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PHOTOVOLTAIC MAXIMUM POWER POINT TRACKING CONTROL SYSTEM BY USING MICROCONTROLLER

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Abstract— *Maximum power point tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature, irradiation conditions and 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 designed system has high-efficiency, lower-cost and can be easily modified to manipulate 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.*

Index Terms— DC/DC converter, MPPT, Microcontroller, Photovoltaic System

1. INTRODUCTION

Now-a-days people are much concerned with the fossil fuel exhaustion and the environmental problems caused by the conventional power generation, so 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. It has the advantage of less maintenance and pollution-free energy, but their installation cost is very high [1]. Photovoltaic energy has been attracting more attention in the last few years as it meets the requirements of being environmentally compatible and resource conserving. 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) unit 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 power from the PV module.

2. SYSTEM OVERVIEW

2.1 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. MPPT is not a mechanical tracking system that “physically moves” the modules to point them 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 in which solar inverters are used 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. The purpose of the MPPT system is to sample the output of the solar 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

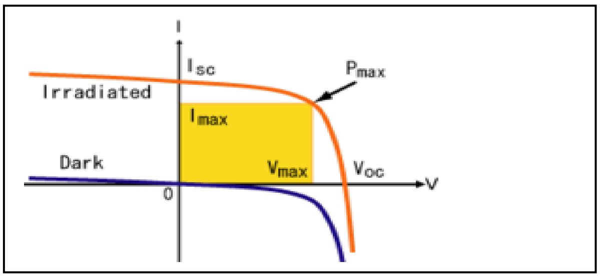

Figure1: Current-voltage characteristics of a solar cell [2]

possible power (since power equals voltage times current) [2]. Current-voltage characteristics of a solar cell at a particular irradiance level and in dark level are shown in figure 1. The area of the yellow rectangle gives the output power and P_{max} denotes the maximum power point.

2.2 SYSTEM BLOCK DIAGRAM:

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 is used to maintain output voltage at a stable voltage level. The input voltage and current to dc/dc converter is measured by different sensors and applied to microcontroller as shown in figure 2. The microcontroller acts as a switching control unit of this system. It calculates the input power to converter and makes 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 available maximum power to load.

3. SYSTEM DESIGN

A Buck-type dc/dc converter is used to interface the PV output to the battery and to track the maximum power of the PV array, the irradiation level is changed from 0.2 KW/ m^2 to 0.75 KW/m^2. The detailed diagram is illustrated in figure 5. Equivalent circuit diagram of the Buck converter and its associated theoretical waveforms are shown in figure 3 & 4 respectively. A buck converter is a step-down DC to DC converter.

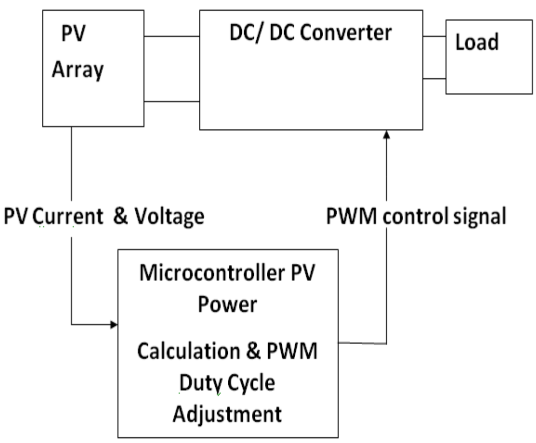

Figure 2: Block diagram of the designed system

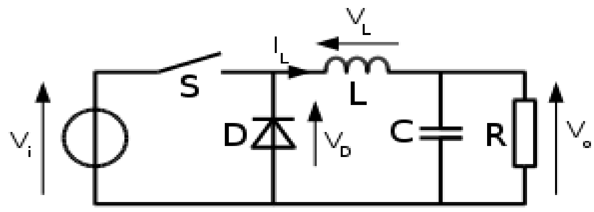

Figure 3: Naming conventions of the components, voltages and current of the buck converter [4].

