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Photovoltaic Battery Charging System Based on PIC16F877A Microcontroller

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Abstract— ***This paper presents the design and practical implementation of a buck-type power converter for Photovoltaic (PV) system for energy storage application based on constant voltage Maximum Power Point Tracking (MPPT) algorithm. A buck converter is used to regulate battery charging. The system is controlled by a Peripheral Interface Controller (PIC) 16F877A microcontroller from Microchip via sensing the solar panel voltage and generating the Pulse Width Modulation (PWM) signal to control duty cycle of the buck converter. This type of microcontroller was chosen because it has the necessary features for the proposed design such as built-in Analog-to-Digital Converter (ADC), PWM outputs, low power consumption and low cost. Simulation and experimental results demonstrate the effectiveness and validity of the proposed system.***

Index Terms— Photovoltaic, MPPT, Buck Converter, PIC16F877A.

I. INTRODUCTION

In recent years, attention towards renewable energy such as wind and solar power has increased dramatically. PV sources are used today in many applications such as battery charging, lighting, home power supply, satellite power systems, water pumping, and many more. PV is becoming more famous in the world of power generation because they have the advantages of free pollution, low maintenance, and no noise and wear due to the absence of moving parts [1, 2]. The main drawbacks of PV systems are high fabrication cost and low energy-conversion efficiency, which are partly caused by their nonlinear and temperature-dependent *V–I* and *P–I* characteristics. So as to effectively use PV array; the PV power system has to track the maximum power point (MPP) of PV array under varied atmospheric conditions (i.e. adjust the panel output voltage to a value at which the panel supplies the maximum energy to the load). Many researches and designs about the MPPT methods have actively been done to track MPP of PV array [2, 3, and 4] One very common MPPT technique is to compare the PV array voltage with a constant reference voltage, which corresponds to the PV voltage at the maximum power point, under specific atmospheric conditions as shown in Fig. 1. The resulting difference signal (error signal) is used to drive a power conditioner, which interfaces the PV array to the load [3]. In the paper, this technique is simulated and experimentally implemented based on PIC microcontroller.

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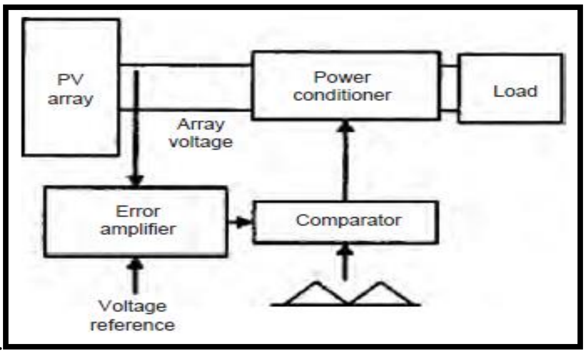

Fig. 1: MPPT control system with constant voltage reference

II. PV ARRAYS CHARACTERISTICS

The PV array characteristics profoundly influences the design of the converter and control system, therefore it will be briefly presented here. The equivalent electric diagram of a PV array is shown in Fig. 2 [2].

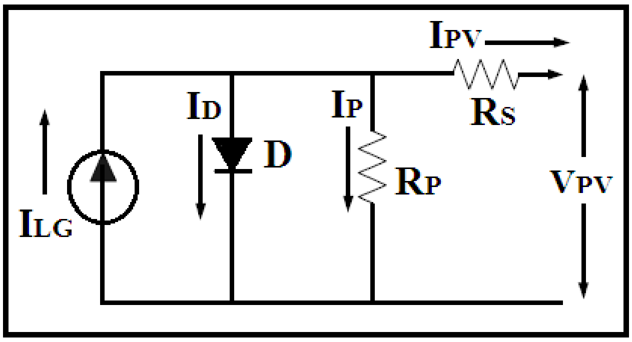

Fig.2: Equivalent electric diagram of a solar array

The characteristic equation for solar panel is given by [2]:

$$I_{PV} = I_{LG} - I_D - I_P \quad (1)$$

$$I_{PV} = I_{LG} - I_{OS}\left[exp\left(\frac{V_{PV} + I_{PV}R_s}{V_T}\right) - 1\right] - \frac{V_{PV} + I_{PV}R_s}{R_p} \quad \textbf{(2)}$$

Where, I_{PV} and V_{PV} is output current and output voltage respectively, I_{LG} is the light generated current, I_D is the Diode current, I_{OS} is the Diode reverse-saturation current, R_S is the series parasitic resistance and R_P is shunt parasitic resistance of the cell, V_T is the thermal voltage [2, 5].

