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# Maximum Power Point Tracking for Photovoltaic Systems by using Novel Microcontroller based Hardware Implementation

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***Abstract: The demand of utilizing alternative energy is increasing due to environmental regulations and rising oil prices. In this respect solar energy using PV cell is a promising candidate. A PV array under constant temperature and uniform period has non-linear current-voltage characteristics. With the change of solar isolation and ambient temperature the operating point of PV cells vary. MPPT is a tracking system to extract maximum power from the solar cell in a PV system. In this paper, an approach for maximum power tracking using microcontroller is proposed. In this sense, we develop a buck converter controlled by perturb and observe, the (P &O) technique for the maximum power point tracking of the photovoltaic panel. The system is simulated and implemented experimentally using a microcontroller device. The analysis by simulations and practical results show an excellent performance of the control technique and the improvement of the efficiency of the system. The performance in power system is evaluated in a mat lab simulation platform. We will also developed a prototype of the system.***
***Keywords: Solar system, MPPT, Microcontroller, Algorithm, PV module, PWM***

## I. INTRODUCTION

A PV array under constant uniform irradiance and the continual temperature has the current- voltage I-V characteristic like that shown in figure 1. There is a unique point on the curve called the maximum power point MPP, at which the array operates does maximum efficiency and produces maximum output power When a PV array is directly connected to a load the operating system point will be at the intersection of the I-V of the PV array and load line shown in the figure 1. This working point is not at the PV array's MPP, which can be seen in figure 1. Thus in a direct-coupled system, the PV array mass usually is oversized to ensure that the load power requirements can be supplied this lead to an overly expensive system. To overcome this problem, a buck converter, with maximum power point tracking control system can be used to maintain the PV array's operating point at the MPP. The PPT does this by controlling the PV array's voltage or current independently of those of the load. If adequately controlled by an MPPT algorithm, the system can locate and track the MPP of the PV array. However, the location of the MPP in the I-V plane is not known a priori. It must be located either through model calculations or by the search algorithm. The situations is further complicated by the fact that the MPP depends in a non-linear way on Irradiance and temperature as illustrated in fig 2. A battery can be connected at the place of load with the implementation of a battery charging algorithm in the microcontroller. This is stand-alone system. It can be connected to the Grid through the inverter. Mechanical sum tracking can be incorporated with the MPPT system to make the system more efficient. Other algorithms can also be implemented, and their comparative study can be done. A low-cost, efficient embedded MPPT system can be developed, and that may be used in conjunction with the conventional household solar applications in the rural areas. In recent decade, researches on solar energy as alternative source of energy become very prominent in the field of electrical engineering. There are many issue concerning the development of PV system such as efficient energy conversion from sunlight to battery or sunlight to inverter and solar power to grid connectivity environment etc. solar cell characteristics are highly nonlinear. This depends upon irradiance and temperature. [1, 2] provides the basics of solar cell characteristics. The characteristics also depends on weather conditions. To achieve maximum power point in solar voltage-current characteristics it is essential to control the current output from a PV cell. This control is called maximum power point. In [6] a MATLAB- Simulink GUI environment to develop the model of PV array. The model is developed using basic circuit, contains the PV cells including the solar irradiance and temperature changes. They tested the new model at various loads. There are different techniques to implement MPPT. [7] Present a buck converter controlled by P & O techniques. A complete analysis of the photo voltaic device and a converter is developed in MATLAB environment. [9] Gives a brief comparison between different algorithms on MPPT. Results are obtained for three optimized algorithms, using a microprocessor-controlled MPPT operating from a PV array. It is found that the P & O algorithm, when properly optimized, we can have MPPT efficiencies well in the excess of 97%.

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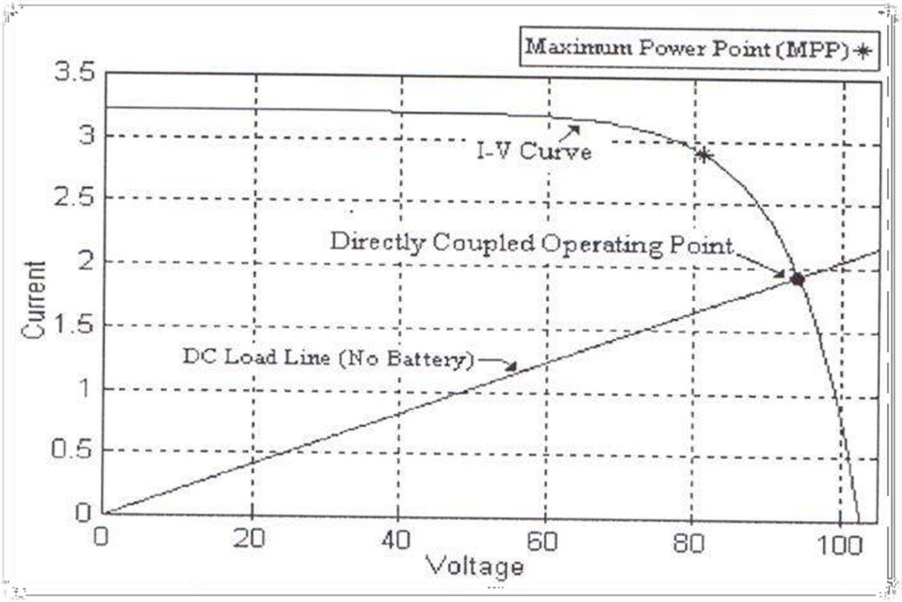


Fig. 1 V-I Characteristics curve of a PV array

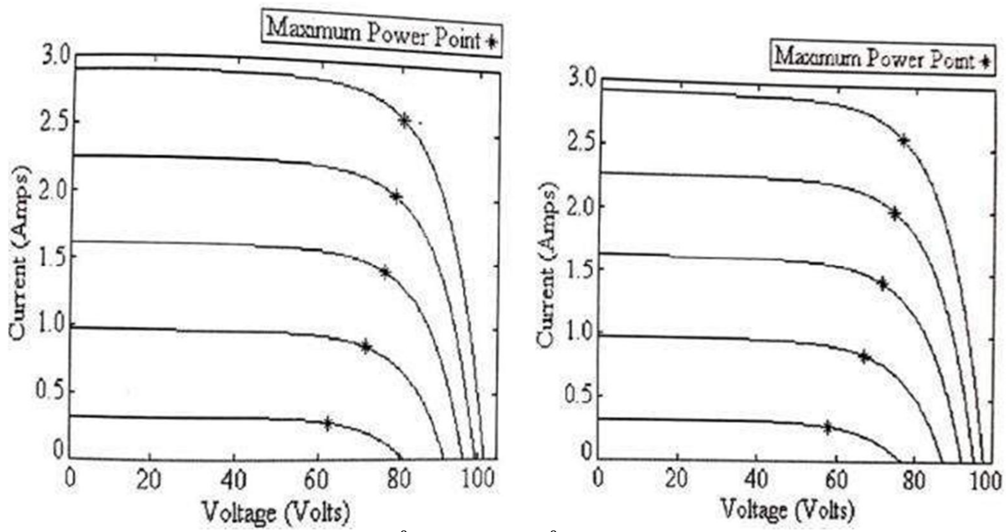


Fig. 2 I-V curves at (a) $40^0$ C and (b) $50^0$ C of PV array at different irradiance

Figure 2(a) shows a family of PV I-V curve under increasing irradiance, but at constant temperature and figure 2(b) shows I-V curves at the same irradiance values, but higher temperature. Several MPPT control algorithms have been proposed. One algorithm the perturb-and-observe (P & O) algorithm is by far the most commonly used in commercial MPPTs.

