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Design and Implementation of Buck Converter for Electric Vehicle's Appliances

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ABSTRACT

Buck converter is a unidirectional DC-DC power converter that primarily steps down potential difference (PD) of the power bank of batteries or supercapacitors. Electric vehicles usually operate on higher voltage ranging from 45 to 72 volts. However, the electrical accessories of automobiles such as horns, trafficators, radio/players and brake or parking lights were designed to operate on 12 V DC voltage. This necessitates the use of buck converter for stepping down the voltage values to 12 volts. Nonetheless, replacing the converter when the need arises is indeed financially challenging, thus, in such a situation, the vehicles are mostly operated during the day time. Herein, we designed a buck converter using Proteus software and then constructed it with the aim of stepping down the voltage values to 12 volts at a reduced price. The design materials and the construction components used are readily available in most of the electronics shops. An outstanding performance was achieved and results indicated that the designed converter is suitable for use in electric vehicles.

Keywords: Converter, Potential difference, Stepdown, Direct voltage

1.0 INTRODUCTION

Solar energy is an alternative energy source aside from petroleum that is receiving great attention for diverse applications ranging from optoelectronics, photonics, photovoltaic and electric vehicles (Chen et al., 2023; Reyes-Belmonte, 2021; Sun et al., 2022). It is an undeletable and environmentally friendly source of energy that is attracting the interests of scientific community for contemporary technological applications. Researchers are still striving to develop efficient methodologies capable of warranting the optimal utilization of solar energy based on demand and resources (Izam et al., 2022).

The main challenge associated with solar energy utilization is that, storage system such as batteries is required. In order to properly integrate an energy storage system, such as a battery bank, along with a PV installation, a converter must interface the connection to a DC link feeding an inverter. Such battery-based power converter must have high efficiency and provide smooth charging and discharging capacity to extend the life-span of the

battery bank. One of the advantages of using DC-DC converter is to reduce costs and improve efficiency, and improve the performance of the system itself (Chao, *et al.*, 2013). In addition to the power converter, a smart-energy management system is required to coordinate the power transfer from photovoltaic (PV) as well as the charging and discharging of the battery bank according to the demand and the grid state as well as energy cost. Energy storage systems have proven to be a vital part of any renewable energy system (Lamichhane, et al., 2013) Qian, et al., (2009). In order to improve intermittency problem, energy storage systems can be placed to store excess energy and provide it at times of deficiency.

1.1 Buck Converters

A buck converter is used to distribute power in complex systems, e.g. server motherboards, broadband communication boards, etc (Hosseinpour et al., 2022). It provides the required local voltage from a higher voltage bus that is

common to multiple converters in the system. The converter itself consists of one active switch controlled by an IC, a rectifier and filter elements. This great simplicity allows for cost effective high efficient power distribution throughout the application. The buck converter has the filter inductor on the output side, which provides a smooth continuous output current waveform to the

load. This could be considered a qualitative benefit but requires special considerations for big load transients (Jens, 2013). The Buck converter is a switch mode power device that outputs a DC voltage that is lower than the input DC voltage Coates, (2018) simplified version of the Buck converter can be seen in Figure 1.

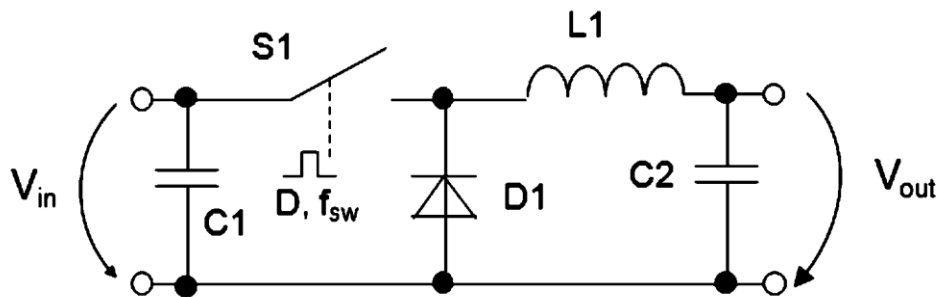


Figure:1 Buck Converter Basic Diagram (Jens, 2013)

The input is exposed to the switch S1. Therefore, the input current is a highly dynamic waveform. This is undesired as the switched current emits noise into the entire system. A proper decoupling is inevitable. That is why capacitor C1 is a crucial part of the circuit (Jens, 2013). Vehicles have become indispensable tools for transportation in modern life. In view of the increasing attention paid to plug-in hybrid electric vehicles (PHEVs) (Song, *et al.*, 2011). In this study a simple buck converter is design and implemented to replace the existing ones that are not commonly available in the markets. The converter should be able to step down 45 to 72-volt DC to 12-volt DC. An overload protection is being added to the design.

