A Solar MPPT Technique for Battery Charging Applications

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Abstract: **In this paper it is shown that for charging batteries from solar panels, MPPT can be achieved by varying the duty ratio of the DC-DC converter feeding the battery so thatthe average battery charging current is maximized. Assuming negligible losses in the converter, this is equivalent to maximizing the power output of the solar panel as in traditional MPPT. A low power(10 W) prototype has been built with a buck-boost converter to charge a lead acid battery (12 V, 7AH), with an Arduino microcontroller to control the duty ratio. The method can be scaled up easily to control even Kilo Watts of power.**

***Index Terms*—Batteries, Converters, Duty ratio, MPPT, Solar Panels.**

I. INTRODUCTION

There is an ever-growing interest in the area of renewable energy. There is an effort to develop energy sources which are clean, efficient and low cost [1]. Solar energy has long been a key area of research and there is further acceleration of research in this area. Methods of storage of energy are alsoimportant and hence batteries are required to store solar energy produced during periods of strong sunlight [1][2]. Lead Acid batteries are still in vogue, though Lithium ion batteries are also being tried out, cost being the determining factor. Fig. 1 shows that renewable energy sources constitute only about 2% of the world's energy production.

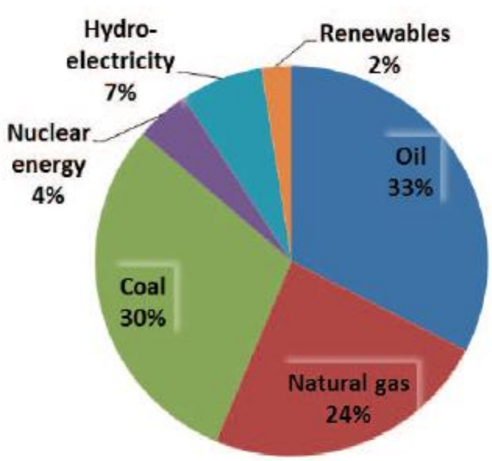

Fig.1: World Distribution of energy production in 2014 [1]

Modern solar cells are simply silicon PN junctions with some additional layers, which develop a potential drop when subjected to irradiation in the form of light [2]. The physics behind this is the photoelectric theory developed by Einstein. These cells maybe connected in series to increase the output voltage and in parallel to increase the output current capacity.

Solar panels are normally specified by the maximum power output, the open circuit voltage and short circuit current. Only 10% of the incident power is converted to electrical energy, though some costly cells can go upto 25% and are used in space applications to conserve weight [3],[4].

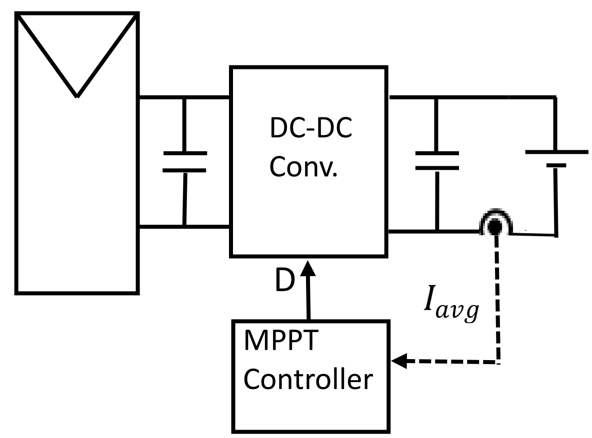

Fig.2: The MPPT method for battery charging

Fig. 2 shows the method adopted in this paper to charge batteries by sensing the battery charging current.

The average power given to the batteries equals the average charging current times the battery voltage which is fairly constant. Thus in order to maximize the power output of the solar panel using MPPT, it is enough to maximize the average charging current of the battery.

Solar panels are non-linear sources of power. Fig. 3 shows the output current and voltage (I-V curve) for a particular intensity of light falling on the solar panel. The power output at a point Pm is the product $P_o=V_m*I_m$.MPPT is about finding the point at which the power output is maximum. This normally occurs on the knee of the curve. Figure 4 shows how the I-V curves vary with the intensity of light falling on the panel and also on the temperature of the cells [4].