## II. DESIGN OF PROPOSED SYSTEM

The objective of this thesis is firstly to develop an equivalent model of a photovoltaic cell. Then the most popular p and o algorithm is analyzed in-depth and tested according to the standard mentioned above. After that, improvements to the p and o algorithm are suggested to succeed in the MTP tracking under conditions of changing irradiance. To test the MPPT algorithm according to the irradiation profiles propose in the standard, a simplified model was developed, because the simulation time required in some of the cases cannot be reached with the detail switching model of a power converter in a standard desktop computer. The reason for that is the machine runs out of memory after stimulating only a few seconds with the complete model. Finally, the simplified model is verified by comparing its results with those obtained from a model containing a detailed model of an inverter.

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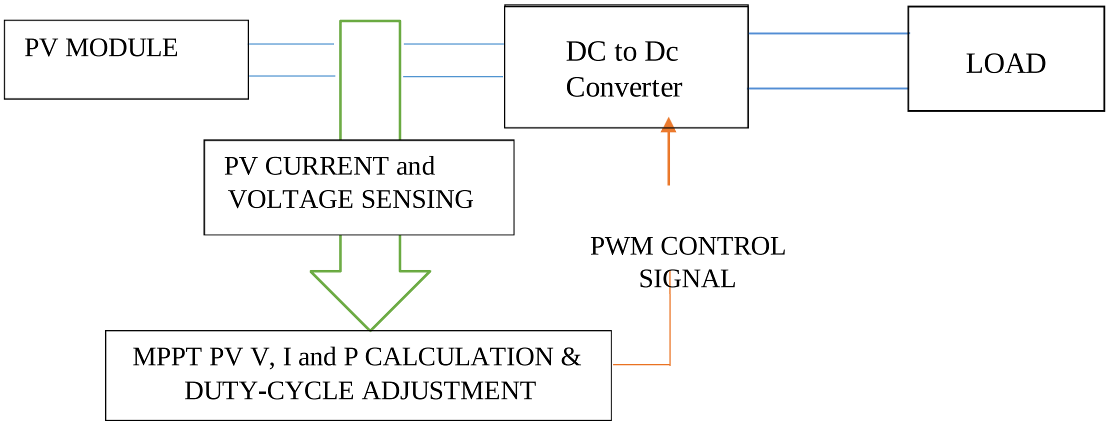


Fig. 3 Block diagram of our proposed system

## III. THE EQUIVALENT-CIRCUIT MODEL OF PV MODULE

The equivalent-circuit model of PV panel is also like a PV cell, as shown in fig 6. A solar module can be seen as a black box that with two connectors, producing a current, I, at a voltage, V. The black box can be described by an electric circuit with only four components. It consists of a light-generated current source Isc, a diode D, a series resistance Rs and parallel resistance Rsh.

1) *Current Source:* This is the source of photo current
2) *Diode:* This non-linear element reflects the dependence on the band gap and losses to recombination. It is characterized by the reverse current, $I_0$, which measures the leakage of electrons and re-combining and by air quality factor, A, with values between 1- 2, an empirical element.
3) *Shunt Register:* It represents losses incurred by conductors. This is also called parallel resistance. It is related to the non-ideal nature of the P-N junction and the presence of impurities near the edges of the cell that provide a short-circuit path around the junction. It is a loss associated with a small leakage of current through a resistive way in parallel with the intrinsic device. This can be represented by a parallel resistor ($R_P$). Its effect is much less conspicuous in a PV module compared to the series resistance, and it will only become noticeable when a several PV module are connected in parallel world more expensive system.
4) *Serial Register:* It represents losses incurred by non-ideal conductors. Rs the series are is the resistance offered by the context and the bulk semiconductor material of the solar cell. In a practical PV cell, there is a set of strength in a current through the semiconductor material, the metal grid, contacts, and current collecting bus. These resistive losses through these are lumped together as a series resistor. Its effect becomes very simple in a PV module that consists of series-connected cells and the value of resistance is multiplied by the number of cells. Upon incidence of light on solar cell, current is delivered to the load. Its current-voltage curve is expressed by the following equation (1):

$$I=I_{ph} - I_d\ [\exp(q/k_bTA) - 1] - (V+IR_s)/R_{sh}\ \text{-------------}[1]$$

Where,

I= solar cell output current, V= solar cell output current, $I_0$= dark satuaration current, Q= the charge of an electron A=the diode quality factor, K=the Boltzman constant, T=the absolute emperature,

$R_s$=the series resistance of solar cell, $R_{sh}$=the shunt resistance of solar cell

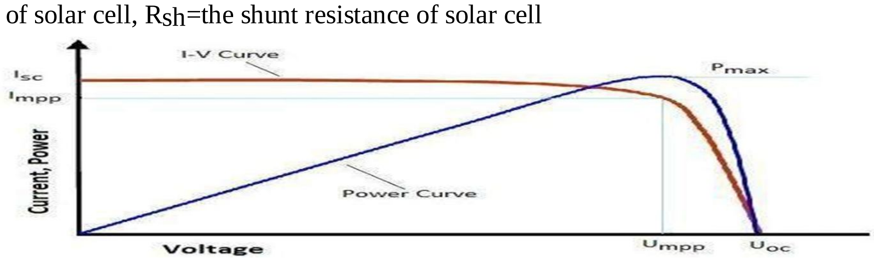


Fig. 4 Characteristics of PV cell

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The output power of a solar panel depends on the amount of light projected on the panel. Time of the day, season, panel position, and orientation are the factors behind the output power. But considering these factors constant, the power depends on the load connected to the panel. From the P-I characteristics we can say that a solar cell operates as an ideal-current source over a range of load. By increasing the resistive load of an irradiated cell continuously from zero (short circuit) to a very high value (an open circuit) the maximum power point can be determined. The output power is zero in both the short-circuited and open-circuited cases.

