Design and Implementation Buck-boost Converter using Arduino Mega 2560

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Abstract: Nowadays, the development of technology cannot be separated from energy demands. An increasing energy requirement needed power electronic circuits to support systems that are producing a direct voltage or commonly called Direct Current (DC). A problem obtained is to convert the desired voltage level according to desired requirements. The development of power electronic circuits can be solving these problems by using a DC-DC converter topology. In general, DC-DC converters have several topologies such as buck converter, boost converter, buck-boost converter, and Cuk converter. In this research, an inverting buck-boost converter topology is designed and implemented to increasing and decreasing voltage. The aim of this research is converting the input DC voltage value to the constant output DC voltage value. A value of duty cycle configuration is depending switch on and switch off from MOSFET, which generated from Arduino Mega 2560. The results of the average output voltage value from the mathematical condition is 12 Volt; after that, from simulation condition is 12,05 Volt and then from implementation condition is 9,92 Volt. The results of the average ripple output voltage from the mathematical condition are 0,4%, after that from the simulation is 0,79% and then from implementation condition is 0,56%. The results of the average ripple value current from the mathematical condition are 6.54% and then from simulation condition is 6.94%. Finally, the buck-boost converter system that has been designed from this research has obtained an average value of power efficiency in the simulation conditions is 65.12% and then from implementation condition is 74,87%.

1 INTRODUCTION

The development of power electronics has played a role in everyday life to produce a Direct Current (DC). DC voltage is generated by the process of converting DC input voltage to DC voltage for lower or higher output desired. This DC voltage conversion is commonly referred to as DC-DC Converter. The application of DC-DC converters on an electronic device has made it possible to use resources that have relatively small voltage values such as batteries and batteries, where the output voltage source can be adjusted according to usage requirements (Forouzesh, 2017).

DC-DC converter or known as DC chopper, is often used as a DC voltage regulator, both decreasing and increasing voltage. In general, DC voltage generated from renewable energy sources is volatile because it is caused by natural factors such as light intensity. Currently, the application of the DC-DC converter is widely applied to renewable energy sources such as solar panels (Choudhary, 2014). DC

Chopper consists of several configurations, and the most commonly used is DC Chopper types of Buck, Boost, Buck-Boost, Cuk, and SEPIC. The buck converter system is a non-isolated switching type DC converter that can reduce the output voltage and then boost converter, which can increase the voltage by adjusting the duty cycle from Pulse Width Modulation (PWM) (Rashid, 2014).

The disadvantages of the buck converter and boost converter can only step down or step up the output voltage level that given and cannot be used in both conditions. When we set a variable input voltage value to be constant, a combination of the buck-boost converter can be used (Kazimierczuk, 2008). Recently, Arduino microcontrollers are becoming increasingly popular in various studies (Jinook, 2016). This open-source platform has been developed for prototype purposes and is based on easy-to-use hardware and software, providing researchers with key features that can translate into both economic and practical benefits (Buesa, 2019). When we applied the buck-boost converter with an integrated energy

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source, it is better to use a microcontroller that has many digital or analog pins such as Arduino microcontrollers and also can be used to generate PWM for switching components. Therefore, in this research, we applied the design and implementation of the buck-boost converter using ArduinoMega 2560 as an alternative solution to maintaining a constant output voltage with varying input voltage and can be applied to renewable energy sources.

2 RELATED WORK

Padillah, Syahrial and Saodah (2014) applied the switching type DC voltage converter topology, which could increase the boost output voltage. The converter output voltage was controlled by the magnitude adjusting of the signal duty cycle of pulse width modulation (PWM), that generated by using the microcontroller of phase correct PWM mode. The results of the converter output voltage were designed for 48 Volt. The test used the variable resistance load by measuring the voltage and current at both the input and output sides. The test performance was used to determine the efficiency of the boost converter to change in the load and duty cycle.

