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323. Enhanced Solar PV MPPT System for 12V Battery Charger

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Abstract

When a Photovoltaic (PV) panel is exposed to sunlight an I-V characteristic curve of that panel is observed. The I-V characteristics of the PV panel continuously changes with the change in irradiance and temperature of the surroundings which also changes maximum power point MPP of the PV panels. This affects the charging process of the batteries connected with the PV panels. This paper presents an efficiently designed Solar PV system for charging the batteries. The system uses Perturb & Observe (P&O) algorithm to track the MPP. The MPP tracking algorithm works in conjunction with a DC-DC Buck (step-down) converter. The power from the PV panels is fed into a charge controller, which equals the PV voltages to the battery voltages with maximum power being delivered from PV panels to the batteries. A dsPIC microcontroller is used which continuously tracks the MPP even with the changing conditions and handles the charging battery voltages. A MATLAB based modelling and simulation is also designed and is first used to test the algorithm along with the charge controller under the changing conditions and then it is implemented on the hardware. The simulation results shows that the algorithm tracks the MPP point of the PV panels, including the hardware results which verifies the efficient working of the proposed design.

Keywords: *Maximum Power Point Tracking (MPPT); Perturb and Observe (P&O); MATLAB; DC-DC Converter.*

1. Introduction

With the increasing crisis in the availability of energy and its resources; like fossil fuels, solar energy has become one of the most demanding resources for the production of electrical energy. Solar panels need to be operated at maximum power point (MPP) in order to extract maximum power out of it. This is done with the help of a power dc-dc converter allowing the panels to thoroughly operate at maximum power point. PV Panels when being operated at the maximum power point gives the highest efficiency. There are numerous algorithms for MPP tracking, the one used here is hill-climbing algorithm commonly known as Perturb and Observe (P&O), which is one of the most extensively used algorithm due to its simplicity and ease of implementation [1] [2]. It operates by perturbing the operating voltages of the PV array. The P&O works well under slight variations in irradiance [3].

The solar panel used is JC120S-12/Zb and the characteristics are enlisted below:

Table 1. Parameters of JC120S-12/Zb Module under STC

Maximum Power at STC	P_{max}	120 Wp
Open Circuit Voltage	V_{oc}	19.8 V
Optimum Operating voltage	V_{mp}	16.0 V
Short circuit current	I_{sc}	8.03 A
Optimum operating current	I_{mp}	7.50 A

For a battery with lower voltages the power rate of charging losses increases when directly connected to the solar panels, which is catered by this MPPT charger. These losses occur because of the current-voltage (I-V) characteristics curve of the solar panels. Every PV module has its own I-V curve which gives information about the characteristics of the module. The proposed power converter for this project is a step-down DC-DC converter known as Buck Converter, which steps down the input DC voltages. This paper focuses throughout on efficient battery charging through solar panels with minimal losses.

2. MPPT Battery Charging System Model

PV panels provides dc output voltages with a certain I-V curve characteristics, each panels has its own curve characteristics depending upon the design. This dc voltage is not stable enough to directly charge the batteries therefore they need to be converted up to a voltage level to stably charge the batteries. This is done with the help of a dc-dc converter which is a buck converter in this case. A MPP tracking algorithm is implemented using a dsPIC microcontroller. This controller keeps tracking the MPP and operates the panels at this point. A simple block diagram of this model is shown in Fig 1.

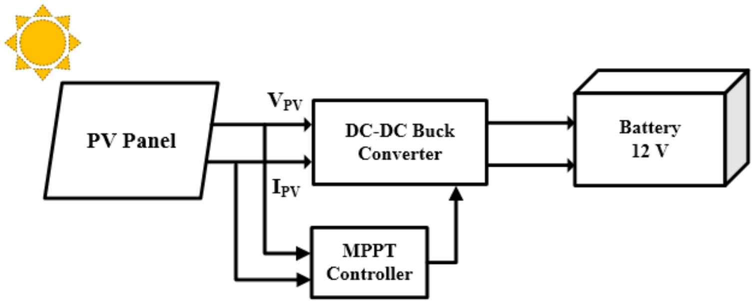

Fig. 1. MPPT Battery Charging system model

3. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking as the name suggests is an algorithm used for the tracking of maximum power of the solar panels being used. MPP can easily be understood referring to a non-MPPT based system; in which if we talk about a non-MPPT based battery charger means that the solar panels are directly connected to the battery terminals without any kind of circuitry in between them. In this case the panels operate only on the battery voltages thereby not delivering their maximum power.