2.0 Materials and Method

2.1 Circuit Design

Figure 2 shows the block diagram of the design set up. The input is high voltage power bank usually from series connections batteries or super capacitors. Power bank is the primary source of the whole system and is being controlled by a programmed high Frequency oscillator that switches the *N* Channel MOSFET transistor. As a result, the buck circuit provides an output power of less than input PD. The output PD is also being controlled by a feedback path reference. An added circuit in the design protects the system from being overloaded or short circuited.

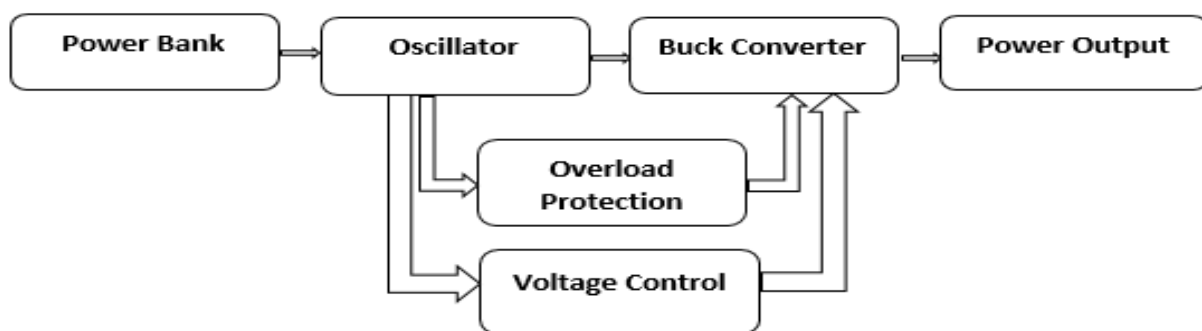


Figure: 2 Bock diagram of the setup

2.2 Buck Converter Design

The parameter of the buck converter is shown in table 1. The buck converter is expected to step down 45 volts to 13.8 volts. The 13.8 V output is chosen because it is the PD of fully charge lead acid battery. The working frequency and inductance

converter were chosen to be 74 kHz. While chosen an inductor for buck converter design certain parameters need to be define. The parameters for this work is shown in table 1. A simplified version of the Buck converter is represented in Figure 3.

Table: 1 Design parameters of the proposed converter

Mode Of Operation	Step Down
Input Voltage (Min)	45 V
Input Voltage (Max)	72 V
Output Voltage	13.8 V
Frequency	74 kHz
Output Current (Max)	12 A
Inductor current ripple	30%
Output voltage ripple	10 mV

For lossless system, the voltage gain is calculated as in equation 1 (Jenica-Ileana and Corcau, 2014)

$$\frac{V_i}{V_0} = \frac{1}{1-D} \tag{1}$$

For ideal circuit, $D = \frac{V_{out}}{V_{in}}$ 2

$$L = \frac{V_{out}}{f_{sw}} * \frac{1-D}{\Delta I_{Li}} \tag{3}$$

Where D, f_{sw} and ΔI_{Li} are duty cycle, switching frequency and change in an inductor current respectively. Duty cycle variation based on power losses in high efficiency converters usually has no big impact on the inductor value and can be ignored

(Jenica-Ileana and Corcau, 2014). The inductor peak current, I_{pk} is giving by:

$$I_{pk} = I_{out} + \frac{\Delta I_L}{2} \tag{4}$$

The output capacitor is deduced in equation 2.5

$$C = \frac{\Delta I_i * T}{V_d * \Delta I_i * R_i} \tag{5}$$

Where ΔI_i is the changing current of the inductor, V_d is the diode voltage drop, R_i is the switching device resistance and T is the time period given by;

