

DC-DC CONVERTER EXPERIMENTAL TOOL

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Abstract

Power electronics received from any source of electrical energy electronic methods of controlling (converted or processed) is the process of transferring the load to be controlled. DC-DC converters which are basic implementation of power electronics are used for obtaining fixed or variable DC voltage by decreasing or increasing.

In this study, the microcontroller controlled DC-DC converter types (buck, boost, buck-boost, cuk and sepic) are performed on an experimental tool. Power and control circuit with high switching frequency, various different load cases and according to the duty ratio, the output voltage has been examined. Electrical operation of the control and measurements in conjunction with teaching; recognition of circuit elements, design, analysis and applied education designed in a modular structure to help. Practice manuals are prepared to help the students.

Key words: DC-DC converter, educational tool, Power electronics.

1. Introduction

Experimental verification is a main factor in engineering education and research methods. However, practical applications remain limited because of time, place and security problems [1]. In education of traditional engineering subjects, combining of theoretical education, practices and laboratory experiments is mandatory [2]. Engineering students must be trained by hard laboratory trainings for gaining practical skills, experiences in addition to theoretical education [3]. By developing technology, computer aided education tools have become more important to learn traditional engineering subjects such as electrical, electronics, mechanical, construction and chemistry [2], [4]–[6].

Power electronics is an inseparable part of modern energy systems. Power electronics based on devices provide an efficient and reliable way to transfer power to main systems [7]. Nowadays, power electronics applications have increased incrementally. Computers, cell phones, cars, planes, industrial and daily stuffs couldn't be produced without power electronics. Furthermore, solar, wind and fuel cells that are being used in energy sector need power electronics [8].

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DC–DC conversion technology is an important research area in the field of power electronics and it has been under development for decades. DC–DC converters are commonly used in applications requiring regulated DC power such as computers, communication devices, battery chargers, switched mode power supplies, and DC machine drive applications[6]. Therewithal, DC-DC converters are used for applications of smooth speed control of engines applications and have advantages such as high efficiency and dynamic response [9].

In this study, the microcontroller controlled DC-DC Converter types (buck, boost, buck-boost, cuk and sepic) were performed on experimental tool. Experimental tool will provide practical training, which is one of the most important part of engineering education and will help to solve real-world problems in an effective way.

2. Materials and Method

DC-DC converters are circuits that generally give steady output and convert DC voltage to another voltage level. DC-DC converters are used for obtaining stabilized or changing DC voltage(s) by increasing, decreasing or multiplexing from any DC source [10].

Commonly, rectified and unregulated DC voltage obtained from line voltage is used as an input for these converters. Thus, step-up and step-down processes are handled a priori as an input to these converters. Unregulated DC voltage levels are regulated by using DC-DC converters [6]. Generally, these converters can be classified under two parts which are non-isolated and isolated DC–DC converters. The classifications of these converters are shown as follows [11]

Non-isolated fundamental DC–DC converters:

- (1) Buck converter.
- (2) Boost converter.
- (3) Buck–Boost converter.
- (4) Cuk converter.
- (5) Sepic converter.

Isolated fundamental DC–DC converters:

- (1) Flyback converter.
- (2) Forward converter.
- (3) Zeta converter.

Three fundamental structures of DC-DC converter circuits are buck, boost and buck-boost converters. Other converters are developed from these three main structures [6]. In Figure 1, DC-DC converter block diagram is shown.

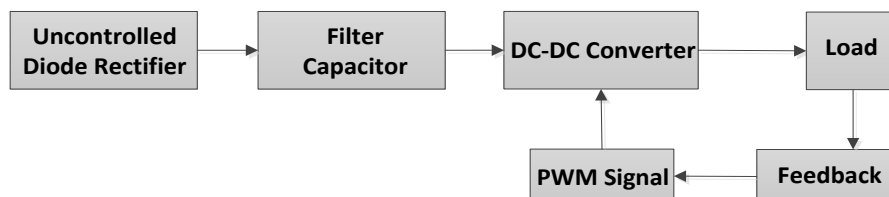


Figure1. DC- DC converter block diagram [6]

2.1 Buck Converter

The Buck or Step-down converter regulates the average DC output voltage at a level which is lower than the input voltage. Circuit diagram of the buck converter is shown in Figure 2.

