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DC-DC Power Converter of 24/320 Volts with Microcontroller Based Proportional Integral Voltage Controller

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Abstract: This study provides a laboratory prototype test results of a DC-DC converter used to convert a lower dc input voltage into a higher dc output voltage. The power converter is suitable to boost an output voltage of renewable energy source such as photovoltaic system into higher and stable voltage level. The converter is constructed using power IGBT. The input voltage in the experimental test is 24 V which is boosted into 320 V. The power converter is controlled using proportional integral voltage controller implemented by using microcontroller. Some computer simulation and experimental test results were presented in the study. The obtained data confirmed that the prototype works well.

Key words: DC-DC converter, voltage, PI controller, experimental, converter, suitable

INTRODUCTION

DC-DC converters are the converters used to convert a certain DC voltage level to another DC voltage level that can be lower, higher or both lower and higher compared to the original DC voltage. The applications of the DC-DC converters can be found in many fields such as in the automotive and in the renewable energy applications. In the automotive application, the DC-DC converter required to control the charging of the battery from an input voltage range of 230-430 V (Jitaru and Bolohan, 2012). In the renewable energy applications such as in PhotoVoltaic (PV) system, the converters are usually used to convert the voltage of the generated electricity to a level required by the load and/or the power grid to which the PV system is connected and to maximize the efficiency of the PV system (Zeng *et al*., 2012; Li and Wolfs, 2008).

In this study, a design of DC-DC converter used to step-up a 24 V DC voltage into 320 V Dc output voltage is presented. The power converter is controlled by implementing a proportional-integral controller in order to obtain a stable dc output voltage. The control method is realized by using microcontroller circuits. The converter is tested using computer simulations and validated experimentally using a laboratory prototype constructed using power switch IGBT.

MATERIALS AND METHODS

System diagram: Figure 1 shows the main components of the proposed 24/320 V DC-DC converter. The DC input voltage can be battery, rectifier or the output terminal of photovoltaic system. The power circuit of the DC-DC converter is the circuits working in high power rating to convert the DC input voltage. The controller part will determine the operation of the DC-DC converter circuits. The output signal of the controller is connected to the power circuits of DC-DC converter through the driver circuits (Suroso, 2011).

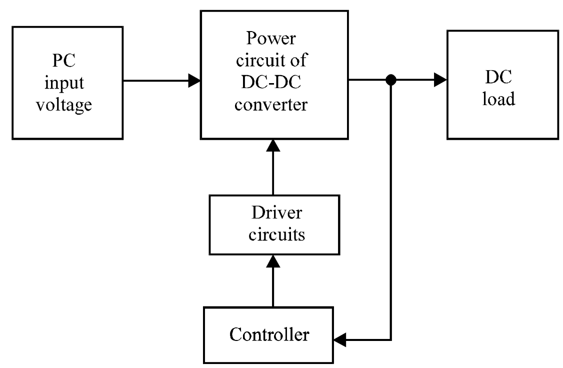

Fig. 1: Diagram of DC-DC converter

Power circuits: Figure 2 presents the circuits of the DC-DC converter. The main components consist of inductor (L), IGBT (Q_C), Capacitor (C) and power Diode (D). The voltage V_{dc_in} is the dc input voltage of the converter. The IGBT switch will operate turn-on and turn-off alternately. The turn-on interval is determined by the duty cycle of the gating signal generated by the controller. The power inductor stored the energy during the turn-on period. When the switch is turn-off the energy will be transfer into the power load. The load voltage will be the sum of the dc input voltage and the voltage across the power inductor (Inaba *et al*., 2002; Rashid, 2010;

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Table 1: Design parameters

Parameters	Values
DC input source	24 V
Output voltage reference	320
Voltage ripple	1%
Switching frequency of converter	28 kHz

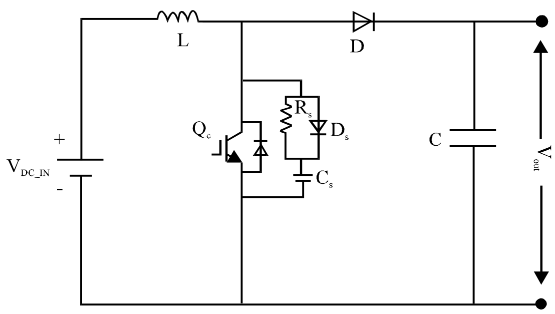

Fig. 2: Power circuit of DC-DC converter (Rashid, 2007)

Mamun *et al*., 2013). This operation is the step-up voltage operation. The resistance R_s, diode D_s and capacitance C_s are the components of the snubber circuits used to protect the power switch Q_c during switching operation of power converter.

