Development And Testing Of Non-Isolated Boost Converter

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Abstract— **Non-Isolated Boost Converter is designed using standard topology and a commercially available application specified integrated circuits (ASIC). Compensator Design has been done. Methodology of choosing components, selection of values, and design of magnetic like Inductors has been expanded. Design is simulated on MATLAB software and tested.**

Key words—Nonisolated Boost converter, Application integrated specific circuit(ASIC), Compensator.

I. INTRODUCTION

Over the years as the portable electronics industry progressed, different requirements evolved such as increased battery lifetime, small and cheap systems, brighter, full-color displays and a demand for increased talk-time in cellular phones. An ever increasing demand from power systems has placed power consumption at a premium. To keep up with these demands engineers have worked towards developing efficient conversion techniques and also have resulted in the subsequent formal growth of an interdisciplinary field of Power Electronics.

A DC-to-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. It is also called as Chopper. It is a class of power converter. DC- DC converters are the power supply that output a fixed voltage efficiently, converting the input voltage. There are three types of DC- DC converters [1]

The non-isolated converter usually employs an inductor, and there is no dc voltage isolation between the input and the output. The vast majority of applications do not require dc isolation between input and output voltages. The non-isolated dc-dc converter has a dc path between its input and output. Battery-based systems that don't use the ac power line represent a major application for non-isolated dc-dc converters.

II. BOOST CONVERTER

Operating Principle**:-**

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, when being discharged, it acts as an energy source. 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.
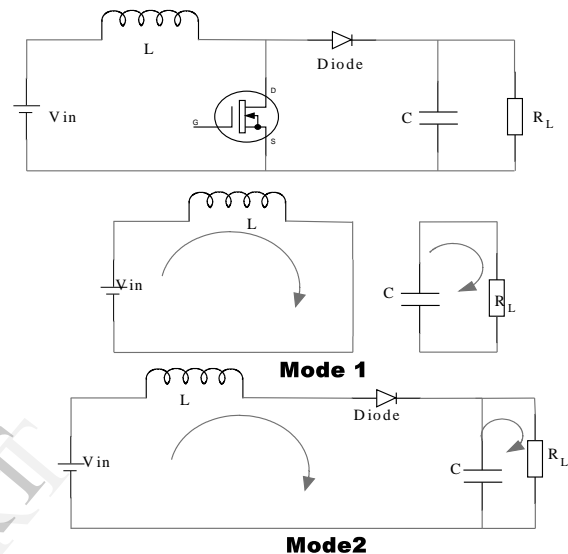

Figure 1: Boost converter when switch is ON and OFF

The above figures are the two configurations of a boost converter, depending on the state of the switch S.

The basic principle of a Boost converter consists of 2 distinct states:

- In the On-state, the switch S (see figure 1) is closed, resulting in an increase in the inductor current.

- In the Off-state, the switch S (see figure 1) is open and the only path offered to inductor current is through the D, the capacitor C and the load R. This result in transferring the energy accumulated during the On-state into the capacitor.

During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

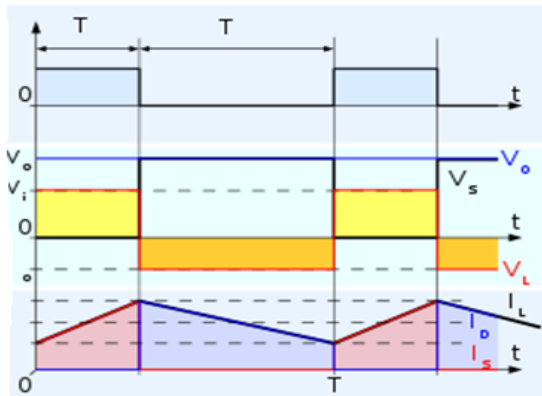$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

Figure 2: Waveforms of current and voltage in a boost converter

The final equation of the two modes is: $\dfrac{V_0}{V_i} = \dfrac{1}{1-D}$

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.

