Study of Maximum Power Point Tracking (MPPT) Techniques in a Solar Photovoltaic Array

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Abstract

Maximum power point tracking (MPPT) is used in photovoltaic (PV) systems to maximize the PV array output power, irrespective of the temperature and irradiation conditions and the load electrical characteristics. This paper presents a practical implementation of perturbation and observation (P&O) and incremental conductance (IncCon) algorithms based on PIC18F452 microcontroller for tracking of the maximum power generation from PV system. These algorithms are widely used because of its low-cost and ease of realization. Proposed P&O and IncCon algorithms are implemented and tested under different loads, and the test results are analyzed and compared. The results show the performance of the IncCon algorithm in tracking MPP is better than the P&O algorithm and the experimental results of IncCon algorithm indicate that the feasibility and improved functionality of the system with has high-efficiency.

Keywords- Photovoltaic (PV), Maximum PowerPoint Tracking (MPPT), Perturb and Observe (P&O), Incremental Conductance (IncCon)

I. INTRODUCTION

PV power systems are one of today's fastest growing renewable energy technologies, providing more secure power sources and pollution free electric supplies. Unfortunately, PV systems have high fabrication cost and low energy conversion efficiency. Since the PV electricity is expensive compared to the electricity from the utility grid, utilization of maximum PV system output power is desired. Therefore, the PV system should be operating at their maximum output power (MPP) in any environmental conditions (1). The system's operating point is at the intersection of the I-V curves of the PV system and load, when a PV system is directly connected to a load. The MPP of PV system is not attained most of the time. The problem is overcome by using a MPPT algorithm which maintains the PV system operating point at the MPP. There are several MPPT continuously searches algorithms that have been proposed in the literature which uses different characteristics of solar panels and the location of the MPP, including perturb-and-observe method, open- and short- circuit method, incremental conductance algorithm, fuzzy logic and artificial neural network⁽¹⁻¹⁴⁾.

To extract the maximum power from the solar PV module and transfer that power to the load, a MPPT system has been developed using Boost type DC-DC converter. A DC-DC boost converter transfer's maximum power from the solar PV system to the load and it acts as an interface between the load and the system. Maximum power is transferred by varying the load impedance as seen by the source and matching it at the peak power of it when the duty cycle is changed. In order to maintain PV array's operating at its MPP, different MPPT techniques are studied. In the literature many MPPT techniques are proposed such as, the P&O method, IncCon method, Fuzzy Logic Method etc(1,10,14). Of these, the two most popular MPPT techniques P&O and IncCon algorithms based on PIC18F452 microcontroller for tracking of the maximum power generation from PV system under a rapid change in the radiation level. The proposed control system algorithm obtains the Data from the PV system through microcontroller's Analog and Digital ports to perform the pulse width modulation to the DC-DC boost converter. These techniques vary in many aspects as: simplicity, convergence speed, digital or analogical implementation, sensors required, cost, range of effectiveness, and in other aspects. Incremental conductance algorithm is used to track the MPP because it performs precise control under rapidly changing atmospheric conditions.

II. MATCHING STAGE BETWEEN A PV SYSTEM AND A LOAD

The commonly used adapter in PV systems is a DC/DC power converter. It ensures, through a control action, the transfer of the maximum electrical power to the load. The structure of the converter is determined according to the load to be supplied.

A. DC/DC Boost Converter

Figure 3 Shows a DC/DC Boost converter which converts a DC voltage into another DC voltage of higher value. DC/DC converter has two modes, a continuous Conduction Mode, CCM for efficient power conversion and Discontinuous Conduction Mode DCM.



Fig. 1: Basic of Boost Converter Topology

B. Continuous Inductor Current (21)

1) Mode 1 ($0 < t \le$) "Transistor on"

Mode 1 begins when the switching transistor is switched on t=0 and it terminates at t=. The equivalent circuit for mode 1 shown in Fig. 2. The diode is reversing biased since the voltage drop across the switching transistor is small than the output voltage. The inductor current i_L (t) greater than zero and ramp up linearly. The inductor voltage is V_s .



Fig. 2: Mode 1 equivalent circuit for the boost converter (o<t<ton)

The output current during this interval is supplied entirely from the output capacitor, C_0 , which is chosen large enough to supply the load current during t_{0n} with a minimum specified drop in output Current. Stored energy in the inductor is

2) Mode 2 ($\langle t \leq T \rangle$ "Transistor off"

Mode 2 begins when MOSFET is switched off at t=ton and terminates at t=Ts. The equivalent circuit for the mode 2 is shown in Fig. 3. The inductor current decrease until the MOSFET is turned on again during the next cycle. The voltage across the inductor in this period is Vs-Vo.



Fig. 3: Mode 2 equivalent circuit for the boost converter (ton<t<T)

Since the current in the inductor cannot change instantaneously, the voltage in the inductor reverses its polarity in an attempt to maintain a constant current. The current that was flowing through the switching transistor will now flow through L, C, diode, and the load. The inductor current decreases until the switching transistor is turned on again during the next cycle. The inductor delivers its stored energy to the output capacitor C, and charges it up via Duty cycle to a higher voltage than the input voltage. This energy supplies the current and replenishes the charge drained away from the output capacitor when it alone was supplying the load current during the on time.