## IV. MAXIMUM POWER POINT TRACKER

When PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its I-V curve and the load line which is the I-V relationship of load. A resistive load has a straight line with a slope of I/R load as shown in figure. In other words, the impedance of load dictates the operating condition of the PV module. In general, this operating point is seldom at the PV module's MPP, thus it is not producing the maximum power. A study shows that a direct-coupled system utilizes a mere 31% of the PV capacity. A PV array is usually oversized to compensate for a low power yield during winter months. This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost. To mitigate this problem, a maximum power point tracker (MPPT) can be used to maintain the PV module's operating point at the MPP. MPPT's can extract more than 97% of the PV power when properly optimized.

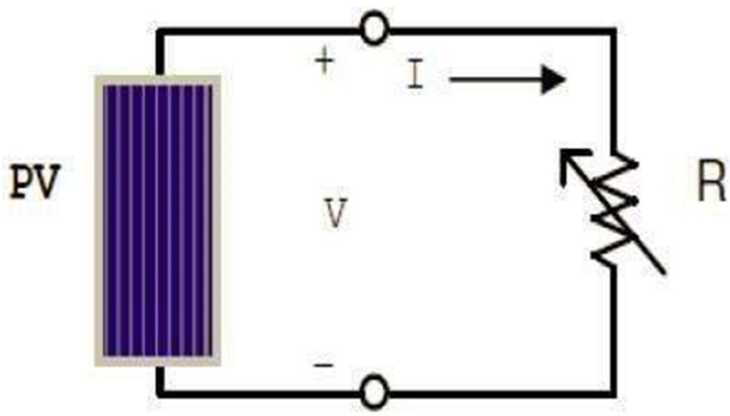


Fig. 5 PV Module is directly connected to a variable resistive load

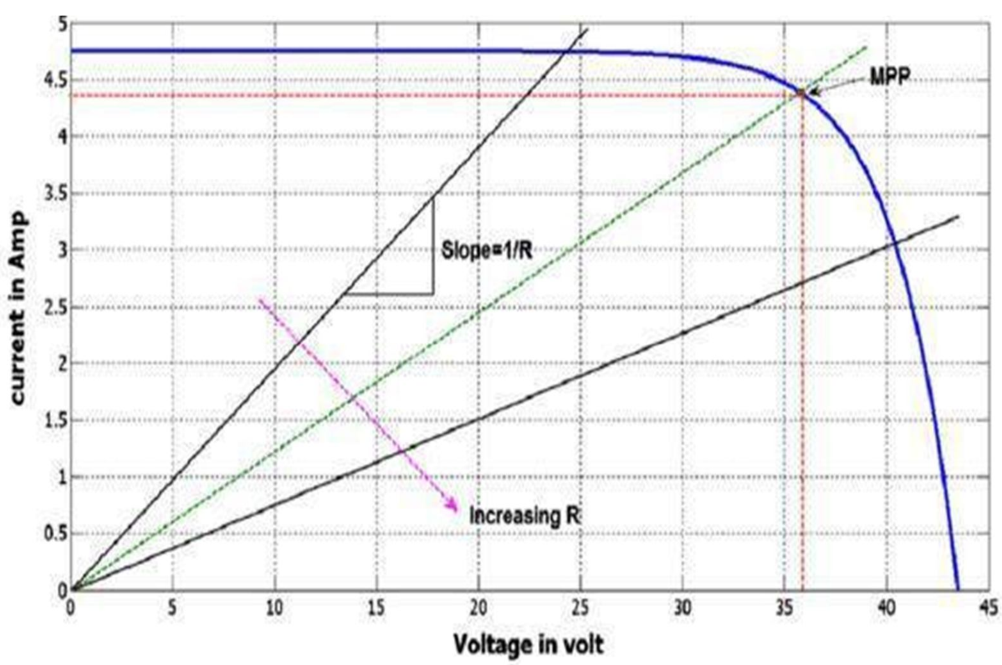


Fig. 6 I-V Curves of PV module and various resistive load

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## V. MAXIMUM POWER POINT CALCULATION

The maximum power point is obtained by introducing a DC/DC converted in between the load and the Solar PV module. The duty cycle of the converter is changed till the peak PowerPoint is obtained. Considering a step down converter is used

Vo = D*Vi ........................................................................................................[2]

Where, Vo is the output voltage and Vi is the input voltage Solving for the impendence transfer ratio

$$Ro = D^2 * Ri \quad [3]$$

Ro is output impedance, and Ri is the input impedance

The output resistance R remains constant, and by changing the duty cycle, the input resistance is seen by the source changes, so the strength corresponding to the peak power point is obtained by breaking the duty cycle.

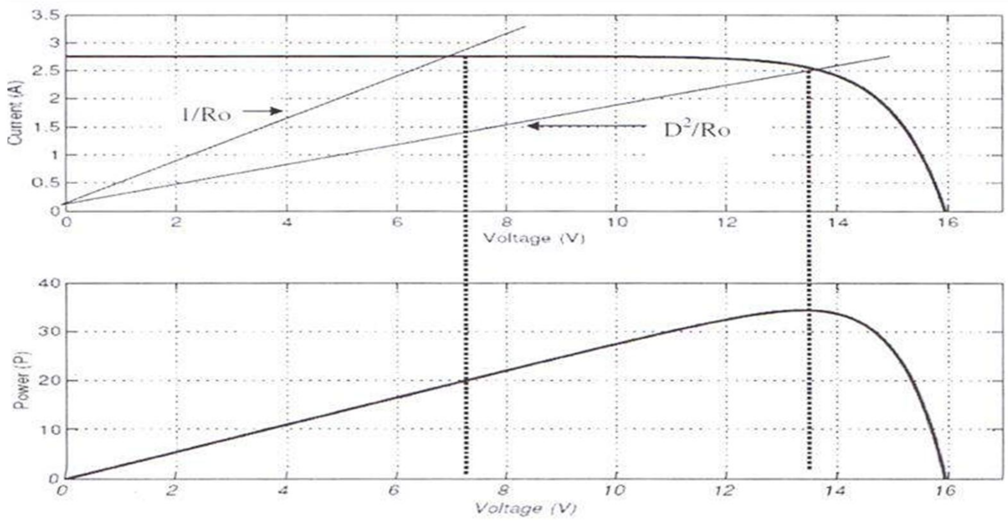


Fig.7 DC/DC converter helps in tracking the peak power point

## VI. ALGORITHMS TO TRACK THE MAXIMUM POWER POINT

The various algorithm used to track the power point of the Solar PV module

*A.* Perturb and Observe
*B.* Incremental Conductance
*C.* Parasitic Capacitance
*D.* Voltage based peak power tracking
*E.* Current based peak power tracking

In this paper, we are considering perturb and observe method. In this algorithm, a slight perturbation is introduced system. Due to this perturbation the power of the module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak is reached the potential at the next instant decreases and hence after that, the perturbation reverses.