In this research, the DC-DC converter circuit is designed to produce 320 V DC output voltage from the input of 24 V DC using parameters as listed in Table 1. Using the above parameters, the duty cycle of DC-DC converter is 92.5%, the minimum size of power inductor and capacitor are 9.904 mH and 33.48 μF, respectively. To protect the converter during switching operation, a snubber circuits is connected across the power IGBT with capacitor and resistor snubber are selected as 2.5 nF and 6607.14 Ω. The snubber circuit will minimize the voltage spikes during switching.

Gating signal generator: Gating signal is required in order to operate the power switch IGBT. In this research, the gating signal is generated by using a microcontroller Atmega series. The pin configuration of this IC is shown in Fig. 3. This IC will proceed the measured output voltage and the reference voltage to generate the error signal. This error signal will be processed by the PI controller to generate gating signal of the IGBT. The duty cycle of the gating signal is determined by the error signal and the reference voltage.

Driver circuits: Optocoupler is an isolated gate drive circuit required to make a power semiconductor switch such as IGBT and power MOSFET works turning ON and OFF. This component is very essential as an interface and isolation between the low power control circuits and the power circuits. The gate drive circuits used in the proposed converter circuits is shown in Fig. 4. The IC TLP 250 optocoupler is utilized.

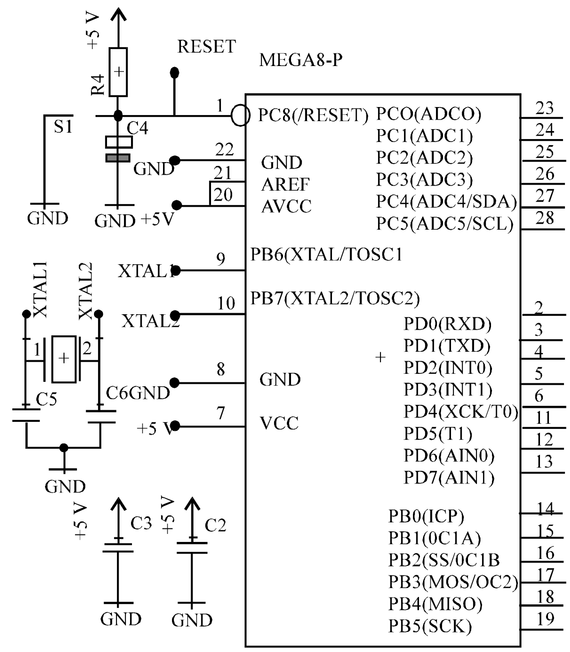

Fig. 3: Gating signal generator circuits (http://www.atmel.com)

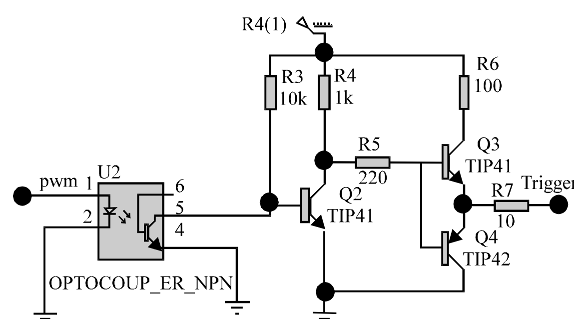

Fig. 4: Gate drive circuits

Voltage controller: A voltage controller with fast response is absolutely necessary in order to obtain the desired dc output voltage of the converter and to assure the circuits works properly. In the proposed DC-DC converter, a simple Proportional controller (PI) is applied to regulate the output voltage of the converter circuits. The parameters of the PI controller are tested and selected using computer simulation. Figure 5 shows the PI controller used in this converter. The output voltage V_{out} is regulated by setting the value of the command voltage V_{ref}. A comparison between the carrier signal and the output signal of the PI controller is done in the LM311 comparator circuits. The PWM output signal of the comparator is fed to the driver circuits to drive the IGBT switch.