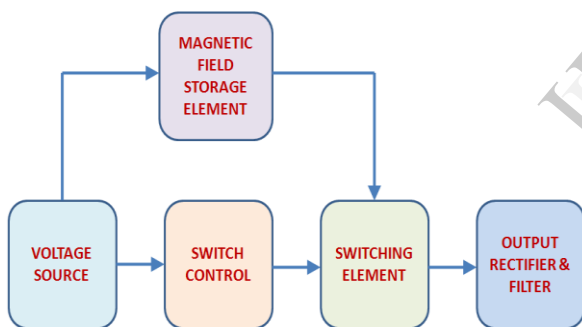### III. BLOCK DIAGRAM OF BOOST CONVERTER

Figure 3: Block diagram of Boost converter

- The voltage source provides the input DC voltage to the switch control, and to the magnetic field storage element.

- The switch control directs the action of the switching element, while the output rectifier and filter deliver an acceptable DC voltage to the output.

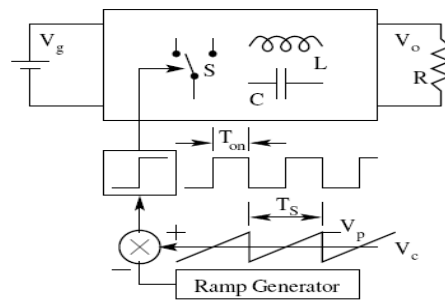### IV. DUTY RATIO CONTROLLED DC DC CONVERTER

Figure 4 Duty ratio controlled dc-dc converter

The block diagram is a duty ratio controlled converter where output voltage is taken as feedback and compared with ramp voltage which gives pulses to the mosfet and gives required output.

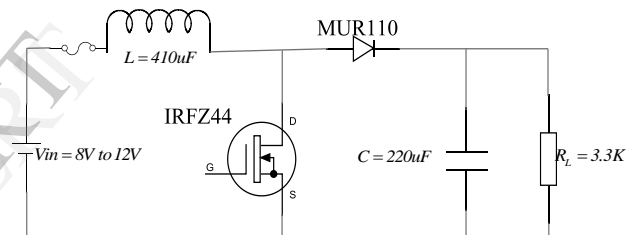### V. DESIGN OF COMPONENTS OF POWER CIRCUIT

POWER CIRCUIT:

Figure 5 : Boost Converter

The designing components of power circuit are inductor Lo, Capacitor C and Diode (MUR110) and a MOSFET.

TABLE I
NECESSARY PARAMETERS OF POWER STAGE

Necessary Parameter	Value
Input Voltage	8V to 12V
Output Voltage	15V
Ouput Current	0.5A
Output Power	7.5W
Switching Frequency	100Khz

From above parameters we can find Duty cycle, Inductor and capacitor values.

SELECTION OF MOSFET: The power MOSFET has to carry about 1A and block about 20V. The device chosen is IRFZ44.

DESIGN OF INDUCTOR L_o:

$$V_g = \frac{L_0 * \Delta I}{T_{on}} \qquad L_0 = \frac{V_g * T_{on}}{\Delta I}$$

