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Implementation of P&O MPPT Method Using ARDUINO Controller for a Standalone Solar PV System

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Abstract *- To improve operating efficiency of solar PV technology, it is essential to have dexterous and robust maximum power point tracking (MPPT) controller. In this paper implementation of a boost converter for control of photovoltaic power using Maximum Power Point Tracking (MPPT) control mechanism is presented. Firstly, the individual photovoltaic module is analyzed using SIMULINK software. The main aim will be tracking of maximum power point of the photovoltaic module, so that by using Arduino Controller with the help of boost converter [5], extraction of the maximum is possible power from photovoltaic module. Hardware implementation is also done. The results of implementation followed by the conclusion are discussed in the paper.*

Keywords- MPPT, P&O, Incremental Conductance, SSM, dc-dc converter

1. INTRODUCTION

Solar energy is liberally available that has made it possible to harvest it and utilize it properly. Solar energy system can be used as standalone generating unit or can be used as a grid connected generating unit depending on the availability of a nearby grid. To develop an efficient way in which power has to be extracted from the incoming solar radiation to tackle the present energy crisis [14]. To increases the efficiency of operation of the solar modules, the use of the most recent power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithm is effective. Solar irradiation that incident on the photovoltaic modules which having a variable characters depending on the orientation of the solar field, latitude, the season and an hour of the day. Also the irradiation and the temperature are important terms on which energy produced by each photovoltaic cell depends [3, 10]. For developing efficient solar PV system advancement in power electronics are helpful. Maximum power can be extracted from PV array by implementing MPPT Algorithm. The problematic consideration by MPPT techniques is to find the voltage Vmpp or current Impp at which a PV array should operate to obtain the maximum power output Pmpp under a given temperature and irradiance condition. The objective of this is to study and analyze different MPP techniques. Different MPP techniques have their own merits, demerits and effectiveness. Analyzing all these methods, implement the effective method out of it. Start from installation, Effective pricing of Solar PV systems is already high. Here in this paper, the main aim is to implement Cost effective system and to maintain reliable supply to avoid massive blackouts [12] with an alternative of solar energy as a part of smart grid technology [15].

2. SOLAR CELL

Solar cell equivalent electrical model as shown in the figure I. where *I* and *V* are the solar cell output current and voltage respectively. *Rs* and *Rsh* are the series and shunt resistances of the solar cell. *Rs* is the resistance offered by the contacts and the bulk semiconductor material of the solar cell.

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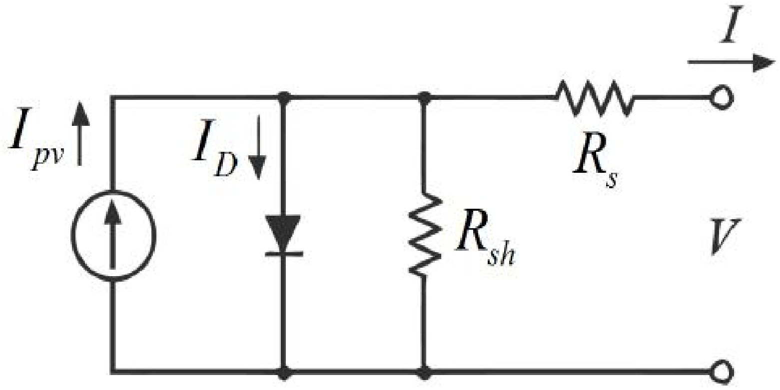

Figure I: Equivalent Electric Circuit of Solar Cell

It’s current, voltage equation expressed by equation 1.

$$I = I_{sc} - I_0 \exp\left[\frac{q(V + IR_S)}{nkT}\right] - \frac{V + IR_S}{R_{SH}} \quad (1)$$

Where as , *I0* is the dark saturation current, *q* is the charge of an electron (*1.602* x 10^{-19} coulombs), *n is* the diode quality (ideality) factor, *k* is the Boltzmann constant (1.38064852(79)×10^{-23} J/K), *T* is the absolute temperature and *Rs* and *Rsh* are the series and shunt resistances of the solar cell.

2.1 O.C. Voltages, S.C. Current & MPPT

As in voltage and current characteristics two points are important i.e. VOC open circuit voltage and ISC short circuit current. At both points the power generated is zero.When the output current of the cell is zero, i.e. *I*=0 and the shunt resistance *RSH* is neglected. The maximum power is generated by the solar cell at a point of the current-voltage characteristic where the product *VI* is maxima. This point is known as the MPP and it is unique.

2.2 Fill Factor

Using the MPP current and voltage, Impp and Vmpp, the open circuit voltage (Voc) and the short circuit current (Isc), the Fill Factor (FF) can be defined as in equation 2:

$$FillFactor\,(FF) = \frac{V_{mpp} * I_{mpp}}{V_{oc} * I_{sc}} \quad (2)$$

It is the ratio of the actual maximum power (*Impp*Vmpp*) to the theoretical one (*Isc*Voc*). The MPP voltage and current of PV cell are always below the open circuit voltage and the short circuit current respectively in the voltage and current characteristics, because of the series and shunt resistances and the diode depicted in fig.1

2.3 Temperature and Irradiance Effect

Two important factors that are mainly effect on solar module i.e. temperature and irradiance. As the photo-generated current is directly proportional to the irradiance level, i.e. as irradiation increases it leads to a higher photo-generated current. Furthermore, the short circuit current is directly proportional to the photo generated current; therefore this relation gives directly proportional to the irradiance. When the operating point is not the short circuit, in which no power is generated, in the PV current photo generated current is also the main factor. For this reason the voltage-current characteristic varies with the irradiation which is mostly affect on solar module. As shown in figure II the effect of irradiance on current-voltage characteristics.