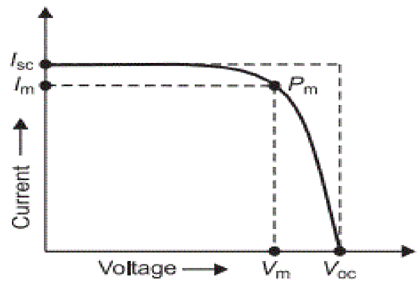

Fig.3: I-V Curve

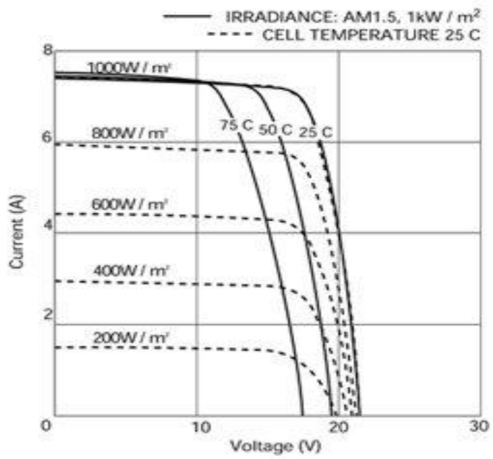

Fig.4: Variation in I-V curves.

The operating point of the solar cell depends on the load applied and the I-V curve of the solar panel, therefore a DC-DC converter is required to control the load seen by the solar panel and thus keep the panel at its maximum power point. There are a large number of MPPT techniques or algorithms. The perturb and observe or P&O method and incremental conductance method are two well known methods [4],[5].

From the I-V curves of the solar panel, a P-V characteristic curve can be constructed. One typical curve is shown below for a particular irradiation level. The MPPT method keeps the operation at the peak of this curve, and follows it if there are variations due to changes in insolation and temperature [6].

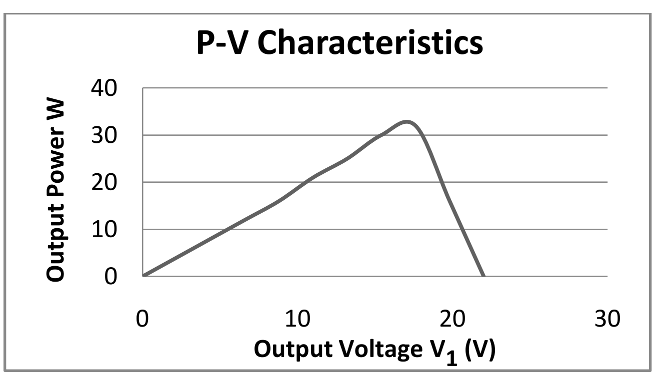

Fig. 5:Typical P-V curve for a solar panel

The algorithm for MPPT by the perturb and observe method is shown in Fig. 6. It is also called a hill climbing technique. To the left of the peak in the P-V curve, the operating voltage is increased and to the right side, the voltage is decreased. This results in the operating point to oscillate about the peak power point [7]-[10].

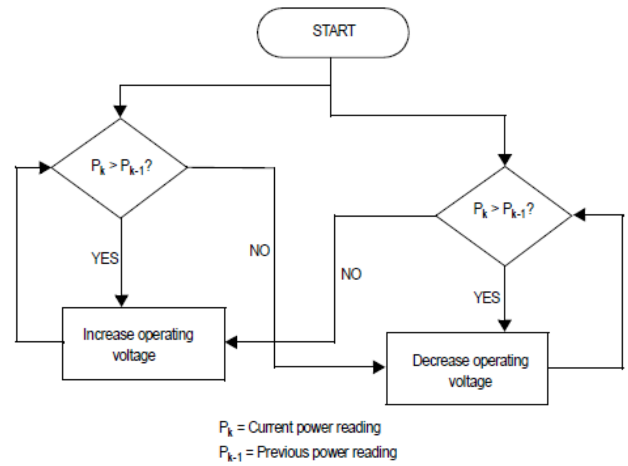

Fig. 6: P&O algorithm

II. CONTROL STRATEGY

A buck-boost converter was chosen as the DC/DC converter. A capacitor is placed at the terminals of the solar cell to smoothen the current output of the solar cell and act as a source of ripple currents. The reverse polarity of the battery is to be noted, which is a hall mark of the buck-boost topology.