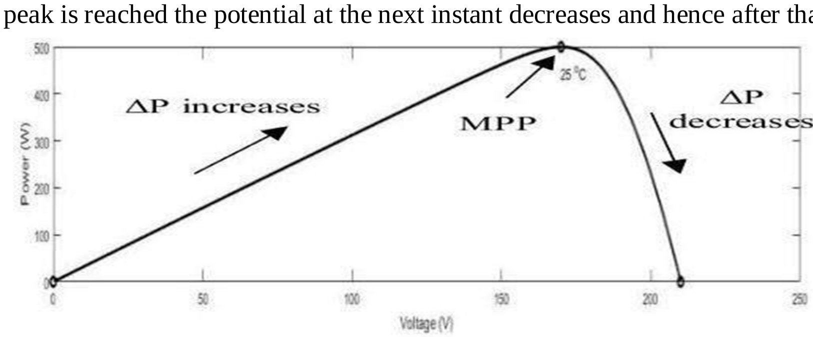


Fig. 8 Perturb and Observe Algorithm method

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When the steady-state is reached, the algorithm oscillates around the peak. To keep the power variation small, the size of the perturbations is kept very small. The algorithm is developed is such a manner that it Sets a reference voltage for the module corresponding to the peak voltage of the module. API controller then acts moving the operating point of the blade to that particular voltage level. It is observed that there is some power loss due to this perturbation also the face to track the power under first varying atmospheric condition. But still, the algorithm is very popular and straight forward.

## VII. ALGORITHM AND ITS FLOWCHART

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 power P is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If P is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed. In a situation where the irradiance changes rapidly, the MPP also moves on the right hand side of the curve. The algorithm takes it as a change due to perturbation and in the next iteration it changes the direction of perturbation and hence goes away from the MPP. However, in this algorithm we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing in both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm.

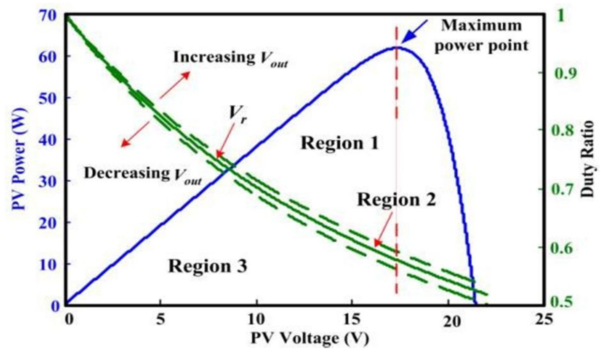


Fig. 9 Power vs Voltage for a solar panel at a given irradiation & temperature

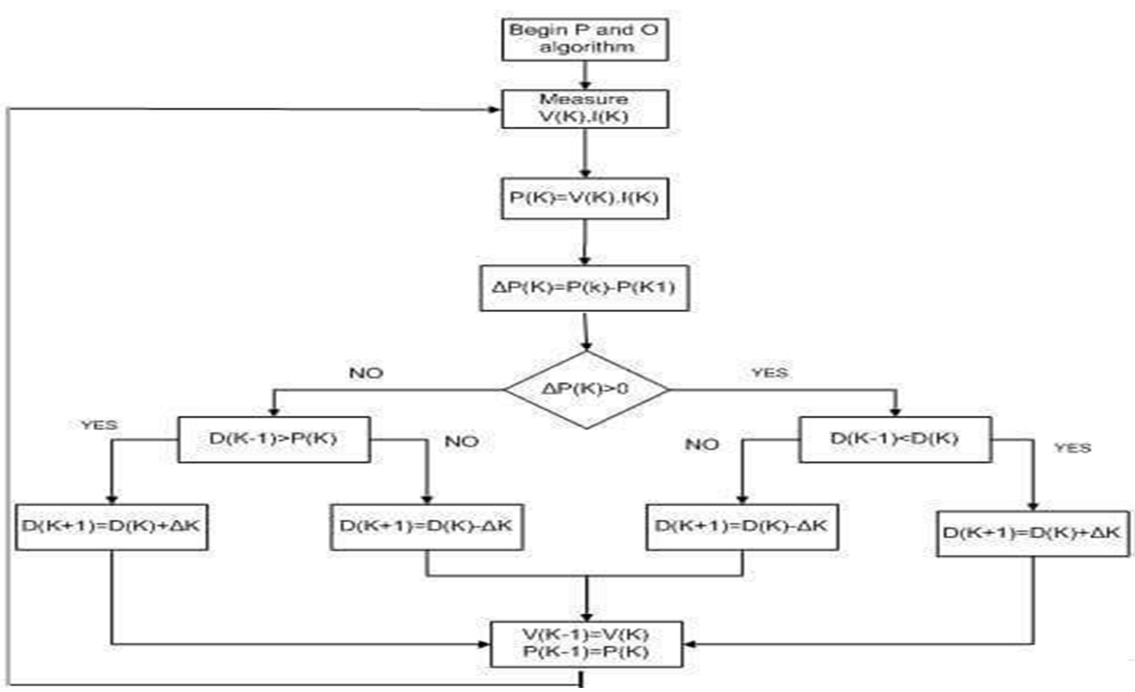


Fig. 10 Flowchart of Perturb and Observe Algorithm

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## VIII. MODELLING OF MPPT ALGORITHM

The perturbation step has been chosen to be 0.01. Direct duty cycle control method is implemented. The algorithm outputs a signal which has a value between 1 & 0.

