IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 4 Ver. I (Jul. – Aug. 2018), PP 20-29
www.iosrjournals.org

Design, Fabrication and Experimentally Testing Of a Buck-Boost Converter System (0-50v) a Prototype

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Abstract-*DC-DC Power Converters are employed in order to transform an unregulated DC voltage input (i.e. a voltage that possibly contains ripples and disturbances) in a regulated output voltage. On citing an example a DC-DC power converter can transform an unregulated (i.e. distorted) 9V input voltage in a regulated (i.e. "clean") voltage of 12V at the output. Some DC-DC power converters have a fixed output reference and ensure that such voltage is always delivered, no matter what the input is; some others can have a variable output reference, which can be therefore set depending on the current need of the device the power converter is used in. The converter discussed in this work belongs to this second category. In particular, the converter is able to deliver output voltages both higher as well as lower than (or even equal to) the input voltage; this is why it is referred to as a "buck-boost" (or "step-up/step-down") power converter.*

Index Terms*—Buck Converter, Boost Converter, PWM Generator, Voltage IC Regulator, Fly Back Diode.*

Date of Submission: 26-06-2018 Date of acceptance: 12 -07-2018

I. Introduction

The converters are the heart of the DC or AC power supply in electrical engineering system. The power source is available in two forms either in AC or in DC form. The AC power can be converted to different levels by using transformer; this technique is very much convenient. Power electronic converters can be found wherever there is a need to modify the electrical energy form (i.e modify its voltage, current or frequency). Therefore, their power ranges are from some milliwatts (as in a mobile phone) to hundreds of megawatts (e.g in a HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Therefore the main metric of power electronics becomes the efficiency as described in [1].

The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors as indicated in [1]. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g., television sets, personal computers, battery chargers, etc. power ranges of VSDs start from a few hundred watts and end at tens of megawatts as cited in [2].

The power conversion systems can be classified according to the type of the input and output power.

- AC to DC (rectification)
- DC to AC (inversion)
- DC to DC (chopping)

As efficiency is at a premium in a power electronic converter, the losses that a power electronic device generates should be as low as possible. The instantaneous dissipated power of a device is equal to the product of the voltage across the device and the current through it (P= VxI). From this, one can see that the losses of a power device are at a minimum when the voltage across it is zero (the device is in the On-State) or when no current flows through it (Off-State). Therefore, a power electronic converter is built around one (or more) device operating in switching mode (either On or Off). With such a structure, the energy is transferred from the input of the converter to its output by bursts.

Power electronic systems are virtually in every electronic device. For example, around us: DC/DC converters are used in most mobile devices (mobile phone) to maintain the voltage at a fixed value whatever the charge level of the battery is. These converters are also used for electronic isolation and power factor correction as cited in [3]. AC/DC converters (rectifiers) are used every time an electronic device is connected to the mains (computer, television) [3].AC/AC converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids as described in [4]. DC/AC converters (inverters) are used primarily in UPS or emergency light. During normal electricity condition, the electricity will charge the DC battery. During blackout time, the DC battery will be used to produce AC electricity at its output to power up the appliances.

It remains high until the charging and discharging of capacitor through the resistor and C values decides the ON time. It is a consequence of the way power MOSFETs are created in the layers of silicon, and can be very useful. In most MOSFET architectures, it is rated at the same current as the MOSFET itself.

II. Main Circuit Of The Project

The schematic combined circuit consisting of power supply, PWM Generator, Buck Converter & Boost Converter is shown in Fig.1 below. The operation of each component in each module has been described vividly and the waveforms of each block have been illustrated in next section.