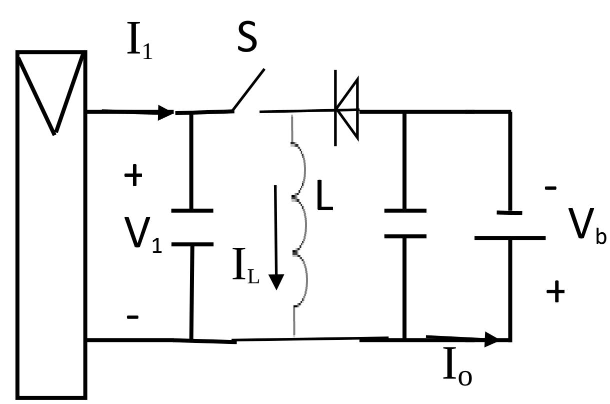

Fig.7:Solar Panel and battery with Buck-Boost Converter

A buck-boost converter is placed after the solar panel and it supplies a lead acid battery. The voltage V_1 at the output of the solar panel is input to the buck-boost converter which feeds the battery at V_b volts. For a buck-boost converter working in continuous conduction mode, the relation between V_1 and V_b depends on the duty ratio D and is as below:

$V_b = \frac{D}{(1-D)} * V_1$ (1)

V_b is the battery voltage, which is equal to the output voltage of the buck-boost converter. Vb is 12 V when the battery is charged properly, but may vary from 10 to 14 V depending on the charging level. From equation 1, the duty ratio required for a particular V_1 is given below:

$$D = \frac{1}{1+\frac{V_1}{V_b}} (2)$$

The power output of the buck-boost converter is P_o where $P_o = V_b * I_o$, where Io is the average charging current of the battery.

Based on equation 2 and the P-V characteristics, the I_o versus duty ratio can be worked out and is typically as below:

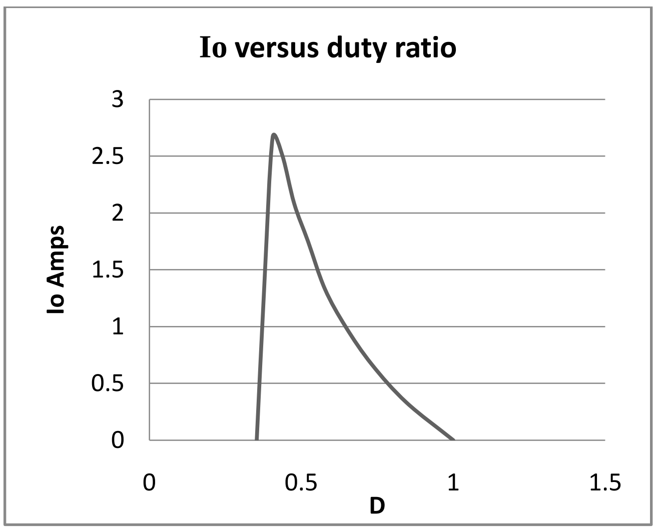

Fig.8: Io versus duty ratio

The duty ratio of the buck-boost converter can be controlled in a manner similar to the perturb and observe method, the duty ratio may be started at 0.5, and iterated towards the maximum "I_o" point. This involves measuring only the battery charging current.

III. SIMULATION STUDY

The simulation of the solar panel with the buck-boost converter and the battery is done using simulink. The solar panel is represented by a look-up table (LUT) with the i-v characteristics for a given irradiation level. A switching function U is generated which is "1" when the switch S is closed and "0", when the switch S is open. The duty ratio being "D". An integrator with reset is used to find the inductor current in the buck-boost converter. The integrator is reset to zero if the inductor current falls to zero and tends to go negative, which happens when discontinuous mode (DCM) sets in. A low pass filter (LPF) is used to find the average input and output currents.

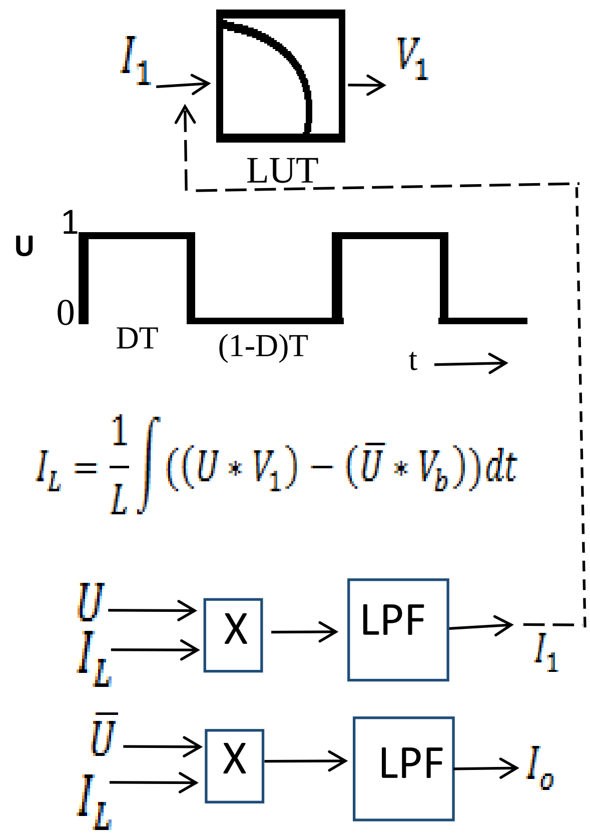

Fig. 9: Simulation method using Simulink models.

