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Design of DC-DC Converter Bench Controlled by an Arduino Microcontroller

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***Abstract*— The main purpose of this paper is to design a DC-DC converter bench controlled by an Arduino board. This DC-DC converter bench is dedicated to the teaching of Power Electronics Labs. Several DC-DC converters topologies can be studied. Proteus simulations were carried out for the different structures.**

***Keywords*—DC-DC converters; Arduino; Proteus simulations**

I. INTRODUCTION

A power converter circuit manages the flow of electrical energy between a source and a load. Until a few years ago, their primary use was in supplying motors in industrial applications and in electric traction systems. Nowadays, in addition to those fields, they are employed in very wide range of applications including domestic applications, renewable energy systems, FACTS (Flexible Alternating Current Transmission System), automotive…

Innovations in the field of power converters are taking place on several axes: new generation of power semiconductors, more and more new configurations of power converters, the use of digital devices such as microcontrollers, FPGA (Field Programmable Gate Arrays) in control circuits.

Modern power converters offer a high grade of precision, flexibility, communication capability, reliability to the end user, with smaller sizes.

This paper presents the design of DC-DC converter bench controlled by an Arduino card. Experiments and Proteus simulations are carried out for elementary structures of DC-DC converters such as buck, boost, buck-boost converters.

A block diagram of the experimental bench is shown in Fig.1. A DC power source, mostly battery is used to power the DC-DC converter. The pulse needed for switching the semiconductor is generated from the Arduino UNO. The code is written with the open-source Arduino Software (IDE). The measurement of the different currents and voltages can be done either by the Arduino card or by an oscilloscope.

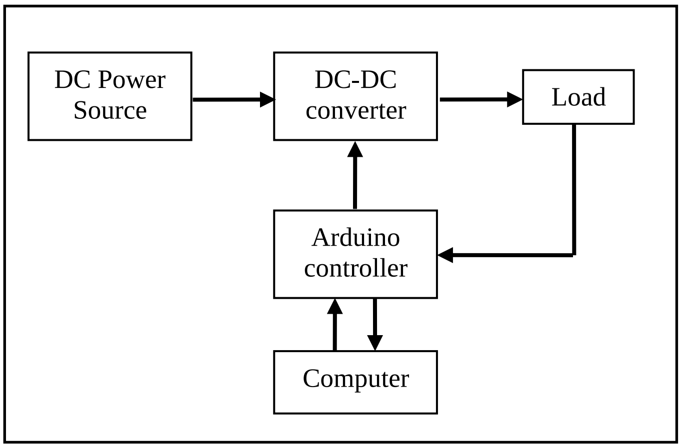

Fig.1: Block diagram

II. CONTROL CIRCUIT

The control circuit is shown in Fig.2.

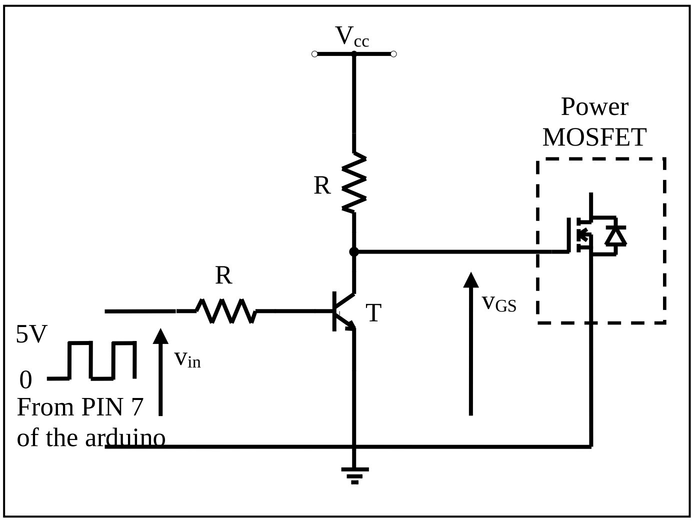

Fig.2: Control circuit

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The type and the values of the components used are as follows:

TABLE I. components of the control circuit

T: NPN transistor	2N2222
R: resistor	1kΩ
V_{cc}: DC source	15V

V_{in} is the voltage delivered by the PIN7 of the Arduino. V_{in} is a square-wave voltage, the low level is 0V and the high level is 5V. In order to have a square-wave voltage with a frequency f=1kHz and a duty cycle D=0.6, the following code must be written with the Arduino Software (IDE).