A. Power Supply:

The power supply designed for catering a fixed demand connected in this project as given in Fig.2. The basic requirement for designing a power supply is as follows: The different voltage levels required for operating the devices. Here +5 Volt required for o0perating microcontroller. And +12 Volt required for drivers etc. The current requirement of each device or load must be added to estimate the final capacity of the power supply. As it is estimate the requirement of power is approximately as follows:

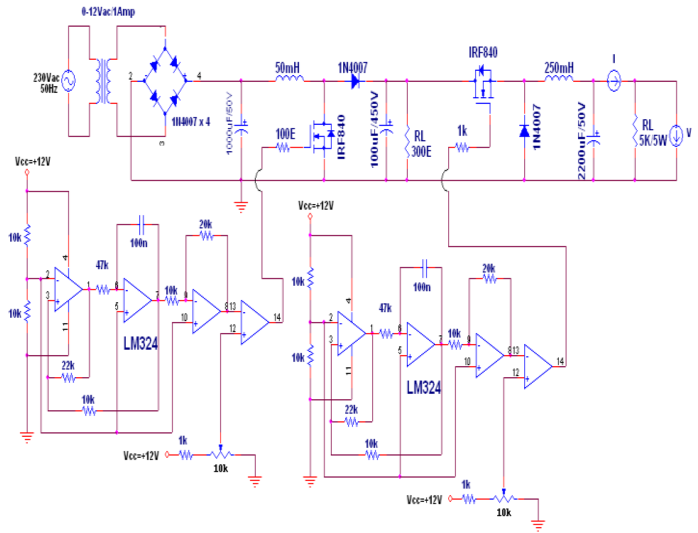


Fig 1: Layout of the Buck- Boost converter with its peripheral components

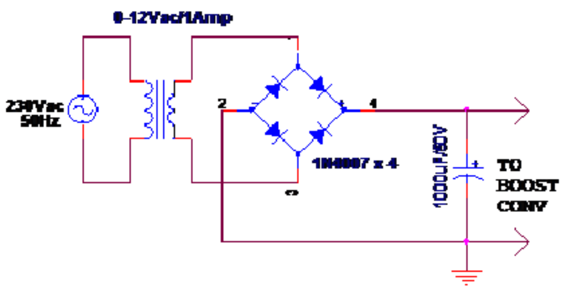


Fig 2: Power Supply for Boost converter

Out Put Voltage = +5Volt, +12Volt, Capacity = 1000mA

The power supply is basically consisting of three sections as follows:

1. Step down section
2. Rectifier Section
3. Regulator section

In this we are using Transformer (0-12) Vac/1Amp, IC 7805 & 7812, diodes IN 4007, LED & resistors. Here 230V, 50 Hz ac signal is given as input to the primary of the transformer and the secondary of the transformer is given to the bridge rectification diode. The o/p of the diode is given as i/p to the IC regulator

(7805 &7812) through capacitor (1000µF/35v). The o/p of the IC regulator is given to the LED through resistors.

$V_{DC} = 2Vm / \pi$

or, $V_{DC} = (Vm – 2Vk)= (12 – 1.4)=10.6$ ……..…………..…. (1)

$\Rightarrow V_{DC} \times 2\sqrt{2} \cong 17Vdc.$ …………………………………. (2)

To overcome this effect, a capacitor is connected to the o/p of the diodes (D2 & D3). Which removes the unwanted ac signal and thus a pure dc is obtained.

We knew,

$Q = C \times V$ ……………………………………………….. (3)

$\Rightarrow C = Q / V= I \times t / V= 1Amp \times 10msec/ 17 \cong 1000\mu F$ …..(4)

Here we need a fixed voltage, that's for we are using IC regulators (7805 & 7812)."Voltage regulation is a circuit that supplies a constant voltage regardless of changes in load current." This IC's are designed as fixed voltage regulators and with adequate heat sinking can deliver output current in excess of 1A. The o/p of the bridge rectifier is given as input to the IC regulator through capacitor with respect to GND and thus a fixed o/p is obtained.

Vmax to 78XX = 35Vdc

Vmin to 78XX = 78XX +2V

Imax = 1Amp DC.

Imin to LED = 5mA

Imax to LED = 30mA

Then to find the value of series resistance by using the OHMs law,

$R_1 = V_1 / I= 5/5mA = 1K\Omega.$ ..……………………………. (5)

$\Rightarrow R_2 = V_2 / I= 12 / 5mA =2.4K\Omega. \cong 2.2K\Omega.$ ……………… (6)

Due to the forward bias of the LED, the LED glows ON state, and the o/p are obtained from the pin no-3. Finally that is fed to the corresponding sub section as a Vcc with respect to GND.

