Modeling, Simulation and Control of Battery Charging Mechanism of PV Array System

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Abstract: **Modelling, simulation and control of battery charging mechanism of photovoltaic (PV) array system is presented. It proposes improvements in energy conversion efficiency using the design and application of a real time "maximum power point tracker (MPPT)" for "photovoltaic array". As photovoltaic system depicts non-linear (i-v) characteristic curve therefore, with variation in solar irradiance and temperature its maximum power point changes. Accordingly, Perturbation and Observation (P&O) MPPT algorithm using single-ended primary inductance converter (SEPIC) is employed to transfer maximum power from PV array. The maximum power point (MPP) can be traced by controlling a small perturbation in to the duty cycle of the control switch and by relating the maximum change in the voltage stress of the control switch and input voltage. The method used is based on a pulse-width modulated SEPIC in discontinuous mode of voltage and constant input current, two solar panels in series and batteries. The efficiency of the system for power transference is increased by using P &O algorithm as compared to the systems that do not have MPPT. This technique reduces the cost and the size of PV panels. Whereas, SEPIC gives an edge because of its capability to adapt any PV output voltage to any battery input voltage.**

Keywords: **"Photovoltaic (PV), maximum power point tracking (MPPT), single-ended primary inductor converter (SEPIC), perturbation & observation (P & O), pulse width modulation (PWM)".**

I. INTRODUCTION

Due to the rapid growth in population, the word energy requirements have been subjected to overwhelming strain. Solar energy has appeared as one of the desirable renewable energy sources from past several decades. Everyday sun radiates a huge amount of energy onto the surface of earth that if properly utilized can be sufficient enough to meet the demand of the whole world. Photovoltaic systems are widely used in many countries because it is reliable, safe, environmental friendly and maintenance free source of power with long term benefits. Regardless of weather and load conditions PV energy conversion system draws maximum solar array's power by continuously tuning the system. To obtain the unsurpassed consumption of PV arrays, maximum power point (MPP) tracker is normally retained in association with the power converter (SEPIC). Perturbation and Observation (P&O) is one of MPP tracking techniques that is most extensively used algorithm [1]. Furthermore, this algorithm is simple and can easily be implemented. Therefore, it is used here to give perturbation in operating voltage of the PV array. Moreover, if the irradiance varies slowly this algorithm gives satisfactory results. It is noteworthy that non-linear behaviour is exhibited by PV array hence output current/power is dependent on the maximum power and terminal voltages of the system that varies with temperature and solar irradiance.

This paper is intended to highlight two implemented ideas: the MPPT algorithm using SEPIC and battery charging mechanism. Therefore, the work presented here depicts the design and implementation of the prototype of a PV system with MPPT for improving energy accession. Maximum power transfer from PV panels is controlled by the "P &O MPPT algorithm". Therefore, it is applied using a microcontroller dsPIC30F4013. Moreover, by adjusting the duty cycle of the PWM the output of the controller is adjusted that drives the SEPIC switching device. It is to be noted that a different operating point is plotted by different duty cycle. With these calculations, the controller also sends the measured output current and voltage. These values are therefore used to track how much electrical energy is generated and spots if there is any failure or error in the system.

The modelling and design of the SEPIC is explained. SEPIC allows the voltage at its output to be more than, less than, or equal to that at its input. To any battery input voltage it easily adapts any PV output voltage. The load of the SEPIC used for this work consists of a two batteries in series. 8Ohms load is used for testing purpose. Finally, the modelled and hardware results of the designed SEPIC and P&O MPPT algorithm are shown with battery charging mechanism.

II. SOLAR PANEL CHARACTERSTICS

The solar panel is the only source of energy available to this system. The internal impedance of solar panel consists mainly of a diode. Since the internal impedance determines the ideal operating point and the diode is a non-linear circuit element. As can be seen from the figure, the p-v characteristic has a maximum at a certain voltage. This voltage is known as the Maximum Power Point.