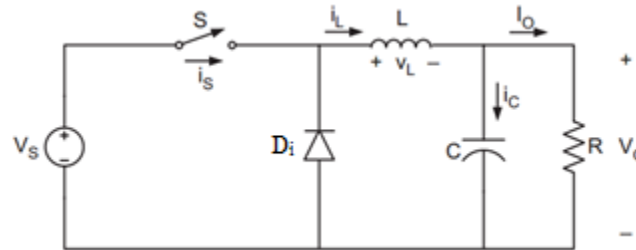


Figure 2. Circuit diagram of buck converter [8].

A buck converter circuit consists of DC input voltage source V_s , controlled switch S , diode D_i , filter inductor L , filter capacitor C and load resistance R . In the circuit, V_o is output voltage [8]. The relationship among input voltage, output voltage and the switch duty ratio (D) is given in Eq. (1).

$$V_o = V_s D \quad (1)$$

The switch S is being operated with a duty ratio D defined as a ratio of the switch on time to the sum of the on the off times. Furthermore, duty ratio changes between (0, 1). It can be seen from Eq. (1) that the output voltage is always smaller than the input voltage [8].

2.2 Boost Converter

The Boost converter regulates a higher DC voltage than input voltage. Circuit diagram of the boost converter is shown Figure 3.

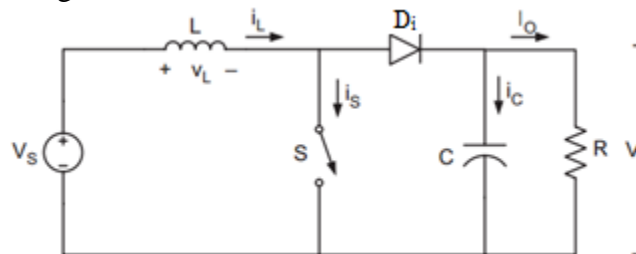


Figure 3. Circuit diagram of Boost converter [8]

The boost converter is comprised of DC input voltage source V_s , boost inductor L , controlled switch S , diode D_i , filter capacitor C and load resistance R . In the circuit, V_o is output voltage [8]. The relationship among input voltage, output voltage and the switch duty ratio is given in Eq. (2).

$$V_o = \frac{V_s}{1 - D} \quad (2)$$

2.3 Buck-Boost Converter

The buck–boost converter is a third type of DC-DC converter. The output voltage magnitude is either less or greater than the input voltage magnitude. In fact, this new converter is obtained by interchanging the diode D_i and the inductor L of the buck converter [12]. Circuit diagram of buck-boost converter is shown in Figure 4.

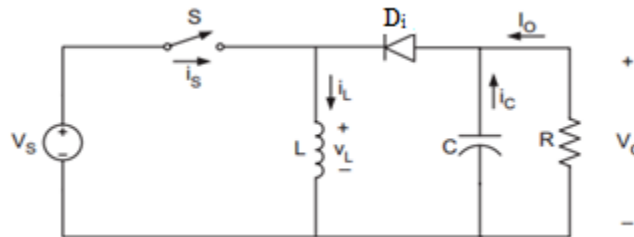


Figure 4. Circuit diagram of Buck-Boost converter [8].

The converter consists of DC input voltage source V_s , controlled switch S , inductor L , diode D_i , filter capacitor C and load resistance R . In the circuit, V_o is output voltage [8]. The relationship among input voltage, output voltage and the switch duty ratio is given in Eq. (3).

$$V_o = -V_s \left(\frac{D}{1-D} \right) \quad (3)$$

2.4 Cuk Converter

Using aforementioned converters, one can develop other beneficial DC-DC power converters. A typical example is cuk converter which is the cascade connection of the boost and the buck converter. Circuit diagram of cuk converter is shown in Figure 5. The input circuit in the cuk converter is a boost converter and the output circuit is seen to be a buck converter [12].

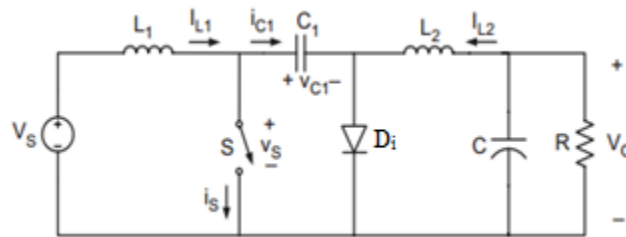


Figure 5. Circuit diagram of Cuk converter [8].