***B*. *PWM Generator*:** In this sub section its aspect is to generate a PWM as output signals for that an Quad OP-Amp (LM324) is used as a generator. This is an op-amp based design for generating PWM output. There are four stages of Op-amp running on a single-rail power supply. The saw tooth is generated with the circuit designed by 1st and 2nd op-amp. The function of different sections is as follows.

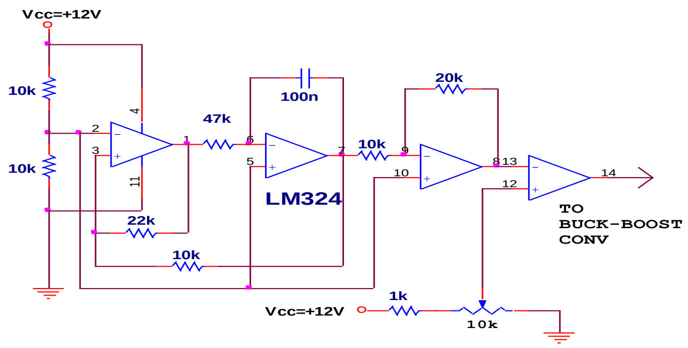


Fig.3: Schematic Diagram of PWM

The 1st op-amp is configured as a Schmitt Trigger

The 2nd op-amp is configured as a Miller Integrator

The 3rd op-amp is used as a low gain amplifier

The 4th op-amp is used as a comparator to compare the saw tooth with the reference voltage and generate PWM with different pulse width.

1. The 1st opamp is Schmitt Trigger. The reference voltage for the Schmitt Trigger is set at Vcc/2 due to the potential divider input given to the inverting input of the opamp1. The Upper limit voltage is dependent on the integrator output. Also the lower limit depends on the integrator output. Its output is shown in Fig.4.

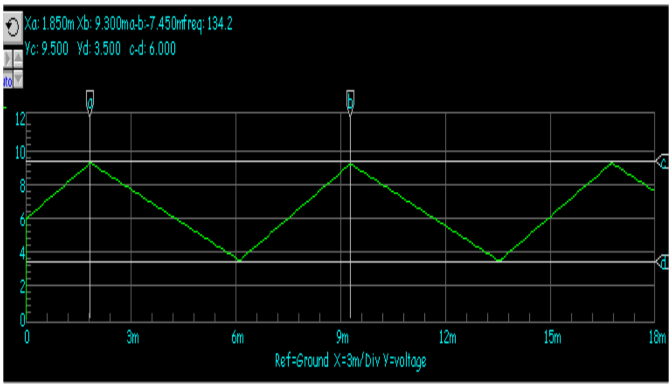


Fig 4: Output of Schmitt Trigger

2. The opamp2 acts as a miller's integrator this inverting type integrator. The slope of the integrated output as shown in Fig.5 depends on RC of the circuit. The opamp1 and opamp2 together generates one triangle wave with Vcc/2 as reference line of symmetry.

3. The 1st two sections of the quad op-amp form a triangle-wave generator, but now the third section is used as a low-gain amplifier, bringing the trough of the wave to just above zero volts and the peak to about 10v or as required by the design.

