EE462L – DC-DC Boost Converter

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Circuit/Lab Overview

Very similar to the DC-DC Buck converter, the DC-DC Boost converter instead takes a DC input, and outputs a higher DC output voltage. Like the Boost converter, the Buck converter has two operation modes, continuous conduction mode (CCM), and discontinuous conduction mode (DCM). CCM is when the inductor current never dips below 0 A, it may momentarily reach 0 A, but never linger there. In DCM, the inductor current reaches and stays at 0 A, and the capacitor attempts to backfeed the inductor but is prevented by the freewheeling diode. In DCM, the power to the load is provided only by the capacitor. The Boost converter, because of its configuration, is also a much more sensitive circuit when compared to the Buck converter. If the duty cycle approaches one, the circuit will short Vin. Additionally, if there is no load connected to the Boost, then the capacitor voltage may exceed its rating.

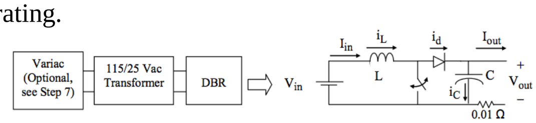

Figure 1: Boost Converter Schematic [1]

Circuit Testing

The boost converter shown in Fig. 1 is constructed and then tested in the manner described in this section. In all cases the output of the converter is connected to a 120V 150W light bulb. First, with the gate driver running at 90 kHZ the duty cycle D is increased to the point where the output dc voltage is about 120V. The values of D, Vin, Iin, Vout and Iout are as shown in Table 1.

Table 1. Summary data for boost converter switched at 90 kHz.

D	Vin (V)	Iin (A)	Vout (V)	Iout (A)
0.755	30.3	6.21	122.4	1.25

Theoretically, the relationship between Vout and Vin for a boost converter is given as [1]:

$$V_{out} = \frac{V_{in}}{1-D} \quad (1)$$

From the data of Table 1, using Vin of 30.3 and D of 0.755 in equation (1) gives Vout = 123.7V. This compares very well with the measured dc output of 122.4V. Regarding power used and transferred by the converter, it is found that the total input power (Vin times Iin) is 188.163W. The output power (Vout time Iout) is 153W. The converter efficiency therefore is 153/188.163 = 81.3%. The converter loses efficiency due to I^2R losses and switching losses in the mosfet. As a result the mosfet heats up. The temperature of the mosfet after several minutes of operation was measured as 33.6°C.

Fig. 2 shows a screen shot of the voltage across the mosfet switch used in the boost converter.

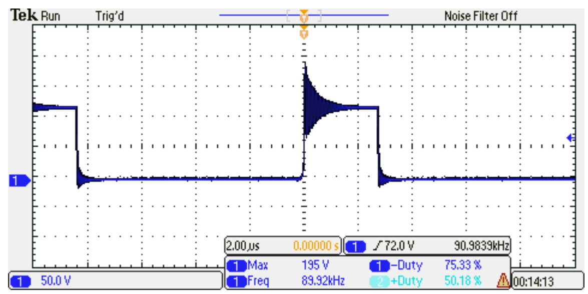

Figure. 2. Measured Vds at 90 kHz switching frequency. Vds is seen to be switching between about 120V and 0V. The peak voltage is 195V due to ringing when the mosfet turns off.

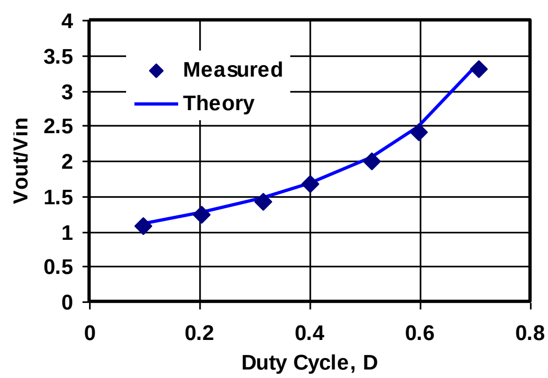

Figure. 3. Measured versus theoretical comparison of Vout/Vin ratio as a function of duty cycle D at a frequency of 90 kHz.

Fig. 3. shows the ratio Vout/Vin of the boost converter as a function of the duty cycle of the mosfet gate voltage at a 90 kHz switching frequency. Both measured and theoretically calculated values are shown. The measured Vout/Vin ratio overlaps with the theoretically expected result. In addition, it is noted that the converter circuit remains in continuous conduction mode (CCM) for the entire range of duty cycles measured above. The inductance required for the circuit to stay in CCM mode is given by [1]:

$$L_{boundary} = \frac{V_{in} D}{2 I_{in} f} \quad (2)$$

For the range of D used, the maximum value of L from (2) was computed to be 45µH using the recorded values of Vin and Iin. Since the inductor used in this circuit is larger, 100μH, it is normal that CCM operation was maintained throughout this experiment.

The above experiments were repeated at 30kHz switching frequency with a duty cycle around 75%. Table 2 shows the summary data for this case.

Table 2. Summary data for boost converter switched at 30 kHz.

D	Vin (V)	Iin (A)	Vout (V)	Iout (A)
0.756	30.18	6.45	120.7	1.25

Theoretically, using (1) and the data from Table 2, the expected output voltage is 123.7V. Once again it is found that the experimentally measured output voltage matches the theoretically calculated value very well. The measured efficiency in this case is 77.5%. This is slightly worse than the 90kHz case. As before, the efficiency loss is due to switching losses and heating losses. Because of increased I^2R losses in the mosfet, its temperature increased to 37.2°C.

