INDIAN INSTITUTE OF TECHNOLOGY, GUWAHATI

PCB Design of Closed Loop Operation of Buck-Boost Converter

Raghuwar Jee Jha (214102112)
Prashant Verma(214102107)

Objective

Realize a closed loop control of buck-boost converter controlled by analogue PI controller. The specifications for the buck-boost converter are given below.

Specifications

Input Voltage (V_{in}): 96 V, Output Voltage (V_0): 48 V and 150 V, Switching Frequency (f_{sw}): 20 kHz, Output Voltage Ripple (V_r): 10 percent, Inductor Current Ripple (IL_r) : 20 percent , Rated Power: 500 W.

Circuit Diagram

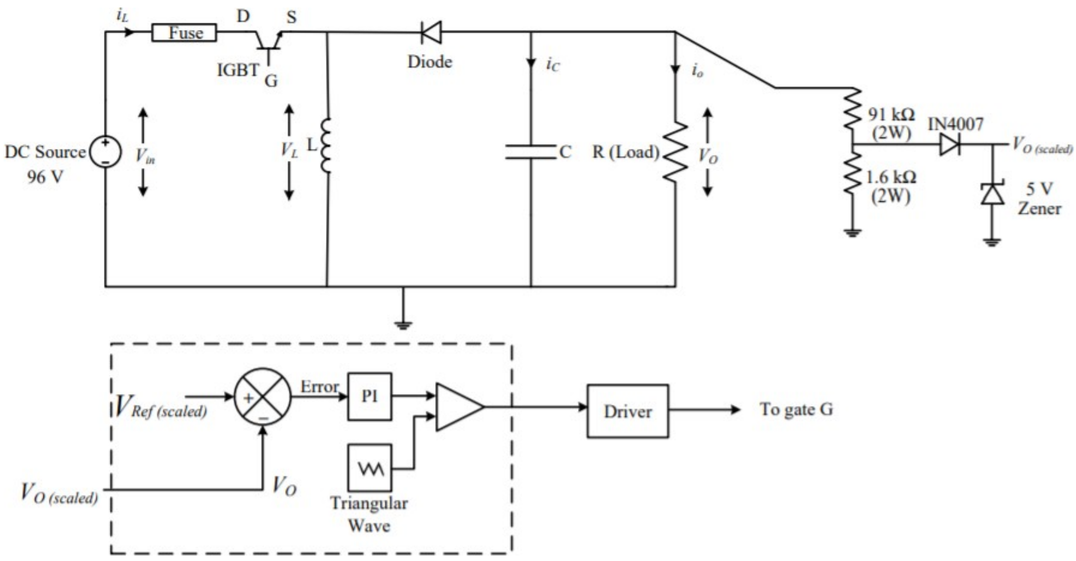

Figure 1: Buck-Boost Circuit

Power circuit design

To design the power circuit firstly, the values D, V_0 and R are calculated for buck and boost mode individually. After this step, the values of L and C are determined by the permissible current ripple and voltage ripple respectively.

If a load of resistance R and output ripple voltage V_r is considered, then the minimum value of filter capacitance required is given by

$$C_{min} \quad \frac{D * V_0}{R * f_{sw} * V_r}$$

The value of the inductor determines the boundary between the continuous and discontinuous conduction modes is given by

$$L_b = \frac{(1 - D)^2}{R * f_{sw}}$$

If input voltage V_{in} and ripple inductor current is $I_{L}r$ is considered, then the minimum value of inductor required is given by

$$Lr = \frac{D * V_{in}}{f_{sw} * IL_r}$$

The results obtained by following the procedure discussed above are shown for buck and boost mode.
In the buck mode (output voltage = 48 V)

$$C_{min} = 3.7\mu F$$

$$L_b = 0.5mH$$

$$Lr = 0.512mH$$

In the boost mode(output voltage = 150 V)

$$C_{min} = 6.77\mu F$$

$$L_b = 0.1713mH$$

$$L_r = 1.7mH$$

After obtaining the critical values of L and C for both the cases, L and C are selected such that whose values are sufficiently larger than the ones calculated in the boost mode.

The values of power circuit used are L=2 mH, C=47 μF and R=45 Ω. All the devices are selected incorporating safety factor as 1.5. A RCD normal snubber circuit is also designed for the power electronic switch.

Controller design

The control circuit has to generate the pulses for the gate driver.The control signal for gate pulse is obtained by comparing the reference signal obtained by the controller and triangular wave.

The Triangular wave is generated with the concept of square wave generator and integrator circuit using OP-AMPs. To generate the reference signal for comparing with the triangular wave we use a PI controller. The input of the PI controller is the scaled output voltage signal and scaled reference voltage signal required at the output.

The scaled output voltage signal is reduced form of equivalent output signal available at the output. It is scaled using an auxiliary circuit at the output side. The scaled output voltage signal and scaled reference signals are given as input for error generation. After this step, the error signal generated is given as input to the PI controller and the controller gives us the desired reference signal for comparing with the triangular wave to give pulses to the gate driver circuit.

The proportionality constant K_p is given by R_6/R_5 and integrator constant K_i is given by $1/(R_8 * C_1)$. Resistor R_9 allows bias current to bypass C_1. Without R_9, bias current on some general purpose, bipolar op-amps are large enough to charge C_1 even with no error voltage. This causes the output of the integrator op-amp to slowly rise until it is saturated. R_9 is taken an greater then $10 * R_8$.