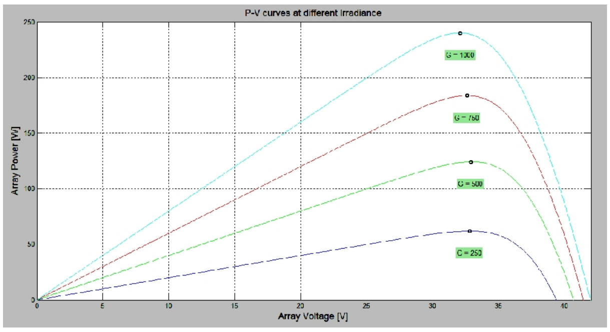

Fig 1 - P-V characteristics of a photovoltaic panel (different irradiances at fixed temperature 25 °C)

It can be observed at the knee of the P-V curve where the MPP of the panel is found; the maximum power is delivered where the internal impedance of the source matches with the load impedance. This is relates to the "maximum power transfer theory".

Therefore, to operate near the MPP it is required to match the internal impedance of solar panel with the impedance seen from the input side of the converter. This impedance can be attuned by control signal of PWM.

It can be concluded from fig. 1 that the most favourable point for the effective use of panel is at the knee of the curve which is its MPP and this point is dependent upon the values of irradiances. Moreover, the primary objective of the MPPT is to alter the output voltages of the panel to a certain value where the panel can supply maximum power to the load [2]. However, section 4 of this paper will discuss the MPPT algorithm.

III. SEPIC DESIGN

SEPIC is used to implement MPPT algorithm. A SEPIC is used here which has its own benefits among all of the DC- Dc Converters. A SEPIC provides an opportunity to get both of the BUCK and BOOST modes. If the system is not providing enough power it BOOSTs it till the requirement of the load is met and vice versa for BUCK. This operation can also be done with a BUCK-BOOST converter but it has more switching losses. Whereas in a SEPIC it has only one MOSFET and diode so it has less switching losses as compared to it.

This project considers SEPIC in continuous conduction mode for the implementation of MPPT.
With the switching frequency of 50 KHz the PWM of the MOSFET switch Q1 is controlled. Whereas, by regulating the duty cycle of the switch Q1 the power transferred is controlled. The schematic of the implemented DC/ DC converter is shown in Fig 2.

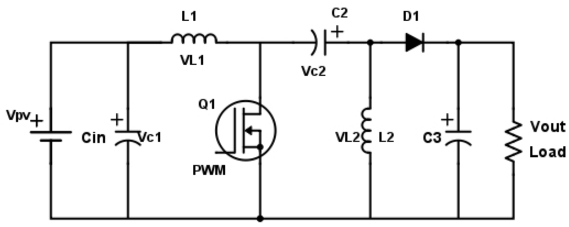

Fig 2 - SEPIC Design

The table below shows the parameters of the PV module.

Table 1 - Parameters of the JC1208-12/Zb PV module at 25 °C

Number of Cells in Series, Ns	2
Maximum Power (W), P_{max}	120
Maximum Voltage (V), V_{mp}	16
Maximum Current (A), I_{mp}	7.50
Open Circuit Voltage(V), V_{oc}	19.8
Short Circuit Current(A), I_{cc}	8.03