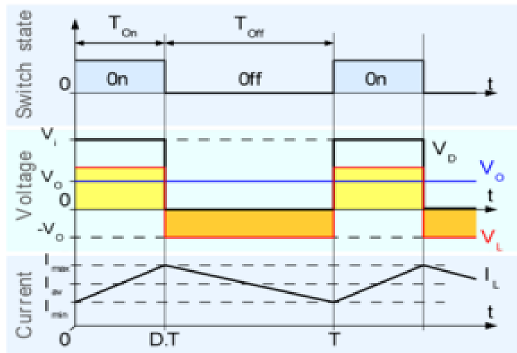

Figure 4: Evolution of the voltages and currents with time in an ideal buck converter operating in continuous mode [5].

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 [3]. 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 4. As can be seen on figure 4, $t_{on} = DT$ and $t_{off} = (1-D)T$. D is a scalar, also called the duty cycle with a value between 0 and 1 [4].

$$(V_i - V_0)\, DT - V_0\, (1- D)\, T = 0$$

$$\text{Or, } V_0 - DV_i = 0$$

Or, D = Vo / Vi………………………….. (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, $V_0 \le V_i$. 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 5v is distributed to whole circuit such as Microcontroller PIC16F877A and 16x2 LCD display.

A capacitor, rating of 1000µF 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, a capacitor, rating of 100µF 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 selected for its some specialty. 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 [6]. To achieve such function from microcontroller, it is programmed accordingly to gain desire logic and algorithm.

4. 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 one 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 one 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 flowchart of the control program is shown in figure 6 where the slope is the variable of program. 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 microcontroller connection diagram is shown in figure 7. The battery voltage is monitored continuously and when it reaches a predetermined level, the battery charging operation is stopped to prevent overcharging [7]. Figure 8, 9 & 10 depicts the observation of performance of designed and implemented circuit.