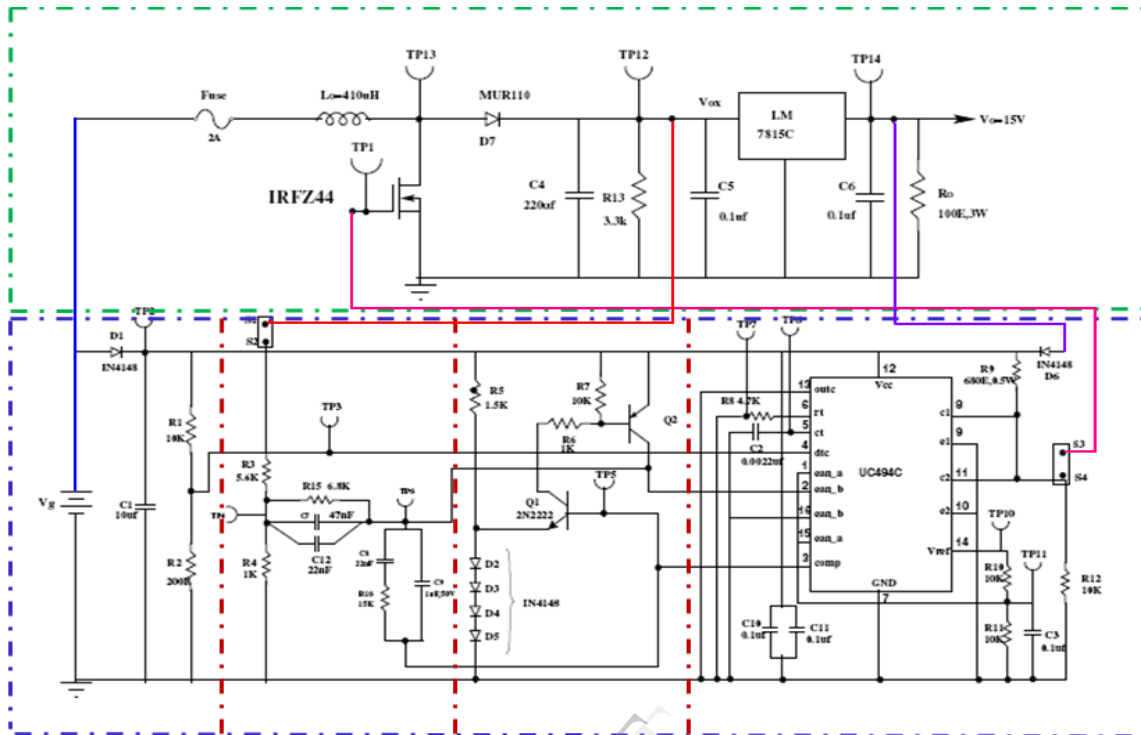*Figure 6 Practical Implementation of Boost converter*

ΔI=20% of rated current

The rated current is 0.5 A. The ripple current is chosen as 0.1 A. With maximum on time of 5.3µs, at input voltage of 8V, this gives an inductor value of approximately 400 µH.

DESIGN OF CAPACITOR C_o:

$$C_0 = \frac{I_{rated} * T_{off}}{\Delta V}$$

$\Delta V = 1\%$ Of output voltage

    Vo=17V;
    I rated=0.5A;
    Toff=5µs;

The output capacitor required has to limit the voltage ripple to about 1 %(0.017V).This capacitor is selected to be 220µF (an order of magnitude higher than the desired value).

According to [2] these filter components design equations have been derived.

SELECTION OF DIODE: The diode carries about 0.5 A average current and blocks about 20 V and suitable for 100 kHz switching. MUR110 is selected. (MUR110) [2]

The figure (6) represents whole connection diagram of the non-isolated power circuit. This circuit consists of all the circuits which are explained above

- Power circuit.
- Start-up circuit.
- Feedback circuit.
- Maximum-pulse width circuit.
- IC controller circuit (UC494C).

The Power circuit provides the dead time control to the fourth pin of the IC controller (UC494C). This dead time control maintains the minimum off time of the circuit. The input voltage given to the circuit is 10V. The diode used here is to avoid the reverse voltage. The input voltage given will be maintained across the capacitor and this voltage is given to the potential divider which provides the dead time control. The minimum ON time is decided by the dead time control circuit R1 (10k) and R2 (220).

The Maximum Pulse Width circuit consists of two transistors Q1 (2N2222) and Q2 (2N2907). The main purpose of this circuit is to limit the voltage [6]

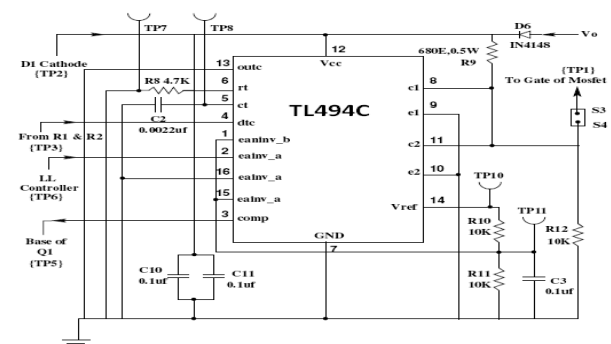**Controller circuit of boost converter:-**