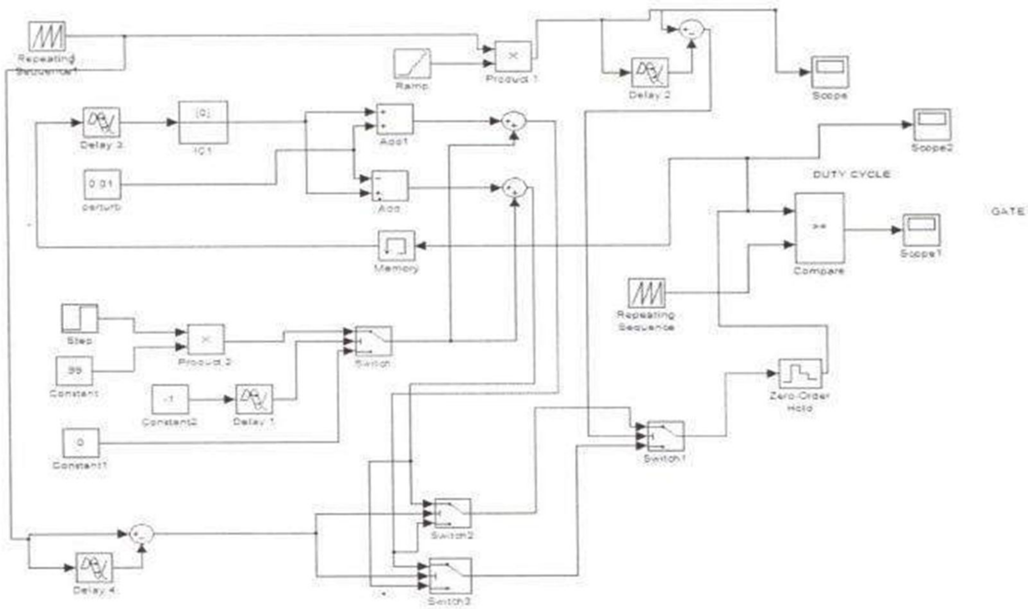


Fig. 11 Simulink Model of MPPT Algorithm

The signal is then given to the PWM generator which consists of a saw tooth generator and comparator. The algorithm output signal is compared with the high-frequency saw tooth wave form. The output of the comparator is a pulse of high frequency which are used to drive the switch. The algorithm gives the duty cycle output. And hence when peak power is reached, the algorithms perturb around the peak power.

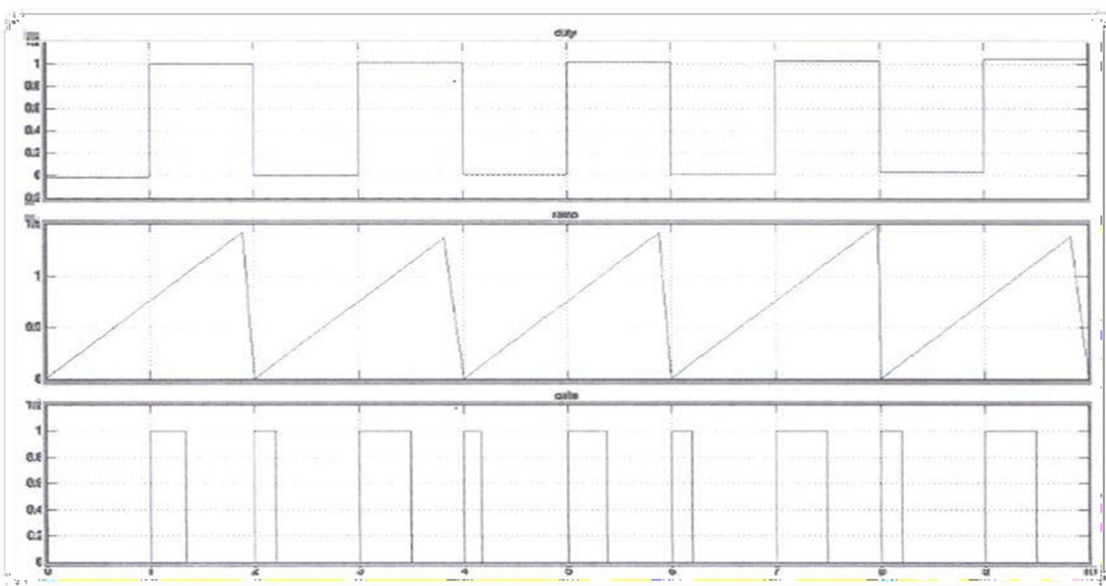


Fig. 12 PWM signal generated from MPPT algorithm

The above-shown waveform shows the output of the PWM generator. The output waveform obtained from the algorithm is compared with the saw tooth signal with the help of Pulse Width Modulation Technique. This resulting acts as the gate signal of the MOSFET having a variable nature.

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## IX.HARDWARE SET UP FOR MPPT

Implementation of the hardware for the MPPT system is done using real-time control. Microcontroller is used for implementing the real-time monitoring. The whole hardware circuit is shown below in block diagram.

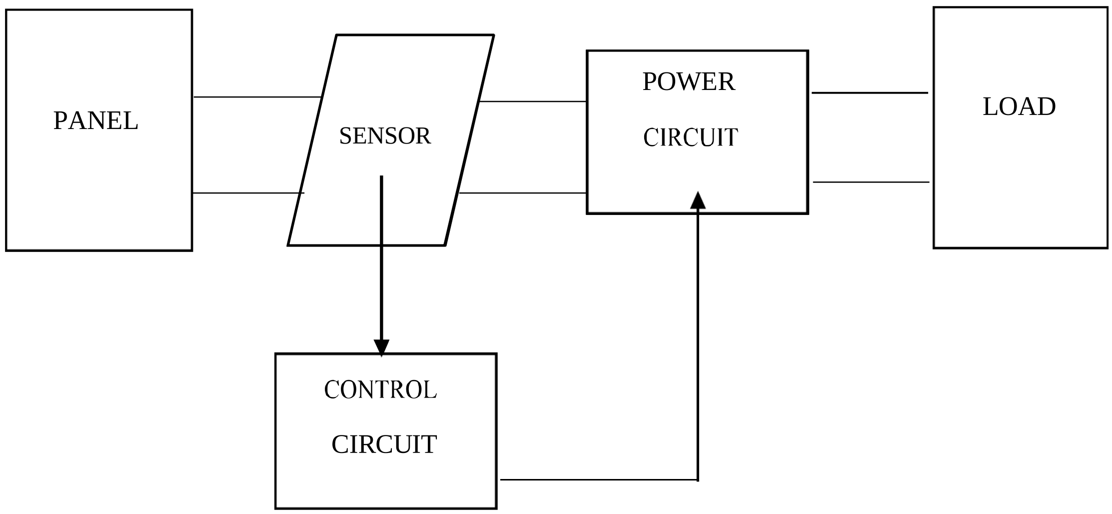


Fig. 13 Hardware Set Up

## X. AT 89C51

The AT89C51 is a low power, high-performance CMOS 8-bit microcontroller with 8K bytes of flash programmable and erasable read-only memory (PEROM). The device is manufactured using ATMEL's high-density nonvolatile memory technology, and it is compatible with the industry-standard 80C51 and 80C52 instruction set and pin out. The on-chip Flash allows the program memory to be programmed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with Flash on a monolithic chip. The Atmel AT89C51 is a powerful microcomputer which provides a highly-flexible and cost-effective solution to many embedded control applications.