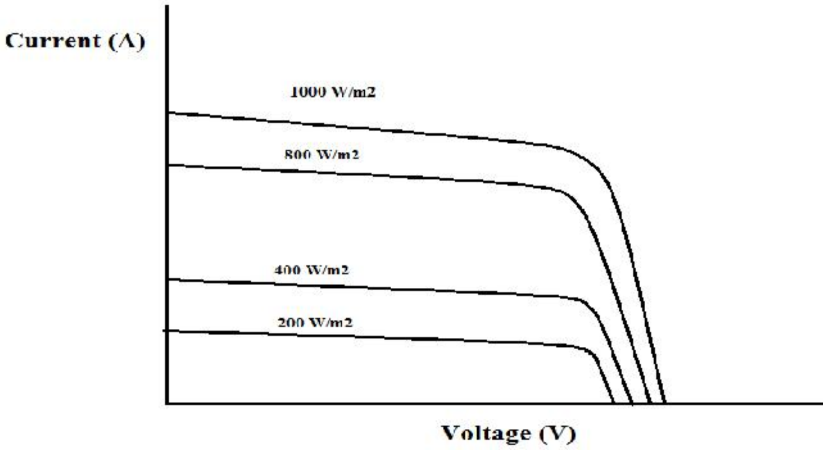

Figure II: I-V Curve of Photovoltaic Array for Different Irradiance

Similarly, the figure III shows the power-voltage characteristics (P-V). Where the curves are shown in per unit, i.e. the voltage and current are normalized using the VOC and the ISC respectively, in order to illustrate better the effects of the irradiance on the V-I and V-P curves.

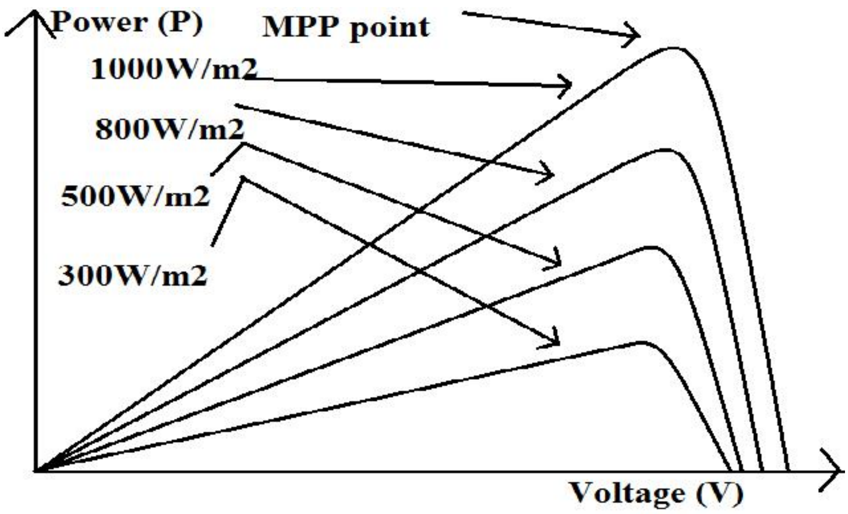

Figure III: Characteristic Power Curve of P-V Array for Different Irradiance

As shown from the graph the effect of current and voltage are both positive i.e. as the irradiation increases power generated by solar cell or module increases. On the other hand effect of temperature mostly on voltage in the system. The open circuit temperature dependent on temperature, this is shown by equation 3.

$$V_{oc}(T) = V_{oc}^{STC} + \frac{K_v}{100}(T - 273.15) \quad (3)$$

Following figure IV shows the effect of temperature on voltage of system. The effect of temperature is negative, i.e. as the temperature increases voltage is decreases.

Simultaneously the little current in system increases and it does not compensate the decrease in the voltage which is caused by a given temperature rise. That is why the power also decreases. Effect of temperature on current is neglected.