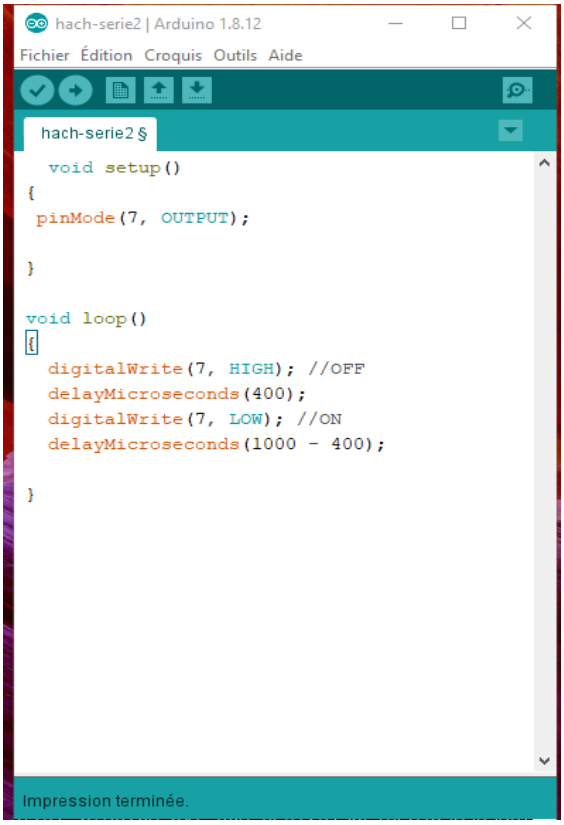

Fig.3: Arduino code

When V_{in} is at the low level (0V), the transistor T is OFF (open), then $v_{GS} \approx V_{cc}$=15V (for R=1kΩ , the voltage across the resistor R can be neglected).

When V_{in} is at the high level (5V), the transistor T is ON (saturated), then $v_{GS} \approx 0$V.

Fig.4 shows a simulation of the control circuit on Proteus.

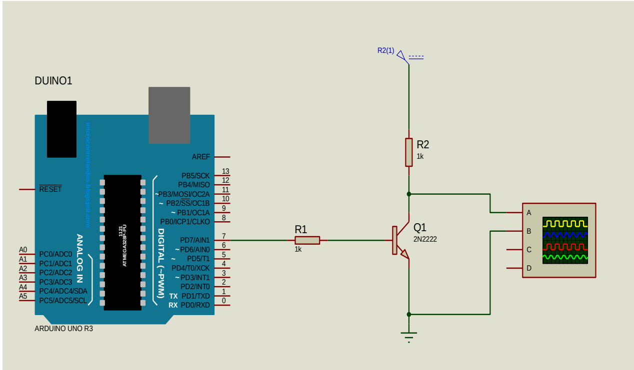

Fig.4: Proteus simulation of the control circuit

The result of the control circuit simulation is as follows.

