Peripheral Interface Controller-Based Photovoltaic dc-dc Boost Converter

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***Abstract*—Fossil-based energy resources used in generating electricity are exhausting and finding alternative energy sources is vital for future energy demand. Photovoltaic (PV) is one of the promising renewable energy sources. However, the inconsistent characteristic of solar irradiation tends to disturb the amount of PV energy extraction. This makes the PV a non-linear power source throughout the daytime. This paper presents the prototype development of a Peripheral Interface Controller (PIC)-based photovoltaic dc-dc boost converter. In order to produce a stable dc output voltage, a closed-loop system is implemented into the converter circuit. The converter circuit was designed and simulated in PROTEUS ISIS Professional Tool and PSpiceOrCAD software environment. The control algorithm of the converter system was developed in the PIC C-Compiler software. The converter utilizes an 18V of 100W capacity PV module to generate a higher voltage for various direct current (dc) applications. With the developed and embedded control algorithm, the PIC microcontroller model PIC16F877A generates an appropriate pulse-width modulation signal to control the switching device MOSFET IRF540. Simulation results show that the controller managed to boost-up the voltage to 58.661V with minimum ripple voltage of 0.488V. The experimental results show that the converter managed to regulate the output voltage at 57.8V which is 1.47% lower than that of simulation. The result signifies the efficacy of the converter system control algorithm.**

***Index Terms*—PV, PWM, dc-dc boost converter, PIC microcontroller**

I. INTRODUCTION

Presently, natural resource such as fossil-based fuel is considered a major source of energy, especially in developing countries and remote areas [1-2]. However, this energy is a non-renewable type of energy resource that tends to pollute the environment. Thus, a photovoltaic (PV) system becomes one of the alternative methods in renewable energy harvesting systems and programs. The energy from PV can be utilized for various direct current (dc) and alternating current (ac) applications, e.g. standalone power source, grid-connected power system and electric vehicles [3-4]. Depending on the nature of the application, the PV system requires power conditioner such as dc-dc converter, rectifier and inverter [5-6].

Unfortunately, the constraint of the PV such as the non-linear output characteristic poses challenges in designing better PV system. The PV output power depends on the intensity of the sun irradiation. A change in the weather condition causes a change in the PV output power [7]. As a result, the continuous flow of input power to electronic and electrical devices is disturbed. Any shadow falls on the PV panel or in the event of irregular solar irradiation causes the PV power to fluctuate. Thus, the need of producing stable output power from electrical devices could not be achieved. Hence, the design of converter control systems must consider the PV output fluctuation characteristic. Addressing these issues, various type of controllers and system control strategies are found in the literature [8-10]. Some of them used voltage feedback techniques [11-14]. The output voltage is controlled by microcontroller unit using output voltage feedback technique determined by the voltage divider at the load voltage. An alternative approach for controlling the converter output voltage is by utilizing the converter input voltage level. The control algorithm specifies that only a specific range of input voltage can produce the desired constant output voltage. In other words, no energy conversion is performed whenever the PV output voltage is lower than the minimum level, thus conserving the system operating energy. The algorithm is designed in such a way that by monitoring the PV output voltage level, a pulse-width modulation (PWM) duty cycle, which is proportional to the corresponding PV output level is produced. By the essence of PWM transistor switching action of the dc-dc boost converter, the specific ranges of the PV output voltage can be converted to a regulated output voltage.

II. SYSTEM CONFIGURATION

The system configuration of the PIC-based PV dc-dc boost converter is illustrated in Figure 1. It consists of a dc-dc boost converter, PIC microcontroller, PV panel, voltage sensor and gate driver. The boost converter receives a dc voltage level from the PV panel and steps-up to a specific dc voltage level. The PIC microcontroller manages the overall operation of the boost converter by generating a pulse-width modulation (PWM) signal for the voltage converter power device such as MOSFET. The generated PWM signal is proportional to the corresponding input voltage. Thus, a specific output voltage requirement can be generated for driving dc loads. Considering the type of power device, a gate driver is employed as the interface between the microcontroller and the power device. The PV output voltage monitoring is made possible by integrating the dc voltage sensor into the system.

By monitoring a specific dc input voltage range, the system ensures the boost converter produces the desired output voltage. At the same time, the output voltage is well regulated.