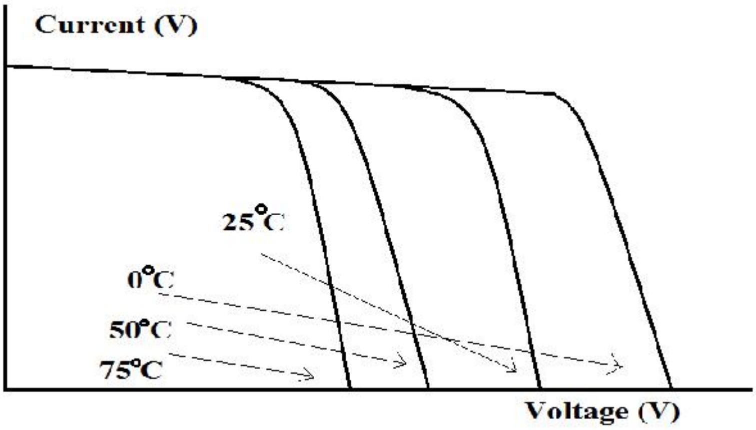

Figure IV : PV Characteristics for Different Temperature

3. MPPT ALGORITHM OVERVIEW

To improve the efficiency of solar modules Maximum Power Point technique is used [6,8]. Total incident irradiation on the module out of all irradiation, only 30% to 45% irradiation produces electrical energy. When source impedance equals to load impedance power output of circuit is maximum by maximum power transfer theorem. So, the main aim is to matching the impedance in the circuit. In this paper at source side by using of boost converter efficiency can be increased by boosting up the voltage. By using different duty cycles of boost converter matching of load impedance can be done.

3.1 Hill Climbing (Perturb and Observe {P&O})

The P&O algorithms functioning by time to time perturbing (i.e. incrementing or decrementing) the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle in the circuit of PV [10]. The control system moves the PV array operating point in that direction, if the PV array operating voltage changes and power increases (*dP/dVPV*>0) otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way. It is observed that as voltage increasing causes rise in power, when working point is on left of MPP and when operating on right of MPP, the power will reduced. If there is rise in power, consequent perturbation operation should be kept same so that to attain MPP. Once MPP is achieved, for next perturbation there is reduction in power in the circuit. This algorithm is not much suitable when there is variation in the solar irradiation is very high. The voltage never actually reaches an exact value or the exact point of MPP but perturbs around the maximum power point (MPP).Following figure V shows how P&O algorithm tries to operate nearer to MPP point.

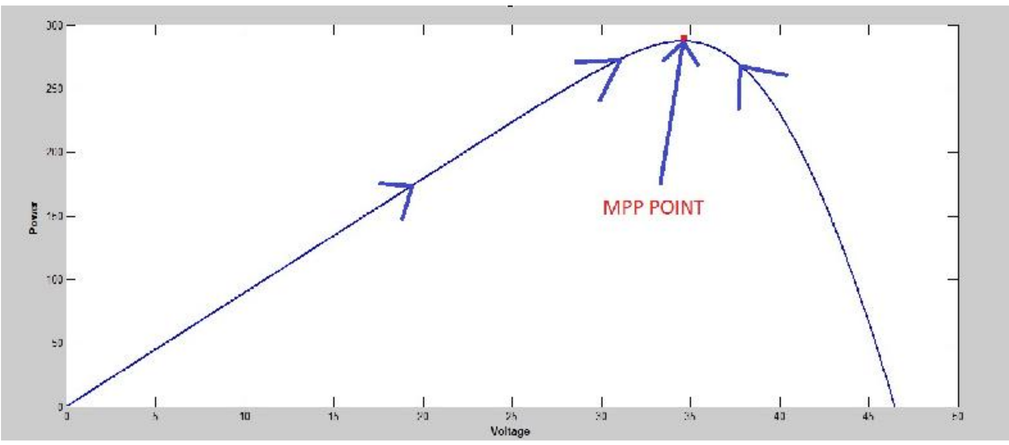

Figure V: PV Curve for P&O Implementation

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4. BOOST CONVERTER

The output voltage of this converter is greater than the input voltage. As shown in figure VI is boost converter that we use to increase the efficiency of solar module [1,2].

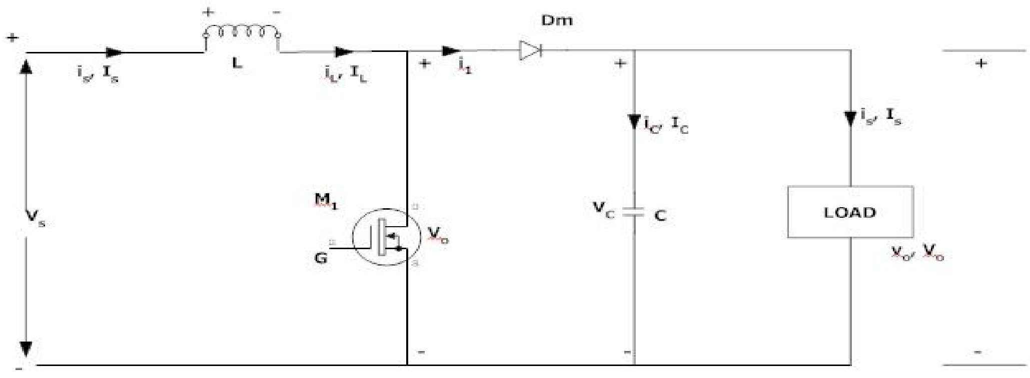

Figure VI: Boost Converter

The output voltage equation of this converter is as follows,

For stable system, changes in Inductor current should be zero i.e. $\Delta i_L = 0$.

$$\frac{V_i}{L} * D * T - -\frac{V_i - V_0}{L} * (1 - D) * T \quad (4)$$

This finally gives following Output Voltage equation.

$$V_0 = \frac{V_i}{1 - D} \quad (5)$$

5. MATLAB SIMULATION

Following figures shows modeled pictures of implemented electrical model of individual PV panel used in industry. Representation of I_{pv} is shown in figure VII.