$$T = \frac{D}{f_{sw}} \tag{6}$$

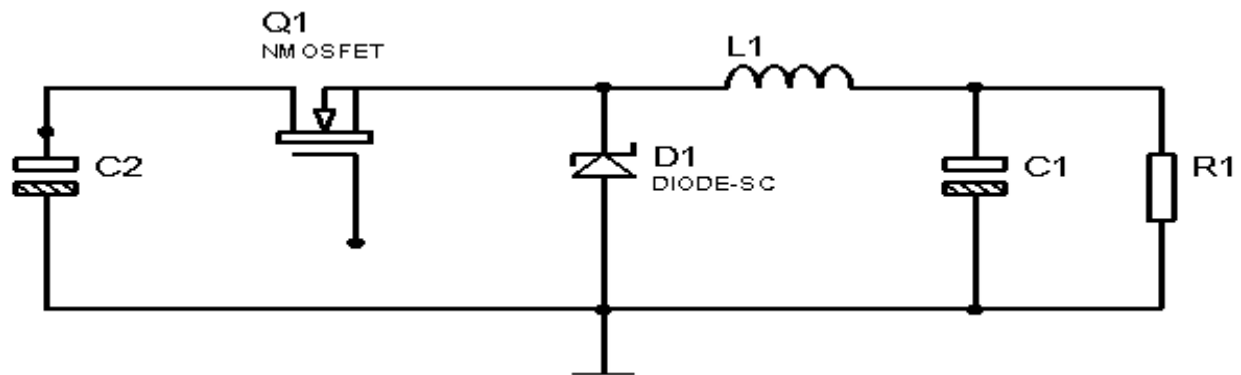


Figure: 3 Analogue Design of buck converter in Proteus

2.3 Choice of the Oscillator

Pulse width modulation (PWM), is being generated by a current mode PWM integrated circuit UC3845. It is preferred due to availability and requires few components to operate. It was inbuilt with low start up current, high gain error amplifier, pulse-by-pulse current limiting, high current totem pole output that makes it possible to drive a power MOSFET, and also optimized for DC-to-DC Converters (UC3845datasheet, 2017). UC3845 obtain a duty-cycle range of 0% to 50% by the addition of an internal toggle flip-flop, which blanks the output off every other clock cycle. The frequency of operation was set by the timing capacitor charging current by connecting a resistor from V_{REF} to R_T/C_T and connecting timing capacitor from R_T/C_T to ground. The recommended range of timing resistor values is between 5 k Ω and 100 k Ω ; the recommended range of timing capacitor values is between 1 μ F and 100 μ F. The frequency of the oscillator can be estimated with the equation 7:

$$f_{osc} = \frac{1.72}{R_{RT} * C_{CT}} \quad 7$$

where f_{OSC} is in Hertz, R_{RT} is in Ohms and C_{CT} is in Farads. Inverting input to the internal error amplifier, V_{FB} is used to control the power converter voltage-feedback loop for stability (K3845 datasheet, 2012). In this work R_{RT} and C_{CT} were chosen to be 8.6 K Ω and 27 μ F respectively, which gives an oscillation of 74 kHz. EL817 photocoupler is being use as a signal transmission between circuits of different potentials and impedances (Yusuf, *et al.*, 2013). The device was programmed with two external resistors; R_1 and R_2 . The total dynamic impedance of the circuit is defined as:

$$Z_{KA'} = Z_{KA} \left(1 + \frac{R_1}{R_2}\right) \quad 8$$

(TL431 datasheet, 2015)

Where Z_{KA} is the dynamic impedance, R_1 and R_2 are programmed external resistors. To have potential difference of 13.8 V 10 k Ω and 2.2 k Ω were chosen for tis work.

The materials used in system construction are shown in table 2. The circuit diagram prepared with “Proteus Intelligent Schematic Input System (ISIS)”, is presented in Figure 4.

Table: 2 Material and tools use for system construction

S/N	Component	Description	Quantity
1	Integrated Circuit	UC3845	1
2	Shunt regulator	TL431	1
3	Photo coupler	EL817	1
4	Inductor	0.02mH	1
5	Schottky Diode	MBR20150(F)CT	1
6	Diode	1N4003	2
7	LED	Red	1
8	Capacitor	470 μ F	1
9	Capacitor	1000 μ F	1
10	Capacitor	10 μ F	1
11	Capacitor	33 pF	1
12	Capacitor	27 pF	1
13	Resistor	33 k Ω	1
14	Resistor	2.2 k Ω	2
15	Resistor	1 k Ω	1
16	Resistor	10 k Ω	1
17	Resistor	8.6k Ω	1
18	Resistor	0.33 Ω	1
19	MOSFET	IRFB1410	1