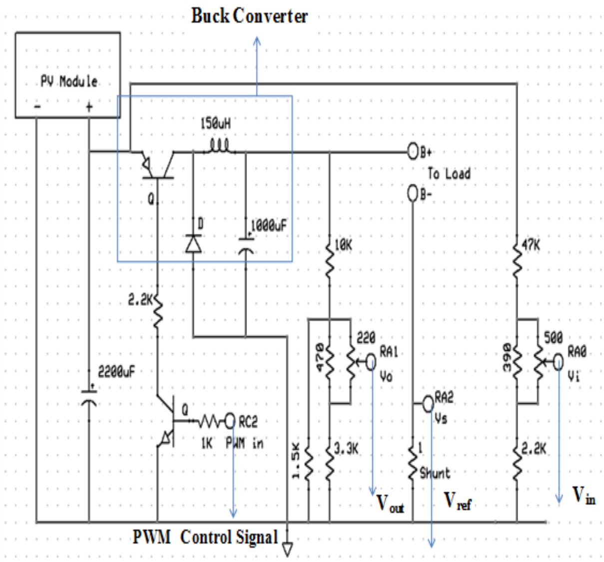

Figure 5: The designed MPPT circuit diagram

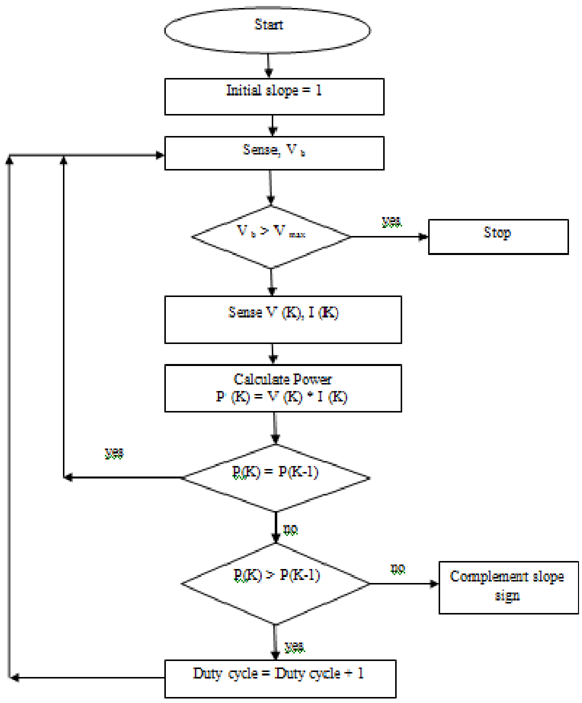

Figure 6: Flow chart of tracking process for the system

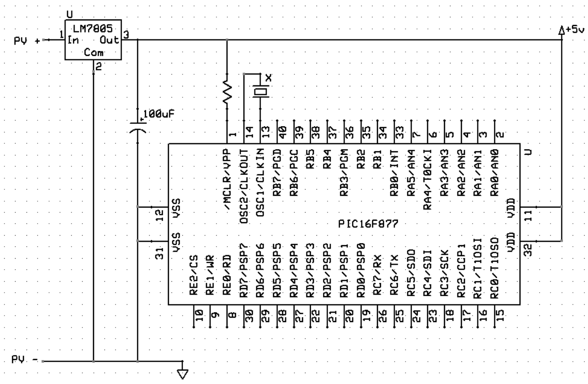

Figure 7: Microcontroller connection diagram

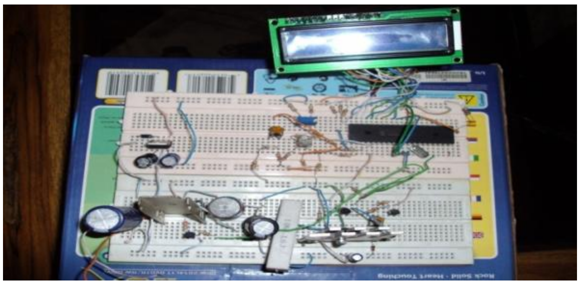

Figure 8: Top view of designed system

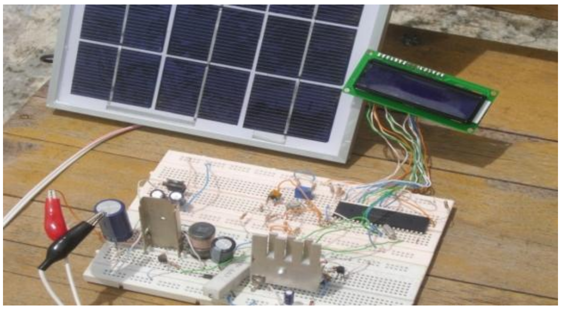

Figure 9: System data measurement with solar panel

Figure 10: Overall view of designed system with a glass box

5. 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, to observe the circuit response. We also made a comparison between system performances with standard tracking process.

5.1 SOLAR PANEL SPECIFICATION:

Figure 11: Top view of the solar panel

The solar panel used for observing 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 = 25^0c

5.2 COLLECTING DATA:

With associate equipments, circuit performance measured at CUET on August 14, 2011 and recorded as shown in table 1.

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

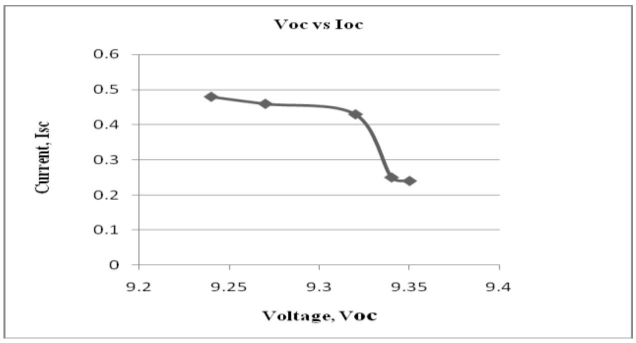

Figure 12: Current vs. Voltage characteristics curve

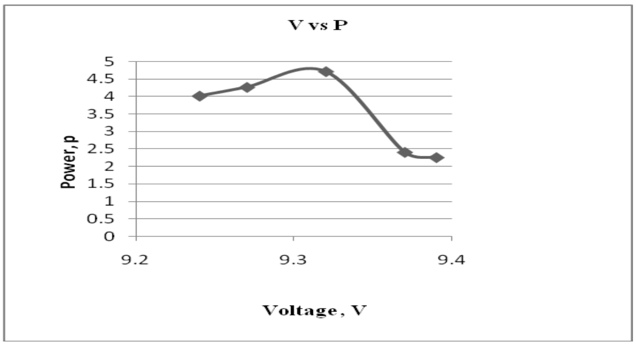

Figure 13: Power vs. Voltage characteristics curve

Figure 12 shows that maximum PV module current is achieved at low PV module voltage point. After a while, with the increase of PV module voltage, module current decreases. Figure 13 shows that PV module power is increasing with the increase of module voltage. The maximum PV module power is obtained at module voltage of 9.32 volt. But, after reaching a certain PV module voltage, module power decreases.

