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Implementation of Microcontroller Based Maximum Power Point Tracker (MPPT) Using SEPIC Converter

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***Abstract*—This paper presents analysis and design of a Maximum Power Point Tracker (MPPT) which is economical and compact in size.The DC to DC converter used in the system is SEPIC converter which eliminates the use of separate ground isolation circuit and reduces tracking time. The efficiency of this converter is better than traditionally used Buck-Boost converter. Here Incremental Conductance method is used to get a stable output in varying solar irradiance level. The proposed system also includes elimination of PI controller for duty cycle modification, elimination of complex circuit for sensing current and elimination of filters for accurate analog to digital conversion of voltage and currents. This system is tested and verified experimentally with 135Wp solar panel in varying insolation levels.**

***Index Terms*—Incremental Conductance (IC) method, DC to DC converter, microcontroller,Maximum Power Point Tracker (MPPT), Photovoltaic (PV) panel ,Pulse Width Modulation(PWM),Single Ended Primary Inductance Converter (SEPIC)**

I. Introduction

In modern days the main concern of civilization is the efficient consumption of available energy resources and reduction of unnecessary environment polluting wastes from electrical appliances which lead to global warming. The mainly used energy sources are coal, fuel-oil, gas etc. will deplete soon .That is why the concept of renewable energy is becoming popular now-a-days. Solar energy is one of the promising renewable energy sources that is non-polluting, reliable, and requires less maintenance compared to other renewable energy sources.

The main problem of solar energy is that the efficiency is very poor as it depends on both insulation condition and temperature [1].Solar cell has non-linear current-voltage characteristic in which only one point provides maximum power known as Maximum Power Point (MPP). For many years researches have been carried out to develop techniques and choosing the most suitable method for extracting maximum amount of power from a PV module [2].Open Circuit Voltage Algorithm, Short-Circuit Current based Algorithm [3], Perturb and Observe (P&O), Incremental Conductance(IC)[4], Fuzzy Logic Based[5],Curve fitting techniques[6], Neutral network based[3] are some well-known methods. Some of these traditional algorithms are modified to improve the tracking efficiency and speed namely Variable Incremental Conductance technique [7], dP-P&O method [4]. Ref [8] incorporates both Open circuit voltage technique (OCT) and slope detection technique (SDT) to improve efficiency and accuracy. As the techniques became more sophisticated, their hardware implementation became more complex and costlier. In commercial MPPTs P&O algorithm is mostly used one because of its simplicity. However it can produce oscillations around maximum power point in constant irradiance level [9]. IC method does not have such disadvantage. It can perform with better accuracy and without oscillations in varying weather conditions [10]. The proposed system simulates IC method in MATLAB Simulink with two types of DC to DC converters namely Cuk and SEPIC and according to simulation result the suitable converter is chosen for hardware implementation. Several researches are based on implementing MPPTs in Field Programmable Gate array (FPGA), some MPPTs are implemented using digital signal processor, or microcontroller [11]. This paper presents simple and cost effective hardware implementation using microcontroller.

II. Proposed Hardware Implementation

The proposed Maximum Power Point tracker mainly consists of PV panel, SEPIC converter, battery, load and a microcontroller. Method of selecting the different parts of it is discussed in this paper.

A. Choice of DC to DC Converter

The DC to DC converter serves like an interface between the load or battery and the photovoltaic module. The duty cycle of the converter is changed according to algorithm to match the load impedance seen by the PV panel so that the source can transfer maximum power.

The output voltage of the converter can be less than or greater than the input voltage depending on the converter topology. Most of the traditional MPPTs are based on Buck or Boost converters. Buck converter can only be used when PV input voltage is greater than the battery voltage whereas Boost converter is used when PV voltage is less than the battery voltage. For flexible operation Buck–Boost is preferred because if the battery requires lesser voltage from the panel Buck converter reduces the voltage while Boost converter increases the voltage if the battery needs more voltage from

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the panel [1]. But the problem with Buck-Boost converter is that input current ripple is much higher as input current is discontinuous [12]. It needs additional filter for reduction of harmonic component in the current [13]. Therefore Buck-Boost converter is not a good choice. Studies reveal that Cuk and SEPIC converter can be good alternative to Buck Boost converter. Ref [10] has proposed an elegant technique for MPPT using SEPIC and Cuk converter. Our proposed technique simplifies the circuit further by eliminating the error amplifier, peak detector and use of small signal perturbation.