Muthukrishnan (2014) also studied about boost converter. In this research, about boost converter specialty is achieved 10 times that of input voltage, and more than 10 times of input voltages is possible from the output side by using coupled inductor and parallel capacitor. The output voltage is high, and the voltage stress across the active switch is minimized, and output ripples also minimized. (Chin Wei Chang et al., 2011) applied to prolong the service time of batteries, a good power management strategy should have high conversion efficiency and also take advantage of the full battery voltage range. There are three types of regulators- linear regulations, switching regulators, and switched-capacitor-based converters. The switching regulator is chosen in this research because it can achieve the highest efficiency among them

Khalif Ahadi (2012) explaining about design buck converter. Two units of a buck converter using P-Channel MOSFET (Metal Oxide Semiconductor Field Effect Transistor) and N-type IGBT (Insulated Gate Bipolar Transistor) as a switch are already designed. Experimental results show each buck converters are able to flow a current as high as 60 Ampere on the adjusted voltage of 12.6 volts, but this output voltage is still fluctuating influenced by the input voltage and load. The efficiencies also fluctuate, but they'll reach above 60% under maximum load.

(Arif Muslih Jainudin et al., 2017) also studied DC-DC converter, which concentrated in a buck converter. The switching component used in this research is the MOSFET IRFZ44N type. Based on the measurement results, buck converter with feedback can constrain the output current on 1 Ampere. Meanwhile, when the output voltage feedback working, the value of output voltage can be constrained on 14,4 Volt, and 13,5 Volt with the average efficiency of buck converter without feedback was 87,39%.

Viswanatha (2017) studied circuit modeling, design, simulation, and analysis of non-inverting buck-boost converter. In this research, a voltage control technique is employed to regulate the output voltage irrespective of the variations in input voltage and load variations. To generate the PWM signals to turn on and off the switches of the converter, the control circuit is employed, which consists of very simple basic logic gates to realize closed-loop control with good regulations of load and line. This method can be replaced by the current control technique to generate the pwm signals to regulate the output voltage. A non-inverting converter can be used in the photovoltaic system, which uses a conventional buck-boost converter to charge the battery. Noninverting converters will replace the conventional buck-boost converters used in the battery charging alongside the MPPT logic. (Farah Shabila Dinniyah, 2017) also applied DC-DC converter. This research discusses designing a buck-boost converter for solar panels, with a voltage input range of 10 to 50 Volt. The regulation of output voltage is the main aim in analyzing the success of the design created. The design is simulated with Proteus 8.4 and yields a voltage output with an efficiency of ninety to ninety-nine

In summary, the previous studies used different features and methods for step down and step up output voltage desired; after that, these studies were limited in simulation only, especially a buck-boost converter. So in this research, we design and implementation of buck-boost converter using Arduino Mega2560 and which consists of the specification with a voltage ripple and current ripple desired.

3 IMPLEMENTATION OF BUCK-BOOST CONVERTER

3.1 System Architecture

The proposed DC converter system, as shown in Fig.1, consists of five main components: 1, DC power variable; 2. buck-boost converter; 3, a resistive load; 4, a microcontroller and 5, measuring tools such as AVO meter and oscilloscope. The key from the buck-boost system is regulating a voltage output value to be a constant value, which considers the variation of input voltage from the DC power variable and the value of the duty cycle.
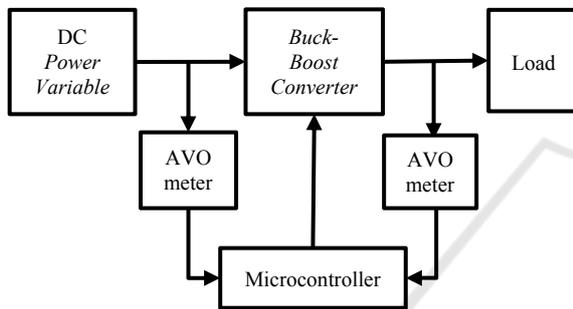

Figure 1: Proposed of block diagram system

The buck-boost converter system process started from input voltage variation, which obtained with a DC variable source. The value of the voltage and current variable readings that have been obtained from measuring tools is used as a reference to do the large duty cycle used. The microcontroller used in this research is ArduinoMega 2560. A value of the duty cycle that has been programmed is processed in the microcontroller to generate PWM for the duty cycle desired. The results of the PWM then forwarded for the gate at the MOSFET to be able to set the switching on the MOSFET. The value of the output voltage depends on the amount of duty cycle given to the system. If the duty cycle value is below 50% system will be in a buck condition, and vice versa, if the value of the duty cycle is above 50% system, it will be in a boost condition.

3.2 Calculation of Components

In this research, we designed the specification of the buck-boost system as a reference for calculating component values.

Table 1: List of Parameters.