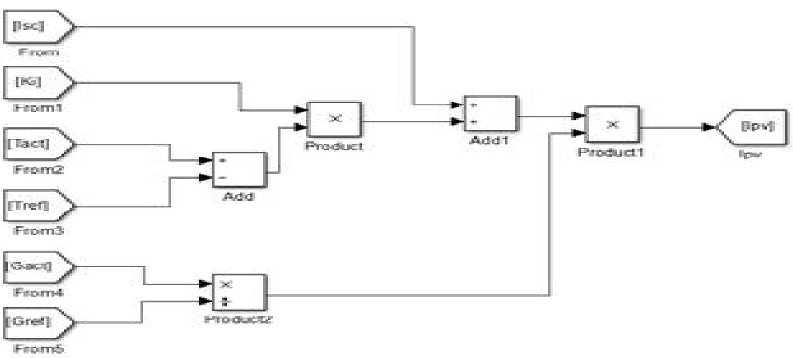

Figure VII: Ipv

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Representation of Ish as shown in figure VIII.

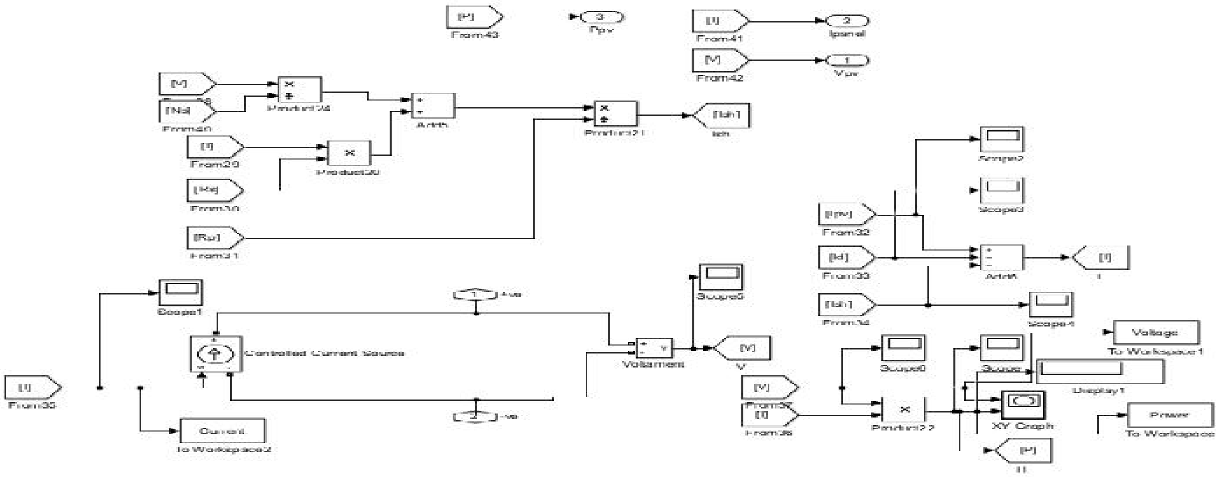

Figure VIII: Ish

From above implemented equations in MATLAB, we get I-V and P-V characteristics of said individual PV module. Following figure IX shows I-V characteristics of P-V module

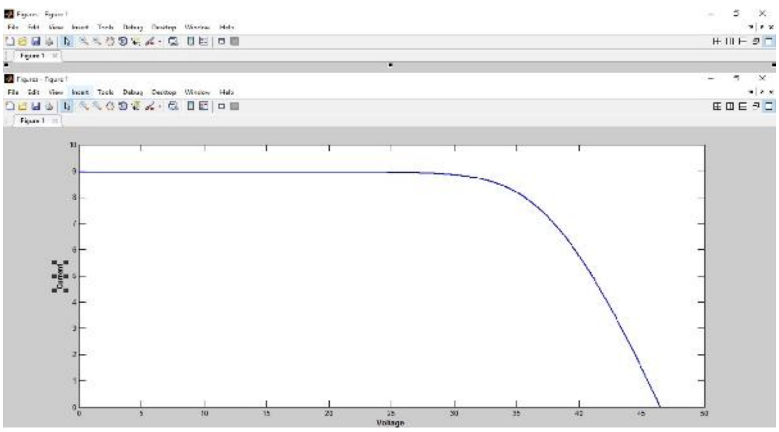

Figure IX: I-V characteristics

As shown below Figure X shows power and voltage curve, P-V characteristics for PV module and result of this simulated equations.