C. Discontinuous Inductor Current

If the current flowing through the inductor falls to zero before the next turn-on of the switching transistor, the boost converter is said to be operating in the discontinuous inductor current. The voltage conversion ratio of the boost converter for the discontinuous inductor current of operation can be derived by imposing a constant volt-second requirement on its inductor. The critical inductance, L_c, is given by the inductance at the boundary edge between continuous and discontinuous modes.

The switching frequency has been chosen arbitrarily to minimize the size of the boost inductor and limit the loss of the semiconductor device. At higher frequencies the switching losses in the MOSFET increase, and therefore reduce the overall efficiency of the circuit. At lower frequencies the required output capacitance and boost inductor size increases, and the volumetric efficiency of the supply degrades ⁽²¹⁾.

III. MPPT CONTROL ALGORITHMS⁽²²⁾

MPPTs play a main role in PV power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, a MPPT (22) can minimize the overall system cost. There are many algorithms for maximum power point tracking methods available. In this paper P&O and IncCon techniques are used and described in the following subsection, because these require less hardware complexity and low-cost implementations (14, 23). MPPT operate at very high frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with small components. In present work, the boost converter is used as load matching device between input and output by changing the duty cycle of the converter circuit. A major advantage of boost converter is that high voltage can be obtained from the available voltage according to the application.

A. Perturb and Observe Technique

P&O technique ^(17, 22, and 25) operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle. P&O strategy states that a small change in the PV module working voltage causes the following effects ⁽²⁵⁾

- If the corresponding variations in power ΔP are positive, a change fall towards the maximum power point and continue variations in the same track until MPP is reached.
- If the change in ΔP is negative, this implies that a changes are going far as of MPP and so the change in the perturbation direction is needed.

Fig. 4, shows an illustration of the PV panel output power against panel voltage at a given irradiation. The spot indicated shows the MPP.

Let us define two operating positions as point A (dP/dV > 0) and B (dP/dV < 0). The point A is perturbed in a given direction and that the power increases (dP/dV > 0), then it is clear that the perturbation has moved the operating point toward the MPP. The P&O algorithm will continue to perturb the tension in the same direction. In contrast, the point B locates in such a way around the maximum power point, so as to move nearer to that specific operational point by giving a negative variation to the voltage (dP/dV < 0) then the perturbation has moved the operating point away from the MPP. The technique will reverse the direction of the next perturbation. The process is periodically repeated until the MPP is reached. The system oscillates around MPP, which causes power loss. The oscillation can be minimized by decreasing the size of the perturbation. One drawback of the P&O algorithm is that it can fail during a rapidly changing climatic conditions (17).



Fig. 4: Sign of dP/dV at different positions of the power characteristic curve

B. Incremental Conductance Method

IncCon offers good performance under rapidly changing atmospheric conditions. The IncCon method based on the fact that, the slope of the PV array of the power curve is zero at the MPP, positive on the left of the MPP. And negative on the right of the MPP (7-12). This can be given by different equations which has shown in above diagram.

IV. IMPLEMENTATION OF HARDWARE

Prototype hardware are implemented to test the performance of the proposed MPPT algorithms is shown in Fig. 5. The circuit consists of one PV panel, a DC/DC converter, a microcontroller kit, PC-based application, Voltage sensor and Current sensor as well as other peripherals for ensuring the robustness of the system. The voltage and current sensors are used to periodically sample the panel's voltage and current. These sensors are passed to signal conditioning to improve the quality of the signal. Followed by that, these signals are fed into the microcontroller through the analog to digital (A/D) channels. The microcontroller performs process to the voltage and current readings, to calculate the direction and the value of the next step-size. The output of the microcontroller is the pulse-width-modulation (PWM) signal to control the boost DC/DC converter.



Fig. 5: Schematic hardware of the proposed MPPT

A. PV Module

The electrical characteristics of a PV module, given by manufacture's data sheet at the nominal temperature of 25 °C and irradiation of 1000W/m², The PV module specifications are given by the manufacturer are shown in Table 1. The panel equipped with LM35 temperature sensor to monitor its temperature during experiments.

Parameter	Value
Number of series cells	36
Maximum power rating	30Wp
Open circuit voltage (Voc)	21 V
Short circuit current (Isc)	1.94 A
Maximum power voltage (Vmp)	16.8 V
Maximum power current (Imp)	1.78 A

Table 1: Electrical characteristics of a PV module

B. DC/DC Converter

In this work The DC/DC converter is a 50W boost converter working at a switching frequency of 50 kHz, it is used to interface the PV panel output to the load and to track the maximum power point of the PV panel. The parameters of the converter are given in Table 2.