Legend	Specification	Value
$V_{s(min)}$	Minimum voltage input	7 V
$V_{s(max)}$	Maximum voltage input	17 V
V_o	Voltage output	12 V
$\Delta V_o / V_o$	Voltage ripple	<1%
$\Delta I_L / I_L$	Current ripple	<10%
F_s	Frequency switching	62500 Hz
R	Resistance	100 Ohm

3.2.1 Duty Cycle Value

$$D_{max} = \frac{V_O}{V_S + V_O} = \frac{12}{7 + 12} = 63\% \qquad (1)$$

$$D_{min} = \frac{V_O}{V_S + V_O} = \frac{12}{17 + 12} = 41\% \qquad (2)$$

Based on specification from table 1, the results of the duty cycle maximum from the equation above is 63%, and the duty cycle minimum is 41%.

3.2.2 Inductor Value

$$L = \frac{V_{in} \times D}{F_s \times \Delta I}$$
$$= \frac{7 \times 0,63}{62500 \times 0,33 \times 0,1} = 2171,75 \; mH \qquad (3)$$

$$L = \frac{V_{in} \times D}{F_s \times \Delta I}$$
$$= \frac{17 \times 0,41}{62500 \times 0,20 \times 0,1} = 5498,22 \; mH \qquad (4)$$

Mentioned to table 1, a limit of the current ripple less than 10%. So, from equation 2 we got inductance value on inductor is 5498,22 μH. Thus according to the literature obtained, in this research, the inductance on inductor value is 6 mH determined as a parameter in the buck-boost converter system. The result of the value on inductor that has been calculated in equation 2 used as a reference to determine the number of turns needed to reach the inductance value on the inductor. The calculation to find a number of turns an inductor can be searched by equation 4. The result of calculation using equation 4 obtained a number of turns on the inductor is 27 turns by using a toroidal design.

$$N^2 = \frac{L \times \pi \times D}{\mu_r \times \mu_o \times A}$$

$$= \frac{6\ mH \times \frac{22}{7} \times 62,14}{6731 \times 4 \times \frac{22}{7} \times 10^{-7} \times 60} \qquad (5)$$

$$= 27\ turns$$

3.2.3 Capacitor Value

Then, by using a limit of the voltage ripple less than 1%, the result of calculation from equation 3 we obtained the highest results from the minimum and maximum duty cycle is 10,11 μF. From this result, we can approach 20 μF.

$$C = \frac{V_O \times D}{R \times \Delta V_O \times F_s} \qquad (6)$$

$$= \frac{0,63}{100 \times 0,01 \times 62500}$$

$$= 10,1\ uF$$

$$C = \frac{V_O \times D}{R \times \Delta V_O \times F_s} \qquad (7)$$

$$= \frac{0,41}{100 \times 0,01 \times 62500}$$

$$= 6,62\ uF$$

3.3 Design of Circuit Simulation

Figure 2 can be explained that an inverting buck-boost converter circuit arranged into several components, including voltage source DC, square wave voltage source, on-off switch controller, MOSFET switch, inductor, diode, capacitor, resistor, inverting op-amp voltage probe, and a current probe.

In the simulation design, the condition of all the components buck-boost converter is in the ideal condition. The function of a square wave voltage source is to initialize the parameters according to the frequency value and the large duty cycle used. The inverting component of the op-amp to obtain the output voltage value measured in polarity according to the input voltage source.
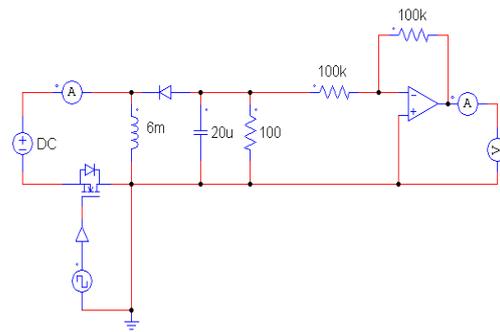

Figure 2: PSIM simulation circuit on the buck-boost converter system.

