ASSIGNMENT 4 - REPORT

Power Electronics and Applications

ELEC3204

BY 470416309
Vishant Prasad

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Forward Converter

Table 1: Forward Converter Specifications

Symbol	Description	Value
P_{norm}	Nominal Power Rating	$240W$
V_{in}	Nominal Input Voltage	$330V$
V_o	Nominal Output Voltage	$12V$
f_{sw}	Switching Frequency	$100kHz$
ΔI_L	Nominal Peak – to – Peak Ripple of Inductor Current	$4A$
ΔV_o	Nominal Peak – to – Peak Ripple of Output Voltage	$1.2V$
L_m	Magnetizing Inductance of the Transformer at Primary Side	$10mH$

Section 1 - Steady – State Analysis and Concept Design

a. The winding turns ratio can be expressed as:

$$1: n$$

The selected n value for this investigation is can be found through the following calculation:

$$\therefore we\ assume: D_{ON} < 50\%$$

$$n = \frac{V_o}{V_{in}D_{ON}} = \frac{12}{330 \times 0.5} = 0.0727$$

$$\therefore n > 0.0727\ (is\ above\ steady - state)$$

Hence, for this investigation the n value will be $n = 0.085$.

b. The on-state duty ratio can be determined as follows:

$$D_{ON} = \frac{V_o}{nV_{in}} \rightarrow D_{ON} = \frac{12}{0.0727(330)} = 0.4278 = 42.78\%\ (2dp)$$

$$\therefore D_{ON} \approx 0.4278 \ldots = 42.78\%$$

c. The computation for the on-state time can be determined as follows:

$$T_{ON} = \frac{D_{ON}}{f_{sw}} = \frac{0.4278}{(100 \times 10^3)} = 4.278 \times 10^{-6}s = 4.278\mu s$$

$$T_{sw} = \frac{T_{ON}}{D_{ON}} = \frac{(4.278 \times 10^{-6})}{0.4278} = 10 \times 10^{-6}s = 10\mu s$$

d. The derivation for the inductance of the forward converter is:

$$T_{DOWN} = 5.722 \times 10^{-6}$$

$$L = \frac{V_O}{\Delta I_L} T_{DOWN} = \frac{12}{4}(4.278 \times 10^{-6}) = 12.83\mu H$$

e. The derivation for the capacitance is as follows:

$$C_O = \frac{\Delta I_L}{8\Delta V_O f_{sw}} = \frac{4}{(8)(1.2)(100 \times 10^3)} = 4.166\mu F$$

f. The peak-to-peak ripple of i_{L_m} can be expressed as:

$$\Delta I_{in} = T_{ON}\frac{V_{in}}{L_m} = (4.278 \times 10^{-6})\frac{330}{10 \times 10^{-3}} = 0.141174A$$

$$\therefore i_{L_m} = \Delta I_{in} = 0.141A$$

g. The evaluation of the BCM condition regarding the levels of the output current and the load resistance were resolved as follows:

$$I_{o,crit} = \frac{\Delta I_L}{2} = \frac{4}{2} = 2A$$

$$R_{crit} = \frac{V_o}{I_{o,crit}} = \frac{12}{2} = 6\Omega$$

h. The output voltage when the load resistance becomes 6Ω with the duty ratio D_{ON} is applied (without loss consideration), is determined as follows;

Since, the circuit is operating in BCM, the voltage will not change. This can be illustrated using the formulation below:

$$(2T_{sw}L)V_o{}^2 + (-2V_{in}T_{sw}L)V_o + \left(-V_{in}{}^2RT_{ON}{}^2\right) = 0$$

$$(2 \times 10 \times 10^{-6} \times 20.1 \times 10^{-6})V_o{}^2 + (-2 \times 330 \times 10 \times 10^{-6} \times 20.1 \times 10^{-6})V_o + (-330^2 \times 6 \times (3.3 \times 10^{-6})^2) = 0$$

$$\therefore V_o = 11.952V \approx 12V$$

i. The on-state duty ratio to maintain a specified output voltage of $12V$ without any loss consideration, with a load resistance becoming 12Ω is:

$$(2T_{sw}L)V_o{}^2 + (-2V_{in}T_{sw}L)V_o + \left(-V_{in}{}^2RT_{ON}{}^2\right) = 0$$
$$\&$$
$$T_{ON} = D_{ON}T_{sw}$$
$$(2T_{sw}L)V_o{}^2 + (-2V_{in}T_{sw}L)V_o + \left(-V_{in}{}^2RT_{ON}{}^2\right) = 0$$
$$(2 \times 10 \times 10^{-6} \times 12^2 \times 20.1 \times 10^{-6}) + (-2 \times 330 \times 20.1 \times 10^{-6} \times 12 \times 10 \times 10^{-6}) - (330^2 \times 12 \times (3.3 \times 10^{-6})^2) = 0$$
$$D_{ON} = 0.2571 = 25.71\%\ (2dp)$$

Section 2 - Simulation

a. The following *figure 1*, displays the simulation model of the forward converter (buck and transformer arrangement):

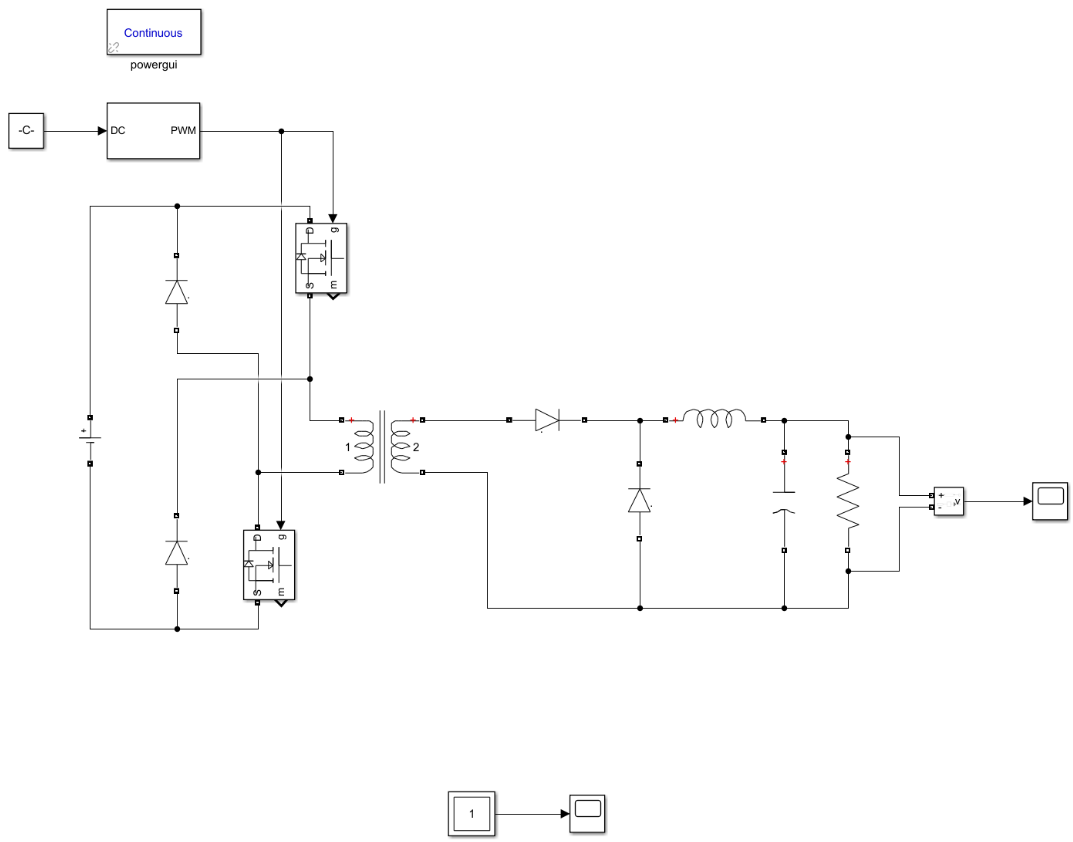

Figure 1: Forward Converter

b. The simulated results of v_{sw}, i_L and v_o are illustrated as follows below respectively:

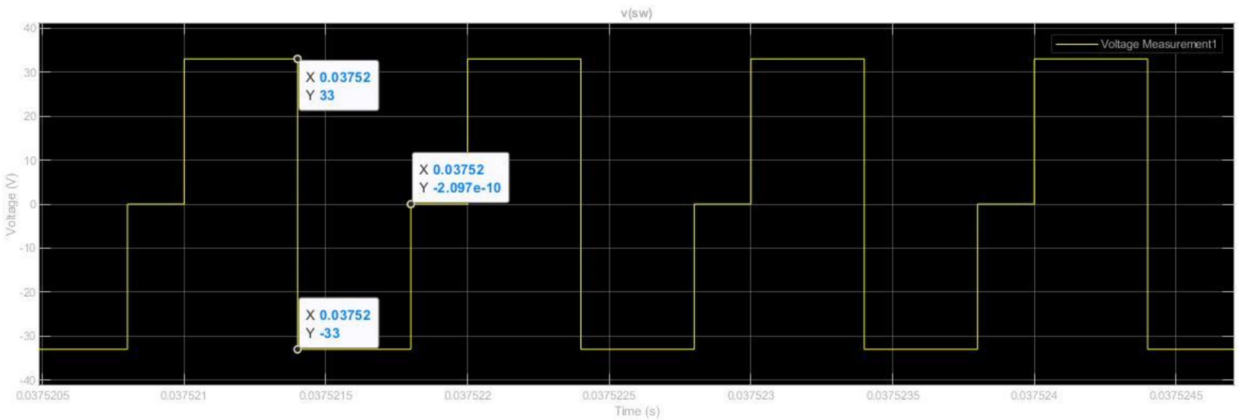

Figure 2: Voltage v_{sw}

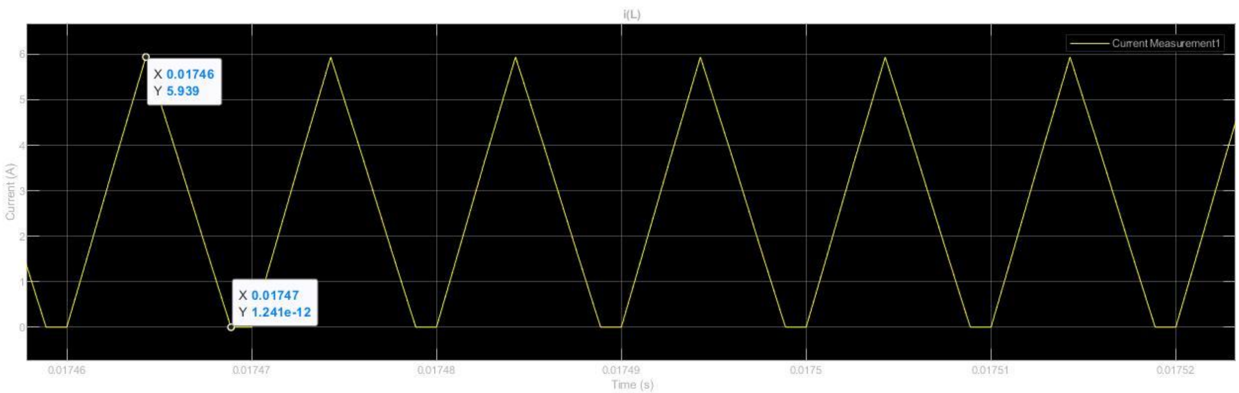

Figure 3: Current i_L

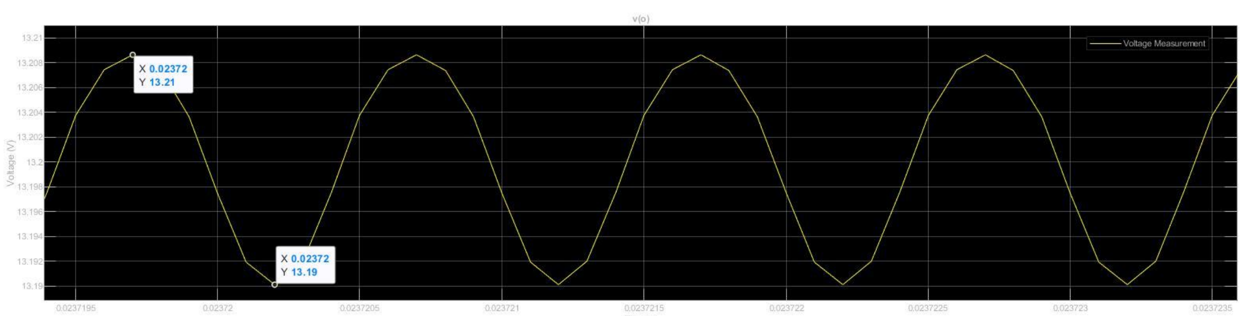

Figure 4: Voltage Output

c. The simulated results of v_{sw}, i_{IN} and i_{L_m} are illustrated as follows below respectively:

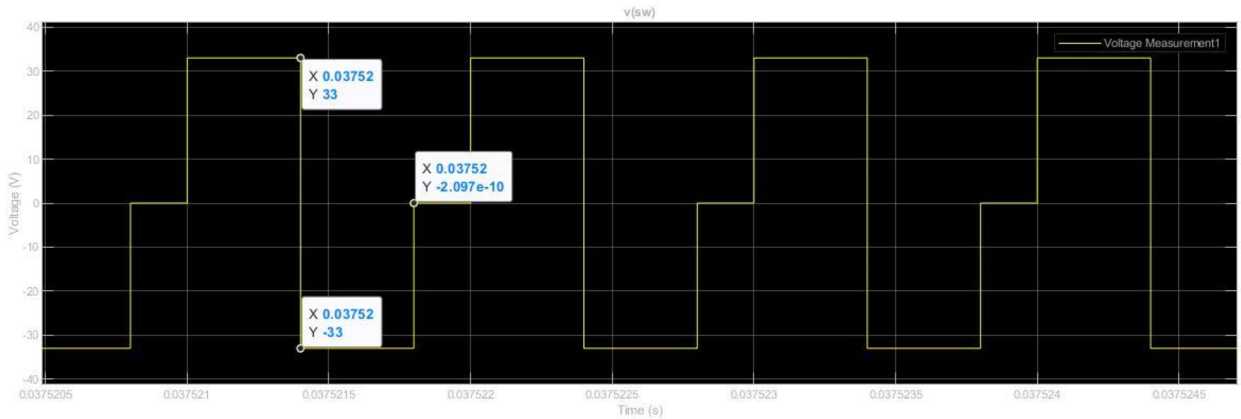

Figure 5: Voltage v_{sw}

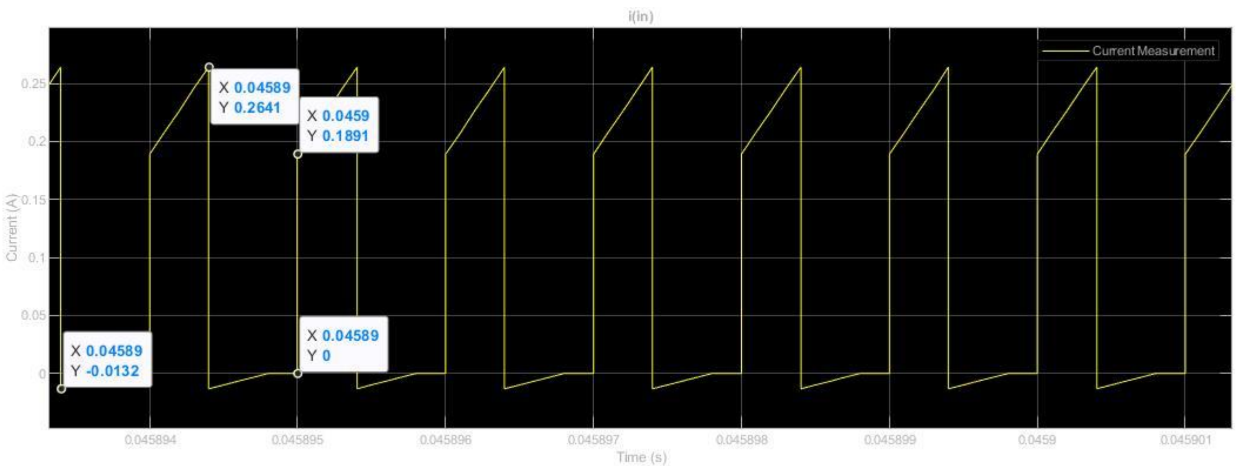

Figure 6: Current Input

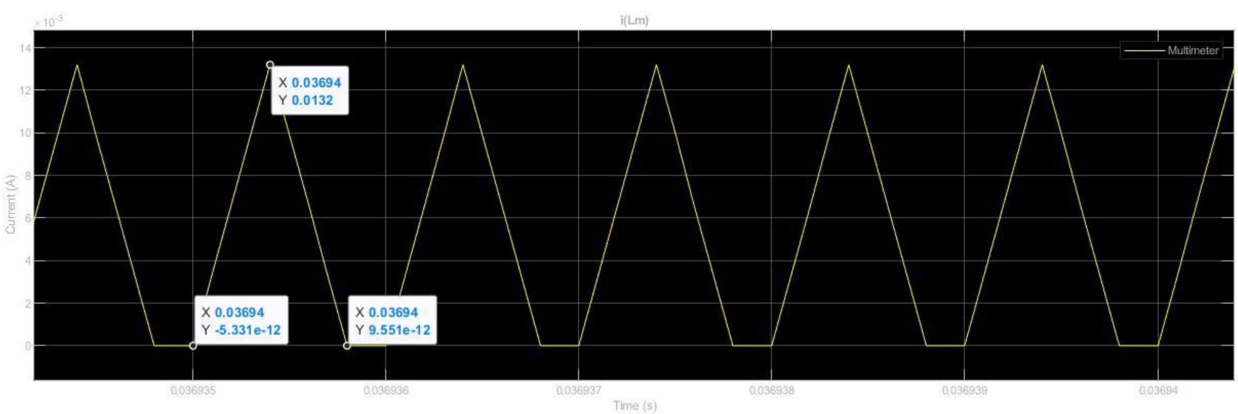

Figure 7: Current i_{L_m}

d. Simulation confirms the design of the nominal condition partially. The voltage output is overshooting the expected $12V$ due to the selected n value along with the D_{ON} and the diode configuration. See *figure 8* for the diode options selected for the simulation design.