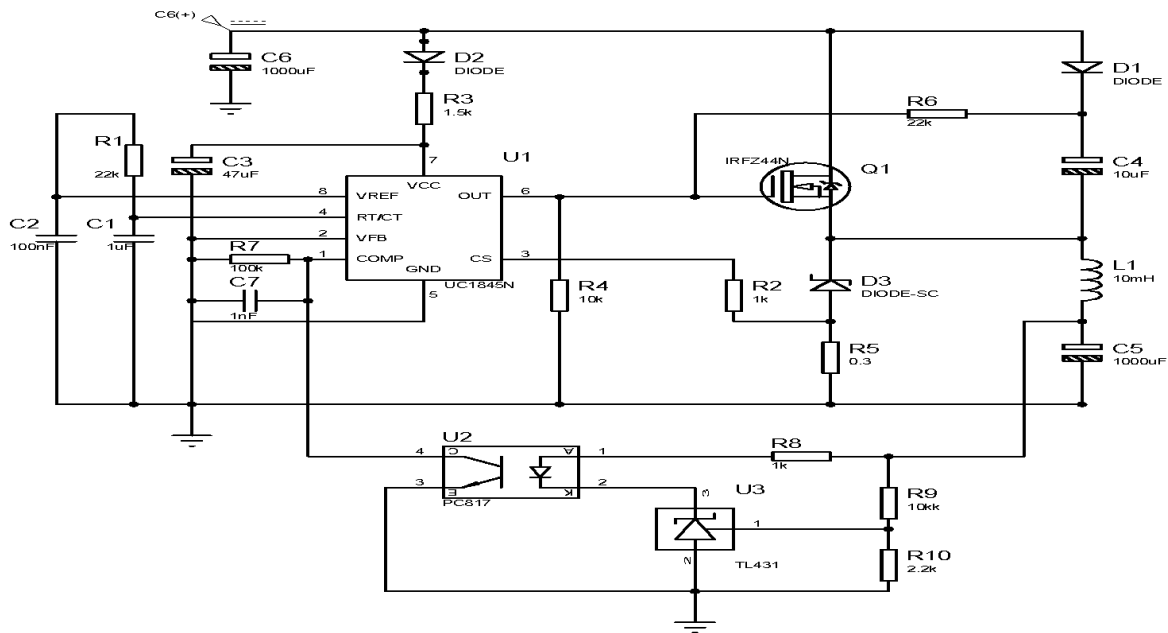


Figure: 4 Complete circuit design

2.4 System Construction

Continuity test was conducted for the MOSFET transistor and diodes using a digital multimeter. Resistors were also checked and found to be within their tolerance values. The tip of the soldering iron and that of the components were thinned with lead

for easier soldering. The components were soldered one after the other to their places in the circuit. Active components were held by the pliers to help radiate the excessive heat quickly during the soldering. All components were soldered on plane Vero board as shown in Plate 1.