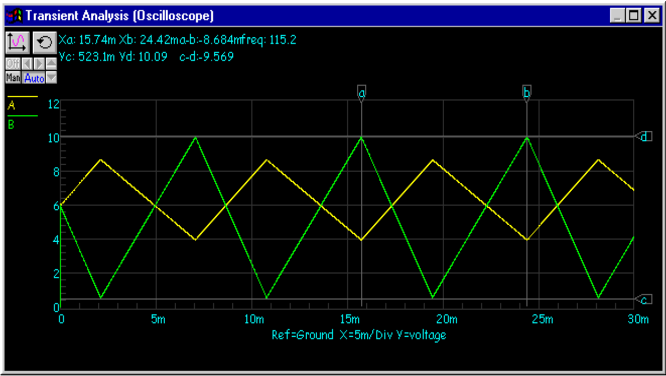


Fig 5: Output of Miller's Integrator

4. The fourth op-amp section is connected as a comparator, comparing the triangle wave voltage with a reference voltage set by the potential divider. When the wave voltage goes above the voltage at the pot wiper, the comparator output as shown in Fig.6 goes high, else the comparator output goes low.With the pot turned fully clock-wise the wiper voltage is below about 0.5v and the load is on 100% of the time. Increasing the wiper voltage (by turning the pot anti-clockwise) reduces the duty cycle, and it's easy to set a minimum speed just by changing the value of R8. Above is the effect of a low reference voltage, with the output "on" for most of the time, and below the reference voltage is near maximum giving a low duty cycle.

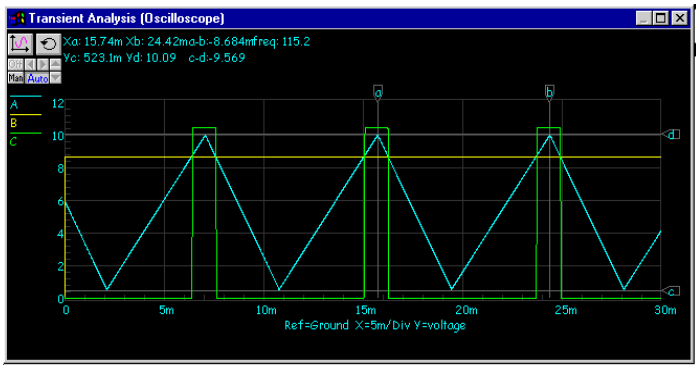
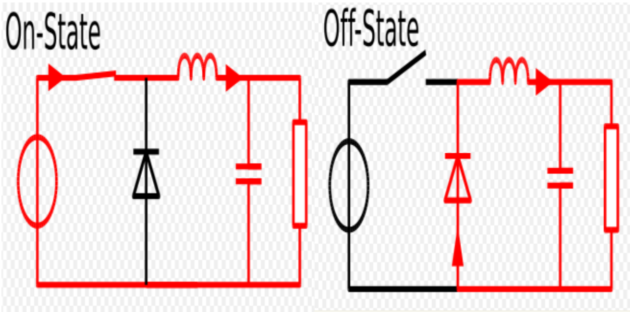


Fig 6: Output of opamp used as Comparator

Above is the effect of a low reference voltage, with the output "on" for most of the time and below the reference voltage is near maximum giving a low duty cycle.

C. Buck Converter: A Buck Converter is a step-down DC to DC converter as shown in Fig.7. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode) and an inductor and a capacitor. The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess power as heat; also, output voltage isn't regulated (varies with input voltage). A buck converter, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self- regulating, making it useful for tasks such as converting the 12-24V typical battery voltage in a laptop down to the few volts needed by the processor.



(a) (b)

Fig 7: The two circuit configurations of a Buck converter (a) On state, when the switch is closed, and (b) off-state, when the switch is open.

The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load. A Buck converter operates in continuous mode if the current through the inductor (I_L) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the chronogram:

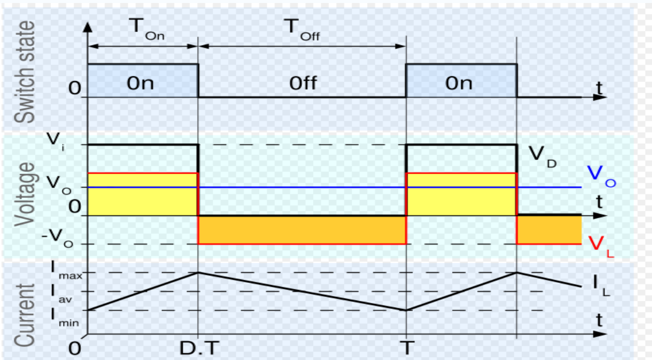


Fig 8: Operation of Buck converter in continuous mode

When the switch pictured above is closed (On-state, as in Fig.7a), the voltage across the inductor is $V_L = V_i - V_o$. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it; when the switch is opened (off state, as in Fig.7b), the diode is forward biased. The voltage across the inductor is $V_L = -V_o$ (neglecting diode drop). The current I_L decreases. Therefore, it can be seen that the energy stored in L increases during On-time (as I_L increases) and then decrease during the Off-state. L is used to transfer energy from the input to the output of the converter.