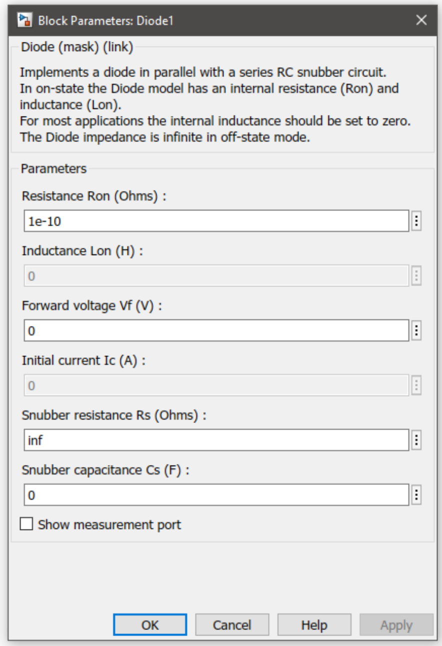

Figure 8: Diode Configuration

The voltage output trace can be smoother by increasing the PWM sample time and period. The configuration for the PMW is specified in *figure 9* below.

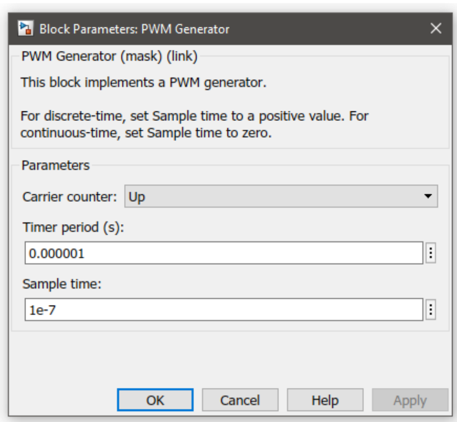

Figure 9: PWM Configuration

The values of i_{L_m} current may also be altered with the above selection explaining the discrepancy from the expected peak value of $0.141A$ approximately.