A study was conducted, with a switching frequency of 1 kHz, and with a inductor of 10 mH. The battery voltage $V_b$was taken as 12 V as in a lead acid battery. The duty ratio was varied from 0 to 98 % and the corresponding average battery current observed. The results were plotted to get a graph (Fig. 10).The graph is similar to the one in Fig. 8 obtained in a different way.

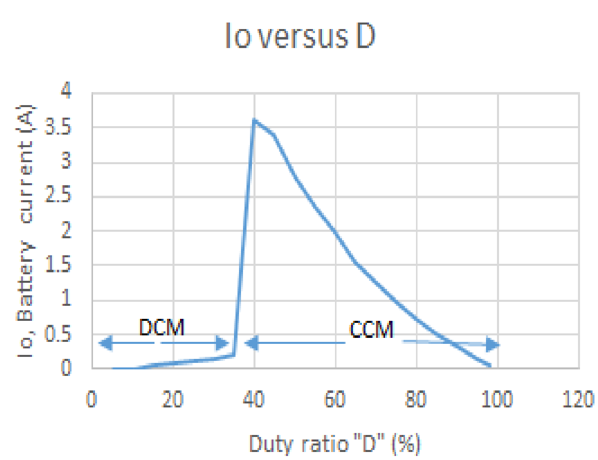

Fig. 10: Average battery current versus duty ratio of switch

IV: HARDWARE IMPLEMENTATION

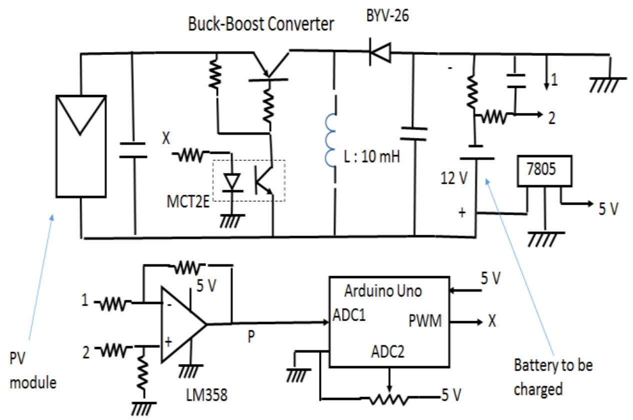

Fig.11: Complete Buck-Boost converter for battery charging

A PNP transistor (TIP 125) is used as the main switch as it can be controlled easily by the Arduino Uno board using anopto-coupler. A 0.25 Ω resistor is used as a current shunt. A RC filter is used to find the average value of the battery current. An opamp differential amplifier is used to boost the current shunt and filter output to a voltage level that can be read by the ADC in the Arduino board.

A switching frequency of 1 kHz was used, the inductor being a EE-25 Ferrite cored inductor of 10 mH.

A Perturb and Observe (P&O) algorithm is used to control the duty ratio of the switch in such a way that the average battery current is maximum. Instead of the power signal, the average battery current by itself may be used in the algorithm.

With a 10 W solar panel with open circuit voltage of 21 V, the Arduino was programmed to deliver maximum average battery current using a P&O algorithm. The prototype could deliver 800 mA of charging current under maximum sunlight conditions.

V. RESULTS

The panel was tested under varying sunlight and weather conditions. The P&O algorithm tracks the maximum power point and maintains the average current at the peak point.

Sl, No.	Time	Sunlight	Battery Voltage	Charging current (Avg)
1	9.00 am	Moderate	12.5	400mA
2	10.00 am	Good	13.0	650 mA
3	12.00 am	Strong	13.5	800mA

VI. CONCLUSION

In battery charging applications,the voltage across the terminals is a stiff quantity.A solar panel can be used to charge the battery while maintaining MPPT using a converter to deliver maximum average charging current by varying the duty ratio alone. It is easy to scale up the hardware requirements with this method, which can be done using converters of higher capacity with an inexpensive microcontroller for control.

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