The converter consists of DC input voltage source V_s , input inductor L_1 , controllable switch S , energy transfer capacitor C_1 , diode D_i , filter inductor L_2 , filter capacitor C , and load resistance R . In the circuit, V_o is output voltage [8]. The relationship among input voltage, output voltage and the switch duty ratio is given in Eq. (4).

$$V_o = -V_s \left(\frac{D}{1-D} \right) \quad (4)$$

This input-output relationship of cuk converter is the same as that for the buck–boost converter.

2.5 Sepic Converter

A converter similar to the cuk is the single-ended primary inductance converter [12]. Circuit diagram of sepic converter is shown in Figure 6.

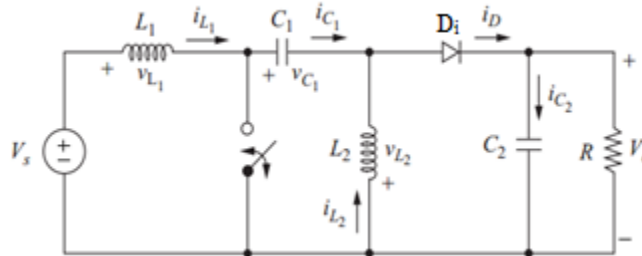


Figure 6. Circuit diagram of sepic converter [10].

The sepic converter consists of DC input voltage source V_s , input inductor L_1 , controllable switch S , energy transfer capacitor C_1 , diode D_i , filter inductor L_2 , filter capacitor C_2 , and load resistance R . In the circuit, V_o is output voltage [8]. The relationship among input voltage, output voltage and the switch duty ratio is given in Eq. (5).

$$V_o = V_s \left(\frac{D}{1-D} \right) \quad (5)$$

3. Experimental Study

DC-DC Converter types (buck, boost, buck-boost, cuk and sepic) can be performed on experimental tool. Input voltage can be adjusted between 5-12 Volts. Switching can be triggered with 20 kHz PWM frequency by microcontroller. Three buttons, on the experimental tool, can adjust the PWM duty ratio. 0.25, 0.50 and 0.75 duty ratio PWM signals are being sent to switch by buttons. Output voltage is being measured by voltmeter. Switching frequency and duty ratio is shown in LCD screen.

Modules are made separately for each material types in order to make experimental tool easy to understand. Each circuit element fixed by born screws and made easy to design experiments on tool. Experimental tool is shown in Figure 7 and each module on the experimental tool is explained in Table 1.

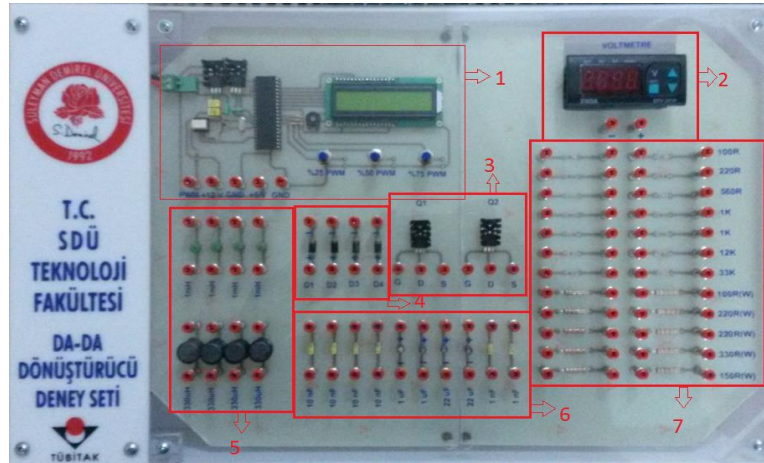


Figure7. Experimental tool

Table 1 Experimental Tool's Modules

Number	Module Name
1	Control Module
2	Measurement Module
3	Mosfet Module
4	Diode Module
5	Coil Module
6	Capacitor Module
7	Resistor Module

4. Discussion

Buck, boost, buck-boost, cuk and sepic converter circuits can be separately tested and results can be observed on experimental tool. For example, boost converter with 5V input voltage, semiconductor switch is being triggered with %50 duty ratio and 11.1 V output voltage is observed. The experiment sheets of converters were produced separately to help the student while designing an experiment. Experiment is shown in Figure 8 and its experiment sheet is shown in Figure 9.