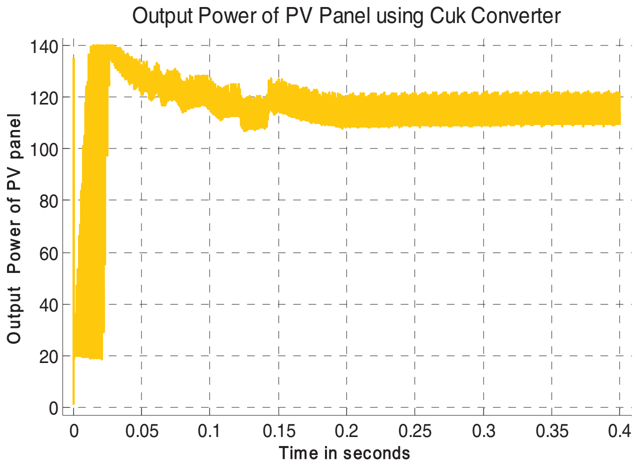

Fig. 1. Output power of the PV panel using Cuk Converter

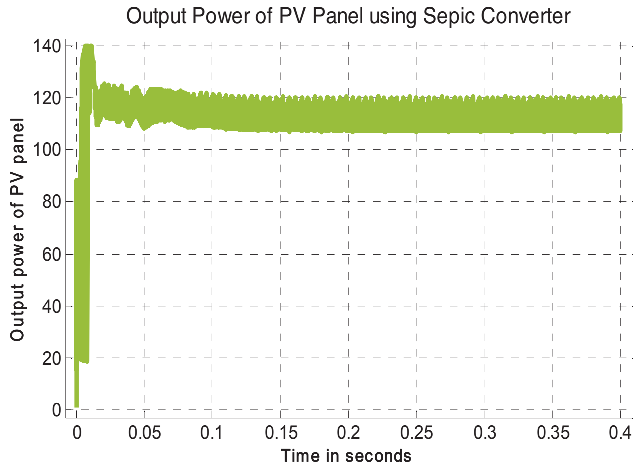

Fig. 2. Output power of the PV panel using SEPIC Converter

From Fig 1 and 2 we can see that the maximum power point tracker tracks the MPP faster when a SEPIC converter is used. It takes more than 0.2 seconds to reach MPP with Cuk converter, while it takes less than 0.1 seconds to reach MPP with SEPIC converter. For faster tracking the SEPIC converter is chosen.

Inherent nature of SEPIC converter is that it does not need filter to filter out high frequency harmonics. Another advantage of SEPIC converter in comparison to traditional Buck and Boost converter is that it does not need a separate ground isolation circuit. As a result the size of the MPPT circuit is reduced to some extent.For small solar energy system SEPIC converter is the best choice.

B. Design of SEPIC Converter

We have used 135Wp Solar panel with Voc=19.1 Volts and Isc=8.37 Amps. So the SEPIC converter must be compatible with the high ratings of current and voltage. The major parts of SEPIC converter design are discussed.

1) Power MOSFET/IGBT Selection: The switch of the SEPIC converter can either be Power MOSFET or IGBT. In selecting the MOSFET the power loss in this switch is the most important parameter to be considered. The conduction loss of the switch(Q1) depends on the on–state resistance RON.

$$P_{conduction\ loss} = I_D^2 \mathrm{RON} \tag{1}$$

The peak switch current depends on both the peak current of inductor L1 and L2 is given by

$$I_{Q1\,(peak)} = I_{L1(peak)} + I_{\,L2(peak)} \tag{2}$$

Considering all the ratings MOSFET IRF3205 is chosen which can withstand 55V, 98A and RON is .008Ω.

2) MOSFET Driver Selection: The microcontroller cannot supply enough current to charge the FET before it can turn on as the gate of the MOSFET is capacitive. Therefore a separate gate driver is required which will provide higher current to turn on the MOSFET. The proposed Maximum Power Point Tracker uses the non-inverting MOSFET driver IC TC4427 which has highest peak current of 1.5A and operating voltage range from 4.5V to 18V.