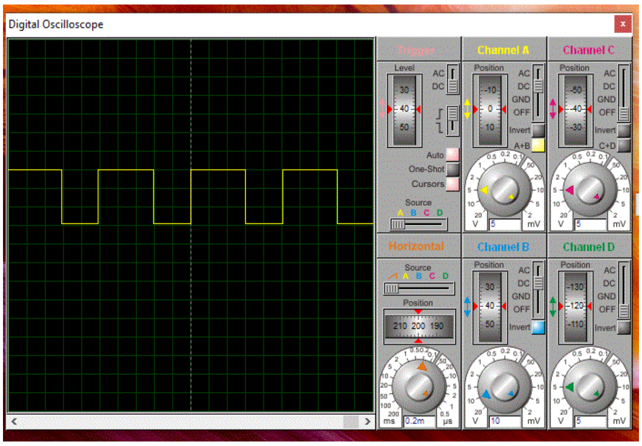

Fig.5: control voltage simulation

After simulation, the complete control circuit has been tested, the following result is obtained:

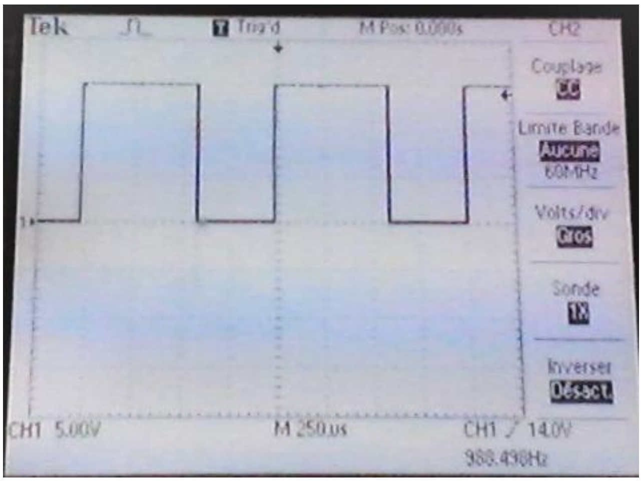

Fig.6: control voltage measured

III. POWER CIRCUIT

Experiments are carried out for three DC-DC converters structures that are: Buck converter, Boost converter and Buck-Boost converter.

The type and the values of the components used are as follows:

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TABLE II. Components of the power circuit

M: MOSFET	IRF540
D: Diode	BYY56
R: Resistor	25Ω
L: Inductor	0.1H
C: Capacitor	54μF
V_S: DC source	15V

A. *Buck converter*

The buck converter is shown in Fig.7. It operates by periodically opening and closing an electronic switch (MOSFET). It is called a buck converter because the output voltage is less than the input.

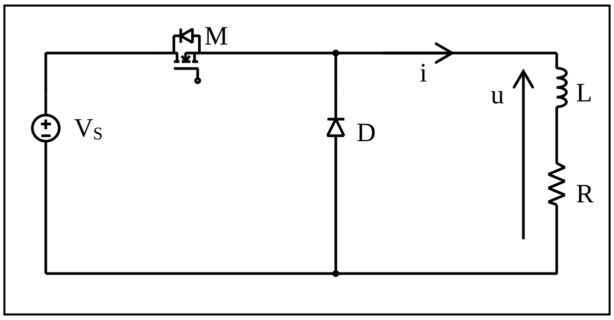

Fig.7: Buck converter

In practice, the following configuration (Fig.8) is preferred. Its main advantage is the common ground for both control and power circuits.

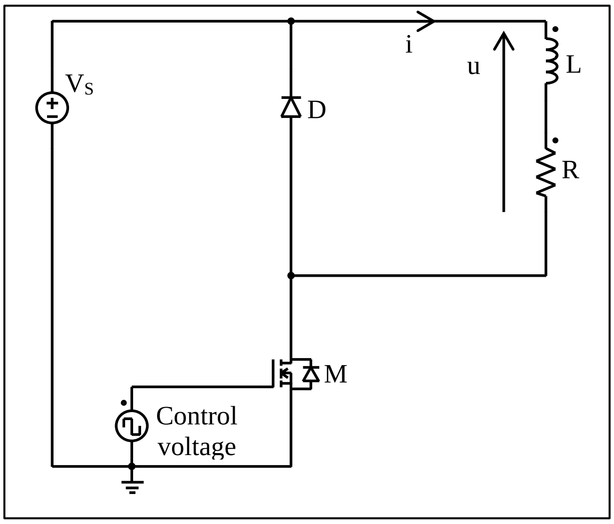

Fig.8: Buck converter with common ground

Theoretical waveforms for buck converter are as follows:

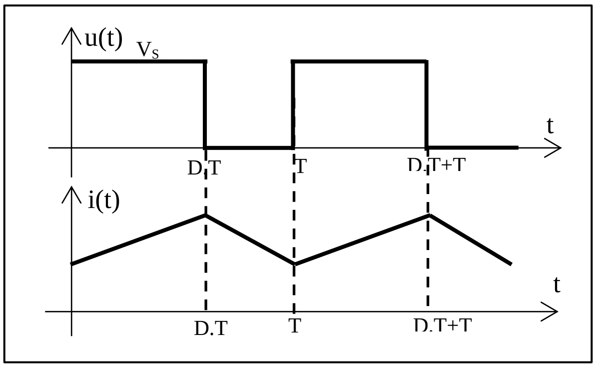

Fig.9: Theoretical waveforms of the buck converter

u(t) and i(t) are output (load) voltage and current.

The average of the output voltage u(t) is given by:

$$\overline{U} = D.V_S \tag{1}$$

D is the duty cycle.

B. *Boost converter*

The boost converter is shown in Fig.10. It is called a boost converter because the output voltage is larger than the input.

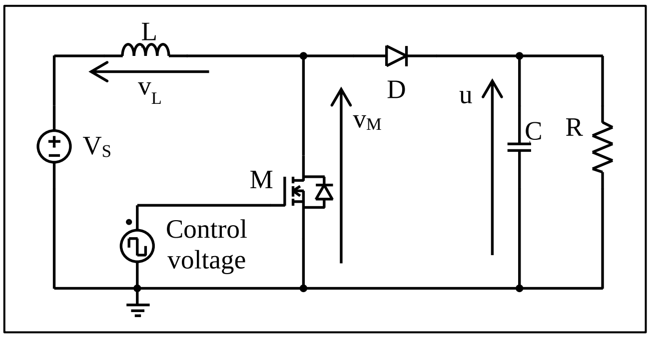

Fig.10: Boost converter

In theory, the capacitor C is considered so large that the output voltage u is held constant at $u = U$.

The analysis proceeds by examining the inductor voltage (v_L) and the switch voltage (v_M) for the switch closed and again for the switch open.

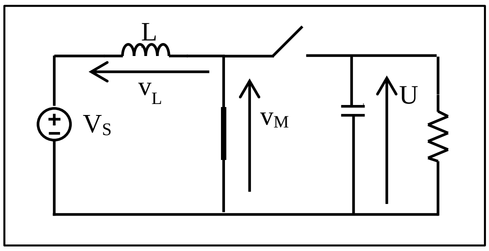

Fig.11: Equivalent circuit for the switch closed

When the switch is closed:

$$\begin{cases} v_L = V_S \\ v_M = 0 \end{cases} \tag{2}$$

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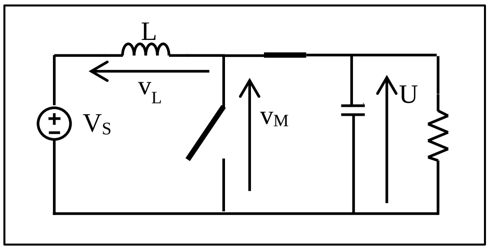

Fig.12: Equivalent circuit for the switch open

When the switch is open:

$$\begin{cases} v_L = V_S - U \\ v_M = U \end{cases} \quad (3)$$

Theoretical waveforms for boost converter are as follows:

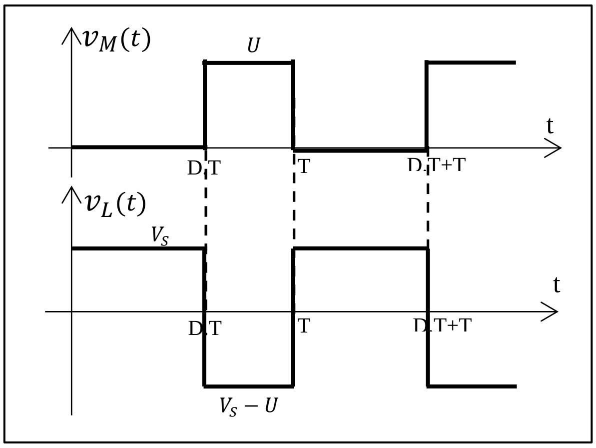

Fig.13: Theoretical waveforms of the boost converter

The average inductor voltage must be zero for periodic operation, then:

$$D.V_S + (1 - D)(V_S - U) = 0 \quad (4)$$

Which gives:

$$U = \frac{V_S}{1-D} \quad (5)$$

Since $0 \leq D \leq 1$, then $U \geq V_S$

C. Buck-boost converter

The buck-boost converter is shown in Fig.14. The output voltage of the buck-boost converter can be either higher or lower than the input voltage.

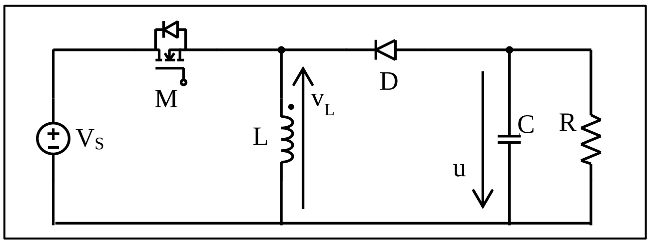

Fig.14: Buck-boost converter

In practice, the following configuration (Fig.15) is preferred. Its main advantage is the common ground for both control and power circuits.

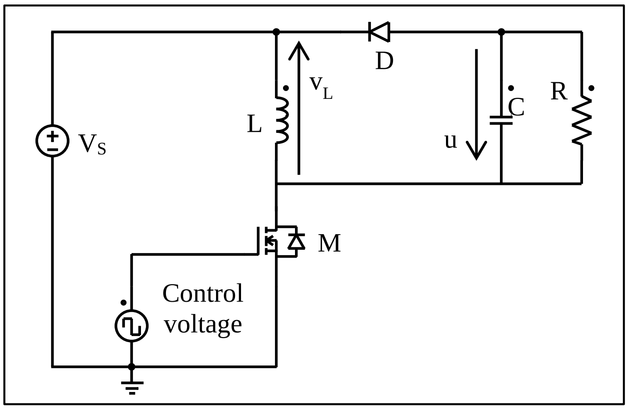

Fig.15: Buck-boost converter with common ground

In theory, the capacitor C is considered so large that the output voltage u is held constant at $u = U$.

The analysis proceeds by examining the inductor voltage (v_L) for the switch closed and again for the switch open.

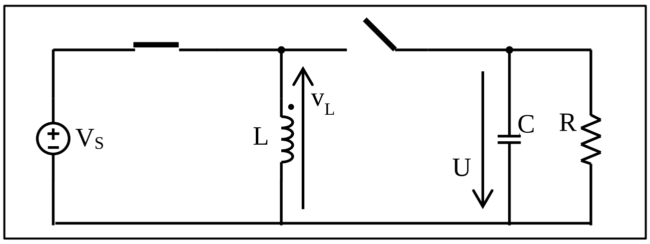

Fig.16: Equivalent circuit for the switch closed

When the switch is closed:

$$v_L = V_S \quad (6)$$

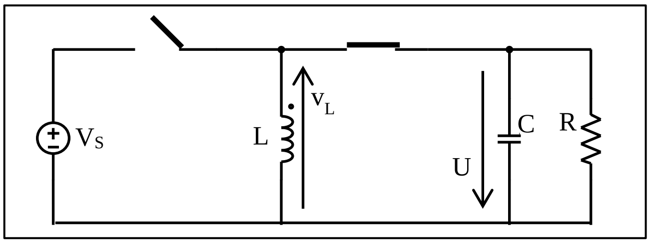

Fig.17: Equivalent circuit for the switch open

When the switch is open:

$$v_L = -U \quad (7)$$

Theoretical inductor voltage v_L for buck-boost converter is as follows:

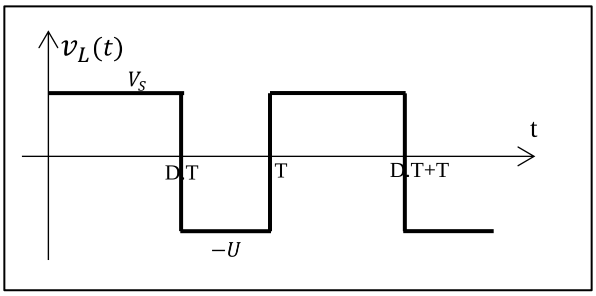

Fig.18: Theoretical inductor voltage v_L for buck-boost converter

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The average inductor voltage must be zero for periodic operation, then:

$$D.V_S + (1 - D) \times (-U) = 0 \qquad (8)$$

Which gives:

$$U = \frac{D \cdot V_S}{1-D} \qquad (9)$$

If $0.5 < D$, $U > V_S$: the output voltage is larger than the input.

If $D < 0.5$, $U < V_S$: the output voltage is smaller than the input.

IV. SIMULATIONS AND RESULTS

In this section, Proteus simulations and real measurements are shown for the three configurations of DC-DC converters.

A. Buck converter

The complete buck converter circuit (control + power) is simulated using the Proteus software. Simulation is carried out for the practical values.

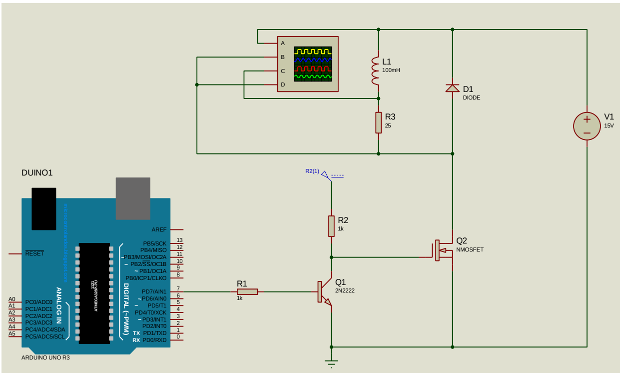

Fig.19: Proteus simulation of the buck converter

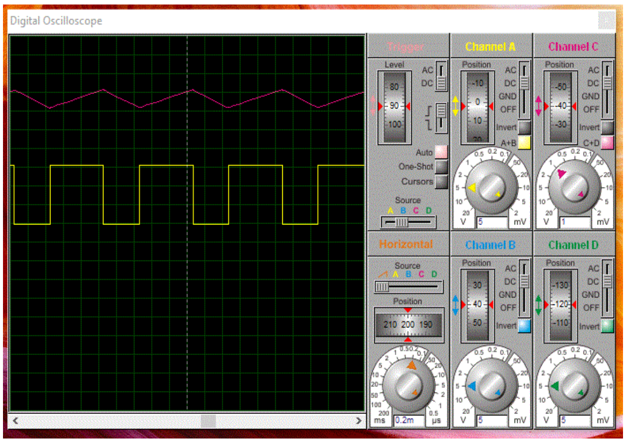

Fig.20: Proteus waveforms

The yellow waveform represents the load current and the red waveform represents the load voltage.

Practical Measurements are in accordance with theory and simulation as shown in Fig.21.