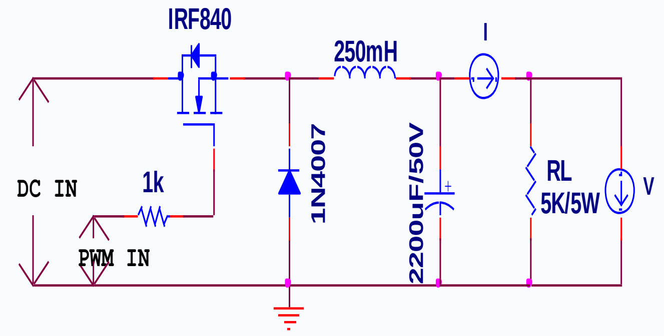
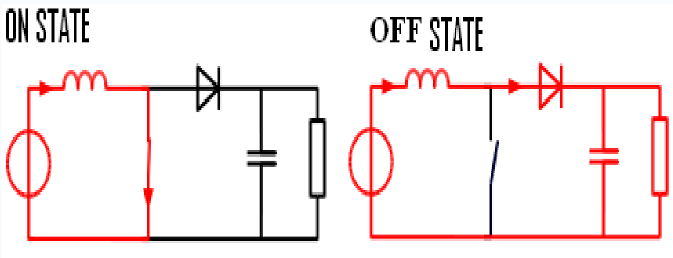


Fig 9: Schematic Diagram of Buck Converter

D. Boost converter: A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

The basic principle of a Boost converter consists in 2 distinct states (as given in Fig.10) In the On-state, the switch S (as given in Fig.10a) is closed, resulting in an increase in the inductor current. In the Off-state (as given in Fig.10b), the switch is open and the only path offered to inductor current is through the **flyback diode** D, the capacitor C and the load R, results in transferring the energy accumulated during the On-state into the capacitor. The input current is discontinuous, stepping between a very high inductor current. The large ripple usually requires a large input bypass capacitor (not shown) to reduce the source impedance.



(a) (b)

Fig Fig.10: ON state and OFF state for Boost converter

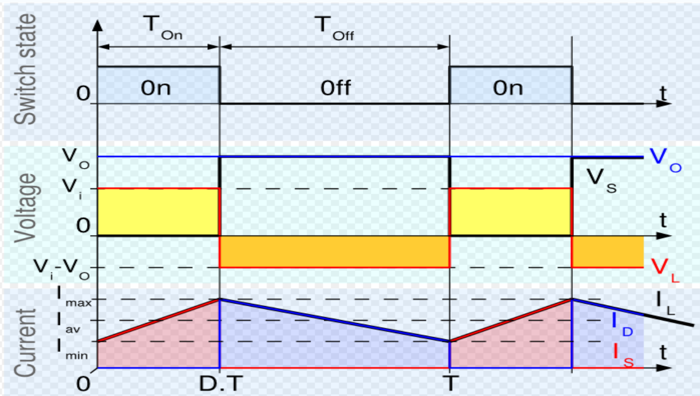


Fig. 11: Waveform of the current and voltage of Boost Converter

Waveforms of current and voltage in a boost converter operating in continuous mode is given in Fig 11. When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. Figure 3 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e using components with an ideal behaviour) operating in steady conditions:During the On-state, the switch S is closed, which makes the input voltage (V_i) appear. D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (S is always on). During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remains constant. As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. Therefore, the inductor current has to be the same at the beginning and the end of the commutation cycle. From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter. In some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see waveforms in figure 4). Although slight, the difference has a strong effect on the output voltage equation. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current. In the project the boost converter is designed with continuous mode.