3) Inductor Selection: The DC to DC converter must operate in continuous current conduction (CCM) mode to reduce input current ripple. So there should be minimum value of inductor L1 and L2.For SEPIC converter the minimum value of L1 and L2 is given by

$$L1_{min} = \frac{(1 - D_{max})^2 R}{2 D_{max} f_{sw}} \tag{3}$$

$$L2_{min} = \frac{(1 - D_{\max})R}{2 f_{sw}} \tag{4}$$

Where R is found by Output Power and Output voltage. To have a moderate Electromagnetic interference and a stable PWM operation it is suggested to allow 40% ripple in inductor current i.e.

$$\Delta i_L = I_{in} \times 40\% \tag{5}$$

The inductors can be wound on same core to reduce cost and size .Where D_{max} is the maximum duty cycle for CCM mode and is given by

$$D_{max} = \frac{V_{OUT} + V_D}{V_{OUT} + V_D + V_{IN(min)}} \tag{6}$$

f_{sw} is the switching frequency which is chosen as 40kHz for faster operation and for keeping the losses due to frequency to a moderate value. The inductors are made using ferrite core wound with wire of 19AWG so that the wires can carry high current.

4) Capacitor Selection: The capacitors must be rated for high RMS current relative to output power.
Tantalum and ceramic capacitors are the best choice for this operation, having high RMS current ratings relative to size.

5) Output Diode Selection: The output diode must be selected to handle peak reverse voltage and highest peak current. It also has to be able to operate in fast switching frequency. The peak reverse voltage the diode must withstand is $V_{RD1} = Vin_{(\max)} + Vout_{(\max)}$

A Schottky Diode is chosen for this operation.

C. Measuring Current:

Measuring the current of solar panel has always been matter of concern. In most cases current is measured using current sensing resistor [9]. This method increases I^2R loss. The Current transducer ICs are also used in measuring the current [14]. Since microcontroller can only measure voltage these transducers need additional circuitry with Op-Amps [14] to convert the current to voltage which makes the current measuring part more complex. Other methods like estimating current from voltage ripple or inductor current sensing technology [15] are also not good choices for simple and cost effective implementation.

The proposed system measures current using Hall Effect current sensor, which is a very small IC and the I^2R losses are reduced to minimum value with reduced complexity and size of the whole circuit. This IC gives a analog voltage Vout within the range 0-5 Volts that varies linearly with the input current.

D. Microcontroller:

The microcontroller used in the proposed system is Atmega328P. It has 6 channel 10 bit ADC, six PWM channels, 512 bytes of EEPROM, 1Kbytes of SRAM.

As the microcontroller has the entire built -in ADC and Counters additional Analog to Digital converter is not required. This microcontroller has eliminated the use of PI controller for duty cycle modification. The duty cycle is modified in the code by comparing the current and voltage samples taken by ADC.

Since the microcontroller can perform arithmetical operations very quickly, a moving average system is introduced in the code so that the random noise in the voltage and current samples taken at any instances is reduced. As a result the use of external filters [14] to reduce the noise is eliminated.

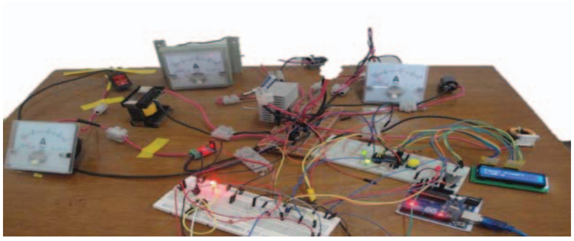

Fig. 3. Laboratory prototype of Maximum Power Point Tracker

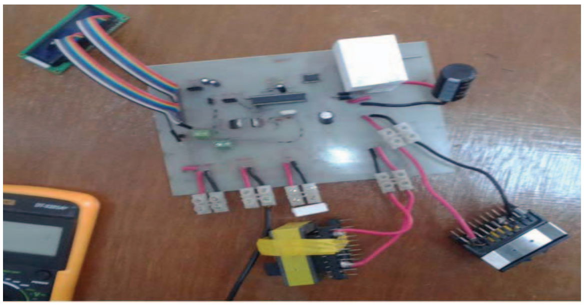

Fig. 4.Final compact and low cost PCB

III. EXPERIMENTAL RESULTS

The prototype of MPPT was tested for several days and data of voltage, current and power were taken for 11 days. The tabulated data are the voltage and current at maximum power point obtained from 11:00 am to 12:00pm noon. Data reveals that in a sunny day with high insolation maximum power obtained is 117.81 Watts while in a rainy day the maximum power is quite low, 15.31 Watts.

The voltage at MPP ranges from 12.9 to 14.1 which is quite close to 76% of Open circuit voltage. On a bright shiny day the proposed system is able to harness 8.14 Amps current which is quite high.