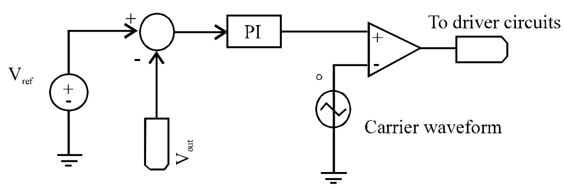

Fig. 5: PI controller

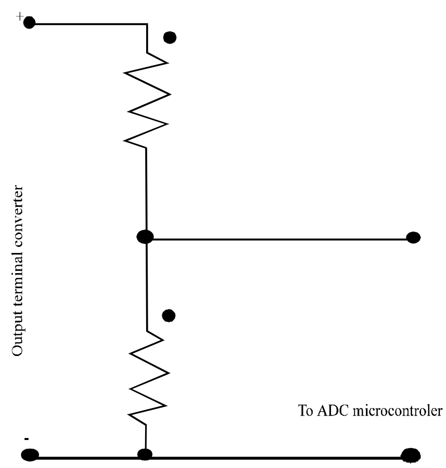

Fig. 6: Voltage sensor circuits

Voltage sensor circuits: A DC voltage sensor is required to measure the output voltage generated by the power converter circuit. This voltage measurement will set duty cycle of the gating signal to keep a constant output voltage of the converter. Figure 6 shows the circuits used as the voltage sensor of the DC-DC converter. This circuit is a simple resistive voltage divider. The output of the voltage sensor will be sent to the microcontroller via. Analog to Digital Converter (ADC) port. This signal will be processed by the PI controller using microcontroller.

RESULTS AND DISCUSSION

The DC-DC converter with circuits parameters as explained in the previous part is tested by using computer simulation with power PSIM software. The power converter as shown in Fig. 7 is examined. The results of the computer simulations are given in Fig. 8-14.

Figure 8 is the DC input voltage waveform of the converter circuits. The current waveform passing through the inductor component of the DC-DC converter is indicated in Fig. 9. It presents also the transient current waveform when the converter starts working. Figure 10 is the current flowing through the diode component of the

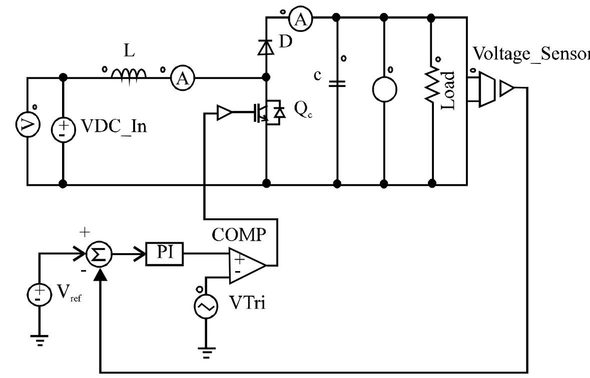

Fig. 7: DC-DC converter simulation circuits

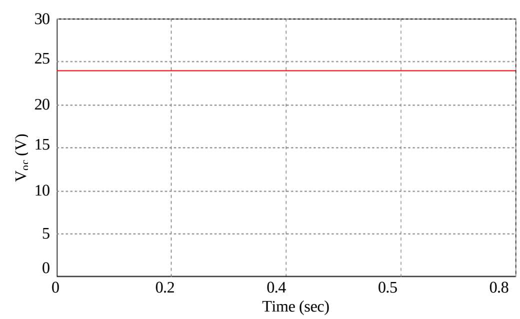

Fig. 8: DC input voltage

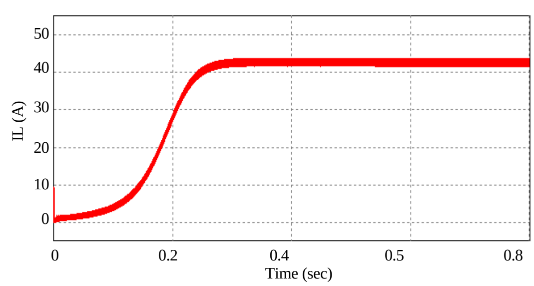

Fig. 9: Inductor current waveform

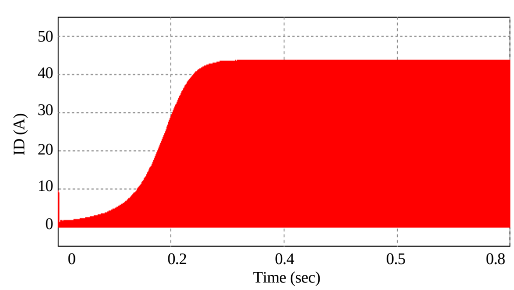

Fig. 10: Diode current waveform

DC-DC converter. Figure 11 presents the current pattern of the controlled switch IGBT. The magnitude of this current is the same with the inductorcurrent waveform,