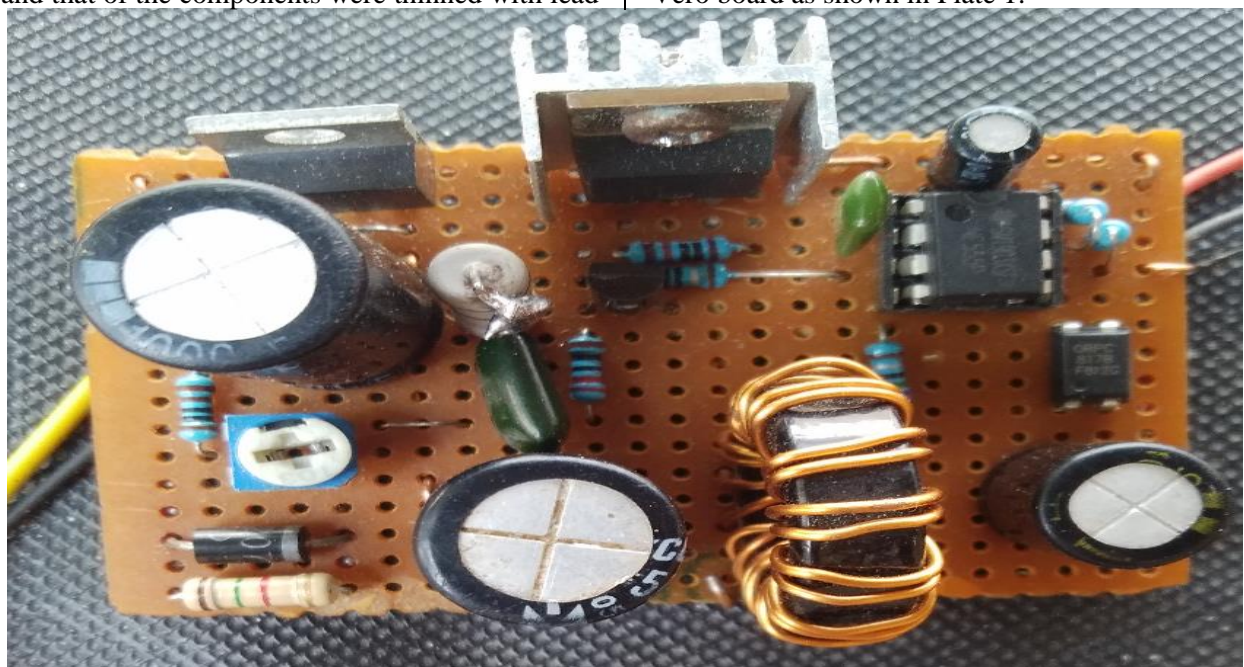


Plate: 1 Photograph of the constructed circuit

3.0 RESULTS AND DISCUSSION

3.1 Simulations Test Results

The computer simulation results of basic circuit on buck converter is shown in figure 5. It shows DC 's input of 45 volts, AC square wave on the inductor terminal and overall output stage of 13.805 volt respectively. Computer simulation test conducted on oscillator output (Figure 6)

shows a square wave of 50% duty cycle. The frequency of the oscillation is found to be 74 kHz, it tallies with the calculation design. Figure 7 shows the simulation result of converter output. It was found to have potential difference of 13.8 volt.