Figure 7: Control Circuit TL494C

The above circuit represents the control circuit (TL494C) of the non-isolated boost converter. R8 (4.7k) and C2 (2.2 nF) are the resistor and capacitor used to determine

the switching frequency. An inbuilt oscillator is present which has two pins Rt & Ct opened. By connecting R8 & C2 ramp voltage signal is produced and its magnitude is decided by dtc (dead time control) Pin no 4. The switching frequency is given by

$$F_s = \frac{1.11}{R_t C_t} = 100\,KHz$$

The control circuit IC TL494C consists of two error amplifiers of which only one is used i.e. pin no1 & pin no2. Pin no15 & pin no16 forms another error amplifier which is grounded. Pin no 14 i.e. V_{REF} is divided by a potential divider by resistors R10 (10KΩ) and R11 (10KΩ) to 2.5V is fed to non-inverting terminal of error amplifier i.e. pin no1.The feedback voltage is connected to inverting terminal i.e. pin no2. The voltage gets subtracted and compared with ramp voltage. There are two inbuilt transistors in which emitters are grounded, the collector C1 is connected with pull-up resistor and C2 with pull-down resistor. An inbuilt PWM comparator is present which is connected to base b2 and pulses are taken out by pin no 11.OutC i.e. pin no 13 is grounded. When error amplifier voltage exceeds 2.7V pin no3 i.e. compensation pin gets enabled and maximum pulse width modulation circuit operates.

VI. COMPENSATOR DESIGN

Closed Loop Control:

Control Requirements:

The control specification of the converter will be in two parts.
   ❖ Steady state accuracy
   ❖ Settling time and allowed transient overshoot in the event of disturbances or command changes.

The approximate transient overshoot is related to the phase margin (Φm) of the loop gain according to the Table (below) for acceptable transient overshoot, the phase margin may be taken as 45°.

The first design step in closed loop controller design is to convert the control specification to the following.
   ➢ Desired T(0) [to meet the steady state error]
   ➢ Desired ωc [to meet the settling time]
   ➢ Desired phase margin Φm [to meet the transient overshoot]

Table II:
Phase margin vs transient overshoot

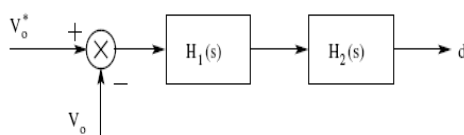| Phase Margin(Degrees)	30°	35°	40°	45°	50°	55°	60°
Transient Overshoot(%)	37%	30%	35%	16%	9%	5%	1%

Compensator Structure:

Figure 8: Structure of a closed loop controller

Design of Compensator:

The important rule that is used here is that, if the loop gain crosses 0 dB (unity gain) with a single slope (-20dB/decade), then the closed loop system will be stable. The reason is that the phase gain of a function crossing 0dB with a single slope at a frequency of ωc is approximately the same as the function K/ωc(s) and is equal to -900. This argument is valid only when the loop gain is a minimum phase function. The actual phase angle will depend on the poles and zeroes nearest to the crossover frequency. With the above simple rule in mind, the compensator function H1(s) is selected to be simple lead-lag compensator [4-6].

$$H_1(S) = K_1 \frac{1 + \dfrac{s}{\omega_{z1}}}{1 + \dfrac{s}{\omega_{p1}}}$$

The purpose of is to make the slope of crossover section of the loop gain to -20 dB/decade near the desired crossover frequency, and to improve the phase margin.
   ➢ If G(s) is a first order system in the vicinity of ωc, then H1 may be just K1.
   ➢ If G(s) is a second order system in the vicinity of ωc, then select ωz1 and ωp1 such that ωz1<ωc < ωp1
   ➢ If G(s) is a second order system with a complex pole pair ωo then ωz1 may be taken as ωo, ωp1 is usually as ten times ωz1.
   ➢ Now K1 may be selected to meet the requirements of ωc and Φm.