III. BUCK CONVERTER

The step-down dc–dc converter, commonly known as a buck converter, is shown in Fig. 3: (a). It consists of dc input voltage source V1, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R. The buck circuit has two modes of operation as shown in Fig. 4: (b) and Fig. 4: (c) [3, 6].

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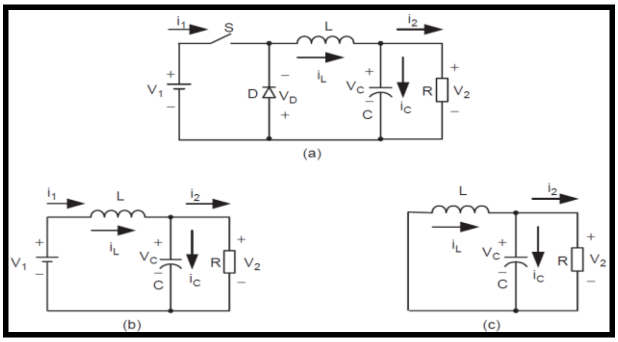

Fig. 3: Buck converter: (a) circuit diagram; (b) Mode 1 (switch-on) equivalent circuit; and (c) Mode 2 (switch-off) equivalent circuit

Mode 1: When the switch is connected, L is connected to the switch which tends to oppose the rising current and begins to generate an electromagnetic field in its core. Diode D is reverse biased and is essentially an open circuit at this point. The inductor current increases, inducing a positive voltage drop across the inductor and a lower output supply voltage in reference to the input source voltage. The inductor serves as a current source to the output load impedance [6].

Mode 2: In the OFF state the switch is open, diode D conducts and energy is supplied from the magnetic field of L and electric field of C. The current through the inductor falls linearly. When the switch is off, the inductor current discharges, inducing a negative voltage drop across the inductor. Because one port of the inductor is tied to ground, the other port will have a higher voltage level, which is the target output supply voltage. The output capacitance acts as a low-pass filter, reducing output voltage ripple as a result of the fluctuating current through the inductor. The diode prevents the current flowing from the inductor when the switch is off [6].

The state of the converter in which the inductor current is never zero for any period of time is called the continuous conduction mode (CCM) as shown in Fig.4 [3].

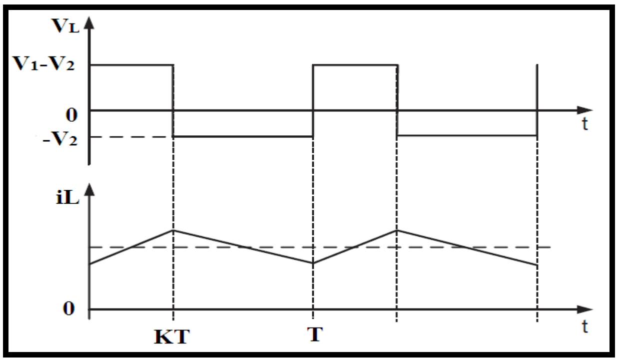

Fig. 4: The waveform of the inductor voltage and inductor current

IV. PROPOSED SYSTEM

The block diagram of the proposed PV battery charger system is shown in Figure 5. This PV system consists of six major parts: (1) solar panels, (2) buck converter circuit as the battery charger, (3) potential divider circuit, (4) PIC16F877A microcontroller to control power MOSFET switching duty cycle on the buck converter circuit, (5) gate drive circuit, and (6) rechargeable battery.