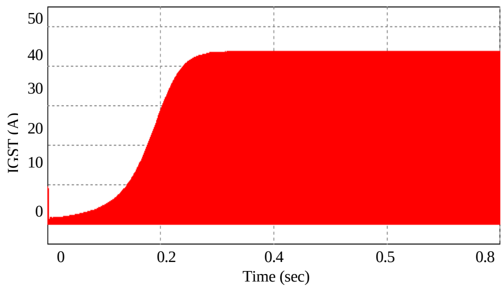

Fig. 11: Current waveform flowing through IGBT

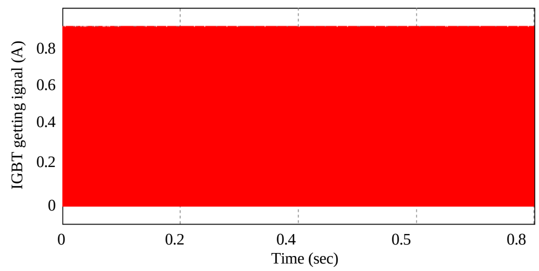

Fig. 12: Gating signal of IGBT switch

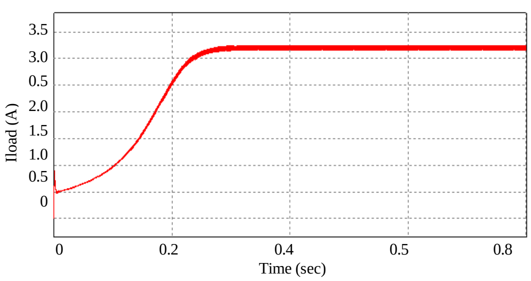

Fig. 13: Load current waveform

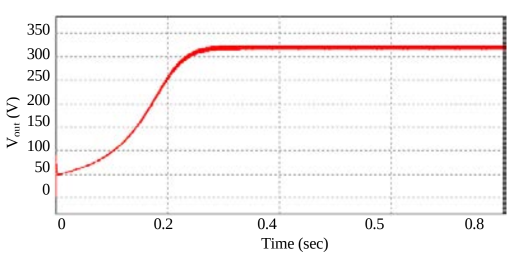

Fig. 14: Output voltage waveform of converter

however, this current is a PWM current waveform formed by the switching pattern of the converter's power IGBT switch as denoted in Fig. 12. The current and the voltage across the power load of the DC-DC converter circuits are presented in Fig. 13 and 14, respectively. The starting transient waveform also can be observed in these figures. The DC-DC converter works properly generating a 320 V DC output voltage from the 24 DC input voltage.

Laboratory prototype test results: In order to prove the computer design and simulation test results, a DC-DC converter prototype has been constructed using IGBT switch IRG4BC20UD. This IGBT is equipped with ultrafast soft recovery diode. The prototype was tested experimentally in laboratory. Figure 15 shows the prototype picture. The laboratory test is done to verify the DC-DC converter performance. The prototype of the DC-DC converter is connected to the dc voltage source which is set to 24 V. The data were measured using a digital oscilloscope. Some measurement waveforms using oscilloscope of phe prototype test results are shown in Fig. 16-19.