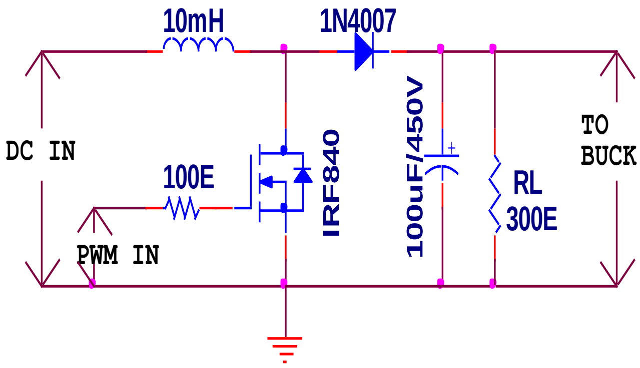


Fig 12: Boost Converter Schematic Diagram

III. Result Analysis

In this chapter results of practical tests of project conducted on the experimental set-up prototype are presented. The tests verify proper working of the hardware modules developed in the laboratory. Different waveforms (oscilloscope traces), tables, etc presented here; uphold the success of the entire scheme, the experimental set-up as also its parts.

A. Power Supply

The circuit diagram of the power supply is given in Fig.2 and the fabricated circuit is illustrated in Fig.13. All the components are inbuilt in this power supply. The output waveform of the secondary transformer is shown in Fig.14 which is sinusoidal in nature. The Oscilloscopic output of Voltage IC Regulator is shown in Fig.15.

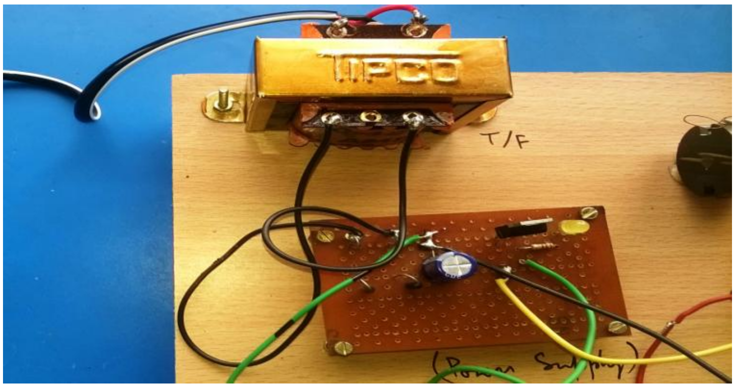


Fig 13: Fabricated circuit for Power Supply

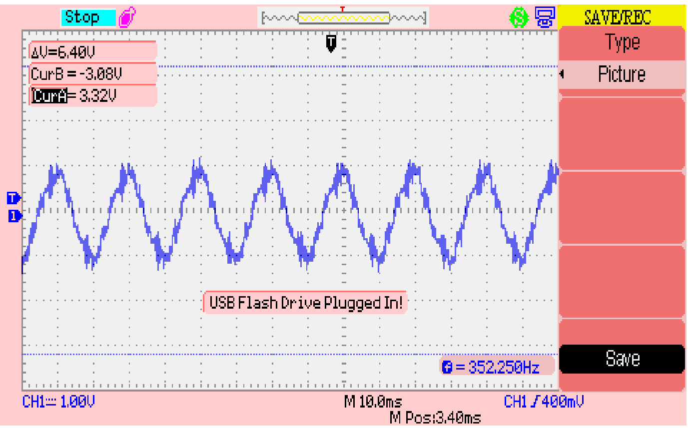


Fig: 14: Oscilloscopic output of Input power supply (12 volts)