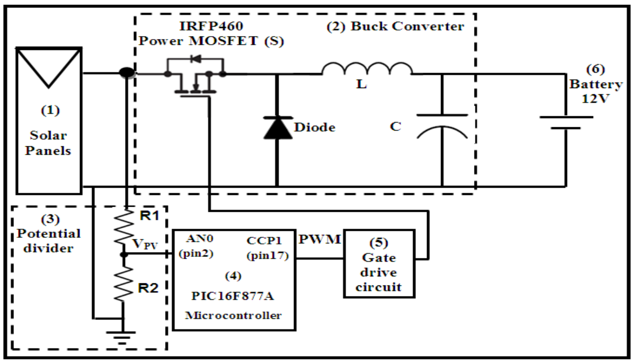

Fig. 5. Block diagram of the proposed PV battery charger system

A. Solar Panels

Two of solar panels are connected in parallel connection for increasing the current in the panels (source current) as shown in Figure 6. The specifications of the solar panels used for this paper are shown in table (1).

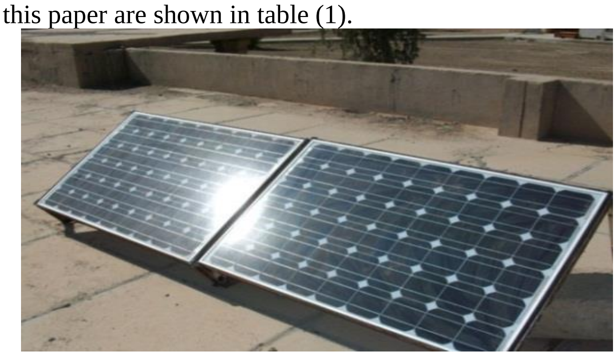

Fig. 6. The solar panels that used in the work

Table 1. Solar panel specifications under standard test conditions

Maximum Power (P_{max})	100W
Maximum Power Voltage (V_{MP})	26V
Maximum Power Current (I_{MP})	3.85A
Open Circuit Voltage (V_{OC})	31.2V
Short Circuit Current (I_{SC})	4.25A
Maximum system voltage	1KV

B. Buck Converter Circuit Design

The buck converter commonly known as step down dc–dc converter, it consists of dc input voltage source V_1, controlled switch S, diode, filter inductor L, filter capacitor C, and load. Where the output voltage V_2 depends linearly on the duty cycle D as in equation (3) [3, 6]:

$$V_2 = D * V_1 \quad 0 \leq D \leq 1 \tag{3}$$

Here the buck converter is used to step down the voltage from the solar panels and this controlled voltage is applied to battery. The values of L and C of the output filter of the buck converter can be calculated from the peak-to-peak ripple current and ripple voltage of L and C, respectively. Therefore, the peak-to-peak ripple current ΔI of the inductor is expressed as [3]:

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$$\Delta I = \frac{V_2(V_1 - V_2)}{f\ L\ V_1} \quad (4)$$

Where f is the switching frequency of the pulses.

And the peak-to-peak ripple voltage ΔV_c of the capacitor is expressed as:

$$\Delta V_c = \frac{V_2(V_1 - V_2)}{8LC\ f^2 V_1} \quad (5)$$

The calculation of the converter output filter L and C which are the fundamental components of the circuit depend on some parameters, as shown in table (2).

Table 2. Experimental circuit parameters for the buck converter

Parameter	Value
Input voltage V_1	28 V
Output voltage V_2	13 V
Switching frequency f	5 KHz
peak-to-peak ripple voltage ΔV_c	0.13 V
peak-to-peak ripple currentΔI	1.2 A

Then the values of L and C can be calculated according to equations (4), (5), and table (2) as follows: $L = 1\ mH$, $C = 268\ \mu F$.

C. Potential Divider

The solar panels voltage is feed-forwarded to the microcontroller through a simple potential divider (consists of R1and R2) which limits the feed-forward voltage to a maximum of 5V (i.e. suitable voltage range which is acceptable by the built-in ADC in the microcontroller). The reference voltage corresponding to the required output voltage is fed into the microcontroller using software program.

D. PIC16F877A Microcontroller

Error between the actual (feed-forwarded) voltage and the reference voltage (13 V) is used for modulating the duty cycle of the buck converter in pulse.

PIC16F877A has a built-in hardware, called Capture /Compare /PWM (CCP) module. To generate a pulse signal the CCP module most be work in PWM mode [7]. The code for the control system has been written in mikroC PRO v4.15 which was burnt into the PIC16F877A to sense (measure) the solar panels voltage (V_{pv}) and generate the pulse signal. The hex code of the control system is then downloaded to the PIC microcontroller chip from the PC by using Top programmer version 6. Figure 7 shows the flowchart for the pulse generator program.