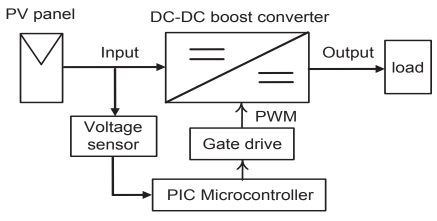

Figure 1: Dc-dc boost converter system configuration

III. SYSTEM SIMULATION

The boost converter circuit simulation is carried out in the PSpice OrCAD environment. Figure 2 presents the circuit simulation of the boost converter. The configuration is a fixed type control strategy which functions to ensure that the designed converter circuit is capable of generating the required output voltage in the presence of certain input voltage level. Considering the dc input voltage and desired output voltage level of 15V and 60V, respectively, the PWM signal duty cycle is set to 75%. The input voltage (V_{in}) and output voltage (V_{out}) transfer function of the converter related to the input and output voltage is described by equation (1)[15].

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \tag{1}$$

where D is the duty cycle of the switching device (IRF540). Substituting 15V for the V_{in} and 60V for the V_{out} into equation (1), the duty cycle D is calculated to be 0.75 or 75%.

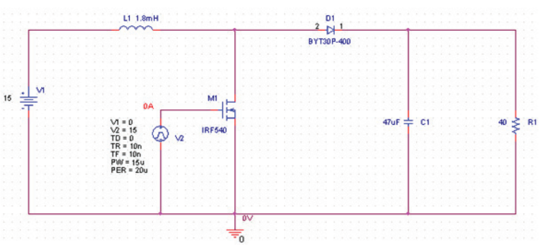

Figure 2: Dc-dc boost converter circuit simulation

As shown in Figure 2, the dc input voltage supply of 15V is used to represent the PV panel due to the unavailability of the device in the PSpice simulation library. Considering the input voltage of 15V, desired power capacity, and output voltage of 90W and 60V, respectively, a 40Ω resistive load is used. The desired output voltage ripple is based on the 0.9% voltage ripple, which is 0.54V. In order to reduce the power loss due to the switching process and to reduce the output voltage ripple, the switching frequency of 50 kHZ is selected. In this work, a power transistor MOSFET IRF540 is used for its parameter suitability. The selection of the capacitor is described by equation (2) [16-17].

$$C_{out} = \frac{V_{out} \times D}{f \times R_L \times \Delta V_{out}} \tag{2}$$

where f is the switching frequency, ΔV_{out} is the ripple voltage and R_L is the load resistance.

In order to observe the system performance and the integration of dc-dc converter and its control system, the simulation is carried out in PROTEUS ISIS Professional environment. The simulation serves as the justification for the prototype development. Figure 3 and Figure 4 depict the converter circuit and the PIC microcontroller, respectively. Instead of low in cost, the development of the control algorithm and the system simulation are made simple and handy by utilizing this type of microcontroller. The PIC and its architecture are shown in Figure 5. It contains a central processing unit, memory; e.g. random–access, read-only memory, ports; e.g. input/output, serial and parallel port, analog-to-digital and digital-to-analog converters [18]. In Figure 3, the input power for the load is provided by the battery, BAT1, due to the unavailability of the PV device in the software library. Both voltmeters display the input and output converter stages.

As can be seen in Figure 4, the PIC16F877A, which has been embedded with the control source code, monitors and measures the input voltage through pin 2 (RA0/AN0) by means of voltage division provided by both R2 and R3. The microcontroller output pin 17 (RC2/CCP1) provides PWM signal to MOSFET, M1, which can be seen in Figure 3.

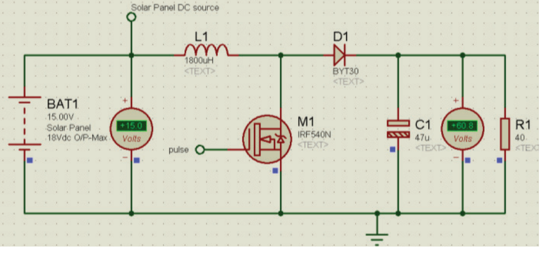

Figure 3: Dc-dc boost converter circuit simulation in PROTEUS ISIS

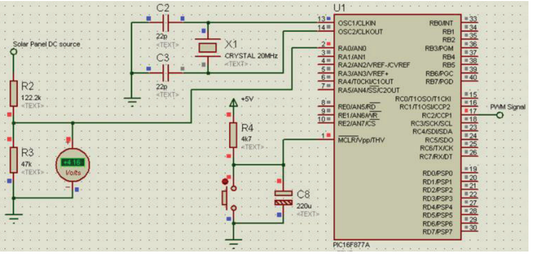

Figure 4: PIC control circuit simulation in PROTEUS ISIS

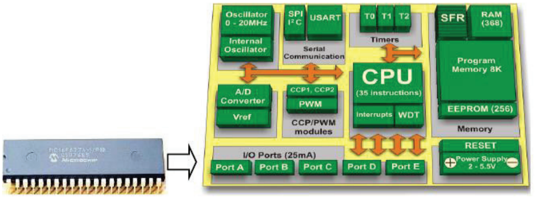

Figure 5: PIC microcontroller and architecture

The generation of PWM signal is made possible by the utilization of PWM built-in function available in the PIC microcontroller called Capture/Compare/PWM (CCP). With the integration of the measured PV output voltage level, specific control strategy, and the PWM built-in module, a corresponding PWM signal is generated.