A. SEPIC Design Equations

Using volt-sec balance $\langle V_{L1}\rangle$, $\langle V_{L2}\rangle$

$$\frac{V_o}{V_{PV}} = \frac{D}{1-D} = \frac{D}{D'} \quad (1)$$

$$V_{C1} = V_{PV} \quad (2)$$

$$V_{C2} = \frac{D}{D'} \times V_{PV} \quad (3)$$

Using charge balance $\langle i_{C1}\rangle$, $\langle i_{C2}\rangle$

$$I_{L1} = \frac{V_{PV}}{RD'} \quad (4)$$

Using equation 1

$$I_{L1} = \frac{V_o D}{RD'} \quad (5)$$

$$I_{L2} = \frac{V_{PV} D}{RD'} \quad (6)$$

Using equation 1

$$I_{L2} = \frac{V_o}{R} \quad (7)$$

From equation 1

$$D = \frac{V_o}{V_{PV} + V_O} \quad (8)$$

B. Peak to Peak Ripple Calculation

$$\Delta i_1 = \frac{V_{PV} \times DTs}{L_1} \quad (9)$$

$$\Delta i_2 = \frac{V_{PV} \times DTs}{L_2} \quad (10)$$

$$\Delta V_1 = \frac{D^2 \times V_{PV} Ts}{D' RC_1} \quad (11)$$

$$\Delta V_2 = \frac{D^2 \times V_{PV} Ts}{D' RC_2} \quad (12)$$

Transistor peak inverse voltage

$$VC_1 + VC_2 + \frac{\Delta V_1}{2} + \frac{\Delta V_1}{2} \quad (13)$$

Transistor peak inverse current

$$iL_1 + iL_2 + \frac{\Delta i_1}{2} + \frac{\Delta i_1}{2} \quad (14)$$

Diode peak inverse current = Transistor peak current

$$I_{batt} = \frac{V_o}{R}$$

Two batteries are in series so, V_o = 24V

V_{PV}= 32V, f_s=50 KHz, T_s=20us

Using equation 7

D = 0.42;

$$I_{batt} = \frac{V_o}{R}$$

I_{batt} = 10A;

Using equation 5

I_{L1}= 7.421A; Δi_1 =1.48A;

I_{L2}= 10A; Δi_2 =2A;

Using equation 8

L_1=188.10uH;

Using equation 9

L_2=140uH;

Using equation 10 & 11

C_1=C_2=350uF (but used 220uF);

Using equation 12

Transistor peak inverse voltage = 55.41V;

Diode peak inverse voltage= 55.41V;

Using equation 13

Transistor peak inverse current = 19.161A;

Diode peak inverse current = 19.161A;

Table 2 illustrates the summary of the calculations used for component selection.

Table 2 - Component Selection

V_{PV}	32V	L_1	188uH
V_o	24V	L_2	140uH
D	0.42	C_1	220uF
I_{batt}	10A	C_2	220uF
D1(inverse current)	20A	Q1(inverse current)	20A
D1(inverse voltage)	56V	Q1(inverse voltage)	56V

IV. GATE DRIVER

Gate driver used for this scheme is IR 2104 that is IGBT and MOSFET drivers of high speed with dependent low and high side referenced output channels. Down to logic 3.3V its input is attuned with standard CMOS output. Hence, for minimum cross conduction of the driver it features current buffer stage with high pulse. However, its floating channel is used in high side configuration of the N-channel MOSFET which operates up to 600V.

V. MPPT CONTROLLER BASED ON P& O

As shown in Fig 3 SEPIC with current and voltage sensor resistance is used for implementing P & O MPPT algorithm because it only need current and PV voltage information.

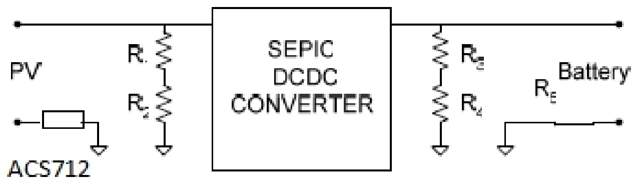

Fig 3 - Voltage and current sensor for MPPT

R1=R3=100k R2=R4=13k

For current sensing we used ACS712. In contemplation of MPPT controller to calculate the voltage delivered by the solar panel, R_1 and R_2 (resistors) are connected in parallel combination such as a voltage divider with the solar panel. An analog- to- digital converter (ADC) takes the voltage across R_2 as its input.The value selected for R_1 and R_2 are 100KΩ and 13KΩ respectively however, the maximum amount of current being delivered to the load. The current through voltage divider (I_2) is small enough, considered negligible even in the adverse scenario.

It is noteworthy that in MPPT controller the allowable range for each ADC is 0-5V dc. Therefore, the voltage across R2 that are voltages representing the scaled-down value of solar panel voltage must not surpass 5V dc. Hence, by selecting the value 13KΩ for R_2, the maximum voltages delivered to ADC is 5V dc.