The next part of the compensator H2(s) is needed to meet the steady state error specification. If G(0)H1(0) is already compatible with the steady state error, then H2(s) is 1. However, if G(0)H1(0) is not compatible with the desired steady state error, H2(s) is different from unity. The conditions on H2(s) are
   ➢ G(0)H1(0)H2(0) = T(0).
   ➢ H2(s) must not affect the gain & phase margin already designed. Or in the other words, phase and magnitude gain of H2(s) in the vicinity of ω_c must be 0° and 0dB respectively.

   ➢ A PI controller of the form $H_2(S) = \dfrac{1 + \dfrac{s}{\omega_{z2}}}{\dfrac{s}{\omega_{z2}}}$ satisfies the

above requirements. The overall compensator is

$$H(s) = \frac{1 + \dfrac{s}{\omega_{z2}}}{\dfrac{s}{\omega_{z2}}} K_1 \frac{1 + \dfrac{s}{\omega_{z2}}}{1 + \dfrac{s}{\omega_{p1}}}$$

And can be realized using operational amplifiers.

Theoretical Compensator Design:

Consider one pole and one zero compensation.
Considering Open-loop Transfer Function

$$G(s) = \frac{(\dfrac{1-k}{LC})}{S^2 + \dfrac{1}{RC} S + \dfrac{(1-k)^2}{LC}}$$

Here duty cycle k is taken as 0.3.
Load resistance R=3300Ω.
Inductor L=400µH.
Capacitor C=220µF.

Substituting the above values in G(S), we get from bodeplot of G(S) shown in figure we can obtained the values of ωn, Gain-Margin (Gm), Phase-margin (Pm), Gain-crossover frequency (ωgc) and Phase-crossover Frequency (ωpc)

Therefore,

ωn = 2359.69 rad/sec
Gm = Inf
Pm = 0.2502 dB
ωgc = Inf
ωpc= 2.5226e+003 rad/sec
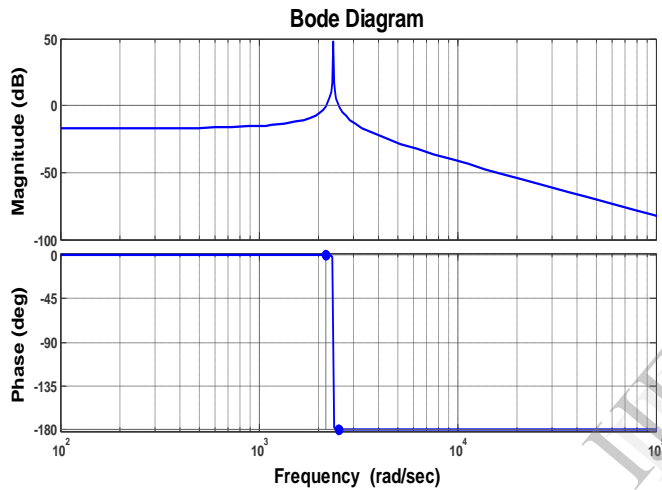
Figure 9: Bode plot of Open-loop Transfer Function G(S)

Step 1: Let   ωz1= 1.2842 ωn
                     ωP1= 2.9537 ωn
ωP1 and ωz1 are chosen as per the stability requirement.

From bode-plot of GH1(S) shown in figure we can obtained the values of Gain-Margin (Gm), Phase-margin (Pm), Gain-crossover frequency (ωgc) and Phase-crossover Frequency (ωpc)

Step 2:

To meet the Steady-State Error specification we choose a PI Controller of form

Let $\omega_{z2} = 2131.8 \, rad / sec$

$$H_2(S) = \frac{1 + \dfrac{s}{\omega_{z2}}}{\dfrac{s}{\omega_{z2}}} \qquad \frac{R_4}{R_3} = \frac{1}{5.6}$$

Therefore Closed-loop Transfer Function of the System is

$$\frac{GH_1H_2 * 0.17}{1 + GH_1H_2 * 0.17}$$

Therefore, Closed-Loop Transfer function (CLTF)

$$= \frac{9336.81s^2 + 28473676570s + 60276144300000}{s^4 + 6971.337s^3 + 567108627s^2 + 41657372130s + 602761442300000}$$