The voltage v_{sw} is as expected from the trace with specifications from the transformer causing negligible discrepancies. The transformer specifications is illustrated in *figure 10*.

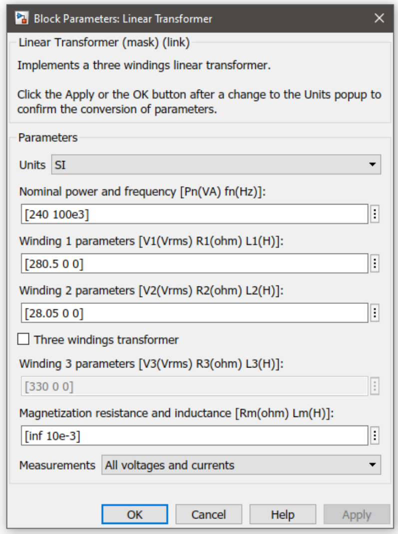

Figure 10: Transformer Specifications

The current input is also as the investigation expected from the parameters calculated and the shape of the trace that was outputted from the scope.

e. The simulation of the results that was investigated in *Section 1 Part h* of the investigation are as follows:

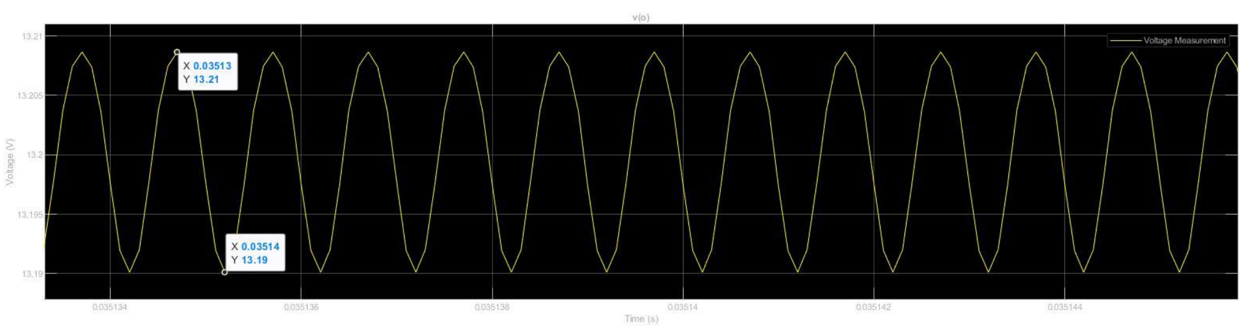

Figure 11: Voltage Output – 6 ohms

As expected, the voltage illustrates the same voltage in *Part a* of this section, *Section 2*. This is due to the operation of the circuit in BCM.

