

Photovoltaic Maximum Power Point Tracking Control System by using Microcontroller

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Maximum power point tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions and of the electrical load characteristics. A new MPPT system has been developed, consisting of a Buck-type dc/dc converter, which can be controlled by a microcontroller-based unit. The resulting system has high-efficiency, lower-cost and can be easily modified to handle more energy sources. Here, the PIC 16F7877A Microcontroller is used to measure the PV array output power and to change the duty cycle of the dc/dc converter control signal. By measuring the array voltage and current, the PV array output power is calculated. Duty cycle is continuously changed accordingly and the process is repeated until the maximum power point has been reached. All the data are displayed by a LCD display interfaced with microcontroller.

Field of Research: Dc/Dc Converter, MPPT, Microcontroller, Photovoltaic System.

1. Introduction

As people are much concerned with the fossil fuel exhaustion and the environmental problems caused by the conventional power generation, renewable energy sources and among them photovoltaic panels and wind generators are now widely used. Photovoltaic sources are used today in many applications such as battery charging, water pumping, swimming-pool heating system, satellite power systems etc. Though it has the advantage of being maintenance and pollution-free but their installation cost is very high (Maheshappa et al 1998). Photovoltaic energy has been attracting more attention in the last few years as it meets the requirements of being environmentally compatible and resource conserving. They have the advantage of being maintenance and pollution-free. A solar cell may operate over a wide range of voltages and currents, depending directly on the illumination. They require a power conditioner (dc/dc or dc/ac converter) for load interface. Since PV modules still have relatively low conversion efficiency, the overall system cost can be reduced using high efficiency power conditioners which, in addition, are designed to extract the maximum possible power from the PV module.

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2. Literature Review

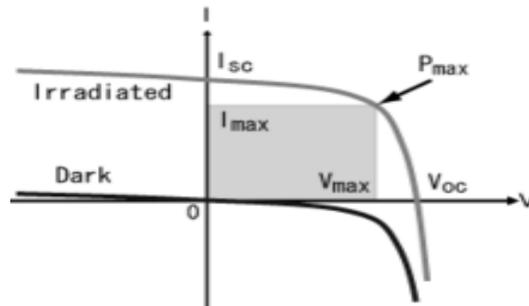
In past, the proposed system was implemented by using boost type dc/dc converter to interface the PV output to the battery and to track the maximum power point of the PV array. The controller scheme utilizes PWM techniques to regulate the output power of boost type dc/dc converter at its maximum possible value and simultaneously controls the charging process of battery. Irradiation level was changed from 1KW/m^2 to 600 W/m^2 . In our proposed system we have used a buck type dc/dc converter to interface the PV output to the battery and to track the maximum power point of the PV array. The irradiation level is changed from 0.2 KW/ m^2 to 0.75 KW/m^2 .

3. System Overview

3.1 Maximum Power Point Tracking

Maximum power point tracking, frequently referred to as MPPT, is an electronic system that operates the photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of.

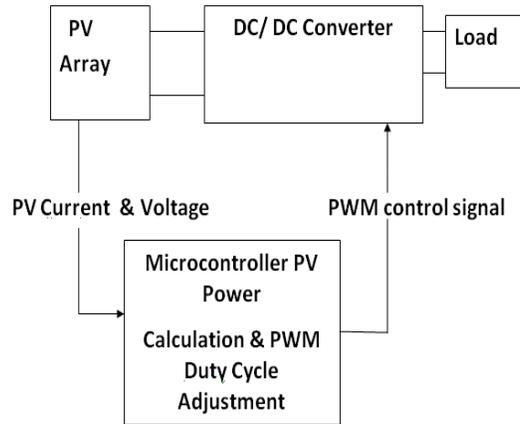
Figure1: Current-Voltage Characteristics of a Solar Cell



MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies with the electrical operating point of the modules so that the modules are able to deliver maximum available power. Maximum power point tracking (MPPT) is a technique that solar inverters use to get the maximum possible power from the PV array. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply a resistance (load) to obtain maximum power for any given environmental conditions. Essentially, this defines the current that the inverter should draw from the PV in order to get the maximum possible power (since power equals voltage times current). Current-voltage characteristics of a solar cell at a particular light level and in darkness are shown in figure 1. The area of the yellow rectangle gives the output power. P_{max} denotes the maximum power point.