5.3 CIRCUIT RESPONSE:

The following data shown in table 2 measured at 18th August, 2011 at 2.30 pm and the plotted response is revealed in figure 14.

Table 2: Collected data from the designed 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

6. RESULTS AND DISCUSSION

6.1 STANDARD CURVE VS. SYSTEM CURVE:

The MPPT tracking process shown in figure14, where the starting point vary depending on the atmospheric condition while the duty cycle of system is changed continuously[7]. 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 25^0 c. In the obtained curve of figure 12, we found that the initial charging current depends on solar irradiation which is responsible for the curve of figure 14.

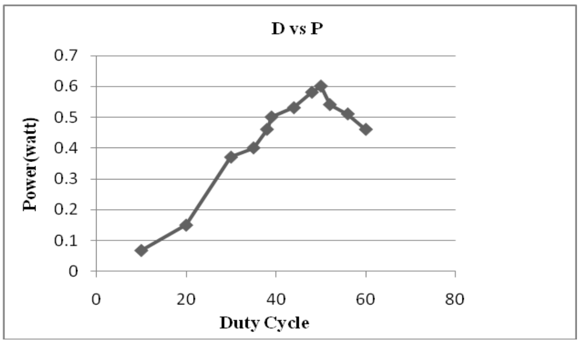

Figure14: Power vs. Duty Cycle characteristics curve

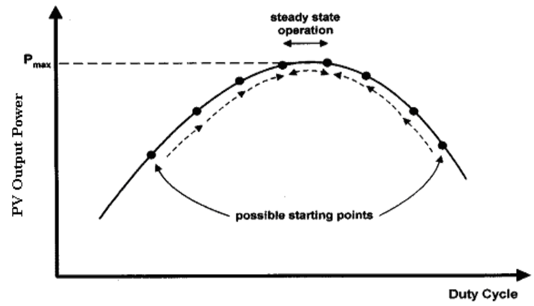

Figure 15: Ideal MPPT tracking process [7]

As a result, the starting point differs because power delivered to output at different instant of tracking process changes with different periods of day time. Initially, the output power varies significantly with duty cycle indicating by the stiff slope of the curve in figure 13. As the circuit delivers more power to output, the slope of the curve becomes flatter. After reaching the peak power point, the power delivered to load decreases with duty cycle value. The microcontroller monitors this point and extracts maximum power from PV panel. The open circuit voltage increases as the day time progresses but the short circuit current decreases, for that reason current output from the PV panel decreases. The system curve of figure 14 and the ideal curve of figure 15 are similar which proves the functionality of the designed system.

6.2 COST CALCULATION OF DESIGNED SYSTEM:

The cost of the equipments to implement the designed system is shown in table 3.

Table 3: The overall cost of the system

Item No.	Equipments	Rating	Qua-ntity	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, 240Ω , 470 Ω	6	10
7	Variable resistor		3	9
8	Capacitor	4700μF 100 μF, 1000 μF	5	69
9	Bread board		2	480
10	Wires			20
11	Inductor	150 μH	1	25
12	LCD		1	250
13	Diode		2	2
14	Glass box		1	500
			Total	1675 tk

7. LIMITATIONS

The designed system has following limitations:-

(i) The system is designed for 20V PV panel. In case of high voltage rating of PV panel, the design should be modified.

(ii) In this design, light load is considered but for MPPT with heavy load other dc/dc converter such as boost, buck-boost converter must be used [8], [9].

(ii) The maximum power delivered to load depends largely on atmospheric condition and load condition. This circuit must be modified for different types of load.

(iii) It can only extract maximum power from the panel fixed at a certain inclination angle. It cannot track the solar position.

8. CONCLUSION

The PV array output power delivered to a load can be maximized using MPPT control system. It 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 experimented. This system consists 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 designed system can be used in a hybrid system where the microcontroller performs simultaneously the MPPT control of more than one renewable energy source [10]. 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.

9. REFERENCES

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