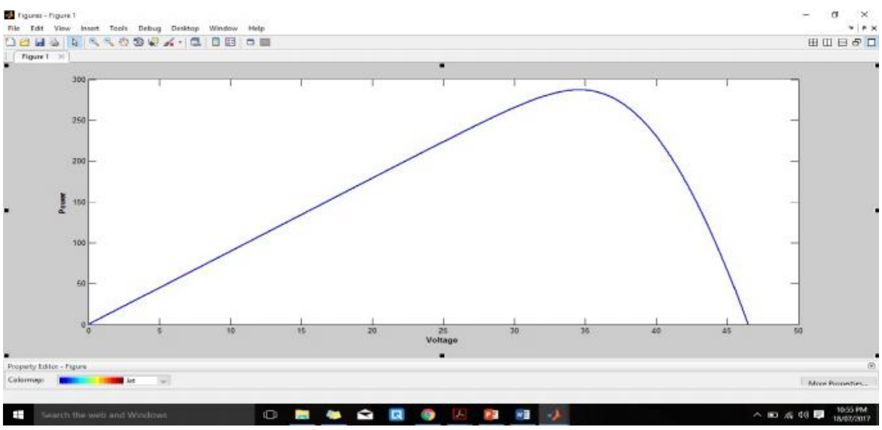

Figure X: P-V Characteristic

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As shown in figure XI and XII Control Circuit for Eagle schematic and layout of Eagle schematic.

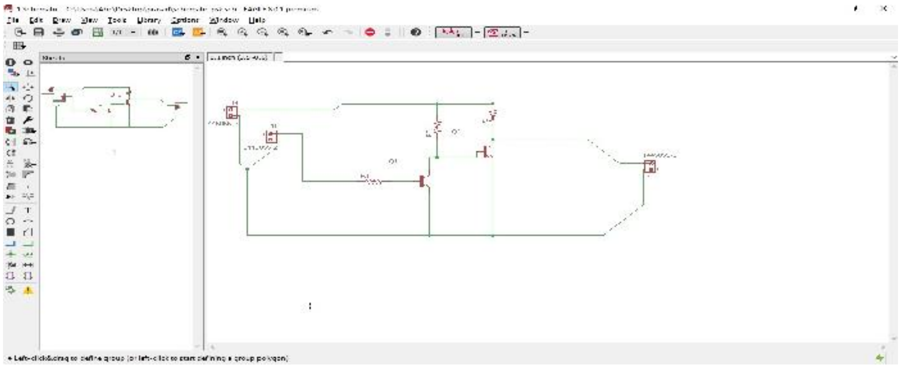

Figure XI: Control Circuit

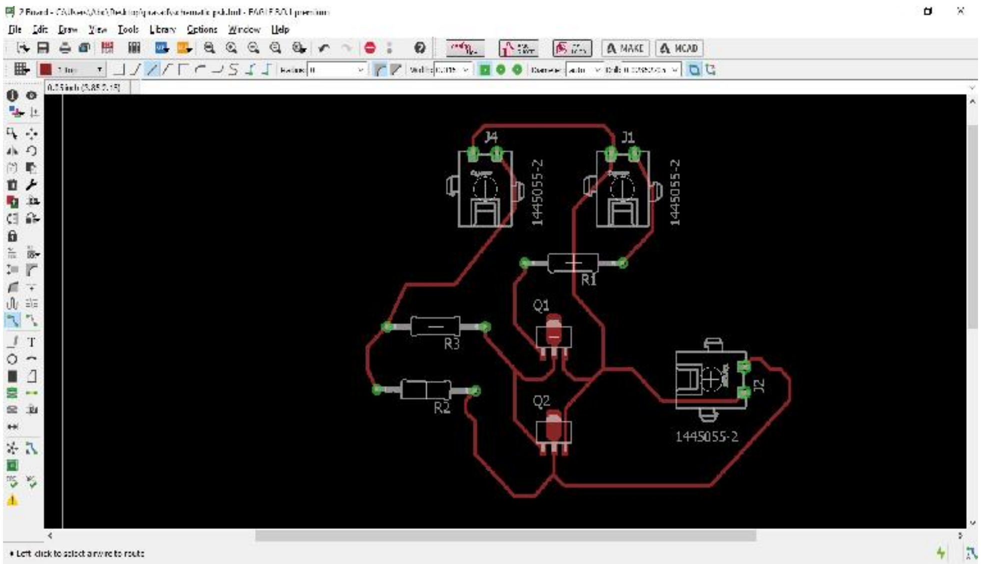

Figure XII: Control Circuit PCB Layout

6. SENSING CIRCUIT

As in the experimental setup voltage and current sensing circuit used to perform further experiments and results. Arduino program is made for the voltage sensing circuit, at the same time current sensor also used .This also produces signal of 0 to 30 A into 0 to 5V range as per requirement of Arduino input. Hence this current sensor is suitable choice. For Current measurement, ACS712, 30A current sensor is used.

7. SIMULATION RESULTS

The system continuously tries to achieve Maximum Power from PV panels [9]. However some results are mentioned below which describe operating region for Corresponding Irradiance level. They are Left of MPP, On MPP and Right of MPP. Constant duty cycle program is written in each case.

Followings are the results obtained from available system.

Table 1

Vin(V)	Iin(A)	Vout(V)	Iout(A)	Duty Cycle (%)
205.5	7.01	214.13	5.89	4

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Input Power Pin = 205.5 * 7.01 = 1440.56W.

Output Power Pout = 214 * 5.89 = 1267.7W.

Converter Efficiency = 88%

This part is on Left of MPP.