3.2 System Block Diagram

Figure 2: Block Diagram of Proposed System



The PV array is interfaced with load using a dc/dc converter to deliver stable power output. PV array output voltage and current is unstable and frequently change with atmosphere. The dc/dc converter maintains output voltage at a stable level. The voltage and current input to dc/dc converter is measured by different sensor and applied to microcontroller as shown in figure 2. The microcontroller acts as a switching control unit of this system. It calculates the power input to converter and make necessary adjustment of the PWM duty cycle. The PWM control signal is then applied to dc/dc converter to change the switching frequency and deliver maximum available power to load.

4. System Design

A Buck-type dc/dc converter is used to interface the PV output to the battery and to track the maximum power point of the PV array. A more detailed diagram is illustrated in figure 5. The Buck converters equivalent circuit diagram and its associated theoretical waveforms are shown in figure 3 & 4 and respectively. A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode), an inductor and a capacitor. The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates by connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load (Rashid 2007). A buck converter operates in continuous mode if the current through the inductor (I_L) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the chronogram in figure 3. As can be seen on figure 2, $t_{on} = DT$ and $t_{off} = (1-D)T$. D is a scalar called the duty cycle with a value between 0 and 1 (Snyman and Enslin 1992).

Figure 3: Naming Conventions of the Components, Voltages and Current of the Buck Converter (Snyman and Enslin 1992)

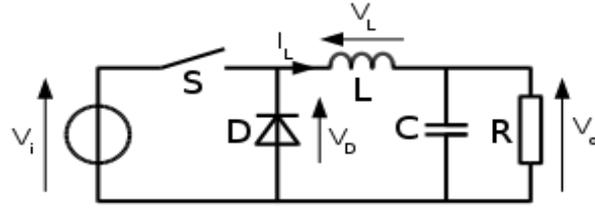
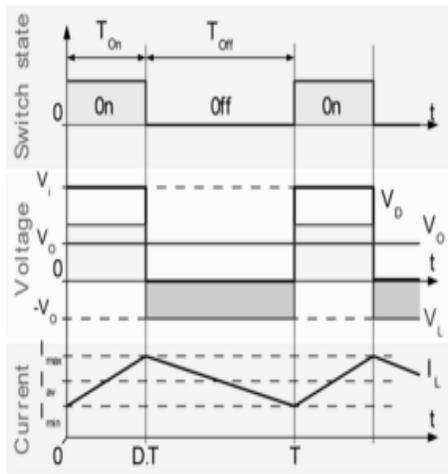


Figure 4: Evolution of the Voltages and Currents with Time in an Ideal Buck Converter Operating in Continuous Mode (Huynh and Cho 1996).



$$(V_i - V_o)DT - V_o(1 - D)T = 0$$

$$\text{Or, } V_o - DV_i = 0$$

$$\text{Or, } D = V_o/V_i \dots \dots \dots (1)$$

From equation 1, it can be seen that the output voltage of the converter varies linearly with the duty cycle for a given input voltage. As the duty cycle D is equal to the ratio between t_{on} and the period T , it cannot be more than 1, therefore, $V_o \leq V_i$. This is why this converter is referred to as step-down converter. The input voltage from the solar panel is applied across 2200 μF capacitor. Voltage and current from the solar panel depends upon solar irradiation level and cell parameters. A voltage regulator LM7805 is used to supply constant voltage 5v. When this supply unit is connected to the main supply then equal 5v is distributed to whole circuit such as Microcontroller PIC16F877A and 16x2 LCD display. A capacitor of 1000 μF is used to smooth out the ripples and to eliminate nearly all ac components, thus confirm the steady supply to buck converter and voltage regulator. On the other hand, capacitor of 100 μF is used after LM 7805 to block the surge and impulse or spike. The diode is used for free-wheeling purpose. Crystal oscillator of 20MHz is used to provide a stable clock signal for PIC16F877A microcontroller. The PIC16F877A microcontroller has been

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selected for its some speciality. As for example, it has an operating range of dc to 20 MHz frequency, each port of it can be used as input-output port. It also has internal ADC, comparator, two internal Capture/Compare/PWM modules, 8 channel 10 bit Analog to Digital module with a resolution of 1mv/bit. It has enriched instruction set and easy to use them. To achieve such function from microcontroller, it is programmed according to desire logic and algorithm.