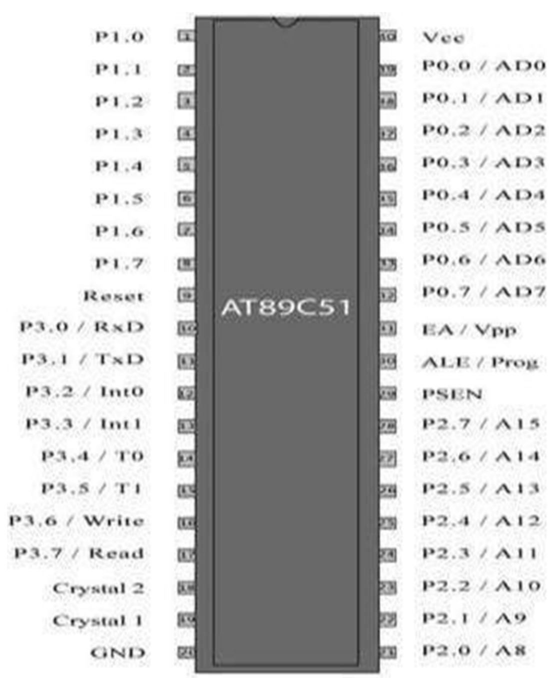


Fig. 14 AT 89C51 Microcontroller

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## XI. HARDWARE IMPLEMENTATION

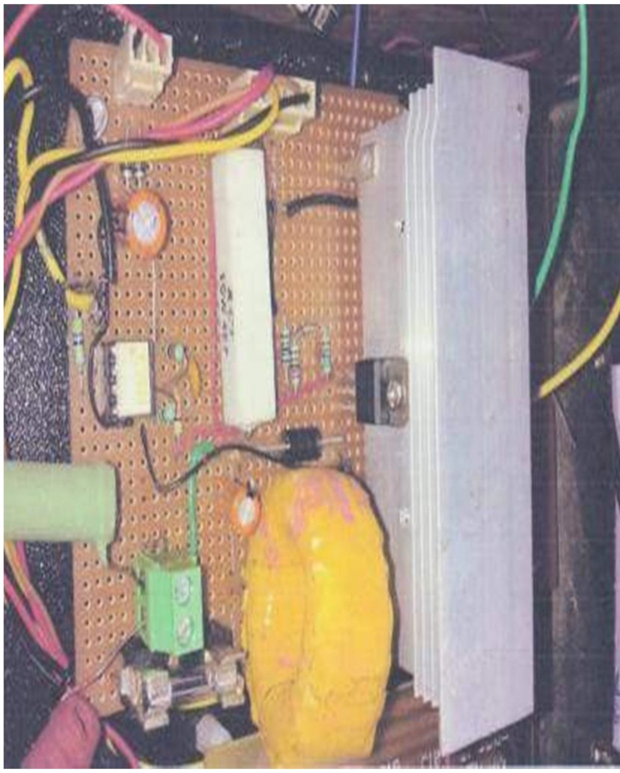

Fig. 15 Actual view of power circuit

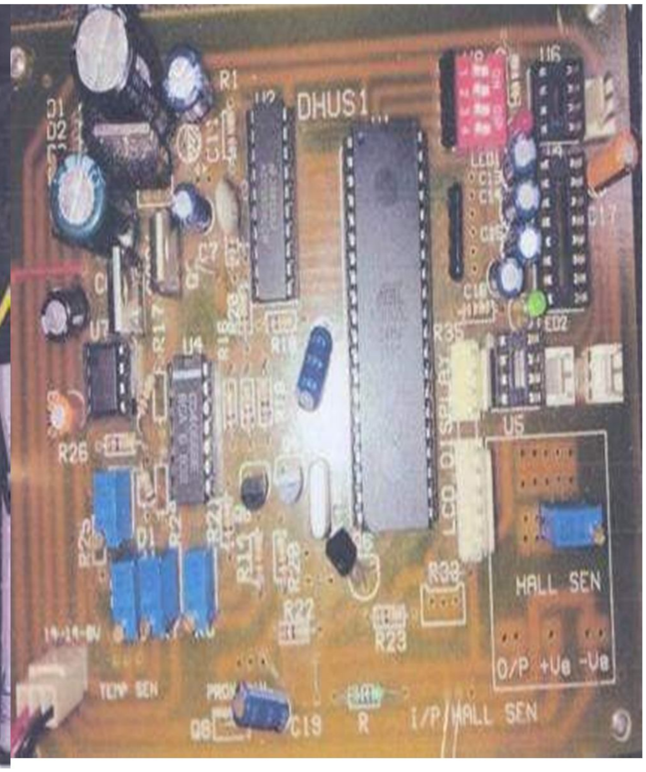


Fig. 16 Actual view of control circuit

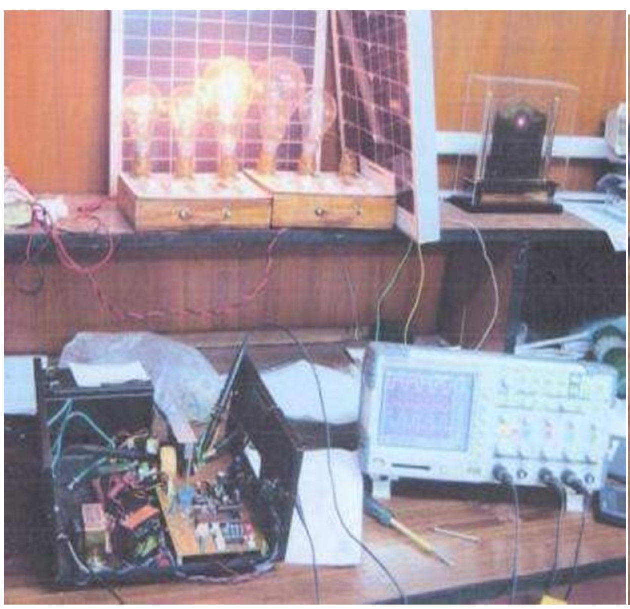

Fig. 17 Actual view of total hardware setup

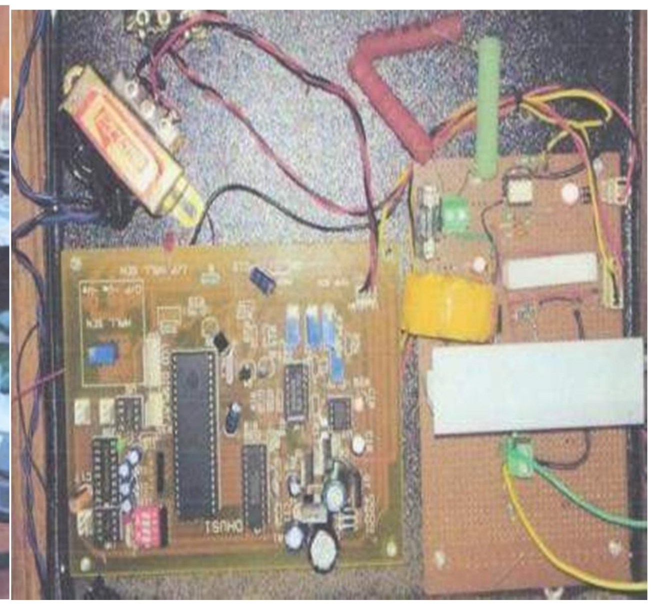

Fig. 18 Actual view of total circuit

The actual view of the power circuit and control circuit developed using practical components is shown in this figure. Also the actual total circuit and the whole experimental set up are shown here.