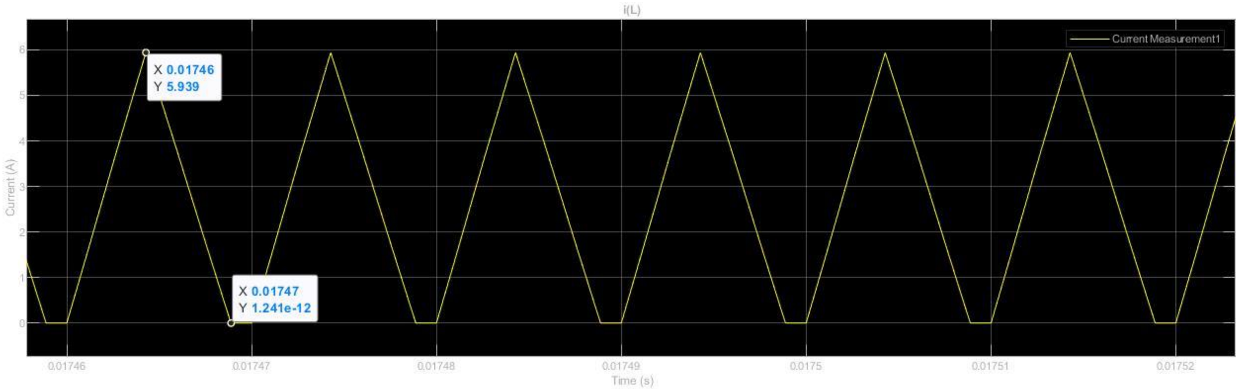

Figure 12: Current Output - 6 ohms

As expected, i_L overshoots slightly from the expected $4A$ peak-to-peak with the explanation from the previous question. Furthermore, the fluctuation with a resistance of six ohms moves between values zero to approximately six.

f. The condition described in *Section 1, Part i* was simulated and the following highlights the results:

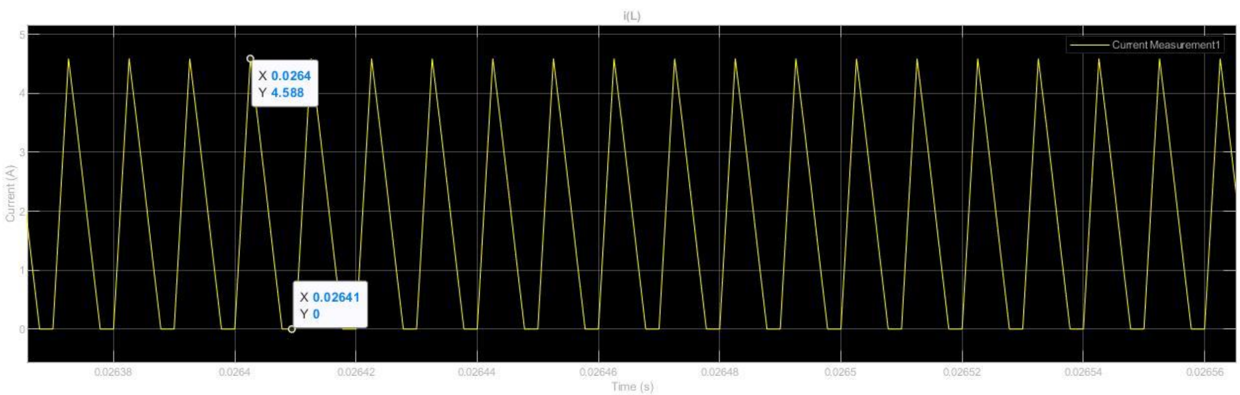

Figure 13: Current i_L

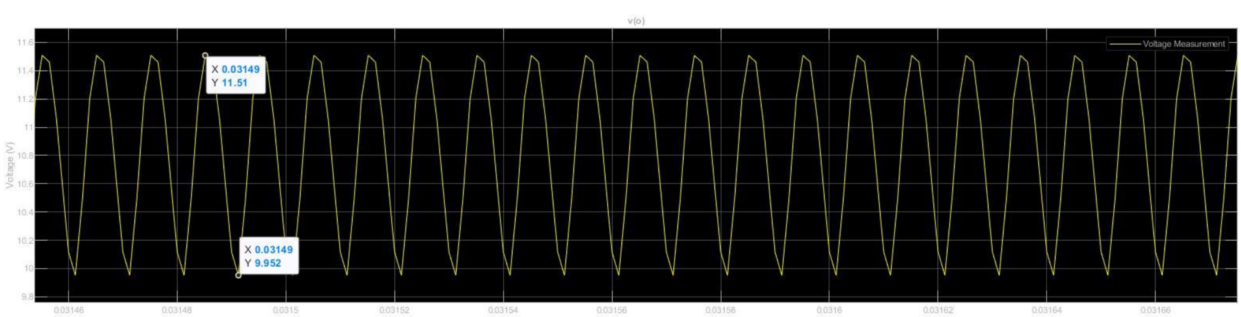

Figure 14: Voltage Output

Bibliography

Hart, D. W. (2010). *Power Electronics.* Valparaiso, Indiana: Pearson Education, Inc.