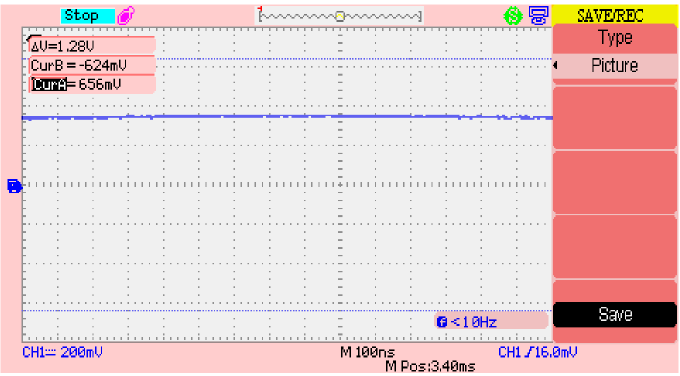


Fig 15: Oscilloscopic output of Voltage IC Regulator

B. PWM Generator

The fabricated circuit of the PWM Generator is given in Fig.16. All the components are inbuilt in this PWM Generator. The output waveform of the PWM Generator before giving it to the Buck-Boost converter is shown in Fig.17. If any tap change is done, the output for the condition is shown in Fig.18.

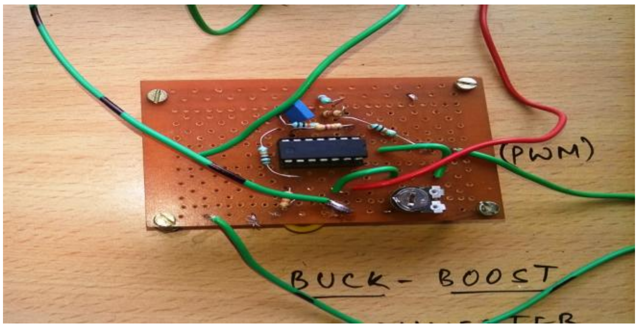


Fig 16: Fabricated Circuit for PWM Generator

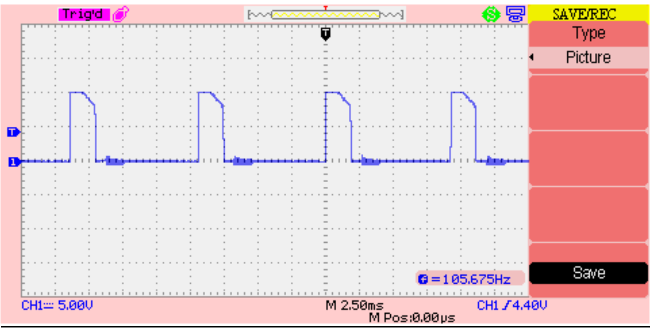


Fig 17: Oscilloscopic output of PWM Generator

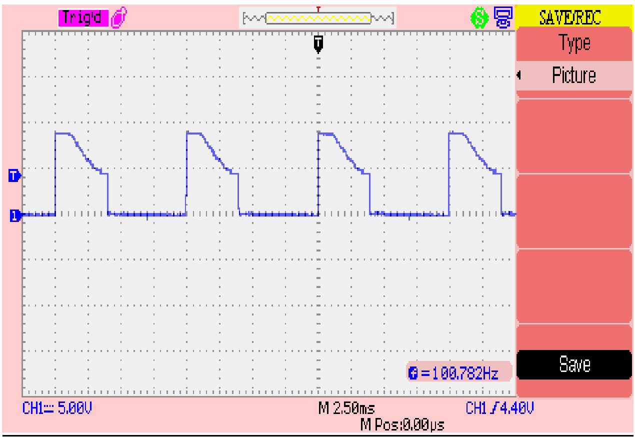


Fig 18: Oscilloscopic output of PWM at a certain Tap

C. Buck Converter

The fabricated circuit of the Buck converter is given in Fig.20. All the components are inbuilt in this Buck converter. The Final output waveform of the Buck converter is shown in Fig.19.