IV. EXPERIMENTAL SET-UP

In order to validate the simulation, a dc-dc converter prototype was built and tested in a laboratory. It is shown in Figure 6. Among the equipment used are Sanwa handheld digital multi-meter, Agilent storage oscilloscope and power supplies.

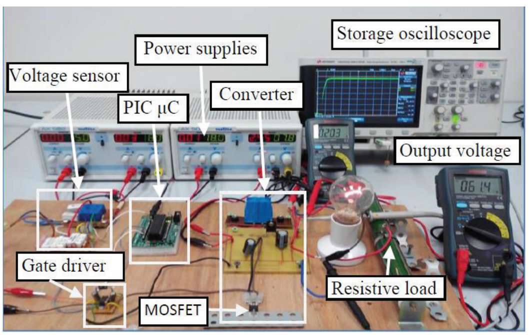

Figure 6: In-lab dc-dc boost converter experimental set-up.

In this experiment, the PV panel HX-100W with a capacity of 100W is used, as shown in Figure 7. The characteristic of the solar panel is shown in Table 1.

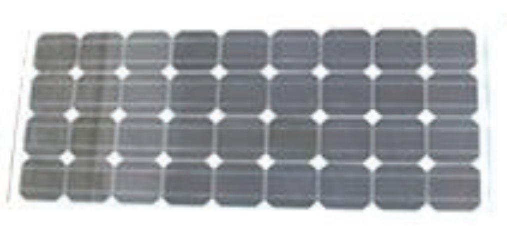

Figure 7: Photo of PV panel HX-100W

Table 1
Characteristic of HX-100W

Symbol	Quantity	Value
V_{oc}	open-circuit voltage	21.24V
I_{sc}	short-circuit current	6.11A
V_{mp}	voltage at maximum power	18.0V
I_{mp}	current at maximum power	5.55A
P_{mp}	maximum power	100W

The voltage sensor LEM LV25-P is used to measure the input voltage and fed to the PIC microcontroller. This transducer outputs a proportional maximum 5V voltage that is compatible with the microcontroller input requirement.

V. RESULT AND DISCUSSION

In this section, the simulation and experimental results are presented to evaluate the effectiveness of the overall dc-dc converter PV system. The results are explained in the following manner.

A. Simulation Results

The PWM signal for the switching device, which is generated by the microcontroller, determines the converter output voltage level. Such simulation signal waveforms are depicted in Figure 8. In the simulation, it can be observed at Ch A of digital oscilloscope, which exhibits 5V level at 50 kHz. Since the switching device requires a 15V input level, a gate driver is used. Ch B shows the output waveform of the driver that acquires 15V level.

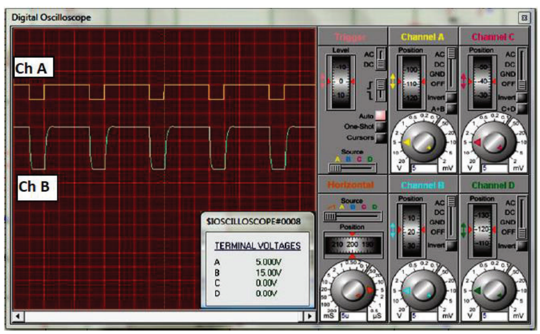

Figure 8: Simulation PWM signals

The output voltage waveform across the capacitor C1 and resistor R1 of the converter circuit in Figure 3 is captured and presented in Figure 9. As seen in the figure, initially the voltage exhibits an overshoot and gradually stabilizes at 58.661V. It shows a good agreement between the theoretical and simulation. A close look at the voltage ripple shows a ripple of 0.488V as seen in Figure 10.