From bodeplot of Closed-loop transfer function shown in figure (30) we can obtained the values of Gain-Margin (Gm), Phase-margin (Pm), Gain-crossover frequency (ωgc) and Phase-crossover Frequency (ωpc).[3]
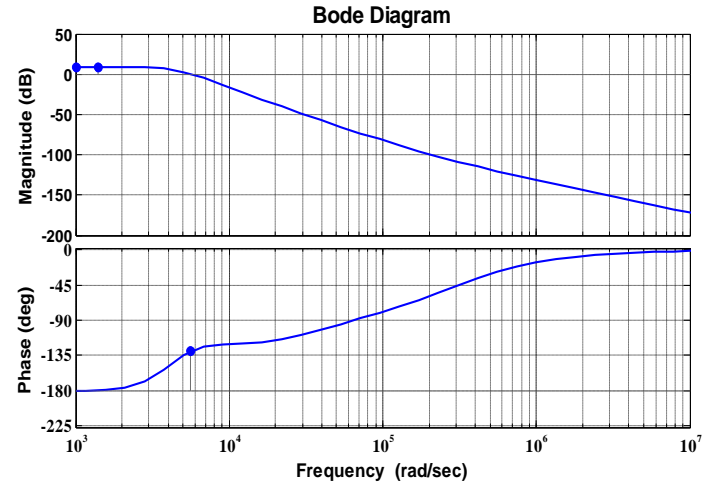

Figure 10: Bode plot of Closed-Loop Transfer Function

Therefore,
Gm = 0.3571 dB
Pm = 50.1342 dB
ωgc = 0 rad/sec
ωpc= 5.6165e+003 rad/sec

The Closed-loop transfer function of above system is stable.

Practical Compensator Design:

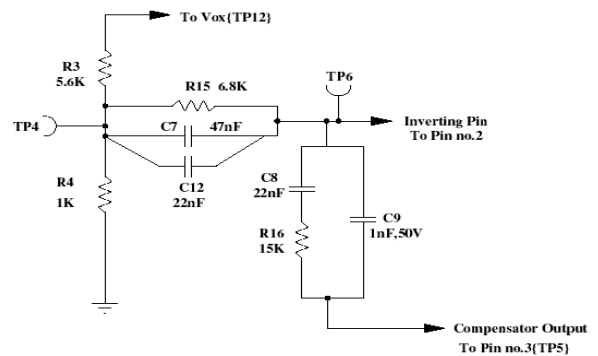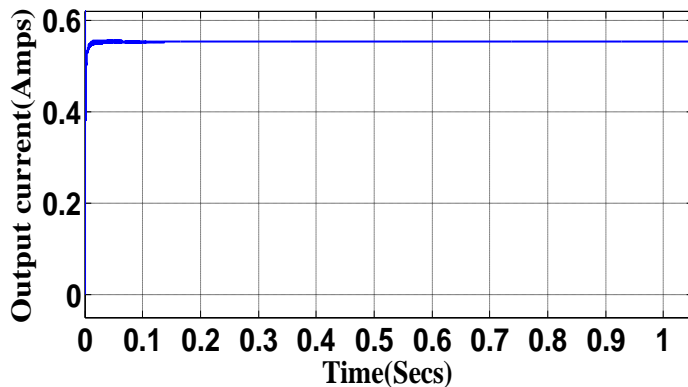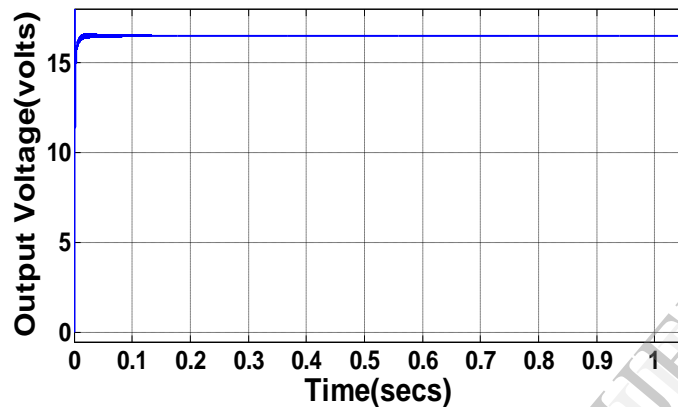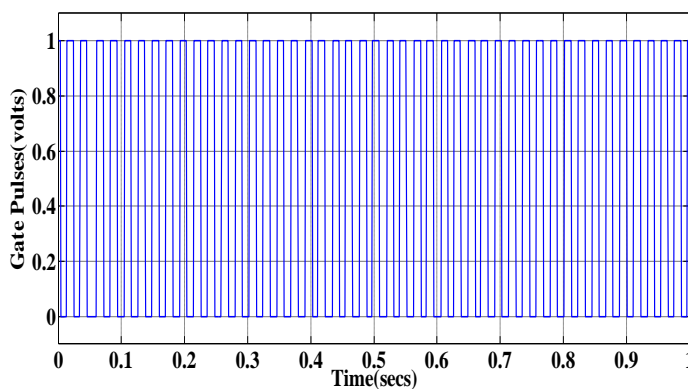*Figure 11:Practical compensator*
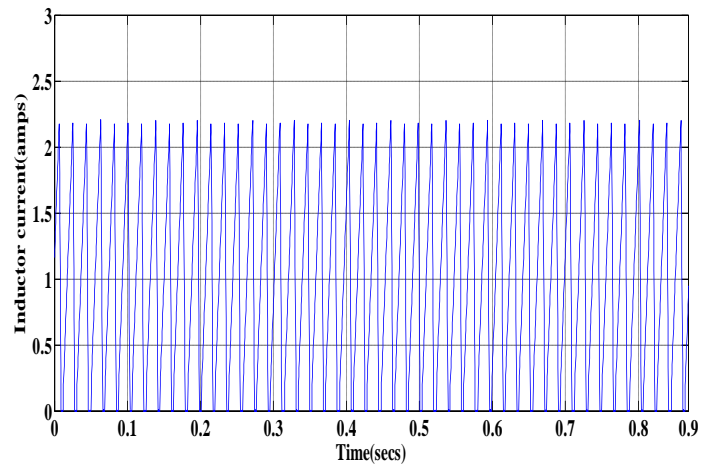
VII. SIMULATION RESULTS

Iout Vs Time

Vout Vs time

Gate voltage Vs time

Inductor current Vs time

CONCLUSION:

NON-ISOLATED BOOST Converter is an efficient step-up DC-DC converter used in numerous electronics devices. It is modeled and simulated using Matlab. A closed loop model is developed and used successfully for simulation. This converter has advantages like reduced hardware, high performance, less weight and accuracy. The simulation results are in line with the predictions.

The same was implemented as a hardware project and an output voltage of 15V was obtained with an input of 8V-12V DC supply.

REFERENCES.

[1] ''Power Electronics: Converters, Applications and Design. Mohan/undeland/Robbins.

[2] M. Pedram and Q. Wu, "Design considerations for battery-powered electronics," *DAC,* 1999

[3] "Mathematical modeling for power dc–dc converters," in *Proc. IEEE Int. Conf. POWERCON'04*, Singapore, Nov. 21–24, 2004, pp.323–328

[4] M. K. Kazimierczuk and R. Cravens, II, "Open and closed-loop dc and small-signal characteristics of PWM buck-boost converter for CCM,"*J. Circuits, Syst. Comput.*, vol. 5, no. 3, pp. 261–3003, Sep. 1995.

[5] R. W. Erickson and D. Maksimovic, *Fundamentals of Power Electronics*, 2nd ed. Norwell, MA: Kluwer, 2001.

[6] Raju.N ,Laxminarasamma.N ,Ramnarayan.V"A do-it-yourself (DIY) switched mode power conversion laboratory"in Proc IEEE Int.IICPE-2006,Bangalore,Dec. 19-21 ,2006,pp.289-292