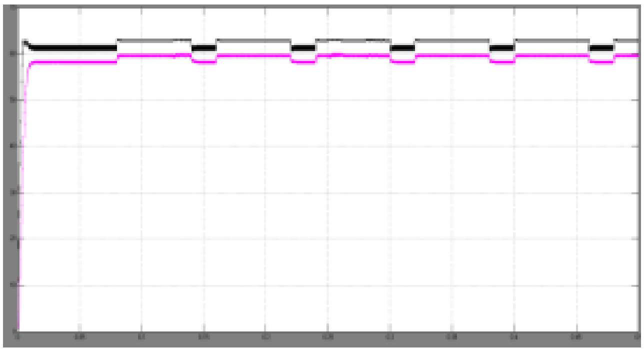


Figure 8 **Power Versus Time Input (Pink) and Output (Black)**

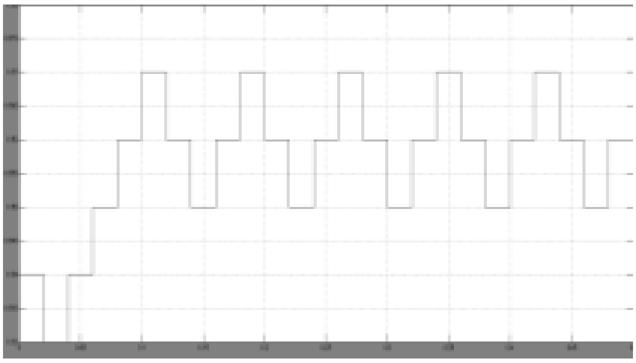
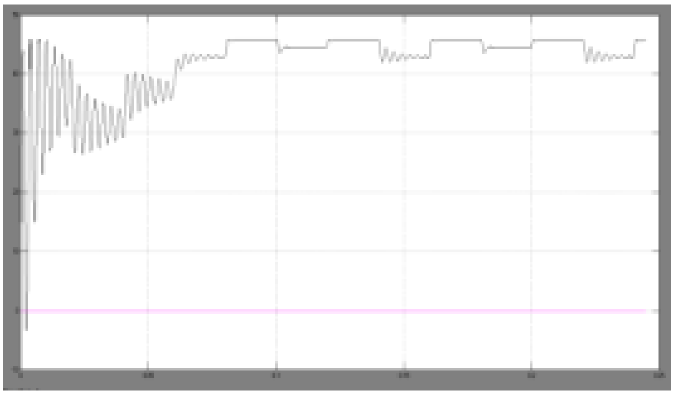
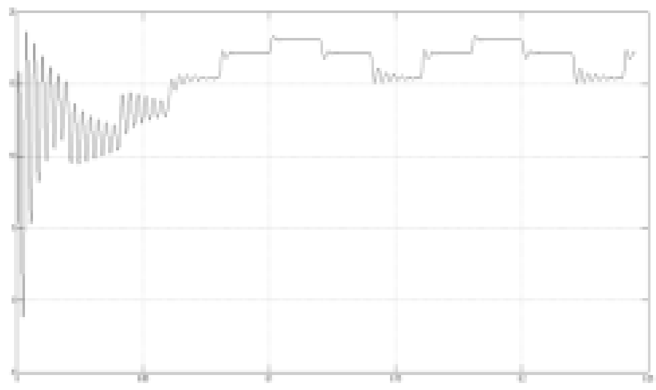


Figure 9 **Duty Cycle Varying from 0 To 1**

Fig.8 represents the graph for power with respect to time of MPPT of solar PV using boost converter for 60W. Here pink color graph represents input power and black graph shows output wave, which reflects the result of boost converter. Duty cycle is shown in Fig.9 which fluctuates between 0 and 1.



(a) Input Power



(b) Output Power

Figure 10 **(a & b) Input and Output Power for a Boost Converter**

MATLAB plots are obtained at various points in system and their waveforms are plotted for the variations in irradiations at different values. Initially circuit oscillates to obtain maximum power point according to P&O method, after that it stops around the maximum power point. Simulation results of MPPT (sample time) of solar PV using boost converter are shown below in Fig.10 (a & b). The frequency of operation is set at 30 KHz, and the algorithm iterates and decides the duty cycle automatically. MATLAB shows a small loss of power from the solar panel side to the boost converter output side due to switching losses and losses in the inductor and capacitor. The boost converter has lower efficiency than the buck converter, but enhances output voltage.

Conclusion

The simulation of PV module is used here with one diode model with four-component system having infinite parallel resistance. The results of various stages are obtained, which are equivalent to the P&O method for 60 watts capacity. The output voltage and current stabilized for a steady state value. The design is less complex than the standard one but gives accurate results. Modified MPPT is effective for rapid climate changes and respond with sample time without any delay in simulation. The system is capable enough to produce required voltage and current. The boost converter is also used as a last stage of system which boosts the voltage and current and gives more stabilization to the output. If the system has to be designed more than 760 watts some moderation will be needed.

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