Table 2

Vin(V)	Iin(A)	Vout(V)	Iout(A)	Duty Cycle (%)
216.1	6.88	232.37	5.7	7

Input Power Pin = 216.1 * 6.88 = 1488.03W.

Output Power Pout = 232.37 * 5.69 = 1324W.

Converter Efficiency = 89 %

This part is Almost on MPP.

Table 3

Vin(V)	Iin(A)	Vout(V)	Iout(A)	Duty Cycle (%)
229.36	6.02	266.7	4.76	14

Input Power Pin = 229.36 * 6.02 = 1380.73W.

Output Power Pout = 266.7 * 4.76 = 1270.27W.

Converter Efficiency = 92 %

This part is on Right of MPP.

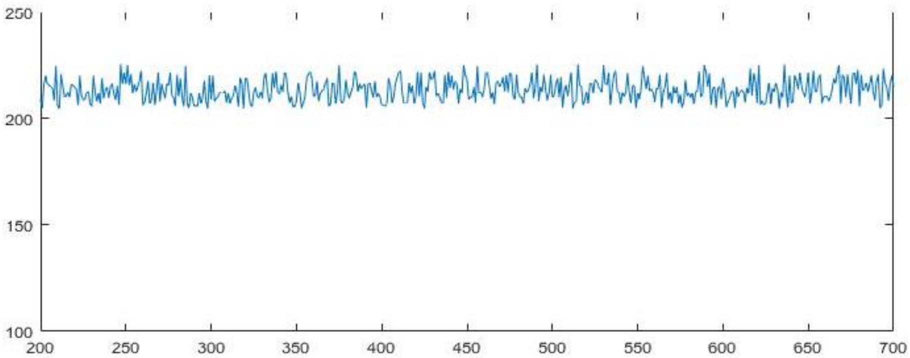

Figure XIII Input voltage for 7% duty cycle almost on MPP

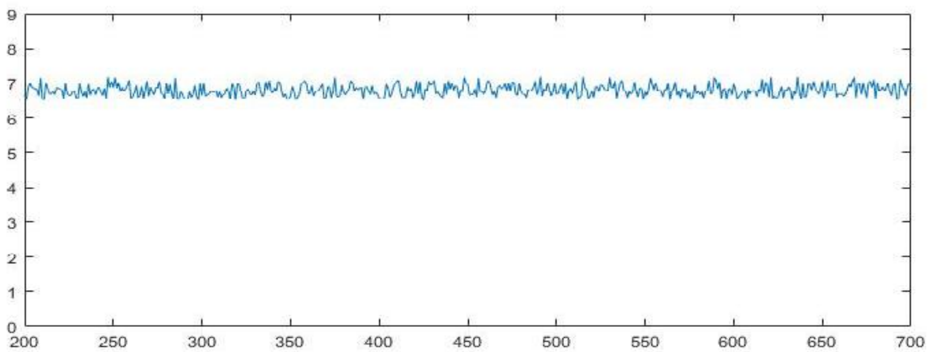

Figure XIV: Input current for 7% duty cycle almost on MPP

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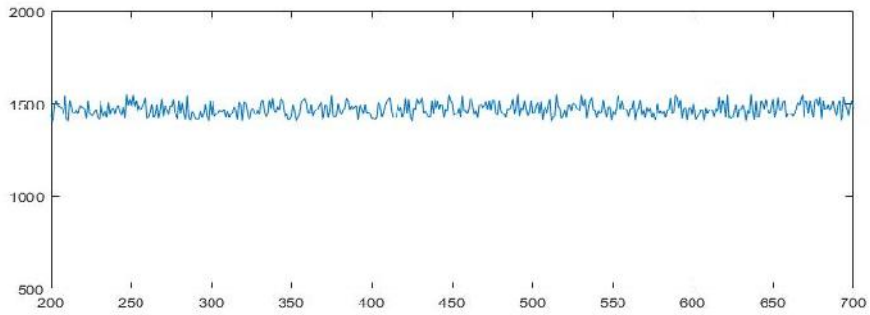