The drop in efficiency and the higher temperature of the mosfet at 30kHz can be explained by considering the I^2R losses in the mosfet. The mosfet can be considered to have a constant on resistance. The rms current through the mosfet is given as [1]:

$$I_{rms,mosfet} = \sqrt{D\left(I_{in}^2 + \frac{\Delta I^2}{12}\right)} \tag{3}$$

where ΔI is the ripple amplitude on the inductor current and is given as [1]:

$$\Delta I = \frac{DV_{in}}{Lf} \tag{4}$$

where f is the switching frequency. Clearly, at lower frequencies the ripple amplitude of the inductor current will be higher. As a result, the rms current through the mosfet will be higher at lower frequencies (per eq. 3 and 4). Consequently, the I^2R losses in the mosfet will be higher leading to loss of converter efficiency and increase in mosfet temperature.

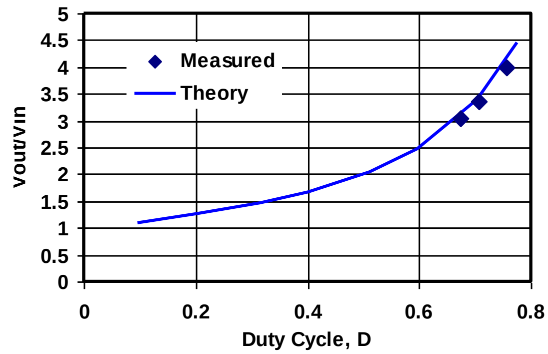

Figure. 4. Measured versus theoretical comparison of Vout/Vin ratio as a function of duty cycle D at a frequency of 30 kHz.

Fig. 4. shows the ratio Vout/Vin of the boost converter as a function of the duty cycle at a 30 kHz switching frequency. Both measured and theoretically calculated values are shown. The measured Vout/Vin ratio overlaps with the theoretically expected result. However, for 30kHz operation it was possible to measure Vout, Vin, etc. for only a few values of D because the converter went into discontinuous conduction mode (DCM) very quickly as D was reduced. This is not unexpected because the minimum L requirement, shown in eq. (2), goes inversely as frequency. At one-third the previous frequency the L would need to be three times higher. Otherwise, the inductor ripple current is three times larger, leading to earlier onset of DCM. Measurements showed that the onset of DCM happens approximately at D = 0.7. At this point, Vin = 31.54V and Iin = 4.36A. Using (2) gives a minimum L of 84.4μH which is reasonably close to the actual value of L used (100μH).

Using the above data from 30kHz operation, ΔI, rms inductor current, and rms capacitor current are computed. The values are as follows.

$$\Delta I = \frac{DV_{in}}{Lf} = 7.6A$$

$$I_{L,rms} = \sqrt{I_{in}^2 + \frac{\Delta I^2}{12}} = 6.81A$$

$$I_{C,rms} = \frac{\Delta I}{2\sqrt{3}} = 2.19A$$

Lastly, the boost converter is operated with solar cell input power. The load is still a 150W 120V light bulb. Fig.5 shows the measured and theoretical Vout/Vin versus D behavior. There is good agreement between measurement and theory.

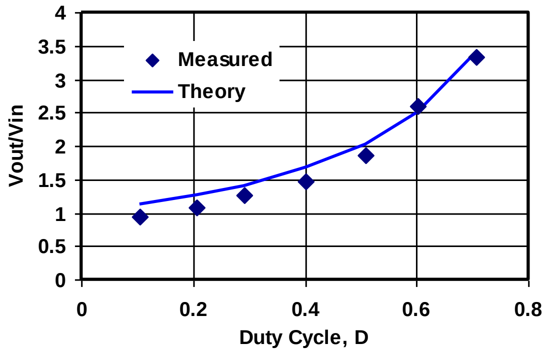

Figure. 5. Measured versus theoretical comparison of Vout/Vin ratio as a function of duty cycle D at a frequency of 90 kHz with solar cell input to boost converter.

Fig. 6 shows the output P-V behavior of the solar cell driven converter. The maximum power extracted is about 78W.

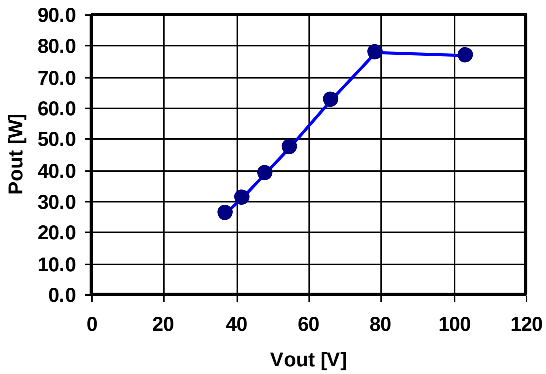

Figure. 6. Measured output P-V behavior with solar cell input power to boost converter.

Conclusion

While very similar to the Buck converter, the Boost converter even uses the same components as the Buck, the Boost is a very different circuit. Unlike the Buck, the Boost takes an input voltage and raises it while sacrificing current to the load. The Boost also makes it look like the load attached to it has a lower resistance to the source, while the Buck did the opposite. Lastly, the Boost converter is much less forgiving than the Buck converter, a no load condition or a high duty cycle puts the Boost converter at risk of harming itself by exceeding the ratings of its components.

	Rounok	Jonathan
Circuit Build	50%	50%
Circuit Testing	50%	50%
Lab Report	60%	40%

References

[1] M. Flynn, "_Lab_Week_7_EE462L_DC_DC_Boost_2014_9_25.pdf", The University of Texas at Austin, Austin, TX, EE 462L: Power Electronics Laboratory course, Spring 2015. [Online]. Available: https://utexas.instructure.com/courses/1129504