3.4 Hardware Implementation

Figure 3 represents the results of the hardware that was made in this research. Hardware that has been implemented in accordance with Figure 2. In this research, we using microcontroller ArduinoMega 2560 as a PWM control and then an active switching component that is N-MOSFET IRFZ44N and passive switching components that is diode Schottky SR3100. A data obtained then processed to obtain the ripple value generated at each specified test interval. The results of this test after that processed to carry out the overall analysis and make comparisons on each condition.
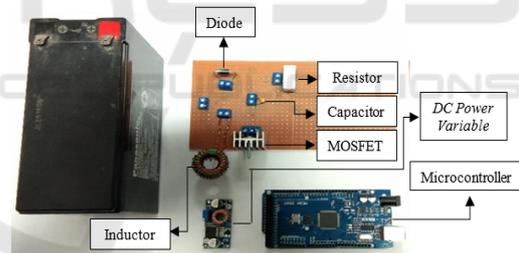

Figure 3: Hardware implementation of the circuit on the buck-boost converter system.

4 EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Analysis of Ripple Voltage in Mathematical Condition

Based on the information from table 2, a value of input voltage from 7 Volt gets the lowest accuracy that is 49.6% with a ripple voltage of 0.060 Volt. When an input voltage from 17 Volt gets the highest accuracy value is 67.2% with a ripple voltage value of 0.039 V. The value of deviation is a reduction in the boundary of ripple voltage specification with

voltage ripple value generated when the test is carried out.

Table 2: Results of voltage ripple in mathematical condition.

V_s	Voltage ripple (V)	Voltage ripple (%)	Deviation (%)	Accuracy (%)
7	0,060	0,504	0,496	49,60
8	0,058	0,480	0,520	52,00
9	0,055	0,456	0,544	54,40
10	0,053	0,44	0,560	56,00
11	0,049	0,416	0,584	58,40
12	0,048	0,400	0,600	60,00
13	0,046	0,384	0,616	61,60
14	0,044	0,368	0,632	63,20
15	0,042	0,352	0,648	64,80
16	0,041	0,344	0,656	65,60
17	0,039	0,328	0,672	67,20

4.2 Analysis of Current-Voltage in Mathematical Condition

It can be seen from Table 3, the highest accuracy value is when the system gave the lowest input voltage value, or we can call it to boost condition. The situation is inversely proportional when the system is given the lowest voltage value or buck condition. The difference value is a reduction of the current ripple specification limit specified by the current ripple value generated when the test is carried out. In table information 3, a current ripple value of 9.08% is generated when the system is given a maximum input voltage value of 17 volts and inversely proportional when given a minimum voltage value of 7 volts.

Table 3: Results of current ripple in mathematical condition.

V_s	Current ripple (V)	Current ripple (%)	Deviation (%)	Accuracy (%)
7	0,012	3,61	6,39	63,89
8	0,013	4,27	5,73	57,33
9	0,014	4,89	5,11	51,14
10	0,015	5,56	4,44	44,44
11	0,015	6,08	3,92	39,21
12	0,016	6,67	3,33	33,33
13	0,017	7,21	2,79	27,89
14	0,017	7,71	2,29	22,94
15	0,018	8,15	1,85	18,52
16	0,018	8,74	1,26	12,63
17	0,019	9,08	0,92	9,20

4.3 Analysis of Ripple Voltage in Simulation Condition

Based on the information from table 4, the largest ripple value obtained when the system is given an input voltage of 8 volts with a large duty cycle of 60%. The situation is inversely proportional when the system is given an input voltage 12 volts with a 50% duty cycle, which experiences the smallest voltage ripple value. Analysis of the current ripple generated in table 4 does not have results that exceed the specified ripple limit of 1%. The results of the ripple voltage analysis of the input voltage are in accordance with the design specified in the information table 1.

Table 4: Results of voltage ripple in simulation condition.

V_s	Voltage ripple (V)	Voltage ripple (%)	Deviation (%)	Accuracy (%)
7	0,110	0,93	0,07	7
8	0,120	0,98	0,02	2
9	0,100	0,83	0,17	17
10	0,100	0,81	0,19	19
11	0,100	0,84	0,16	16
12	0,060	0,50	0,50	50
13	0,090	0,75	0,25	25
14	0,090	0,75	0,25	25
15	0,080	0,67	0,33	33
16	0,090	0,74	0,26	26
17	0,110	0,93	0,07	7

4.4 Analysis of Current-Voltage in Simulation Condition

The results obtained from the information in table 5, the highest accuracy value is at the lowest input voltage level 7 Volt with the highest duty cycle of 63%. The situation is inversely proportional when the system is configured to the highest voltage 17 Volt with the lowest duty cycle, 41%. Analysis of the current ripple value generated in the simulation does not exceed the specifications specified in table 1. The overall current ripple value produced in each input voltage test is below 10% so that it matches the system that has been designed.