5. System Implementation

Initially the duty cycle value is kept to 10. This microcontroller has PWM module which can vary duty cycle. The ADC converts the PV panel voltage to digital value and calculates input power. Similarly, the output power is calculated. If the output power is less than previous value then duty cycle is increased by one. The duty cycle can vary up to 127. The microcontroller calculates the output voltage and current to display in LCD display. We can control the circuit operation by observing those values. It also decreases the duty value by one to find out maximum output power. Here, PORTA of microcontroller is used as input pin and PORTB is used as output pin. The Microcontroller senses PV panel input voltage and output load voltage through two voltage dividers into RA0 and RA1 pin respectively. We designed the circuit for 20v input panel voltage. The divider circuit is designed such that when panel voltage is 20v, the microcontroller input is 1v. This divider circuit resistance ratio is 19:1. The output voltage is also measured in the same process where the ratio is 10:1. The microcontroller connection diagram is shown in figure 7.

Figure 5: The Designed MPPT Circuit Diagram

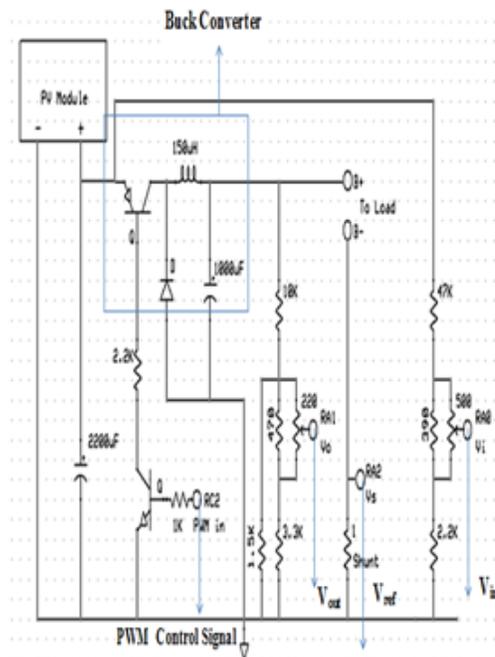
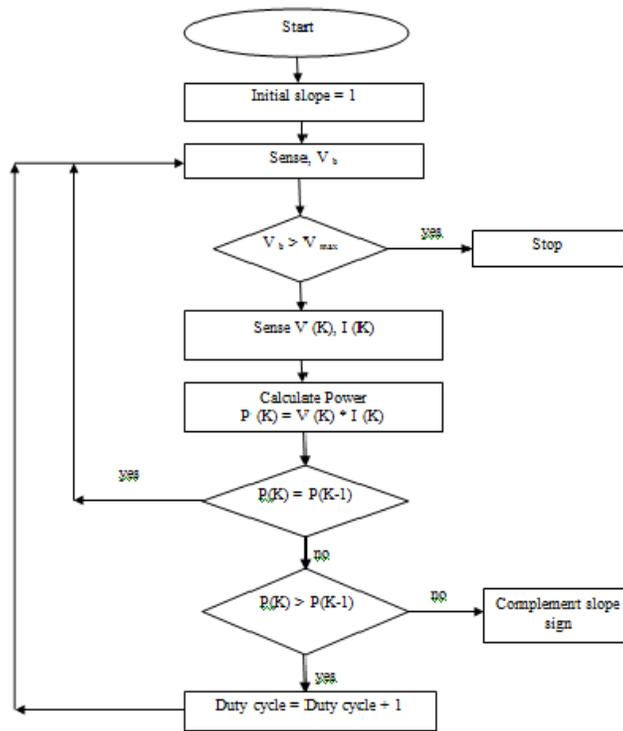


Figure 6: Flowchart of Tracking Process (Koutroulis and Kalaitzakis 2001)



The flowchart of the control program is shown in figure 6 where the slope is the program variable. In each iteration, the dc/dc converter input voltage and current are measured and input power is calculated. The input power is compared to its value calculated in the previous iteration and according to the result of comparison the sign of slope is either complemented or remains unchanged. Then the PWM duty cycle is changed accordingly. The duty cycle is changed continuously according to above-mentioned algorithm, resulting in system steady state operation around maximum power point. The battery voltage is monitored continuously and when it reaches a predetermined level, the battery charging operation is stopped to prevent overcharging (Koutroulis and Kalaitzakis 2001). Figure 8, 9 & 10 depicts the testing of designed circuit.