For implementation of MPPT, P & O algorithm is mostly used. This algorithm requires some measured parameters and a feedback arrangement. Whereas, in this approach the panel voltage receives periodic perturbation whereas, current power is matched with the previous one [3].Hence this perturbation will cause the solar panel's power to vary. It is to be noted that if due to perturbation, the power increases then perturbations are given in the same direction. However, as the maximum power is achieved the perturbation is given in the reverse direction because the power tends to decrease depicted in fig 4.

After achieving a stable condition algorithm oscillates in between the maximum power point. Hence, in order to maintain power's variation the size of the perturbation is kept small. Under fast changing atmosphere due to temperature and irradiance some power losses are observed as perturbation fails to track the maximum power point. However, this technique is still very simple and popular [4]. Fig 4 illustrates the flow chart of MPPT algorithm.

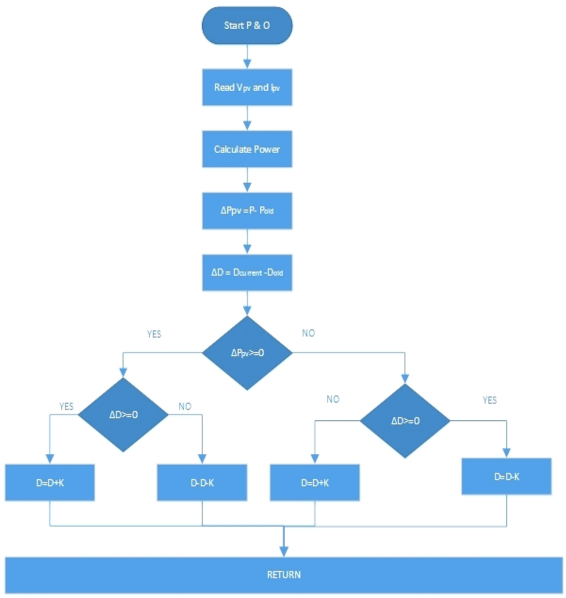

Fig 4 - MPPT Algorithm P &O

MPPT tracking at different irradiances is illustrated in fig 5. This result is obtained using MATLAB based simulation.

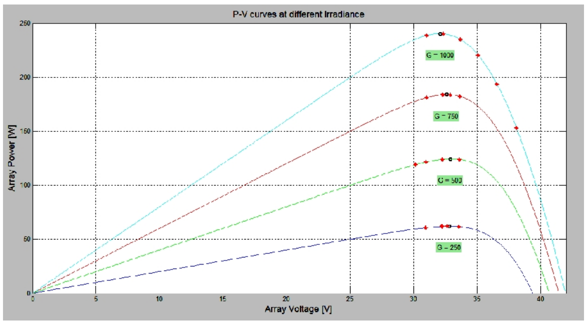

Fig 5 - MPPT tracking at different irradiances

VI. P&O MPPT EXPERIMENTAL RESULT

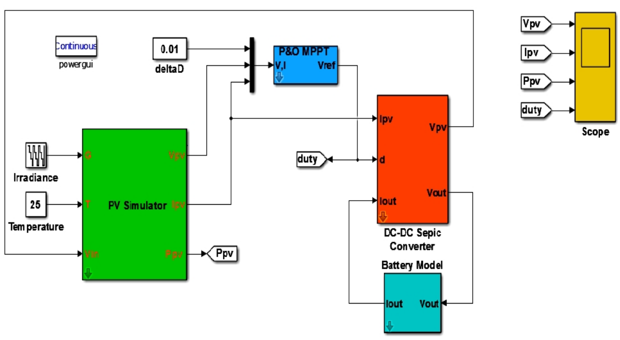

Fig 6 - MATLAB block diagram

In order to obtain real time MPPT and I-V curve o n GUI for solar panel characteristics is designed.