The advantage of MPPT with PV panel is examined on Day 6 with moderate sunshine. From Fig 7 we can see that the proposed MPPT system can provide much power than the system without MPP. The peaks in the curve are due to change in irradiance level. The power with MPP begins to increase according to IC method while the power without MPP is quite constant. It has changed only when solar irradiance level changed. The whole system has reduced the cost by eliminating filters, ground isolation circuitry, error amplifiers, and integrators. The whole prototype circuit cost was around 1500 BDT (21 USD) which is quite low compared to existing MPPT and suitable for use in third world countries.

TABLE I
VOLTAGE, CURRENT AND POWER DATA FROM PRPOPOSED MPPT

Day	**Voltage at MPP (Volts)**	**Current at MPP (Amps)**	**Maximum power (watts)**
Day 1	12.9	1.19	15.31
Day 2	13.1	2.17	28.44
Day 3	13.4	3.74	50.1
Day 4	13.9	5.64	78.36
Day 5	13.61	6.13	83.36
Day 6	13.67	6.10	83.32
Day 7	14.1	8.14	117.87
Day 8	13.5	3.1	41.52
Day 9	13.16	4.06	53.50
Day 10	13.2	1.07	14.10
Day 11	13.3	1.83	24.46

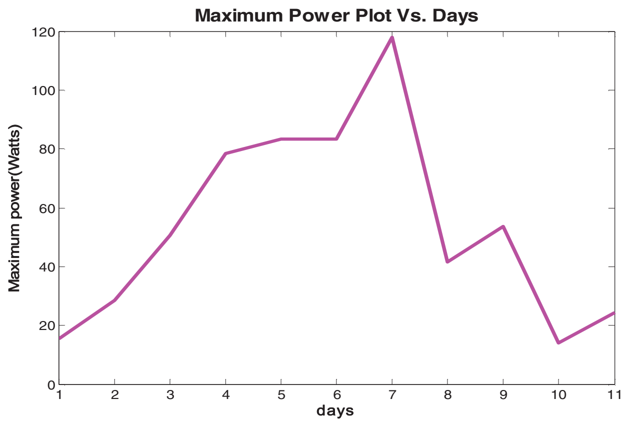

Fig. 5.Maximum Power Vs. Days Plot

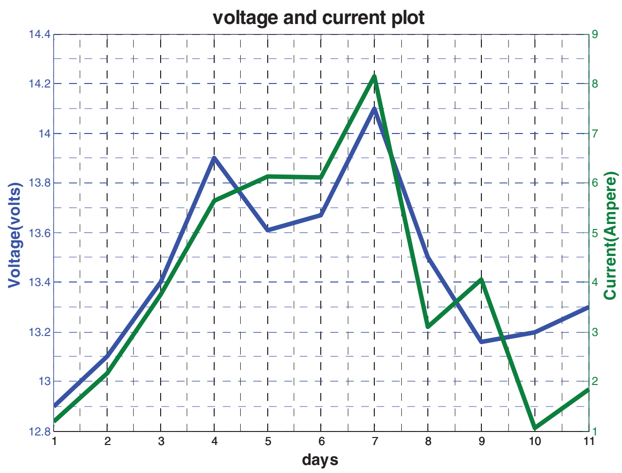

Fig. 6. Voltage and current Vs. Days Plot

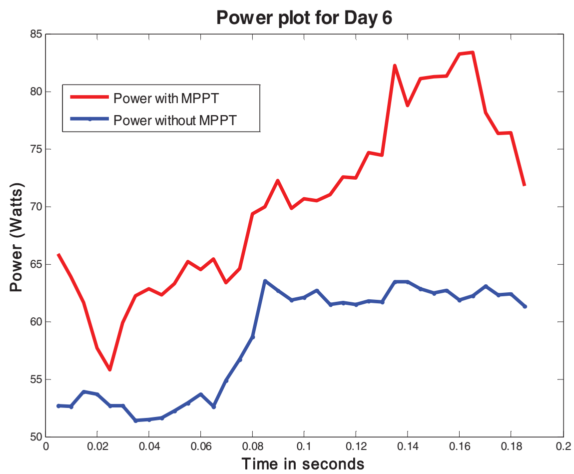

Fig. 7.Comparison between power with and without MPPT

IV. Conclusion

A simple, cost effective and efficient Maximum Power Point Tracker (MPPT) is designed and the final outcome is presented in this paper.For small system less than 1kW solar panel; the proposed design would be suitable. It eliminates some parts of conventional analog MPPT and thus reduces size and cost associated with it. Other advantages of using microcontroller is that the system can drive multiple converters as it has several PWM outputs and it can adapt to other algorithm too with the change of code.

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