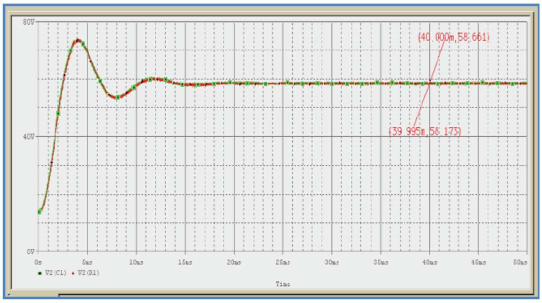

Figure 9: Output voltage waveform across load

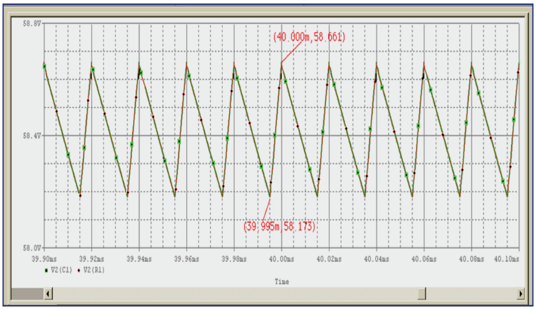

Figure 10: Output voltage ripple waveform

The load current waveform is captured to observe the converter power supply behavior. Figure 11 depicts the waveform of the load current. It shows that the current is stabilized at 1.484A. Thus, the power delivered to the load is 87.5W.

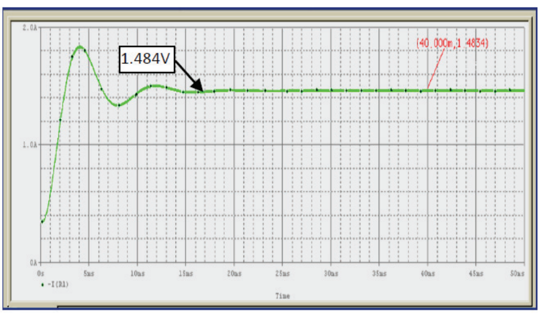

Figure 11: Load current waveform

Table 2 presents the input-output response in the presence of the converter input voltage variations. It shows that as long as the input voltage variations are within the specific ranges (9V to 18V), the converter output voltage is well-regulated. Otherwise, the converter output voltage is zero as shown in the table.

Table 2
Converter input-output response

Input voltage	Output voltage
18V	58.90V
16V	58.90V
15V	58.66V
11V	58.39V
9V	57.80V
8V	0.05V

Figure 12 shows the PWM signals captured by the storage oscilloscope. The signals are obtained from the output of the PIC microcontroller and the gate driver. Channel 1 and Channel 2 display the gate driver input and output signal, respectively. The output signal exhibits 15.3V voltage peak level at the 50 kHZ, which is suitable for driving the MOSFET IRF540.

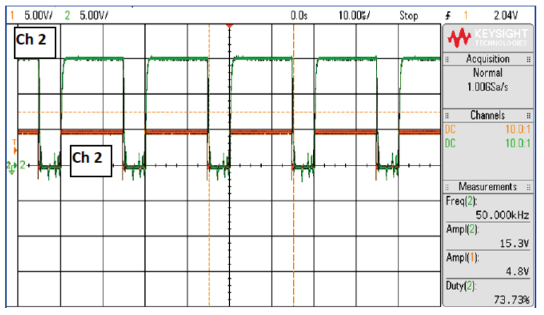

Figure 12: PWM waveform from PIC and gate driver

Figure 13 shows the snapshot of the converter load voltage waveform. As seen, initially, the output voltage exhibits a good transient response without overshoot and gradually stabilized at 57.8V. This is 1.47% lower than the simulation, which is considered a good, acceptable and reasonable figure.

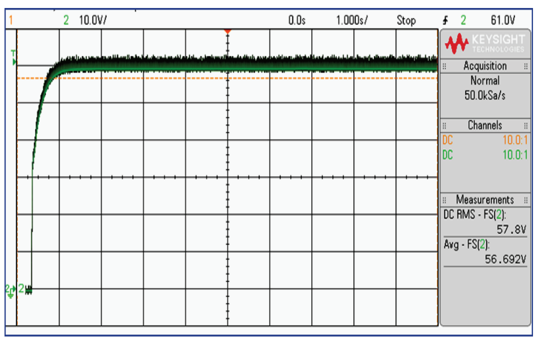

Figure 13: Load voltage waveform

VI. Conclusion

The development of PV dc-dc boost converter system utilizing the PIC16F877A microcontroller was presented. Both the converter circuit and its control algorithm were simulated in PSpice and PROTEUS ISIS Professional environment, respectively. The converter prototype was built and tested in the laboratory. The PV panel with the capacity of 100W and voltage at maximum power of 18V was used to provide dc input power for the converter. With the PV output voltage, the converter managed to generate a boosted dc output voltage of 58.66V. The test results of both simulation and experimental showed that they are in agreement. This shows the effectiveness of the PIC-based boost converter control system in generating, boosting and stabilizing the output voltage.

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