Table 5: Results of current ripple in simulation condition.

V_s	Current ripple (V)	Current ripple (%)	Deviation (%)	Accuracy (%)
7	0,012	3,13	6,87	68,70
8	0,013	3,23	6,77	67,70
9	0,014	7,14	2,86	28,60
10	0,015	3,70	6,30	63,00

11	0,015	4,00	6,00	60,00
12	0,016	8,33	1,67	16,70
13	0,017	8,69	1,31	13,10
14	0,017	9,09	0,91	9,10
15	0,018	9,52	0,48	4,80
16	0,018	9,52	0,48	4,80
17	0,019	10,00	0	0

4.5 Analysis of Ripple Voltage in Hardware Condition

In this case, we analyze the voltage ripple based on information in table 6 using an oscilloscope and obtained a maximum voltage level 7.02 Volt with a duty cycle value of 63%, which exceeded the specified ripple limit of 1%. The condition exceeds the specified ripple voltage limit because when the test is obtained, the switching component is in the hot condition so that a fluctuating voltage value changes on the installed capacitor. The accuracy value obtained in the ripple voltage analysis on hardware is dominated when the system is in a state of the buck with a value above 60%, whereas when the boost state, the accuracy value is below 40%.

Table 6: Results of voltage ripple in hardware condition.

V_s	Voltage ripple (V)	Voltage ripple (%)	Deviation (%)	Accuracy (%)
7,02	0,12	1,31	0,31	31,00
8,02	0,08	0,82	0,18	18,37
9,02	0,06	0,61	0,39	38,90
10,02	0,06	0,59	0,41	40,59
11,02	0,06	0,61	0,39	39,02
12,02	0,04	0,40	0,59	59,76
13,02	0,04	0,39	0,60	60,39
14,02	0,04	0,40	0,60	60,00
15,02	0,04	0,40	0,60	60,00
16,02	0,04	0,39	0,60	60,39
17,02	0,04	0,40	0,60	60,00

4.6 Comparison of Voltage Output

From the graph in figure 4, the value of output voltage generated when the simulation condition gets a value corresponding to output voltage value mathematical condition. The results of output voltage when the implementation produces the lowest value affected by the condition of component is not ideal when tested. The highest output voltage value when the implementation condition is 10.23 Volt with a given input voltage 16 Volt and a large duty cycle of 43%. When the simulation condition, the highest voltage value 12.33 Volt be produced with input voltage 10 Volt, and the duty cycle is 55%.
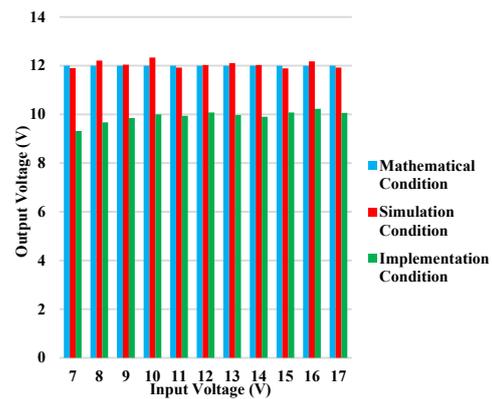

Figure 4: Results of output voltage

The biggest error value is when the implementation condition maximum voltage level 7 Volt with the resulting error value of 22.33%. The difference is obtained with the largest error value of 2.68 Volt against the value of voltage specified at 12 Volt. The results of output voltage values in the implementation conditions do not match the setpoint voltage specified that has been designed, but the system successfully increases and decreases from the input voltage.

4.7 Comparison of Voltage Ripple

In Figure 5, we can infer from mathematical, simulation, and implementation conditions. The lowest voltage ripple value is when the system gave input voltage 12 Volt and a large duty cycle of 50%.
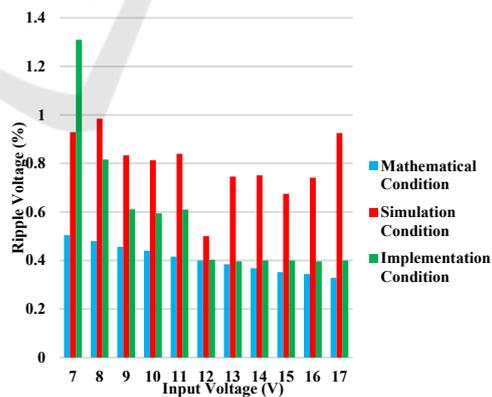

Figure 5: Results of voltage ripple

From the implementation condition, it can be inferred that the smaller value in input voltage given, the greater the ripple value of the resulting voltage. Likewise, if the input voltage value is very large, the ripple of value resulting voltage is getting smaller. This is because the error value is obtained so that the

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value of the output voltage is very fluctuating, which can make an increase in voltage ripple generated. If the error value obtained is greater, the accuracy value decreases and, as a result, is the increase of the ripple generated from the circuit.