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## XII. RESULTS

The load resistance, when directly coupled with solar panel output is varied to check the solar panel characteristics. These characteristics are also stamped with changing the effective load with the variation of duty cycle of the converter. The system performance is tested with and without the MPPT. The production of buck converter has also experimented with fixed input voltage, constant load and varying duty cycle. All the results that we have obtained from our system can broadly be classified as

### *A. Solar panel Characteristics by Varying Load Resistance*

Table 1

| Resistance R in ohm | Measured | | Calculated power in W |
|---|---|---|---|
| | Volt in V | Current in A | |
| 1 | 4.988 | 4.998 | 24.93002 |
| 2 | 9.965 | 4.983 | 49.6556 |
| 3 | 14.59 | 4.864 | 70.96576 |
| 3.5 | 16.43 | 4.695 | 77.13885 |
| 5 | 19.34 | 3.669 | 70.95846 |
| 10 | 21.57 | 2.15 | 46.3755 |
| 15 | 22.09 | 1.47 | 32.4723 |
| 20 | 22.32 | 1.116 | 24.90912 |
| 25 | 22.45 | 0.8979 | 20.15786 |

Table 1: Results obtained when resistance connected to solar panel is varied

### *B. Solar panel Characteristics by Varying duty Cycle*

Originally the resistance is varied to obtain the characteristics curve of the solar panel. Now from the buck converter principle, we know that when duty cycle (D) of the converter is varied, the effective resistance is varied as below:

$$R_i = R_0 / D^2$$

Now the buck converter is connected between the solar panel and the load. The duty cycle is varied. The following results are obtained from the variation of the load by varying the duty cycle (D) of the converter.

TABLE 2

| Ton | %D | Vpan in V | Vcur in V | P |
|---|---|---|---|---|
| 16 | 1.4 | 34.4 | 0.147 | 5.0568 |
| 90 | 8 | 33.1 | 0.4 | 13.24 |
| 204 | 18 | 29.8 | 0.83 | 24.734 |
| 315 | 28 | 26.5 | 1.25 | 33.125 |
| 400 | 35 | 25 | 1.47 | 36.75 |
| 436 | 39 | 23.9 | 1.61 | 38.479 |
| 503 | 45 | 22.6 | 1.82 | 41.132 |
| 530 | 47 | 21.9 | 1.93 | 42.267 |
| 550 | 49 | 21.5 | 1.98 | 42.57 |
| 610 | 54 | 20.3 | 2.16 | 43.848 |
| 666 | 59 | 19.3 | 2.36 | 45.548 |
| 770 | 68 | 18 | 2.59 | 46.62 |
| 870 | 77 | 16.1 | 2.9 | 46.69 |
| 940 | 83 | 15 | 3.13 | 46.95 |
| 1008 | 89 | 13 | 3.58 | 46.54 |
| 1086 | 96 | 11 | 3.83 | 42.13 |
| 1122 | 99 | 9.94 | 3.94 | 39.1639 |

Table 2: Results obtained when converter is connected between solar panel and load

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*C. Performance of the system with & without MPPT*

Here in this section, the following results are obtained and compared with and without the MPPT connected to the system.

TABLE 3

| Light Intensity in LUX | Results without MPPT | | | Results with MPPT | | |
|---|---|---|---|---|---|---|
| | Panel voltage (Vp) in V | Equivalent panel current (Vcu) in V | Power (Vp *Vcu) | Panel voltage (Vp) in V | Equivalent panel current (Vcu) in V | Power (Vp *Vcu) |
| 55 | 2.05 | 0.8 | 1.64 | 9.42 | 0.642 | 6.04764 |
| 210 | 2 | 0.94 | 1.88 | 10.3 | 0.700 | 7.21 |
| 360 | 8.5 | 3.48 | 29.58 | 23.2 | 1.6 | 37.12 |

From the above results it is clearly seen that the system performance has been increased effectively. The load in this case considered was 65 watt. It is observed from the table that the power obtained with the MPPT is more than that it is without the MPPT. The readings are taken for different light intensities. As in the above table at 55 lux light intensity without MPPT at load end power was 1.64 but the introduction of MPPT in the system power increased to 6.04764. Similar results are also obtained with higher light intensities such as for 210 and 360 lux. Thus we can say system efficiency has been increased with MPPT.

*D. Performance of the Buck Converter*

The performance of the buck converter is also tested. For this a constant load is connected in the output. Duty cycle is varied for fixed input voltage of 20 volt.

TABLE 4

| Duty Cycle | Input (in V) | Output Voltage (in V) (Practical) | Output Voltage (in V) (Theoretical) |
|---|---|---|---|
| 90% | 20 | 16.4 | 18 |
| 75% | 20 | 15.3 | 15 |
| 50% | 20 | 13.85 | 10 |
| 25% | 20 | 8.98 | 5 |
| 10% | 20 | 1.69 | 2 |

Table 4: Input and Output voltages for Buck Converter for different Duty Cycle

Duty cycle is varied from 10% to 90%. For different duty cycle the output voltages in the practical circuit is recorded. The actual theoretical value of the output at the load is calculated from the buck converter principle. These two output voltages values are shown in above table. The practical obtained values of the voltages deviates from the theoretical values. This is also shown in graphical form in the following plot.