Figure 7: Microcontroller Connection Diagram

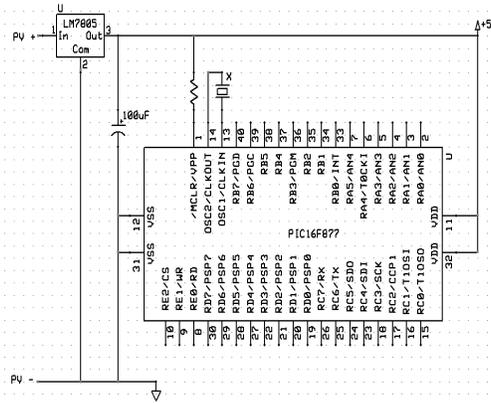


Figure 8: Top View of Designed System

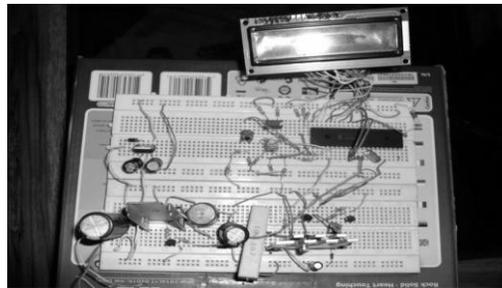


Figure 9: The Data Measurement of the System with Solar Panel

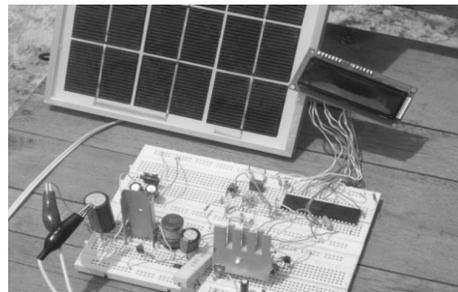


Figure 10: The View of Designed System with In a Glass Box.



6. Performance Analysis

In this research, we measured the performance of the designed system using 5W solar panel. We measured open circuit voltage (V_{oc}), short circuit current (I_{sc}) at different instant of the day at different light intensity, the circuit response and made a comparison with standard tracking process.

6.1 Solar Panel Specification

Figure 11: View of the Solar Panel



The solar panel used for the testing the circuit performance is revealed in figure 11 and its specification is given below:

Maximum power (P_{mp}) = 5W

Open circuit voltage (V_{oc}) = 11.7V

Short circuit current (I_{sc}) = 0.58A

Voltage at maximum power (V_{mp}) = 9.6V

Current at maximum power (I_{mp}) = 0.52A

AM-1.5

Cell temperature-25⁰c

6.2 Data Collection

With associate equipments the performance of the circuit was measured at CUET on August 14, 2011 and recorded as given in table1.

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Table 1: Collected Data from PV Module

Time	Light Intensity x 100 lux	Open circuit voltage (Voc) volt	Short circuit current (Isc) Amp	Available power (p) watt
9 am	893	9.32	0.43	4.01
11am	1035	9.27	0.46	4.26
1 pm	1275	9.24	0.51	4.71
3 pm	508	9.41	0.25	2.35
5 pm	719	9.34	0.35	3.27

Figure 12: Current vs Voltage characteristics

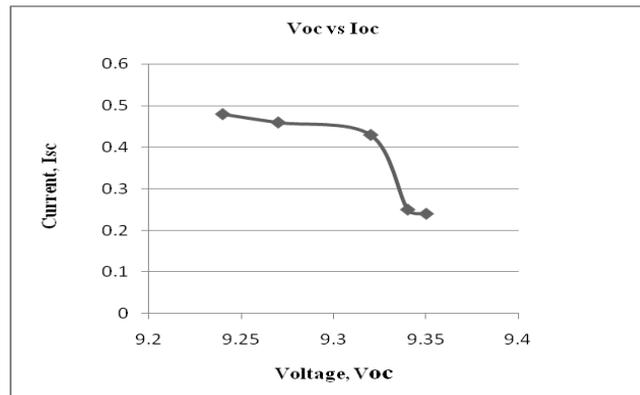
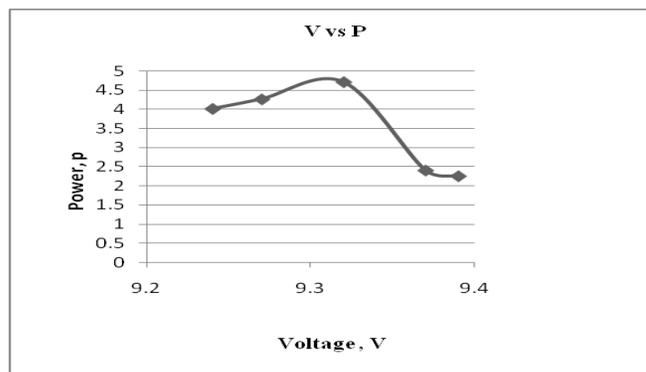


