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Maximum Power Point Tracking Controller for Solar Photovoltaic Systems

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***Abstract* — The solar or the Photovoltaic (PV) cell is a relatively costly and inefficient renewable source of energy. Maximum Power Point Tracking (MPPT) of the PV panel for every type of environmental and climatic conditions is a vital to increasing the efficiency of solar power extraction mechanism. MPPT is implemented as a DC-DC converter, usually a buck converter, used to match the impedance of the load to the panel by varying its duty cycle. This paper presents detailed analysis of the two most well-known MPPT algorithms, viz., the perturb-and-observe (P&O) and the incremental conductance (INC) , for photovoltaic system (PV). These algorithms are implemented using the ATMEGA328P 8-bit microcontroller in Arduino programming language. Pulse width modulated signals are generated by ATMEGA328P microcontroller. MATLAB and Scilab/Xcos simulation results and the hardware result of the buck converter have been compared.**

Index Terms — **Maximum Power Point Tracking, Perturb and observe, Photovoltaic.**

I. Nomenclature

I_{PV}	-- Photon current (A)
I_{sh}	-- Shunt current (A)
I_L	-- Output current (A)
V_O	-- Output voltage (V)
R_{sh}	-- Parallel resistance (Ω)
R_s	-- Series resistance (Ω)
V_s	-- Output voltage (V)
I_d	-- Current of parallel diode (A)

II. Introduction

Energy is being a vital element for the growth and sustenance of modern economy. Future economic growth crucially depends on the long term availability of energy from sources that are affordable, accessible and are environment friendly. This can be achieved by the proper use of renewable energy sources like solar energy, Wind energy, etc. solar energy is gaining more importance in the present era. The heat and light energy from the solar radiation can be very well utilized to generate electricity. The incident solar radiation is converted to electricity by the p-n junction. To yield a higher power solar panel is operated at its maximum power point (MPP). MPP corresponds to the point where the operating voltage and current of solar panel are higher. This maximum power point can be tracked using various tracking systems. Many algorithms are available to track the maximum power point. Some of these include Perturb and Observe, Incremental Conductance, Hill Climbing, etc. The power output from solar panel which is a DC voltage, is fed to a DC-DC converter. The most widely used DC-DC converter is Buck converter. A solar photovoltaic system contains solar panels, MPPT tracker, converters, inverters and load.

III. Literature Survey

Studies show that a solar panel converts 30-40% of energy incident on it to electrical energy. A Maximum Power Point Tracking algorithm is necessary to increase the efficiency of the solar panel. There are different techniques for MPPT such as Perturb and Observe, Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPP and several other economic reasons. Under abruptly changing weather conditions as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiance and sometimes ends up in calculating wrong MPP. However this problem gets avoided in Incremental Conductance method as the algorithm takes two samples of voltage and current to calculate MPP. However, instead of higher efficiency the complexity of the algorithm is very high compared to the previous one and hence the cost of implementation increases. So we have to mitigate with a tradeoff between complexity and efficiency. It is seen that the efficiency of the system also depends upon the converter. Typically it is maximum for a buck topology, then for buck-boost topology and minimum for a boost topology.

IV. Solar PV Panel

A. *PV Cell:*

PV cells are essentially a very large area p-n junction diode where such a diode is created by forming a junction between the n-type and p-type regions. As sunlight strikes a PV cell, the incident energy is converted directly into electrical energy. Transmitted light is absorbed within the semiconductor by using the energy to excite free electrons from a low energy status to an unoccupied higher energy level. Fig.1 shows the equivalent model of a solar PV cell. When a PV cell is illuminated, excess electron-hold pairs are generated by light throughout the material, hence the p-n junction is electrically shorted and current will flow.

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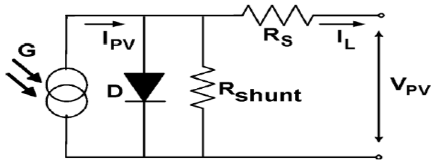

Fig. 1: equivalent model of solar cell

$$I_L = I_{PV} - I_d\left\{\exp\left[\frac{q(V_o+IR_s)}{AKT}\right] - 1\right\} - \frac{(V_o+IR_s)}{R_{sh}} \qquad (1)$$

Equation (1) gives the mathematical modeling of a solar PV cell.