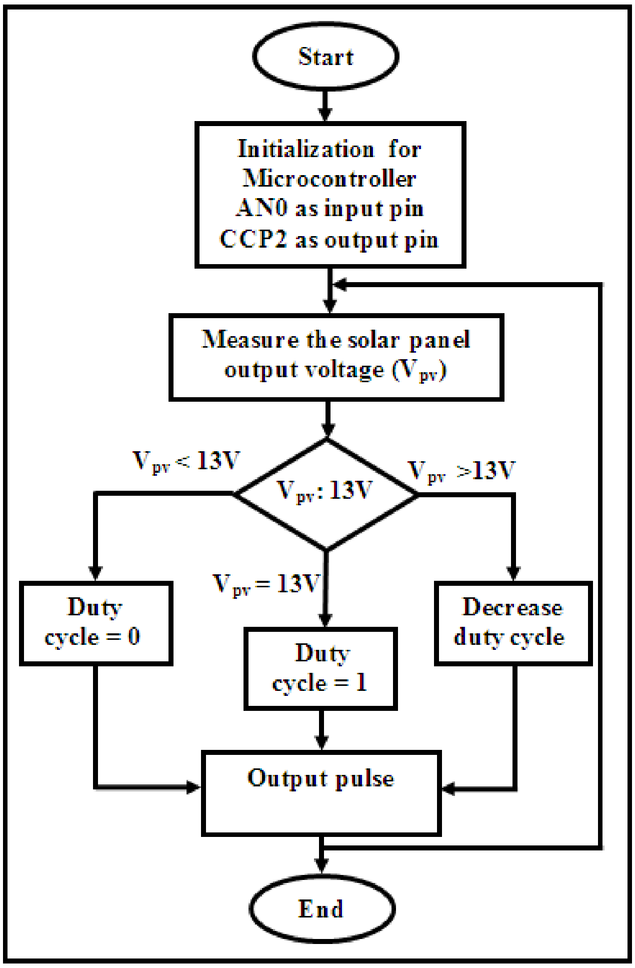

Fig. 7. Flowchart for the pulse generator

E. Gate Drive Circuit

6N136 optocoupler is used to amplify and translate the pulse signal from PIC16F877A microcontroller to the gate pin of the IRFP460 power MOSFET switch S of the buck converter.

F. Rechargeable Battery

The rechargeable battery that used in PV charge controller is 12V-7 Ah Sealed Lead battery which is stored electrical energy in chemical form to operate DC load.

Finally, the picture of the prototype battery charger circuit is shown in Figure 8.