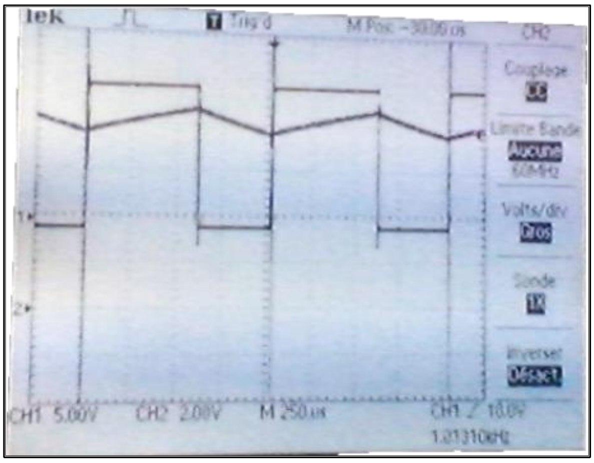

Fig.21: Measured load current and voltage for buck converter

B. Boost converter

The complete boost converter circuit (control + power) is simulated using the Proteus software. Simulation is carried out for the practical values.

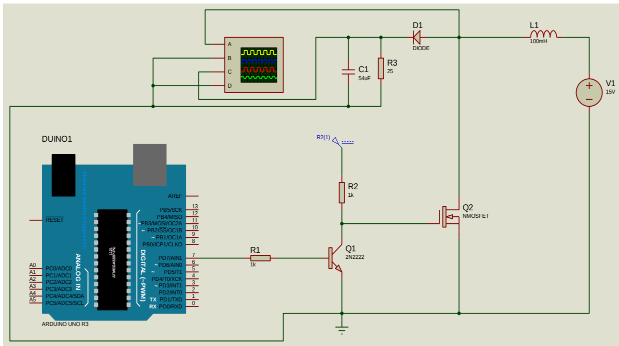

Fig.22: Proteus simulation of the boost converter

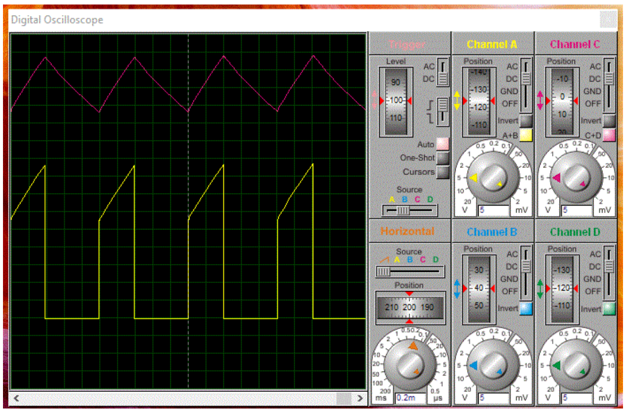

Fig.23: Proteus waveforms of the boost converter

The yellow waveform represents the switch voltage v_M and the red waveform represents the load voltage u. Since the capacitor C has a finite value (C=54µF), the output voltage u is not constant (it has a ripple). Practical measurements confirm Proteus simulation as shown in Fig.24.

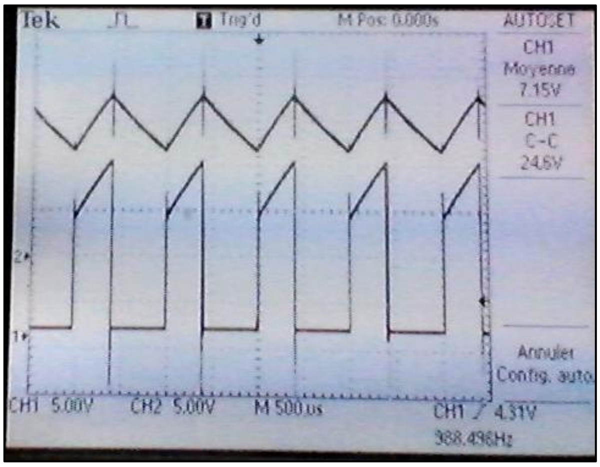

Fig.24: Measured load and switch voltages for boost converter

C. Buck boost converter

The complete buck-boost converter circuit (control + power) is simulated using the Proteus software. Simulation is carried out for the practical values