B. PV Array:

Solar cells are connected in series and parallel to set up the solar array. Solar cell will produce dc voltage when it is exposed to sunlight. Fig. 1 shows the equivalent circuit model for a solar cell. Solar cell can be regarded as a non-linear current source. Its generated current depends on the characteristic of material, age of solar cell, irradiation and cell temperature**.**

V. MPPT ALGORITHMS

All MPPT methods follow the same Goal which is maximizing the PV array output power by tracking the maximum power on every operating condition. A DC/DC converter (Boost, Buck, Cuk) serves the purpose of transferring maximum power from the solar PV module to the load. According to Maximum Power Transfer theorem, it state that maximum power delivered from source to a load when the load resistance is equal to the source resistance. Thus, DC/DC converter is introduced between the solar PV module and the load. By changing the duty cycle (D), the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power. The MPPT algorithm varies the duty cycle of a DC/DC converter that ensures the output voltage of a PV panel follow a reference voltage at any solar irradiance, temperature and load conditions. There are many algorithms are present which are able to track Maximum Power Point (MPP).

These are: Perturb and observe (hill climbing method), Incremental Conductance method, Fractional short circuit current, Fractional open circuit voltage, Neural networks, Fuzzy logic.

The selection of the algorithm depends on the time complexity the algorithm takes to track the MPP, implementation cost and the ease of implementation.

VI. PERTURB AND OBSERVE METHOD

Perturb & Observe (P&O) is the simplest method. Fig.2 shows the flowchart of P&O algorithm. In this 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 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 on 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. However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method.

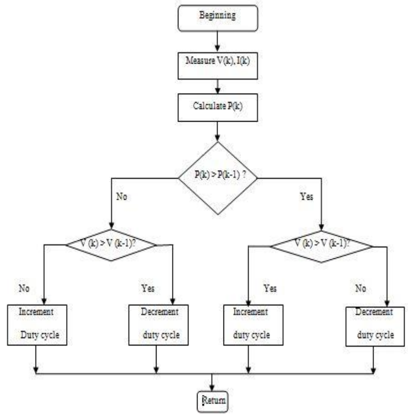

Fig. 2: Flowchart of P&O algorithm

VII. INCREMENTAL CONDUCTANCE METHOD

Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array. Fig.3 shows the flowchart of incremental conductance algorithm. At MPP the slope of the PV curve is 0.

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \qquad (2)$$

$$since\ \frac{dP}{dV} = 0 \qquad (3)$$

$$\frac{dI}{dV} = \frac{-I}{V} \qquad (4)$$

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then MPP is reached. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. However the complexity and the cost of implementation increase. As we go down the list of algorithms the complexity and the cost of implementation goes on increasing which may be suitable for a highly complicated system.

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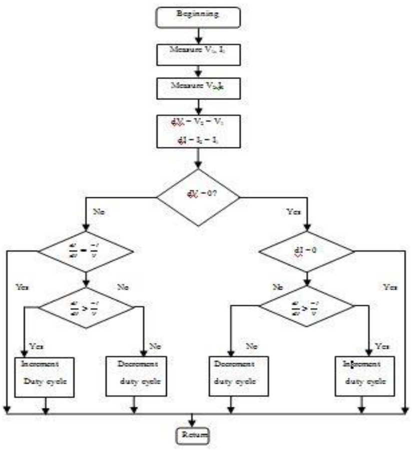


Fig. 3: Flowchart of Incremental Conductance algorithm

VIII. Buck Converter

The DC-DC converter converts the input DC voltage to another DC voltage. The converter used is a buck converter, as the voltage required for the LED's is lower than the output voltage of the solar panel. Fig.4 shows the schematic of Buck Converter. The three main components are the inductor, the MOSFET switching device and the diode. When the switch is closed, the current from the source charges the inductor. When the switch is open, the energy stored in the inductor charges the output capacitor. The duty cycle of a PWM signal determines the ratio between the input and output voltage. In case of an ideal switching device and when losses are neglected, the ratio between V_{in} and V_{out} can be calculated. In the below formula, D represents the duty cycle of the PWM signal and has a value between 0 and 1. V_{in} decreases as the duty cycle increases. We shall use this property to adjust the operating point of the MPPT.