Figure 13: Power vs Voltage characteristics



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Figure 12 shows that when pv module voltage is low at that time pv module current is maximum. But, after sometime with the increase of pv module voltage, module current decreases

Figure 13 shows that pv module power is increase with the increase of module voltage. pv module power is maximum when module voltage is 9.32 volt. But, after reaching a certain pv module voltage, power decreases.

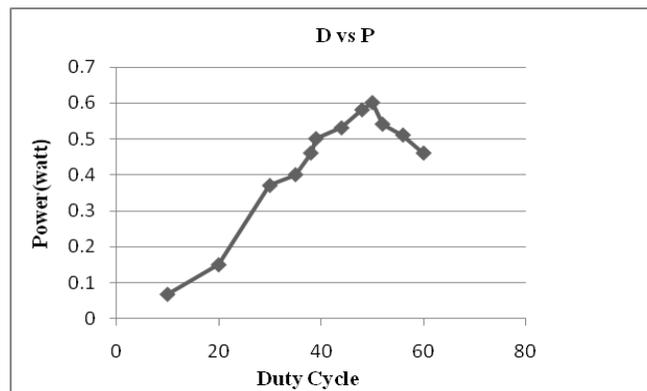
6.3 Circuit Response

The following data was measured at 18th August 2011 at 2.30 pm.

Table 2: Collected Data from Circuit

Vin (volt)	Duty cycle, D	Vo (mA)	Io (mA)	Power, p (watt)
7.3	10	4.53	15	0.068
7.3	20	4.54	32	0.15
7.3	30	4.59	80	0.37
7.3	35	4.68	85	0.41
7.3	38	4.75	96	0.46
7.3	39	4.78	104	0.51
7.3	44	4.88	108	0.53
7.3	48	4.91	118	0.58
7.3	50	4.82	125	0.62
7.3	52	4.76	113	0.54
7.3	56	4.77	107	0.51
7.3	60	4.76	97	0.46

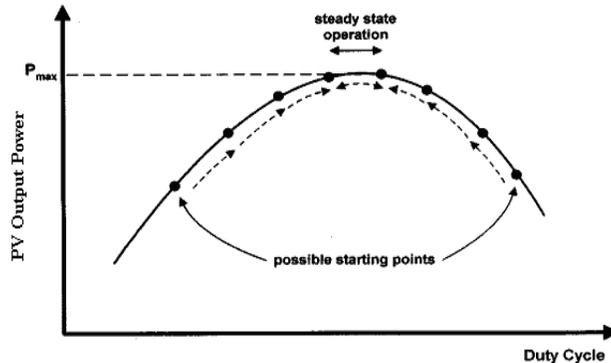
Figure 14: Power Vs Duty Cycle Characteristics



7. Result and Discussion

7.1 Standard Curve

Figure 15: Ideal MPPT Tracking Process (Koutroulis and Kalaitzakis, 2001)



The MPPT tracking process shown in figure 14, the starting point vary, depending on the atmospheric condition while the duty cycle of system is changed continuously (Koutroulis and Kalaitzakis 2001). The tracking process is smoother and slope of the curve is same in either direction from the maximum power point. This curve is obtained under standard testing condition at irradiation level 1kw/m^2 and at 25°c .

7.2 Comparison with Ideal Curve

In the measured data, we found that the initial charging current depends on solar insolation. As a result the starting point of figure 13 differs from each other. Power delivered to output at different instant of tracking process also changes between different period of day time. Initially, the output power varies significantly with duty cycle indicates by the stiff slope of the curve in figures. As the circuit delivers more power to output the slope of the curve becomes flatter. After reaching the peak power point, the power deliver to load decreases with duty. The Microcontroller monitors this point and extract maximum power from PV panel. The open circuit voltage increases as the day progresses but the short circuit current decreases because current output from the PV panel decreases.