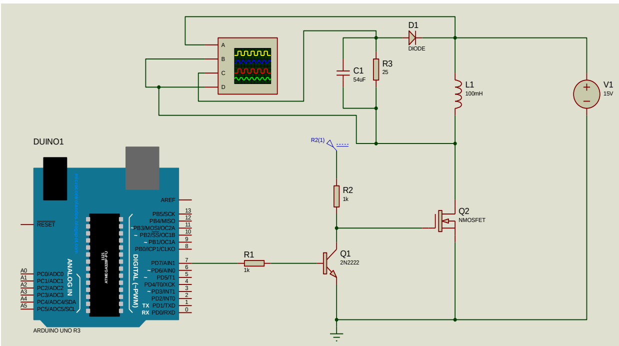

Fig.25: Proteus simulation of the buck-boost converter

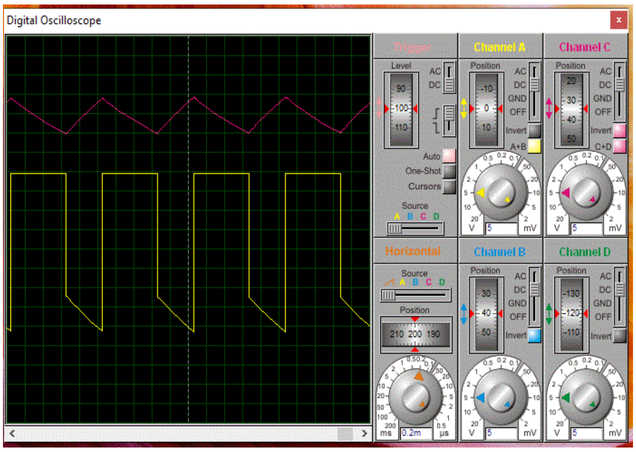

Fig.26: Proteus waveforms of the buck-boost converter

The yellow waveform represents the inductor voltage v_L and the red waveform represents the load voltage u. Since the capacitor C has a finite value (C=54μF), the output voltage u is not constant (it has a ripple). Practical measurements confirm Proteus simulation as shown in Fig.27.

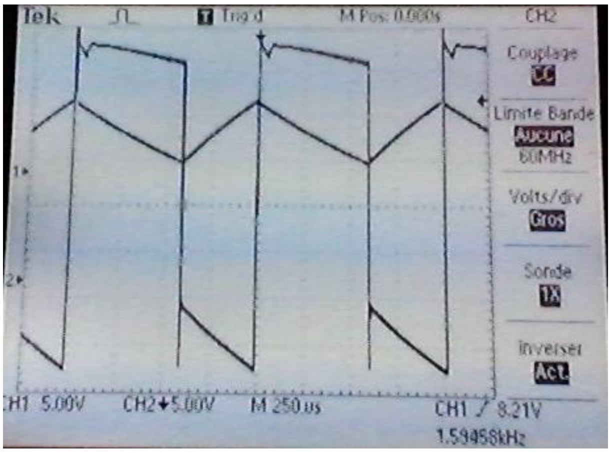

Fig.27: Measured load and inductor voltages for buck-boost converter

V. CONCLUSION

In this project, a DC-DC converter bench is designed. This experimental bench is a multi-topology bench. It allows students to study the elementary DC-DC converters that are buck, boost and buck-boost converters. For this DC-DC converter, the pulse needed for switching semiconductor device is generated using the Arduino Uno.

Before performing experimental measurements, simulations with the Proteus software are carried out. The simulations results obtained are in accordance with measurements.

This project highlights that Arduino offers a simple and efficient way to control power converters.

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