Contrary to it a MPPT charger ensures solar panel to function on voltages at which it is able to supply maximum power to the batteries for charging. A solar panels comes with the specs including Voc and Isc and each panels have different I-V Curve under constant irradiance as discussed. The real-time I-V curve of two *JC120S-12/Zb* solar panels in series is shown in Fig. 2.

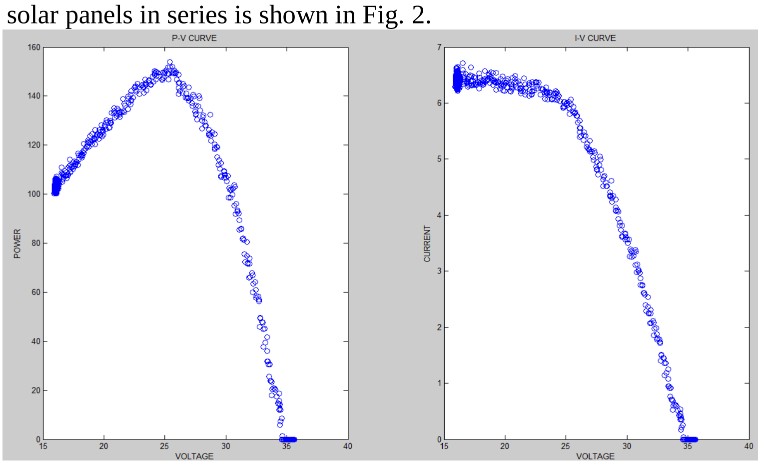

Fig. 2. Real-Time P-V & I-V curve of 2 series connected solar panels

The I-V curve in Fig. 2 is a real time graph plotted on MATLAB. The V_{oc} and I_{sc} are 35 volts and 6.5 Amperes respectively. The maximum power point MPP lies on the knee of this curve which is around the point where I_{pv}=5.8A & V_{pv} = 25V. The basic objective of MPP algorithm is to track this knee. The maximum power can be seen from the PV curve which is at 145 Watt.

3.1 Maximum Power Point Tracking (MPPT)

A number of researches have took place in this field for efficiently tracking the MPP of a panel. There are a number of ways to track the MPP, out which few are listed below:

i- Perturb and Observe
ii- Incremental Conductance
iii- Current Sweep
iv- Constant Voltage

The method used here is Perturb and Observe MPPT algorithm.

4. Perturb & Observe (P&O)

Perturb and Observe, an MPPT algorithm commonly known as P&O algorithm; in this method the voltages in small amount from the PV panel are set by the controller, the controller calculates the power and if there is an increase in power the controller makes further adjustments in that direction until the power no longer changes [4].

The P&O algorithm measures the voltage, current and calculates the power of the PV panels and then perturbs the voltage to estimate the changing direction. Fig. 3 shows a PV curve of a PV panel.

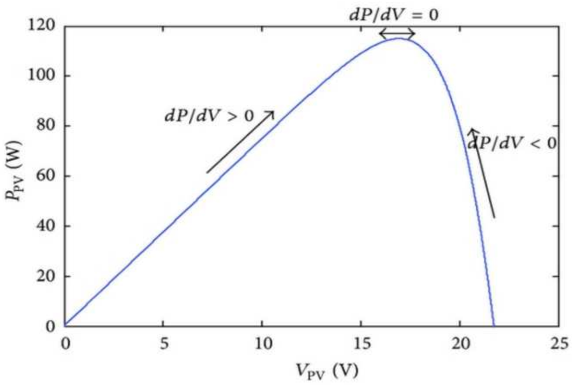

Fig. 3. P-V Curve of a Solar Panel

It can be witnessed from the left side the PV panel power increases with the increase in panel voltages and after the maximum power point (MPP) at the right hand side the power starts decreasing. This concludes that if he power is increasing in a certain direction the perturbation must also be performed in the same direction either from left to right or right to left. Contrary to it if there is a decrement in power reverse perturbation must be performed [5].
The MPP is achieved when the ratio of change in power and change in voltage is equal to zero i.e. dP/dV =0. The functional operation of P&O algorithm can be summarized with the help of the table below:

Table 2. P&O Operation Table

ΔP_{PV}	ΔV_{PV}	Perturbation
>0	>0	Increase V
>0	<0	Decrease V
<0	>0	Decrease V
<0	<0	Increase V

Table 2 with reference to Fig. 3; when the change in power and voltage of the panels is greater than 0 the perturbation must be done so as to increase the panel voltages. If the change in power is greater than 0 and the change in voltage is less than 0, the perturbation must be done in a manner to decrease the voltage of the panels. A flow chart representing the flow of P&O algorithm is shown in Fig. 4.

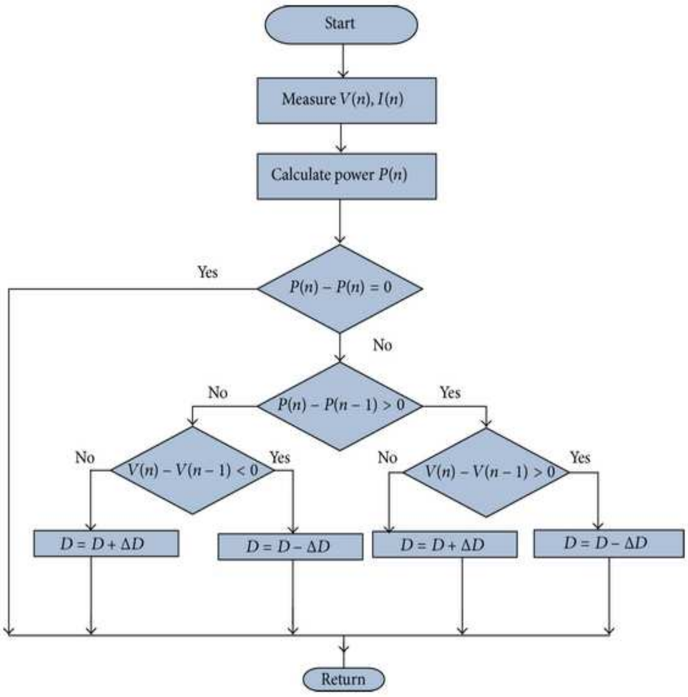

Fig. 4. P&O Algorithm Flow Chart

The solar panel voltage and current is initially measured and the power is then calculated. The change in power ΔP_{PV} and change in panel voltages ΔV_{PV} are then calculated after this the panel voltages are perturbed by a constant value. If this perturbation causes the power to increase the perturbation must be done in the same direction else if the case is opposite then reverse perturbation must be applied. This P&O algorithm is also known as hill climbing algorithm [6].

5. DC-DC Converter

It is a power electronic circuitry that converts DC voltages from one level to another. It can be either a step-up (boost) or a step-down (buck) converter and is a class of power converters. Depending upon the applications there are a wide range of DC-DC converters. There are a variety of DC-DC converters depending on the method of voltage level conversion two of them are:

- i- Linear DC-DC Converters
- ii- Switched mode DC-DC Converter

The dc-dc converter is the main circuitry responsible for the tracking of MPP [7] [8]. There are some drawbacks of linear DC-DC regulator in terms of power losses; like they can only output lower voltages than the input supplied to them. Considering the efficiency of the switched mode converters (75-98%) we will be using these for MPPT purpose to charge the battery.

The dc-dc converter used here for the MPP tracking is a Buck Converter.

5.1 DC-DC Buck Converter

A buck converter is a step-down DC to DC converter which reduces the voltages applied to its input by a certain factor. A general circuit diagram of buck converter is shown in Fig. 5.

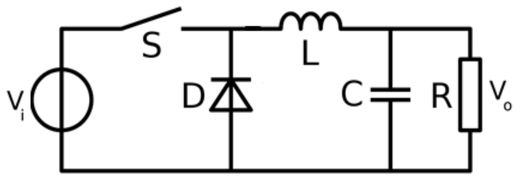

Fig. 5. Circuit Diagram of a Buck Converter

Where V_i is input voltage, V_o is the output voltage, S is an active switching device, D is a diode, L is an inductor and C is the capacitor.