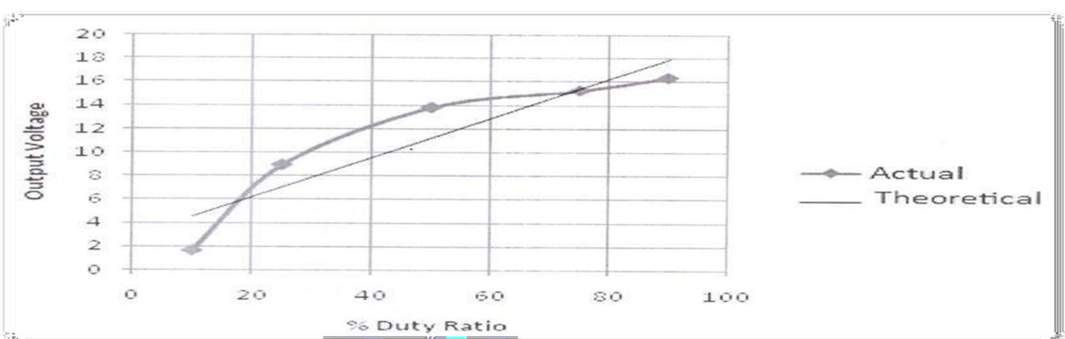


Fig 19 Variation of voltages for different duty cycle

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## XIII. CONCLUSION

In our experiment the MPPT system was first simulated in MATLAB and SIMULINK. Then the hardware setup has been developed. The converter was considered is buck type and load is resistive load of 65 ohm. As the hardware setup developed is for experimental purpose, the overall performance of the system is not too much satisfactory as expected but it is proved that the introduction of MPPT has increased the performance of the conventional system. From experimental results we observed that the power delivered to the load with MPPT is higher than to that the load without MPPT. In the result table in 55 lux light intensity without MPPT the power at the load is 1.64 watt. When MPPT is connected to the system the power at the load found to be increased to 6.04764 watt. The experiment is also done for higher light intensity such as 210 and 360 lux. We found the similar results at previous light intensity of 55 lux. The goal of the project was to increase the efficiency of the system. Hence we say that the efficiency of the system has been increased with the introduction of MPPT. In the experiment we are using 1 ADC and MUX instead of 2 ADCs. For this we are getting 5 KHz sampling rate. If 2 ADCs are used then sampling rate can be increased. The PWM frequency we consider is 1 KHz depending upon the design value of inductor and capacitor and availability of them in the market. A high transient is found in voltage and current waveform of the Solar Panel during the turn on time of the gate pulse of the MOSFET. Due to this some measurement error occurs. The experiment has been performed in the laboratory. Incandescent lights are used as the source of energy in solar panels. Change of irradiance on the solar panel is realized by a regulator. The performance of the system would be better understood if the experiment is done at actual sunlight.

## XIV. FUTURE SCOPE

*A.* A battery can be connected at the place of load with implementation of a battery charging algorithm in the microcontroller.
*B.* This is a stand-alone system. It can be connected to the grid through inverter.
*C.* Mechanical sun tracking can be incorporated with the MPPT system to make the system more efficient.
*D.* Other algorithm can also be implemented and their comparative study can be done.
*E.* A low-cost efficient embedded MPPT system can be developed and that may be used in conjunction with the conventional household solar applications in the rural areas.

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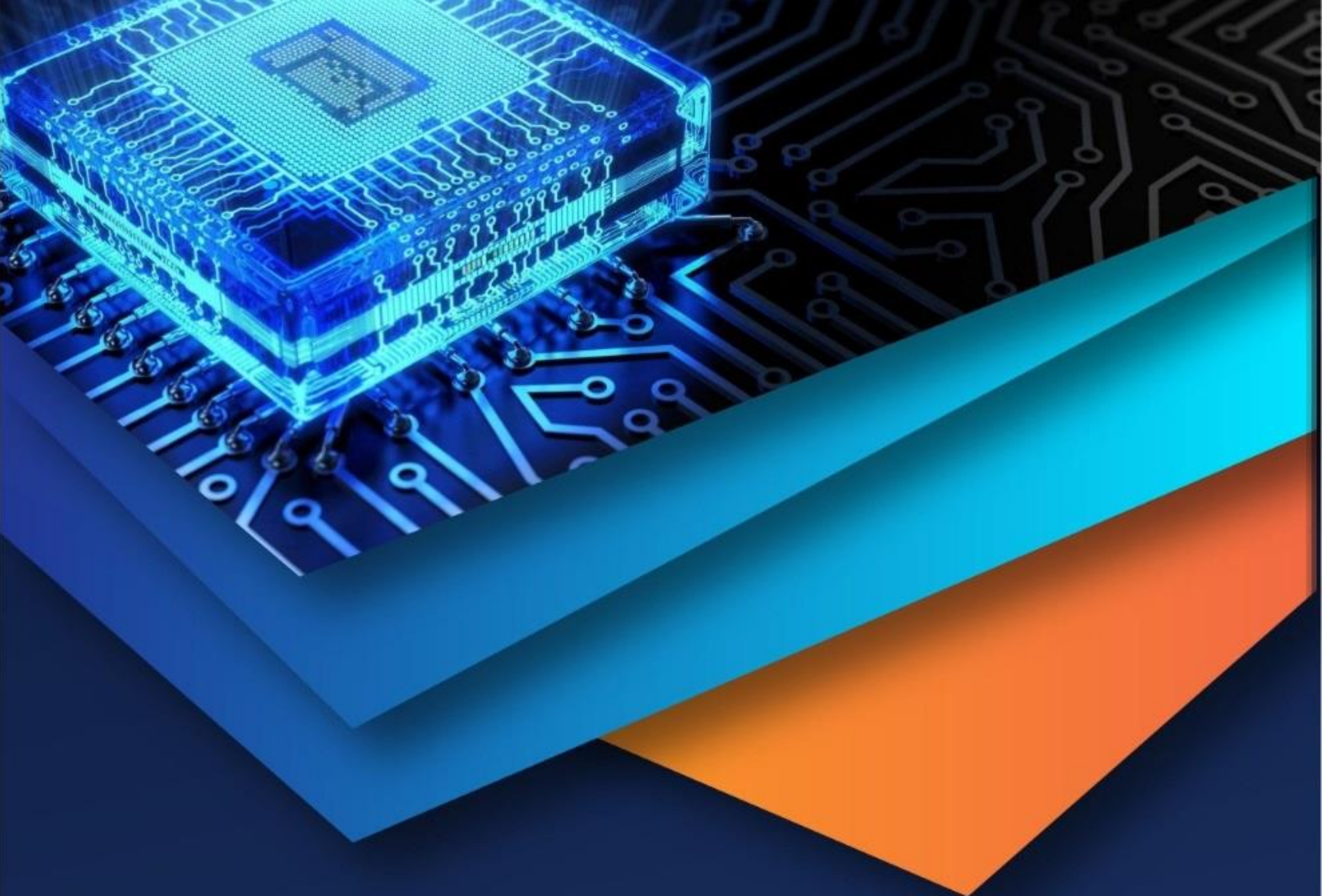


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