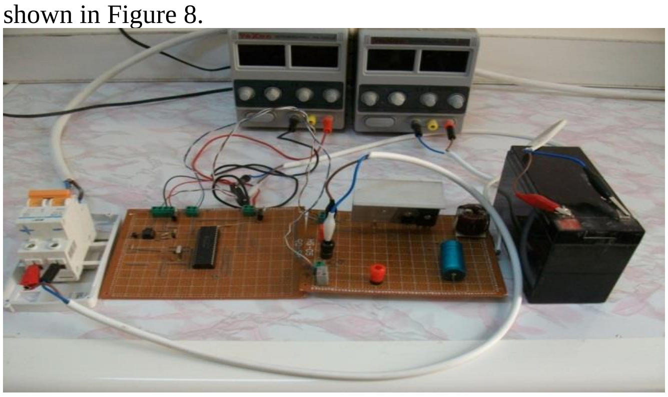

Fig. 7. Prototype battery charger circuit

V. SIMULATION AND EXPERIMENTAL RESULTS

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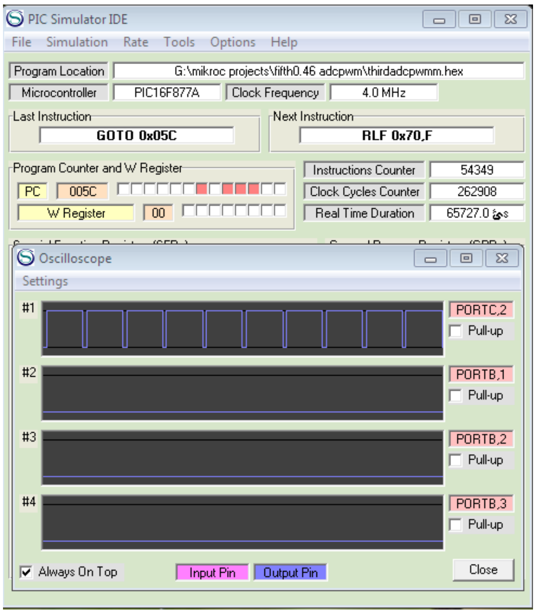
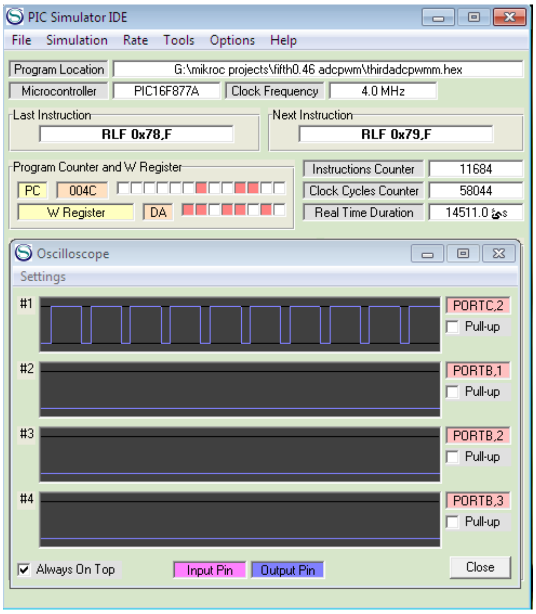
Figure 8 shows different values of duty cycle for the pulse signal that are taken from PIC Simulator IDE simulation v5.33 software.



(a)



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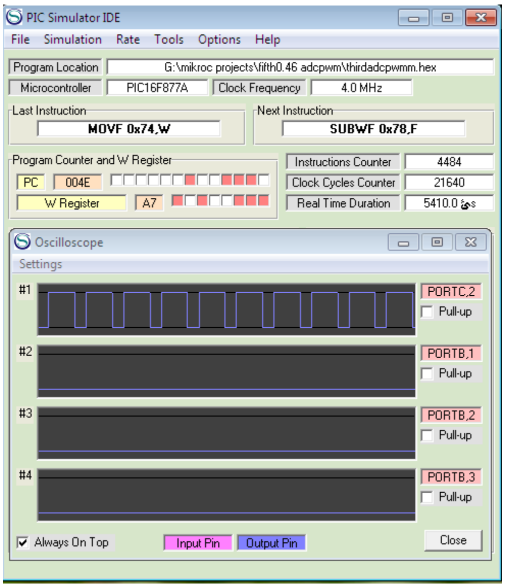
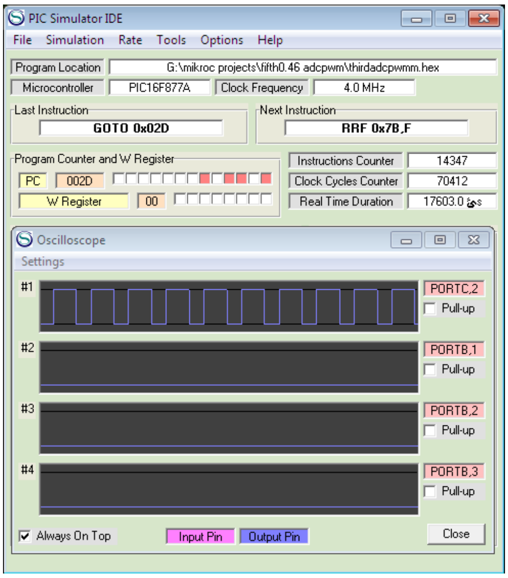


(c)



(D)

Fig. 8. Pulse output of the simulation: (a) duty cycle (93%), (b) duty cycle (76%), (c) duty cycle (65%),(d) duty cycle (46%)

Figure 9 shows the oscilloscope waveforms of the pulse output for duty cycle (93%, 76%, 65%, and 46%) that are generated by the microcontroller. The variation of the pulse depending on the solar panels output voltage (V_{pv}). These signals have been taken from drive circuit. These signals are used to drive the gate of the buck switch (MOSFET).