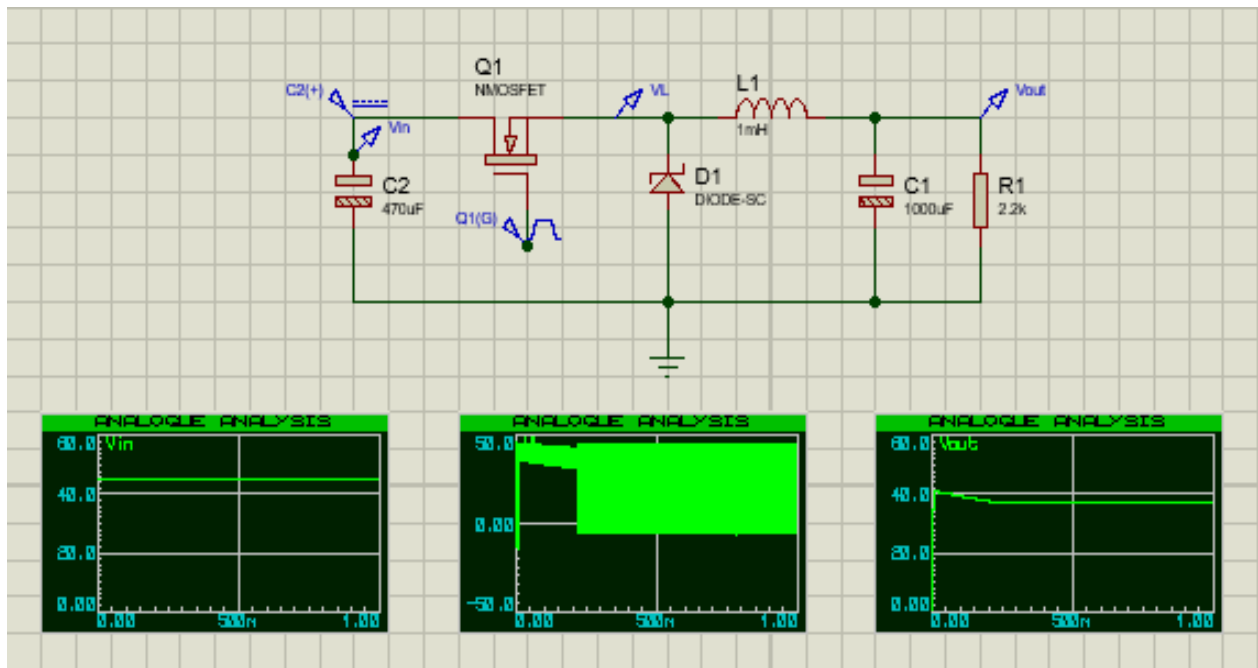


Figure: 5 Analogue Simulation of Buck Converter in Proteus

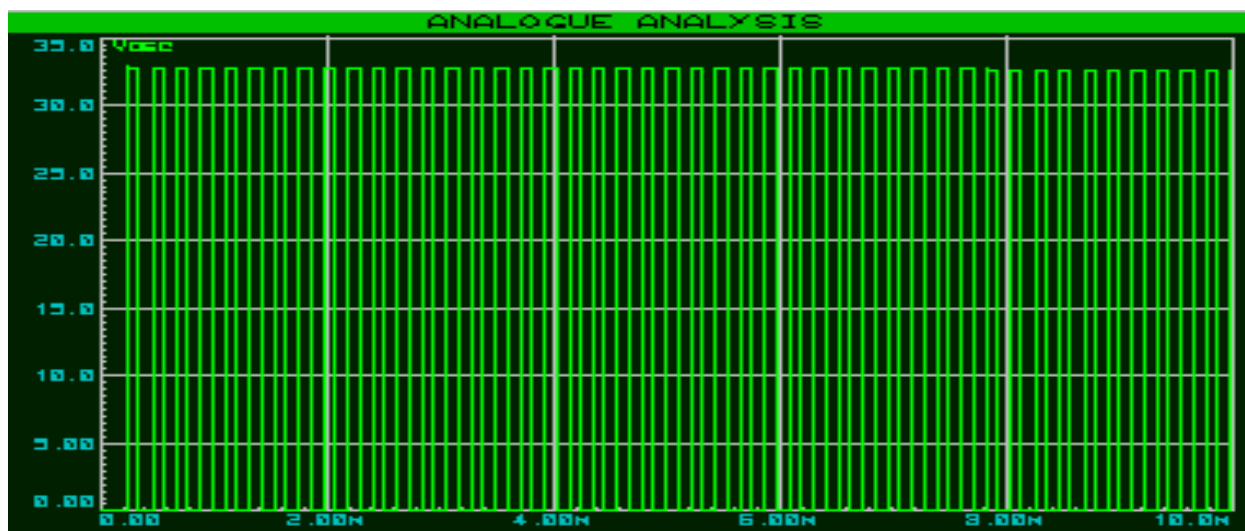


Figure: 6 Output Simulation of UC3845 in Proteus

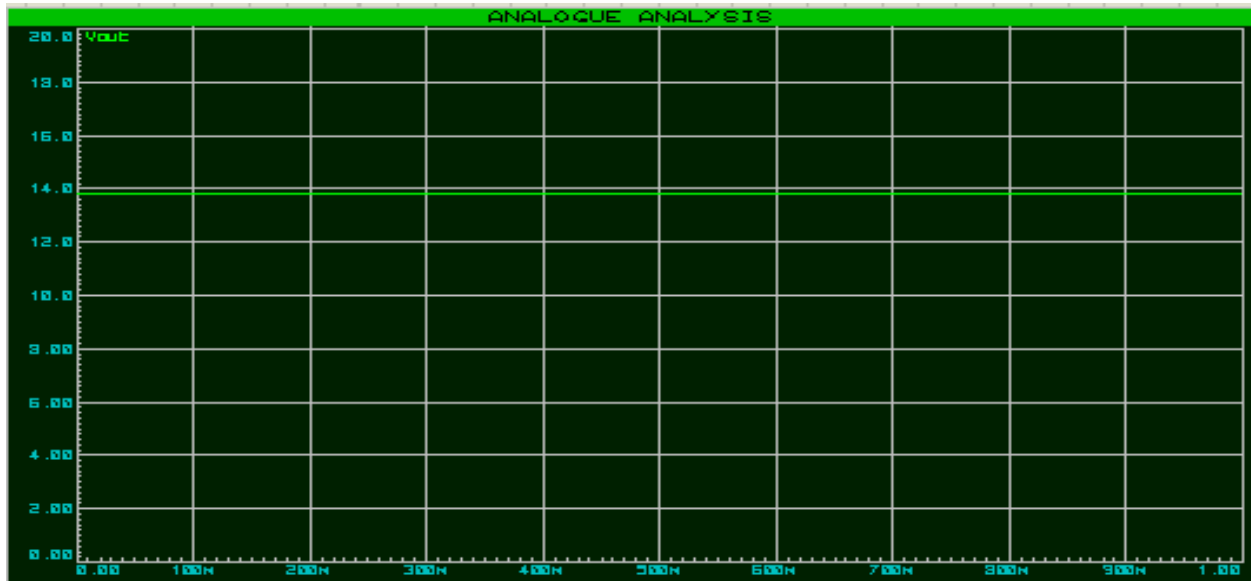


Figure: 7 Simulation of the Converter Output Stage in Proteus

3.2 System Tests

After construction, the converter output was found to be 13.84 V DC in an open loop circuit. The circuit maintained this value for the supply input of 45 to 72 volt. Bulbs of different power were connected across the output stage and found the voltage to be steady with negligible voltage drop of about 0.15 V. The overload/short circuit protection was also tested by short circuiting the output terminals. The result shows that the system turns

OFF, but turns ON again when the terminals were separated thereby protecting the system from being damage due to overload. It was also connected to motorcycles that operates on 45 and 72 V and found be working properly. To estimate output power, it was subjected to different loads by connecting 12 V bulbs of know power in parallel. Results obtained were tabulated and represented graphically as shown in figure 8.