Figure XV: Input power for 7% duty cycle almost on MPP

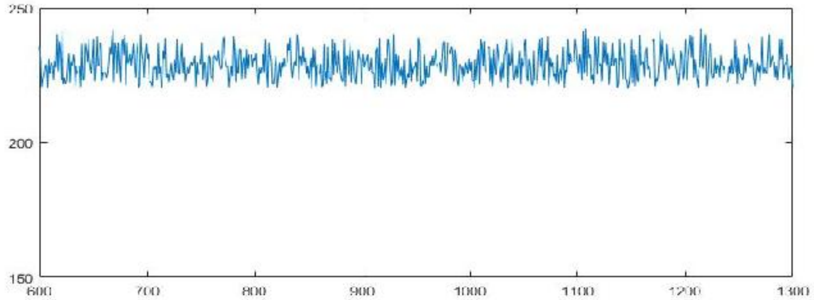

Figure XVI: Output Voltage for 7% duty cycle almost on MPP

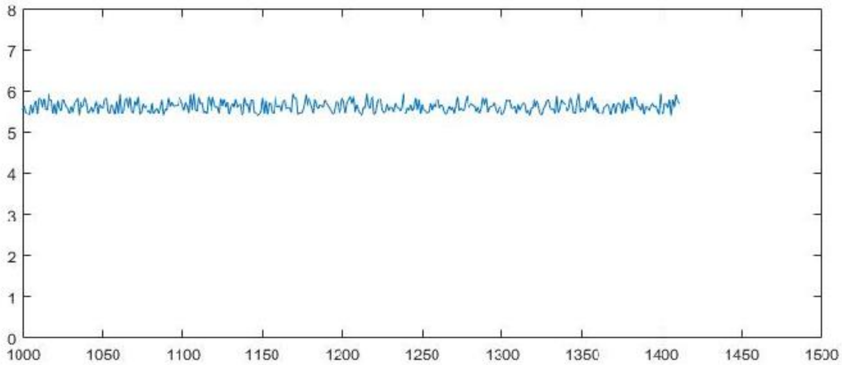

Figure XVII: Output Current for 7% duty cycle almost on MPP

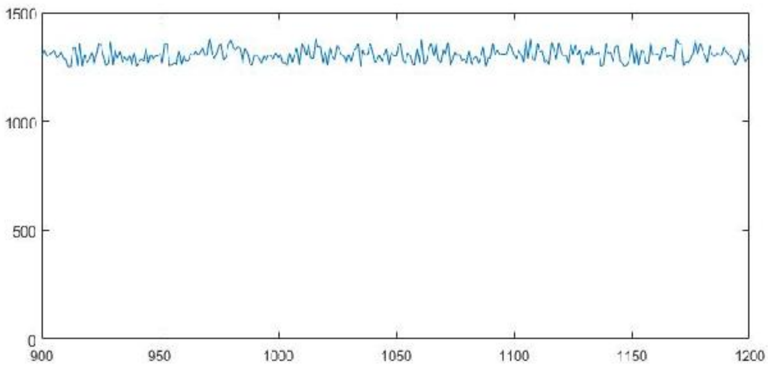

Figure XVIII: Output Power for 7% duty cycle almost on MPP

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Above results are taken at particular instant so as left of MPP, on MPP and Right of MPP. From power curves, it is observed that power is maximized for a particular operating point. From above results waveform, it is observed that as duty cycle is increased, Output voltage increases. However, operating point of PV module also shifts. P&O Algorithm is applied in order to achieve Maximum power from available system. Here, Maximum power is achieved at near around 7% duty cycle. Thus maximum power is extracted from system.