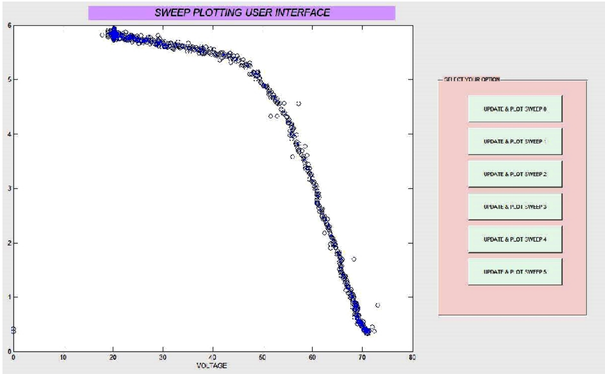

Fig 7 - I-V curve displayed on GUI

Current and voltage curve shown in fig 7 consist of couple of regions that are region of the voltage source and region of the current source. The internal impedance of the voltage panel is small whereas for the current panel is high. The voltage and current curve of the MPP panel is traced at the knee. According to the maximum power transfer theory, maximum power of source is delivering to load when impedance of source is match to load. Fig 8 shows that P & O algorithm successfully tracked MPP.

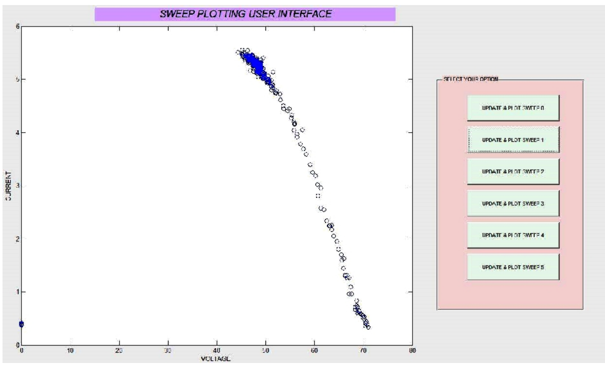

Fig 8 – MPPT displayed on GUI

In fig 9. MPP is tracked at different irradiances (1000, 750, 500 and 250 watt per meter square) and solar panel factors such as current, power and voltage are being observed. Whereas, the last graph shows the perturbations in duty cycle.

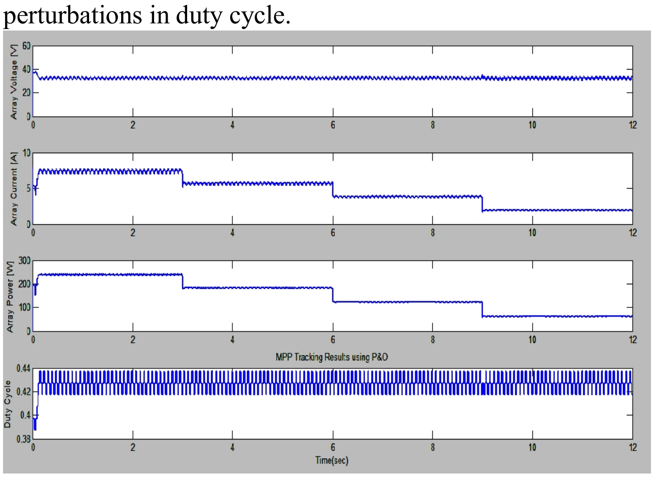

Fig 9 - Solar panel parameters at different irradiances

The experimental results of battery charging by means of P&O MPPT algorithm are:
V_o = 24V (2 batteries in series)
I_{mp} = 5.42A
V_{mp} = 49.44V
P_{mp} = 267.96

CONCLUSION

The work presented in this paper shows that 24V batteries are charged from the first test with P & O algorithm. However, the absorbed power is calculated as 267.96W. Hence, it is verified that PV panel is oscillating about MPP.

The algorithm used successfully implemented the MPPT function enabling according to the maximum power transferred produced by PV panel to the battery and solar irradiance. It is also concluded that this algorithm increases the efficiency of the transference of power in contrast to the systems which do no employ MPPT. It is noteworthy that the cost and size of the PV panel is also reduced. Whereas, use of SEPIC gives an edge since it is capable of adapting any PV output voltage to any battery input voltages as depicted in the experiment shown above.

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