Table 2: DC-DC Converter Parameter			
	Component	Description	
	MOSFET	IRF3205	
	MOSFET driver	IR2112	
	Diode	PBYR2045CT	
	Inductor L	1.15 mH	
	Capacitor Co	220µF	
	Switching frequency	50 kHz	

C. Microcontroller-Based Control Board

The implementation of the MPPT algorithms can be performed using a Microchip PIC18F452 μ C. This microcontroller features a 10-bit, eight channel A/D converter that used by the control program to calculate the PV panel output current, voltage and panel temperature. Also, it features PWM outputs with program controlled duty cycle that used to control the DC/DC converter to track the MPP. PIC18F452 μ C was selected because it has the necessary features that required for the proposed system, such as great memory size, on-chip A/D converter, PWM outputs, low-power consumption and low cost. PIC18F452 μ C has programmed using mikro C compiler that produced by Microelectronic. The developed program performs P&O and IncCon. Choosing between the two algorithms can be operated during the running of the experiment using switches that connected to PIC18F452 μ C ports. The flow chart of the developed program is shown in Fig. 8.

D. PC-Based Application Software

Visual Basic software application was implemented to monitor the selected system parameters online. System parameters include PV current, voltage, power and temperature as well as the controller output duty cycle. The PC reads and monitors system parameters from the PIC18F452 µC by serial port. Visual Basic software can export these parameters to Excel sheet. The Software is basic step to observe, record and display the results of practical work for the MPPT prototype.

V. EXPERIMENTAL RESULTS

An extensive measurements and testing for the selected techniques has been done using the above described system. Selected results are presented with a comparison between P&O and IncCon controllers. DC/DC are implemented and connected with the PIC18F452 μ C as shown in Fig. 9. Fig 10 shows online-monitoring of system parameters (Power, Duty Ratio, Current, Voltage). The following results are presented for different conditions of irradiation and temperature. Performance of the P&O MPPT algorithms under fixed irradiation level and under different conditions of temperature is shown in Fig. 9(a,b,c,d) while performance of the IncCon MPPT algorithms under same conditions is shown in Fig. 10(a,b,c,d). In order to verify the MPP tracker for the photovoltaic simulation system the described MPPT techniques are compared at different ambient conditions to show how they can effectively and accurately tracks the maximum power of the array. IncCon MPPT algorithm gives better performance compared to the P&O algorithm.



Fig. 7: Full hardware prototype with the microcontroller



Fig. 6: PIC18F452 µC Firmware flow chart

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Fig. 8: Online-monitoring of system parameters to get PV Curve and IV Curve by the PC- software









(d) Fig. 9: Output Power, Current, Voltage and Temperature using P&O under different conditions of Temperature at Fixed Irradiation





Fig. 10: Performance of the IncCon under fixed irradiation level and under different conditions of temperature

On the other hand, performance of the P&O MPPT algorithms under different irradiation level and different conditions of temperature is shown in Fig 13 while performance of the IncCon MPPT algorithms under different irradiation level and different conditions of temperature is shown in Fig 14. It is also noted that the IncCon MPPT algorithm gives better performance compared to the P&O algorithm.



(d)

Fig. 11: Performance of the P&O under different irradiation level and different conditions of temperature

Output power of PV panel at fixed irradiation level and temperature with and without MPPT is shown in Fig. 13. It is noted that the MPPT algorithms tracking maximum power from PV panel. It is obvious that the IncCon algorithm has less oscillating and better stable operating point compared to P&O algorithm.





(d) Fig. 12: Performance of the IncCon under different irradiation level and different conditions of temperature



Fig. 13: Output power with different algorithms at constant temperature and irradiation

Performance of the P&O and IncCon MPPT algorithms under fixed temperature and under different conditions of irradiation levels is shown in Fig. 16. The experimental results of PV panel operating power for experiment time for more than 50 second, the irradiation level has decreased at time 23 second then increased at time 38 second at constant temperature of 30oC. It can be noted that the P&O algorithm can't accurately track the MPP. However the IncCon algorithm is succeed to track the MPP accurately. The IncCon algorithm gives less oscillation than the P&O algorithm.



Fig. 14: Output power for different algorithms under change in irradiation and constant temperature

Performance of Output power, current, voltage and temperature with time using different loads under constant value of temperature and irradiation is shown in Fig. 15. From results it can be seen that IncCon algorithm shows less oscillating and better stable operating point than P&O.,



Fig. 15: Output power, current, voltage and temperature with time using different loads under constant value of Temperature and Irradiation

VII. CONCLUSIONS

This paper proposed the maximum power point tracking using P&O and IncCon algorithms based on PIC18F452 microcontroller for tracking of the maximum power generation from PV system. Proposed P&O and IncCon algorithms are implemented and tested under different irradiation, temperature and loads, and the test results are analyzed and compared. The results show the performance of the IncCon algorithm in tracking MPP is better than the P&O algorithm and the experimental results of IncCon algorithm indicate that the feasibility and improved functionality of the system with high-efficiency.

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