5.2 Working Of Buck Converter

A switch mode converter; buck converter in this case contains a switch which is usually a mosfet an active device. When a switching device is introduced there exist a dual state of operation; namely ON state and OFF state. These states are named with reference to the switching device in the converter, a mosfet.
During the ON state, when the mosfet is on the circuit in Fig. 5 becomes as shown below:

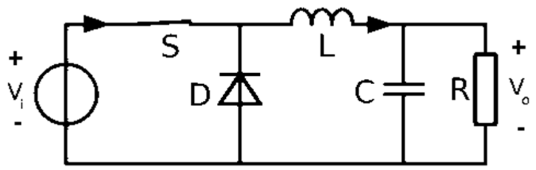

Fig. 6. Buck Converter in ON state.

In this state the switch S is on, the current from the input voltage source passes through the switch, the inductor and capacitor finally it flows through the load. Initially the current does not pass to the load directly when the switch is on because the inductor stores the charge in itself. And as the diode is in parallel with the Vi source therefore a positive voltage occurs on it reverse biasing the diode, hence it acts as if it is not present in the circuit.
During the OFF state the Buck converter looks as shown in Fig. 15.

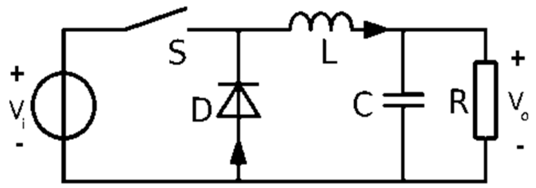

Fig. 7. Buck Converter in OFF state

In this state the switching device (mosfet) is switched off, now the energy stored in the inductor L comes into play this energy is released in the circuit. The voltages developed across the inductor known as electromagnetic force (emf) causes the current to flow in the circuit through the diode D and the load R. The diode in this case is forward biased. When all the energy stored in the inductor is supplied then the capacitor becomes the source for current. Now the current flows till the next ON state occurs.
The major portion here is the switching part for the converter, without which the converter is of no use to us. The switching is done through an external source through a controller or a function generator which supplies a square wave generated at 20 KHz or above. Below 20 KHz is an audible range and the inductor starts producing noise as it gets saturated [9].

5.3 Equation Analysis Of Buck Converter

The transfer function of the buck converter elaborates the functioning of the buck converter. In order to derive a T.F for this converter we will have to consider both the cases i.e. the ON state and the OFF state.
Referring to Fig. 6; the ON state, we can observe the inductor voltages are:

$$v_L(t) = Vi - v_C(t)$$
$$v_L(t) = Vi - v(t)$$
$$v(t) = V - v_{ripple}$$

Where;

$$|v_{ripple}| << V$$
$$v_L(t) = Vi - V$$

Now referring to Fig. 7; the OFF state, we can observe that the inductor voltages are:

$$v_L(t) = -v_C(t)$$
$$v_L(t) = -v(t)$$
$$v_L(t) = -V$$

The ON time is represented by [DT_s] and OFF time is represented by [$D'T_s$] where D is the duty cycle,

T_s is the switching time which is the inverse of switching frequency and D'+D = 1 which is the complete duty cycle. Using the area formula we get the equation below:

$$(Vi - V)\,DT_s + (-V)\,D'T_s = 0$$
$$Vi\,D - V\,D - V\,D' = 0$$
$$Vi\,D - V\,(D+D') = 0$$
$$Vi\,D - V = 0$$
$$Vi\,D = V$$
$$V = D \times Vi \qquad \textit{(Equation A)}$$

Equation *A* above is the final transfer function of an ideal buck converter.

6. Equation Analysis Of Buck Converter

The MATLAB model for 12V battery charger is shown in Fig. 8 is simulated at different values of irradiance at standard temperature conditions STC of 25ºC. The PV simulator simulates the PV characteristics which gives us the P-V curve of the panels. The MPPT controller when comes into play the PV curve shows the red dots on the P_{max} points which indicates that the P&O algorithm is being processed and it tracks the MPP. The P&O algorithm works in combination with the buck converter. The result of processed P&O algorithm is shown in Fig. 9.