4.8 Comparison of Ripple Current

The result of the graph in figure 6, the current ripple value increases when the value of the input voltage given increases. The smallest ripple value is 3.61% when the mathematical condition, and then from simulation condition, is 3.13%. The results of the current ripple value generated in each condition in accordance with the current ripple value limit that has been designed in the information from table 1. The maximum current ripple value is 10% from the mathematical condition when the system is given a maximum voltage value 17 Volt with duty cycle 41%. However, the maximum ripple current is still in accordance with the specified ripple current limit of 10%.
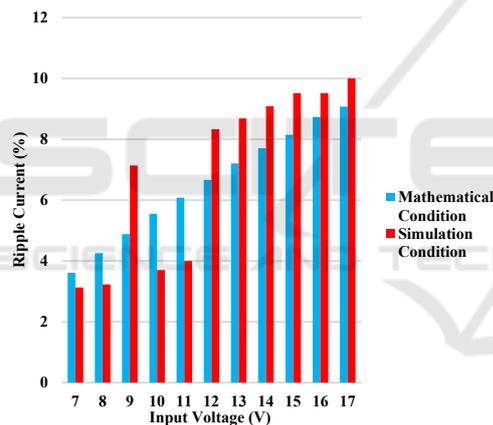

Figure 6: Results of ripple current

4.9 Comparison of Efficiency

In this session, we analyze efficiency by comparing the simulation with the hardware that has been implemented. The incoming power from each input voltage will be calculated with the output power generated.
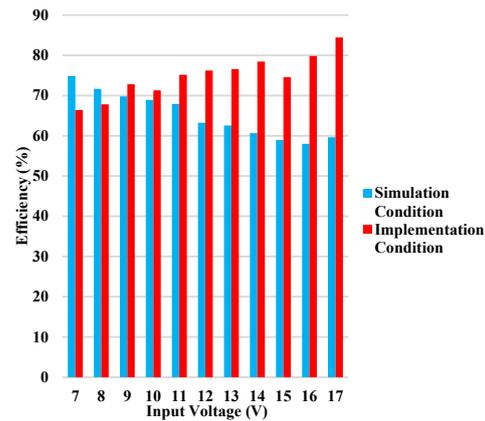

Figure 7: Results of power efficiency

In figure 7, the greatest efficiency value is obtained from the implementation condition. From our research, it is obtained that the power value on the input side increases when the value of the input voltage given increases. The average value of input power is 2.24 Watt under simulation condition and 1.3 Watt during implementation condition. Power values on the output side when simulation and implementation conditions tend to be stable with an average value of 1.45 Watt during simulation conditions and 0.97 Watt during implementation conditions. In the implementation condition, the largest efficiency value of 84.44% is obtained with a maximum input voltage level of 17 Volt with a minimum duty cycle of 41%.

5 CONCLUSION AND FUTURE WORK

This research used a buck-boost as a DC-DC regulator and then can produce output voltage greater or less than the input voltage. The polarity of the buck-boost output voltage is inversely proportional to the input voltage (voltage inverting).

This study also success in applying specification limits to the determination of ripple current and voltage buck-boost converter. In mathematical and simulation conditions, the output voltage value approaches the specified setpoint 12 Volt, but in the simulation conditions, it is only able to produce an average voltage value 9,92 Volt. The current ripple results generated in mathematical and simulation conditions are still in accordance with specifications of less than 10%. The results of voltage ripple in mathematical and simulation conditions are also according to specifications of less than 1%, but when

the implementation condition for input voltage value 7 Volt increases above a predetermined limit.

Based on the results obtained in this study, some recommendations were obtained, namely the addition of a controller to the response of the output voltage generated and the use of bootstrap capacitors in the switching components used.

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