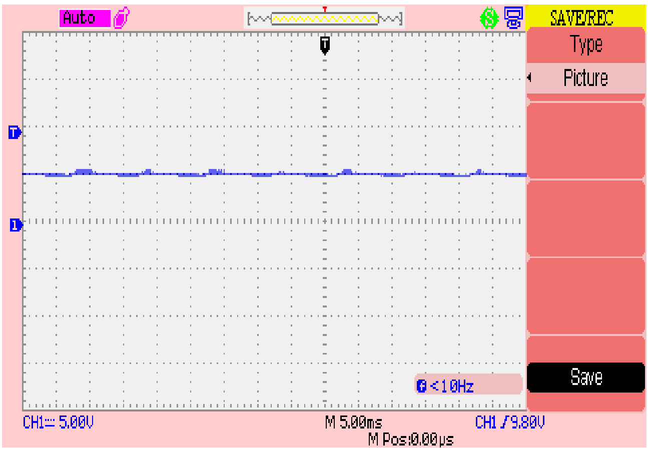


Fig 19: Oscilloscopic trace out of output voltage of buck converter

D. Boost converter

The fabricated circuit of the Boost converter is given in Fig.20. All the components are inbuilt in this Boost converter. The final output waveform of the Boost converter is shown in Fig.21.

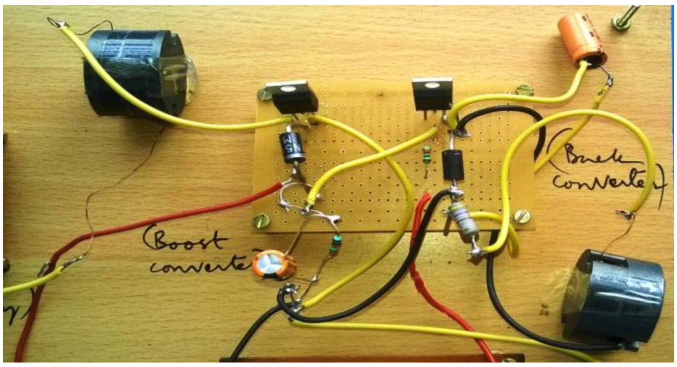


Fig 20: Fabricated Circuit for Boost & Buck converter

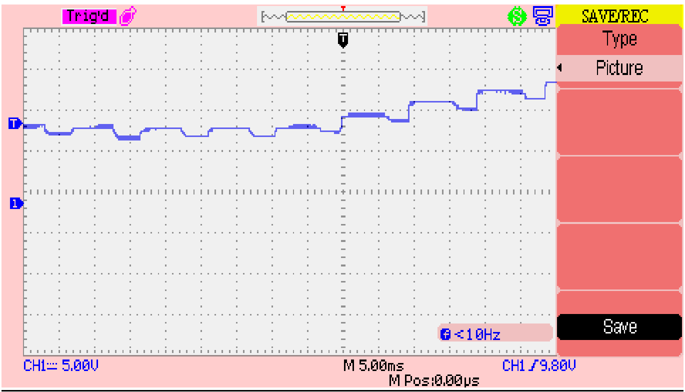


Fig 21: Oscilloscopic output of Boost Converter

The results and the explanations of each block have been described vividly.

IV. Conclusions

The Buck and boost converters are designed and fabricated in lab scale. These converters are tested in the laboratory with laboratory condition and found to have results quite satisfactory. The results obtained are as follows:

BOOST CONVERTER:
V min= 12 V
V max= 40 V
BUCK CONVERTER:
V min= 3 V
V max= 7 V

This paper is designed with constraint of time and cost. The power of the converter can be increased by using higher rating elements. The converters are a transistor based switching, but it can also be implemented using IGBT based driver. The converter is using a PWM of low frequency is around 150Hz. A high frequency PWM converter can also be implemented and efficiency study can be done. The Output voltage range is between 3 Volt to 40Volt in this Buck and Boost converter and can be raised to a higher value such as few hundreds of volts. In this project work BUCK and Boost converters are separated but one integrated single BUCK-BOOST converter can be implemented.

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Design, Fabrication and Experimentally Testing Of a Buck-Boost Converter System (0-50v) a PrototypeJ.K.Moharana." IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 13.4 (2018): 20-29.