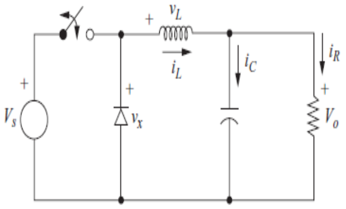


Fig. 4: Schematic of Buck Converter

IX. Controller

Controller is used to control the solar output power so as to maintain the operating point at its maximum power point. Various available controllers are Arduino, Microhope, Microcontrollers, etc. The Arduino board is specially designed and developed for students for learning, experiment and research purpose. It is a single board system which is equipped with 8-bit Atmel AVR microcontroller along with various other components that allow for easy programming and access to various digital and analog input/output pins. The board can be powered by a USB port as well as a DC adapter or a battery source. The Arduino Uno features 6 analogue input pins and 14 digital input/output pins for added functionality. Various shields like prototype shield, Wi-Fi shield, Bluetooth shield etc. can be added to the already feature rich Arduino. The ATmega 328p microcontroller is preloaded with the Arduino boot loader, allowing this chip to be programmed in the Arduino programming language.

X. Specifications of Solar PV Module

Table 1: Specifications of the Given Solar PV Module

01.	Maximum Power [P_{max}]	50.0 W
02.	Voltage at P_{max} [V_{mp}]	17.3 V
03.	Current at P_{max} [I_{mp}]	2.94 A
04.	Open Circuit Voltage [V_{oc}]	21.0 V
05.	Short Circuit Current [I_{sc}]	3.17 A

XI. Results And Discussions

A. *MATLAB Simulation Results:*

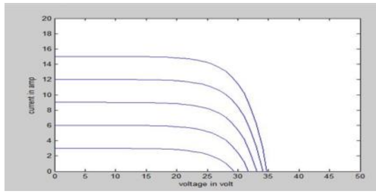


Fig. 5: Solar VI characteristics obtained through programming in MATLAB for various insolation

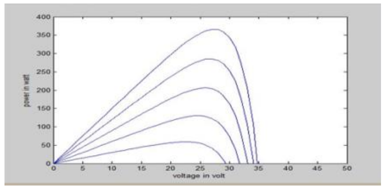


Fig. 6: Solar PV characteristics obtained through programming in MATLAB for various insolation

B. *SCILAB/XCOS Simulation Results*

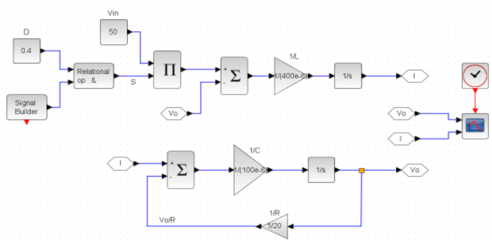
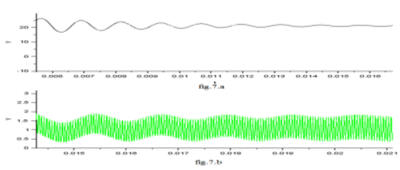


Fig. 7: Mathematical model of Buck Converter in Xcos Tool of Scilab



Simulation Results of Buck Converter
Fig. 7.a: Bucked Voltage
Fig. 7.b: Continuous Current

C. *Hardware Results:*

Fig. 8: Hardware Implementation of Buck Converter using MOSFET as a Switch

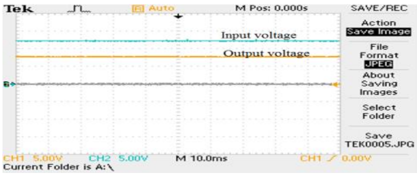


Fig. 9: Results of Hardware Implementation showing input voltage (12 V) and output voltage (6.5V) for a duty cycle of 0.5

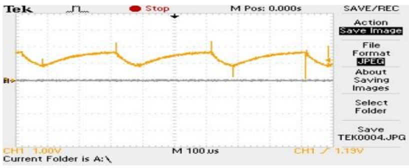


Fig. 10: Inductor current obtained from Buck Converter

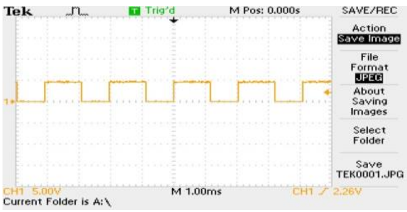


Fig. 11: Switching Pulses from ATMEGA328P which are given to MOSFET

CONCLUSION

Maximum power point tracking controller using arduino is presented. Maximum power point tracking algorithms P&O and Incremental conductance method are implemented through arduino programming. The design of converter is done, taking into consideration the specifications of given PV module. The converter is designed, modeled and simulated in Scilab/Xcos tool which is free and open source software. Hardware implementation of Buck converter is done using TLP-250 MOSFET driver IC. The switching pulses for the MOSFET are given from arduino. These are pulse width modulated signals. The duty ratio of switching pulses is varied through programming so as to give maximum power.

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