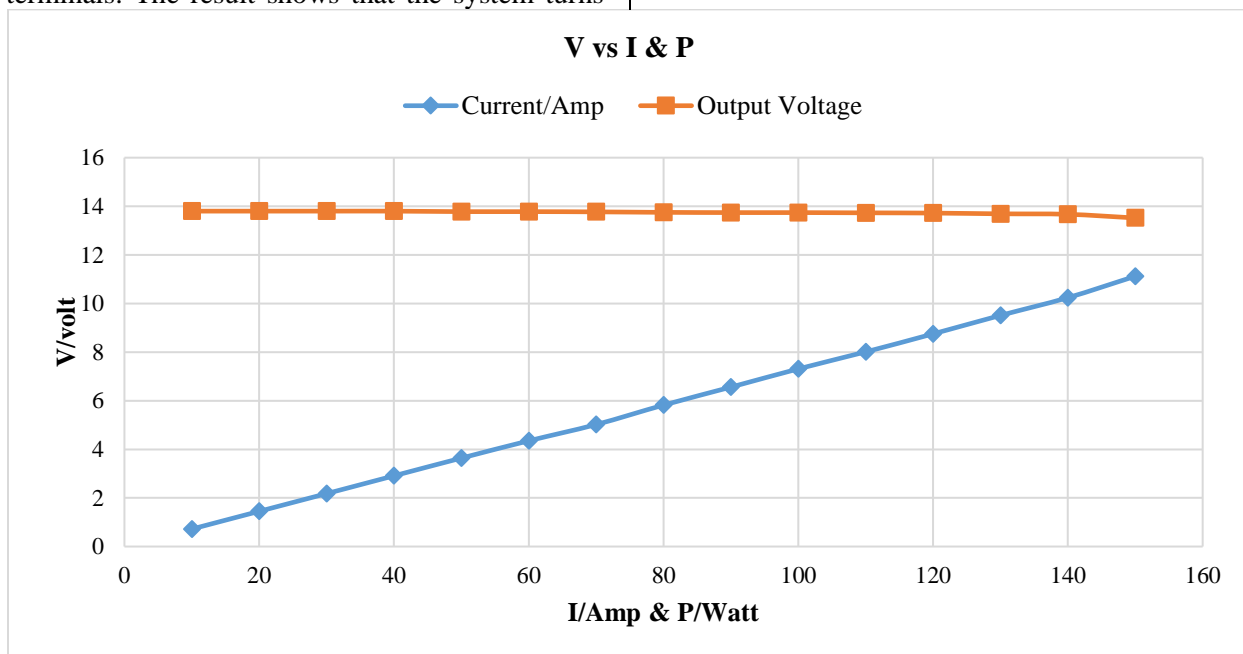


Figure: 8 Plot of Voltage against Current & Power

Figure 8 shows the voltage against current and power. The result shows that the current is directly proportional to the load applied. But the voltage is slightly dropping with respect to the load.

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4.0 CONCLUSION

A DC-DC buck converter was designed and constructed using available materials and found to operate on input voltage range of 45 V to 72 V. The output obtained was found to be steady due to feedback circuitry. The output current was found to be 10 A. It was tested on two different electric motorcycles that operates on 45 and 72 V. During operation, it was observed that for better performance the size of the heat sink need to be increase. From the analysis and test conducted, the buck converter is found to be working satisfactorily.

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