The transfer function of a buck-boost converter is given below.

$$TF = \frac{V_{in}}{D*(1-D)}\left[\frac{(1-D)^2 * R - s * D * L}{s^2 L * C * R + s * L + (1-D)^2 * R}\right.$$

The PI controller is designed using the values for the boost mode. That should make the controller work for the buck mode as well.

Thus, D = 0.61, L = 2 mH, C = 47μF, R = 45 Ω and V_{in} is 96V. Using these values in the above equation and simplifying, we get the transfer function as

$$G(s) = \frac{4320 - 0.7687s}{4.23*(10)^{-6}*s^2 + 0.002*s + 6.853}$$

Therefore, the characteristic equation is written as

$$1 + KG(s) = 0$$

$$4.23 * (10)^{-6} * s^2 + (0.002 - 0.7687K) * s + (6.853 + 4320K) = 0$$

From Routh Hurwitz stability criterion, we obtain the below results

$$K_{critical} = 0.0026$$

$$K_p = 0.6 * K_{critical} = .0016$$

$$K_i = \frac{K_{critical} * w}{p} = 1.7$$

The formula for K_p and K_i are given by

$$K_p = \frac{R_6}{R_5}$$

$$K_i = \frac{1}{R_8 C_1}$$

Thus accordingly R_5, R_6 values will be 100kΩ and 160Ω respectively and R_8, C_1 values will be 5.9k Ω and 10μF respectively.

Simulation Results

Buck mode: V_0 =48V, duty cycle D = 33.33 percent.

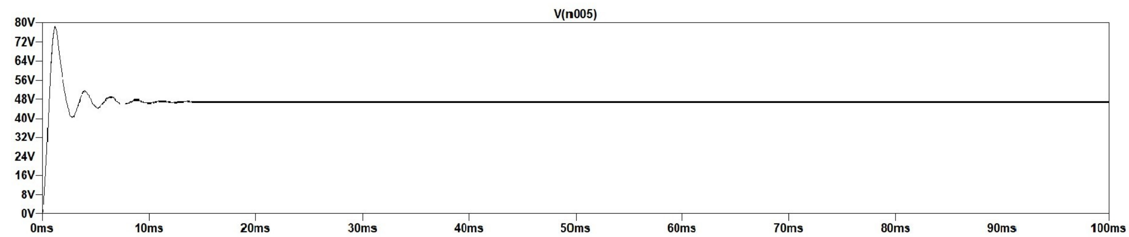

Figure 2: Output Voltage in Buck Mode

Boost mode: V_0 =150V, duty cycle D = 61 percent.

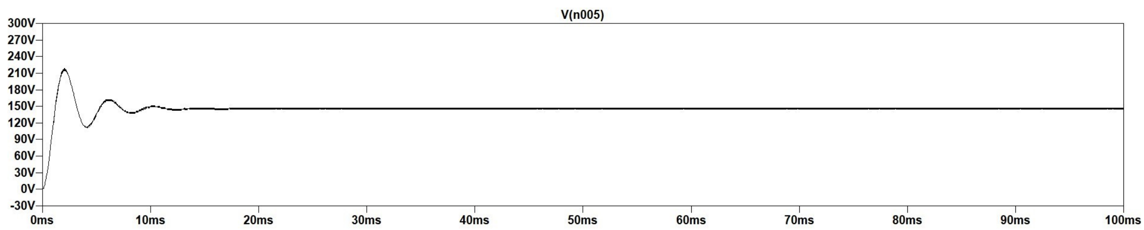

Figure 3: Output Voltage in Boost Mode

PCB Designing

The PCB design is done using the EAGLE software. The components which were used in the simulation are used to create a eagle schematic file. The Board file is created from the schematic file. After that the connections are made accordingly and width of copper is chosen according to the current flowing. After Board connection is completely gerber files are generated using the CAM Processor and by using the software ZofzPCB the figure shown is obtained.

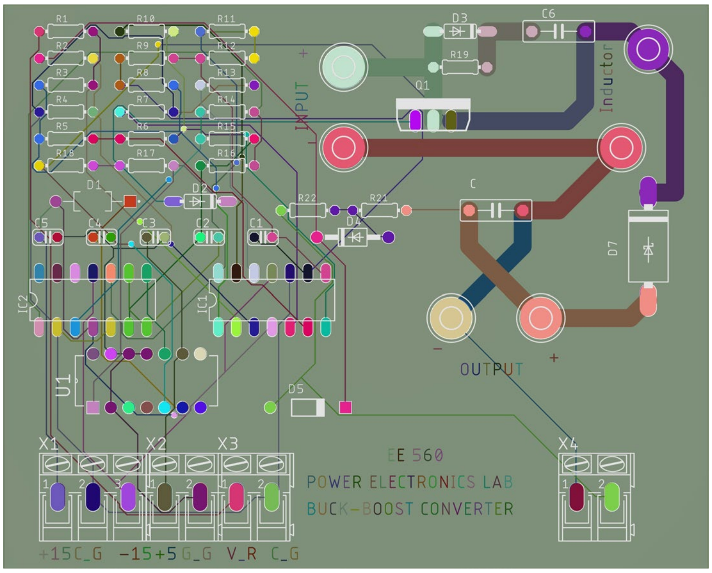

Figure 4: Final PCB Board

Conclusion

The overall circuit is designed using analog circuits with the help of OP-AMPs. In the LT spice software the simulations are done,later PCB designing is done using EAGLE software and finally gerber files are generated for the closed loop operation of the Buck-Boost converter.