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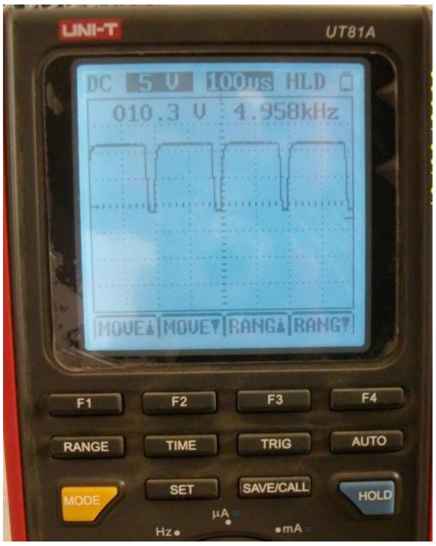
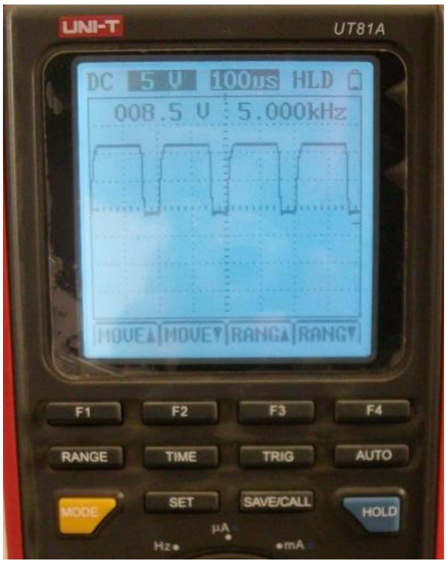
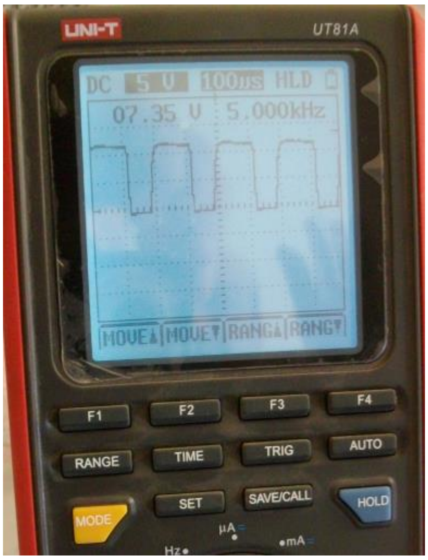


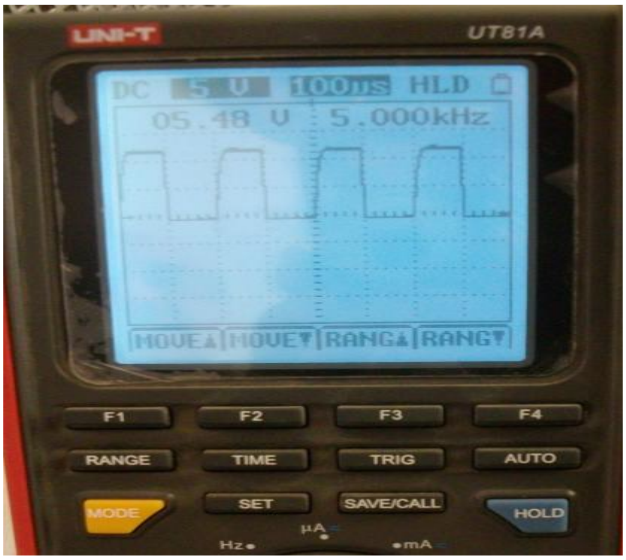
(a)



(b)



(c)



(d)

Fig.9. Pulse output of the experimental circuit: (a) duty cycle (93%), (b) duty cycle (76%), (c) duty cycle (65%), and (d) duty cycle (46%)

VI. CONCLUSIONS

With the flexible proposed control system, any changes of the solar panel voltage due the change of insolation levels (irradiation) and temperature will produce a constant output voltage at the end of the converter on the DC load. The mikroC PRO for PIC is a powerful, feature-rich development tool for PIC microcontrollers.

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