8. Limitation and Cost

We have implemented our project in which the output power is very low. The proposed control unit can be implemented also with analog circuits, but the Microcontroller-based alternative was chosen since it permits easy system modification. But, since it is a Microcontroller based project, if program has not been loaded successfully, then we cannot get desired output from our circuit. The maximum power deliver to load depends largely on atmospheric condition and load condition. This circuit must be modified for different types of load. It can only

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extract maximum power from the panel fixed at a certain inclination angle. It cannot track the solar position. For MPPT with heavy load other dc/dc converter such as boost, buck-boost converter must be used. (Pressman 1994)

In the table given below show the cost of the equipments that we have used to design this proto-type.

No. of item	Parts name	Rating	Quantity	Total taka
1	LM7805(Voltage regulator)	5V	1	20
2	PIC16F877A		1	300
3	PNP Transistor		2	100
4	NPN Transistor		3	15
5	Crystal Oscillator	20 MHz	1	15
6	Resistor	1.5k,3.3k,1k,10k, 240 Ω , 470 Ω		10
7	Variable resistor		3	9
8	Capacitor	4700 μ F	1	40
9	Capacitor	100 μ F	3	9
10	Capacitor	1000 μ F	1	20
11	Bread board		1	240
12	Wires			20
13	Inductor	150 μ H	1	25
	LCD		1	250
15	Diode		1	2
16	Other			100
17	Glass box		1	500
			Total	1675

9. Conclusion

The PV array output power delivered to a load can be maximized using MPPT control system, which consists of a power conditioner to interface the PV output to load and a control unit, which drives the power conditioner such that it extracts the maximum power from a PV array. In this paper, a low-cost and low-power consumption MPPT system for battery charging has been developed and tested. This system consist of a high efficiency, Buck-type dc/dc converter and a Microcontroller based unit which controls the dc/dc converter directly from the PV array output power measurement. The microcontroller based proposed control unit was chosen since it permits easy system modification. The proposed system can be used in a hybrid system where the microcontroller performs simultaneously the MPPT control of more than one renewable energy source (Bose et al1985). Furthermore, it can be coupled with an uninterruptible power supply system in commercial buildings or it can be used to supply power to the electrical grid through a dc/ac converter.

References

- Bose, B. K., Szczesny, P. M. and Steigerwald, R. L. (1985), 'Microcomputer control of a residential power conditioning system,' *IEEE Trans. Ind Applicat.*, vol. IA-21, pp. 1182–1191.
- C. R. Sullivan and M. J. Powers, (1993), 'A high-efficiency maximum power point tracker for photovoltaic arrays in a solar-powered race vehicle,' in Proc. IEEE Power Electron. Spec. Conf., pp. 574–580
- Huynh, P. and Cho, B. H. (1996), 'Design and analysis of a microprocessor controlled peak-power-tracking system,' *IEEE Trans. Aerosp. Electron.Syst*, vol. 32, pp182–189.
- Koutroulis, E., and Kalaitzakis, K., and Voulgaris, N. C. (2001), 'Development of a Microcontroller- Based Photovoltaic Maximum Power Point Tracking Control System', *transactions on power electronics*, vol.16, no.1, January 2001.
- Maheshappa, H. D., Nagaraju, J., and Murthy, M. V. K. (1998), 'An improved maximum power point tracker using a step-up converter with current locked loop', *Renewable Energy*, vol. 13, no. 2, pp. 195–201.
- MPPT tracking process available at
<http://www.blueskyenergyinc.com/mpptracking/windy.html>.
- Microcontroller IC available at
<http://www.Datasheetcatalog.com/PIC16F877A/data.html>.
- Pressman, A. I. (1994), *Switching Power Supply Design*, McGraw Hill, New York.
- Rashid, H. M. (2007), *Power Electronics*, 3rd ed, Dorling Kindersley Pvt. Ltd., p166.
- Snyman, D. B. and Enslin, J. H. R. (1992), 'Simplified feed-forward control of the maximum power point in PV installations,' in Proc. 1992 Int. Conf. Ind. Electron., Contr., Instrum. Automa, vol. 1, pp548–553.