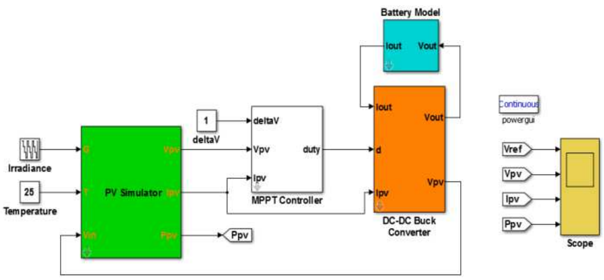

Fig. 8. MATLAB Model for MPPT Battery Charger

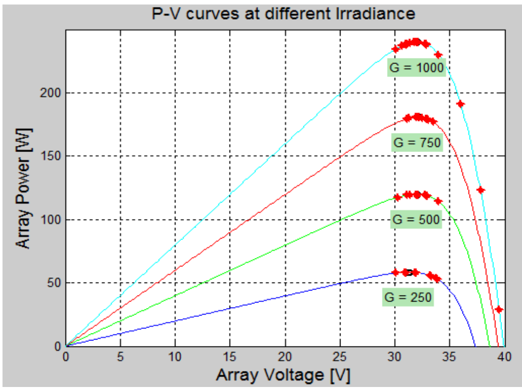

Fig. 9 Processing and output of P&O algorithm

The red dots in Fig. 9 shows that the hill top or in other words the maximum power has been tracked, and that too not only for a single irradiance but for all changes in irradiance.

7. Hardware Results And Discussions

The complete hardware setup designed for this project is shown in Fig. 10.

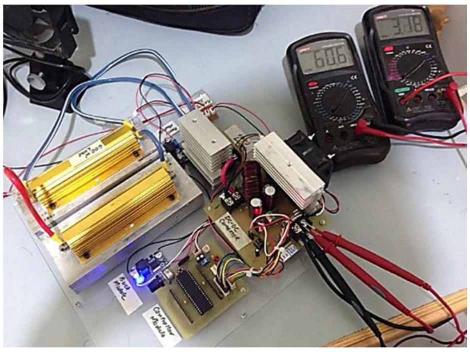

Fig. 10 Hardware setup for MPPT charger.

The real time result of P-V and I-V curve is shown in Fig. 2. The maximum power point MPP lies on the knee of this curve which is around the point where I_{pv}=5.8A & V_{pv} = 25V, the P-V curve also shows that the maximum power is 145 Watts, the MPP tracking algorithm is implemented in a dsPIC30F4013 microcontroller which is responsible for the tracking of MPP throughout the entire function of the designed battery charger. The MPP tracking graph for this system is shown in Fig. 11.

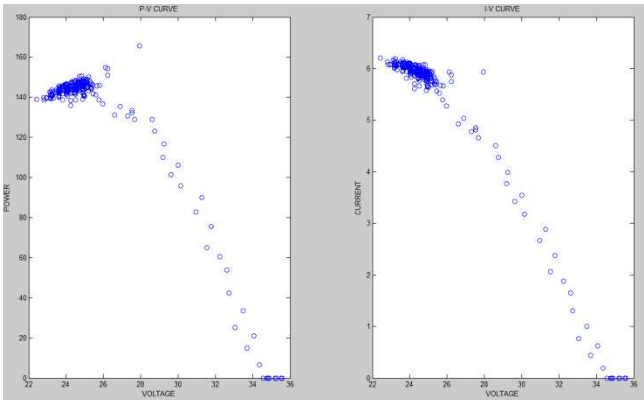

Fig. 11. Real-Time P-V & I-V Curve of MPP Tracking

The MPP algorithm tracks the MPP of the solar panel in real time which can be observed by the dense blue dots at the top left corner of the P-V & I-V curves of the hardware results plotted on MATLAB. The result is more evident in the left graph of Fig. 11 which shows the P-V curve of tracked MPP at 145 Watts.

8. Conclusion

In this paper, P&O algorithm is used for the application of battery charging with MPP tracking for efficient charging of batteries while maximum power is being delivered for the charging process, which increases the efficiency of the system reducing the losses which occurs in the case of direct connectivity of the batteries for charging purpose. The paper shows the results of MATLAB simulations and its implementation on actual hardware.

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