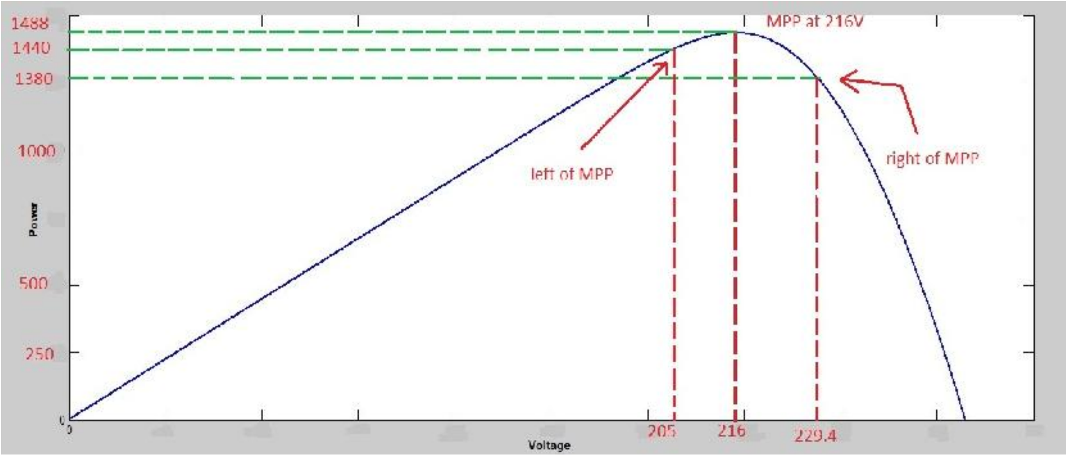

Figure XIX: Results Power Curve 1

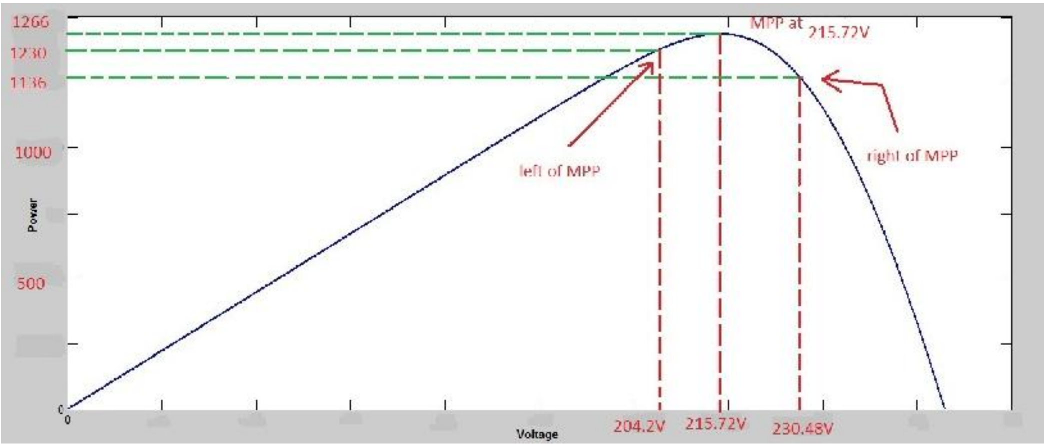

Figure XX: Results Power Curve 2

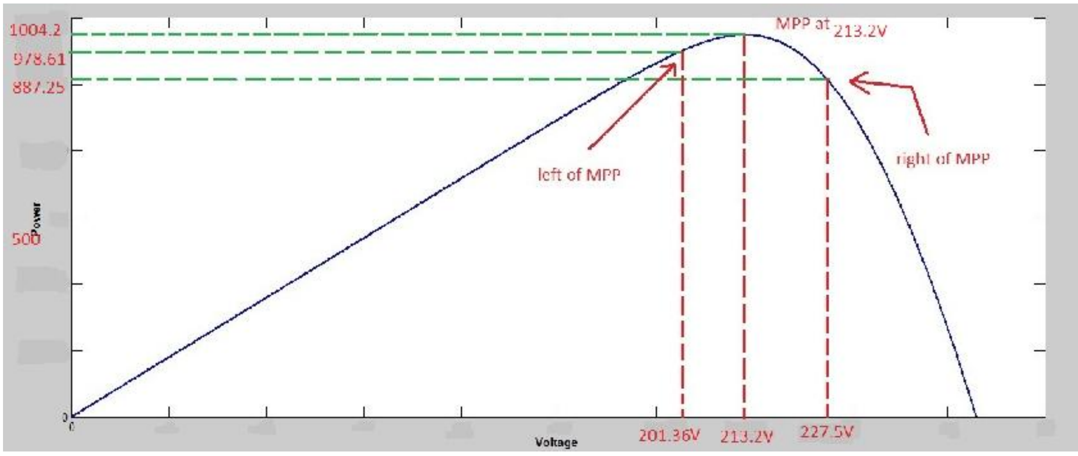

Figure XXI: Results Power Curve 3

For particular irradiance, having I_{sc} **= 7.03A**,
Operating PV panel at 4% duty cycle gives PV output power 1440.56W.
Operating PV panel at 7% duty cycle gives PV output power 1488.03W.
Operating PV panel at 14% duty cycle gives PV output power 1380.73W.
Operating PV panel at 4% duty cycle gives effective output power 1267.7W.
Operating PV panel at 7% duty cycle gives effective output power 1324W.
Operating PV panel at 14% duty cycle gives effective output power 1270.27W.

For particular irradiance, having I_{sc} **= 6.06A**
Operating PV panel at 5% duty cycle gives PV output power 1231.33W.
Operating PV panel at 8% duty cycle gives PV output power 1266.3W.
Operating PV panel at 12% duty cycle gives PV output power 1136.27W.
Operating PV panel at 5% duty cycle gives effective output power 1075.94W.
Operating PV panel at 8% duty cycle gives effective output power 1139.7W.
Operating PV panel at 12% duty cycle gives effective output power 1056.73W.

For particular irradiance, having I_{sc} **= 4.9A**,
Operating PV panel at 4% duty cycle gives PV output power 978.61W.
Operating PV panel at 8% duty cycle gives PV output power 1004.2W.
Operating PV panel at 14% duty cycle gives PV output power 887.25W.
Operating PV panel at 4% duty cycle gives effective output power 861.2W.
Operating PV panel at 8% duty cycle gives effective output power 903.8W.
Operating PV panel at 14% duty cycle gives effective output power 825.14W.

8. CONCLUSION AND DISCUSSION

This paper describes the phenomenon due to voltage sensing circuit sensed by Arduino Controller for further controlling action of MPPT. When MPPT is used, the algorithm iterates and decides the duty cycle by itself. When there is change in the solar irradiation the maximum power point changes and thus the required duty cycle for the operation of the model also changes. But if constant duty cycle is used then maximum power point cannot be tracked and thus the system is less efficient. For this project, 2.1kW solar system is established from available system. Perturbation and Observation method is implemented by Arduino Uno. The required 20 kHz frequency is achieved through bit controlling registers (TCR0A and TCR0B). The driver circuit is also implemented for gating signal for power switch. In this system, pwm pulses for power switch are achieved through Arduino Uno ATMEGA 328 controller. It is observed that maximum power can be achieved near around 7% or 8% duty cycle for particular irradiance at that moment of time. From power curves, it can be seen that maximum power gets achieved at certain operating point of PV array [4, 7, and 11]. Algorithm almost sets duty cycle to operate system at MPP.

9. FUTURE SCOPE

With the MPPT technique, we extract Maximum power available from PV system. Further extension can be given to this system by adding inverter topology in order to run motor application. By Controller based inverter that has built in MPPT and VFD action implemented in software algorithm, 1ph, 1.5 hp AC motor is nice application. This system can be cooperative for agricultural purposes [13].

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