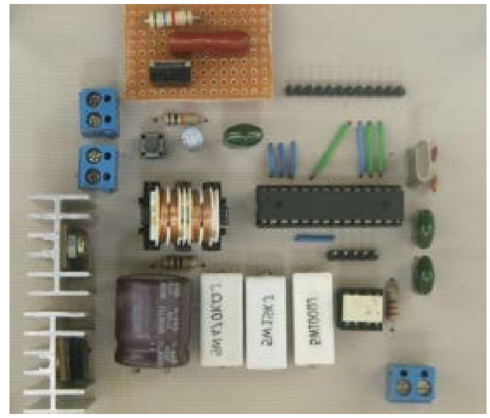

Fig. 15: Prototype of 24 V/320 V DC-DC power converter

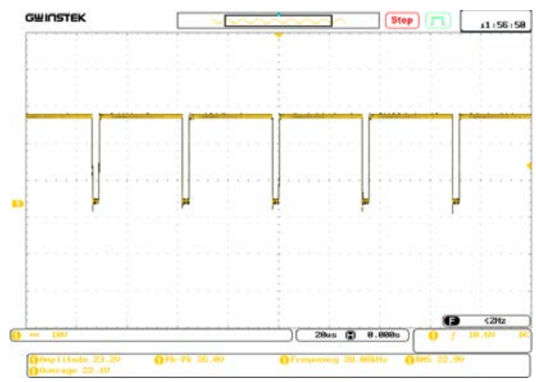

Fig. 16: Measured gating signal of IGBT

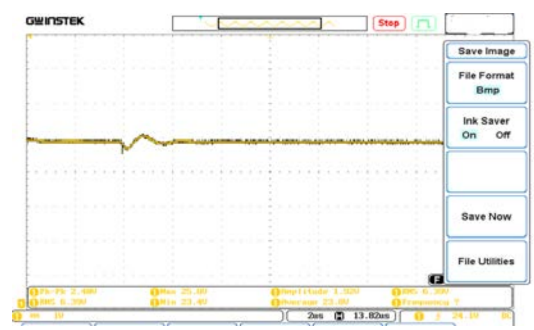

Fig. 17: The measured dc input voltage

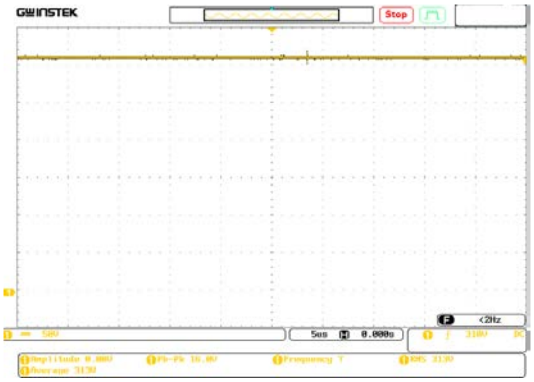

Fig. 18: The DC-DC converter's output voltage

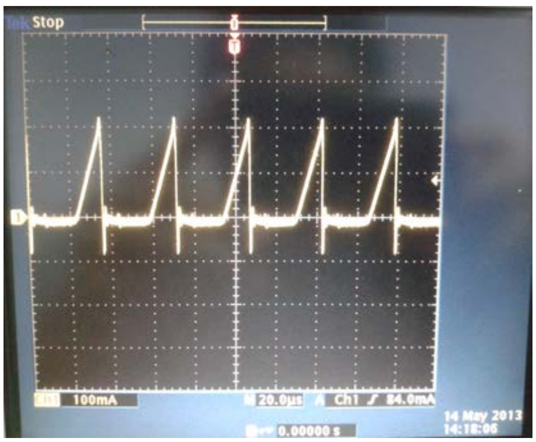

Fig. 19: Inductor current of DC-DC converter

Figure 16 shows the gating signals of the IGBT with duty cycle set to be 92.5%. This signal is the output signal of the driver circuits. Figure 17 and 18 are the DC input voltage and output voltage waveforms of the DC-DC converter, respectively. In Fig. 18, the measured DC voltage generated by the power converter is 313 V. This result is little bit different with the output voltage in the computer simulation. This difference can be caused by non ideal conditions of the components used to construct the converter circuits such as diode voltage drop, resistance of the inductor and collector-emitter saturation voltage of the IGBT. The measured current in the inductor is shown in Fig. 19. The frequency of this PWM current is 28 kHz which is the turn-on and turn off frequency of the power converter circuits.

CONCLUSION

A prototype design of a step-up DC-DC converter is discussed in this study. The converter works to increase the dc input voltage into a higher DC voltage using PI voltage controller. The prototype was build using power semiconductor controlled switch IGBT. The laboratory prototype of the DC-DC converter is tested to boost a 24 V DC voltage into 320 V. The test results proved that, the proposed DC-DC power converter controlled using microcontroller circuit has worked well. Non ideal conditions of the components have caused error in the measurement results of the converter prototype.

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