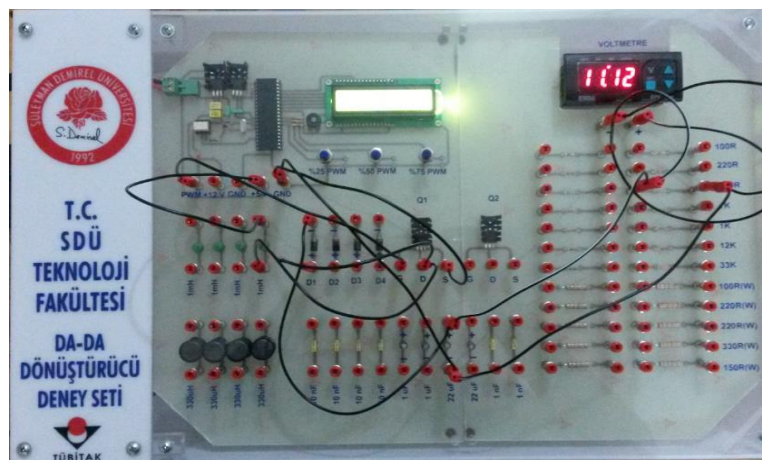


Figure8. Boost converter %50 PWM

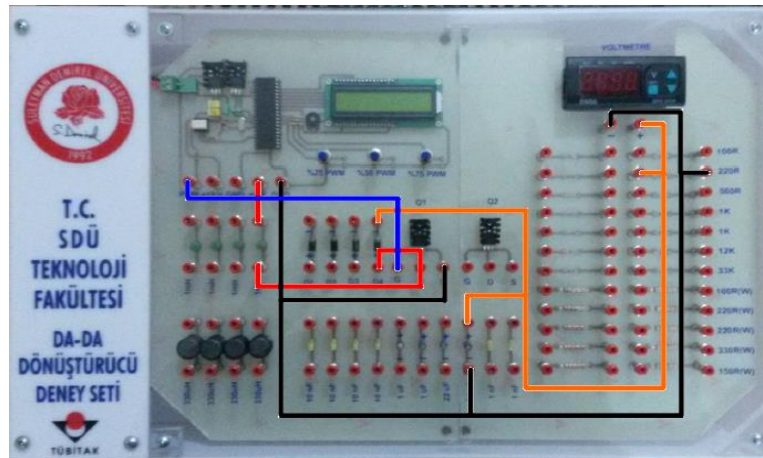


Figure9. Boost converter %50 PWM schema of experiment guide

Engineering students can design experiment easily and see the results of circuit diagram which is shown in Figure 9. Furthermore, circuit of boost converter is designed in Proteus and its circuit is shown in Figure 10.

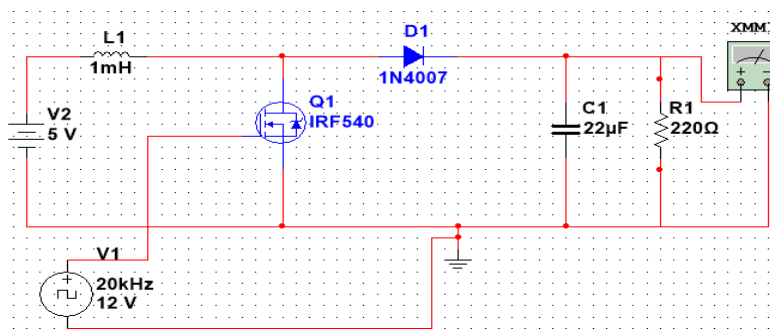


Figure10. Circuit of boost converter in Proteus

Conclusions

In this study, an experimental tool designed and produced for the institutions which train DC-DC converters in power electronics lessons by an efficient and productive way. Training with DC-DC converter experimental tool is more useful according to classical training ways. Moreover, designing and applying experiment will be support students. The lectures will make the training easier for each converter type and can show the student on tool. Engineering student will be well educated and theoretical knowledge can be combined with practice by this way of training.

In DC-DC converter circuits, output voltage, inductor and capacitor's mathematical values must be calculated separately. Experimental tool will help student combining theoretical knowledge with practice. Thus, it will show the students that each application is based on theory and

theoretical subjects must be learn well. With this experimental tool, training can be made more useful and helpful and engineering students will be well educated about the subject of power electronics DC-DC converters which is being used in industry widely. Being modular will enable the experimental tool to be developed.

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