MIDTERM LTSPICE

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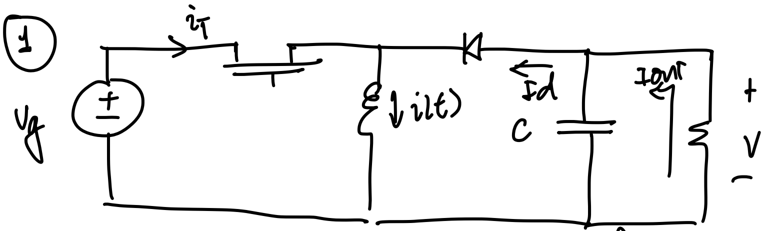


$DT_S := 10\mu s$

$V_g = 30V$ $V = -20V$ $R = 4\Omega$ $f_s = 40KHz$.

① find D and average inductor current.

sol) $V_{out} = \frac{DV_{in}}{1-D} \Longrightarrow D = \frac{V_{out}}{V_{in} + V_{out}}$; Vout has reversed polarity

$$\boxed{D = \frac{20}{30+20} = 0.4}$$

Inductor current:

from KCL: $I_L = I_{in} + I_{out}$, $I_{out} = I_d$

$P_{out} = P_{IN}$

$P_{out} = \frac{(20V)^2}{4} = 100W = P_{IN}$

$I_{out} = \frac{100W}{20V} = 5A$ $\Longrightarrow$ $\boxed{I_L = 8.33A}$

$I_{IN} = \frac{100W}{30V} = 3.33A$

② value of L that will make the peak inductor current ripple equal to 10% of average inductor current I.

sol) $\Delta i_L = \frac{1}{L} V_{in} DT_S = 2(0.10)(8.33A)$; Δi : peak-to-peak ripple.

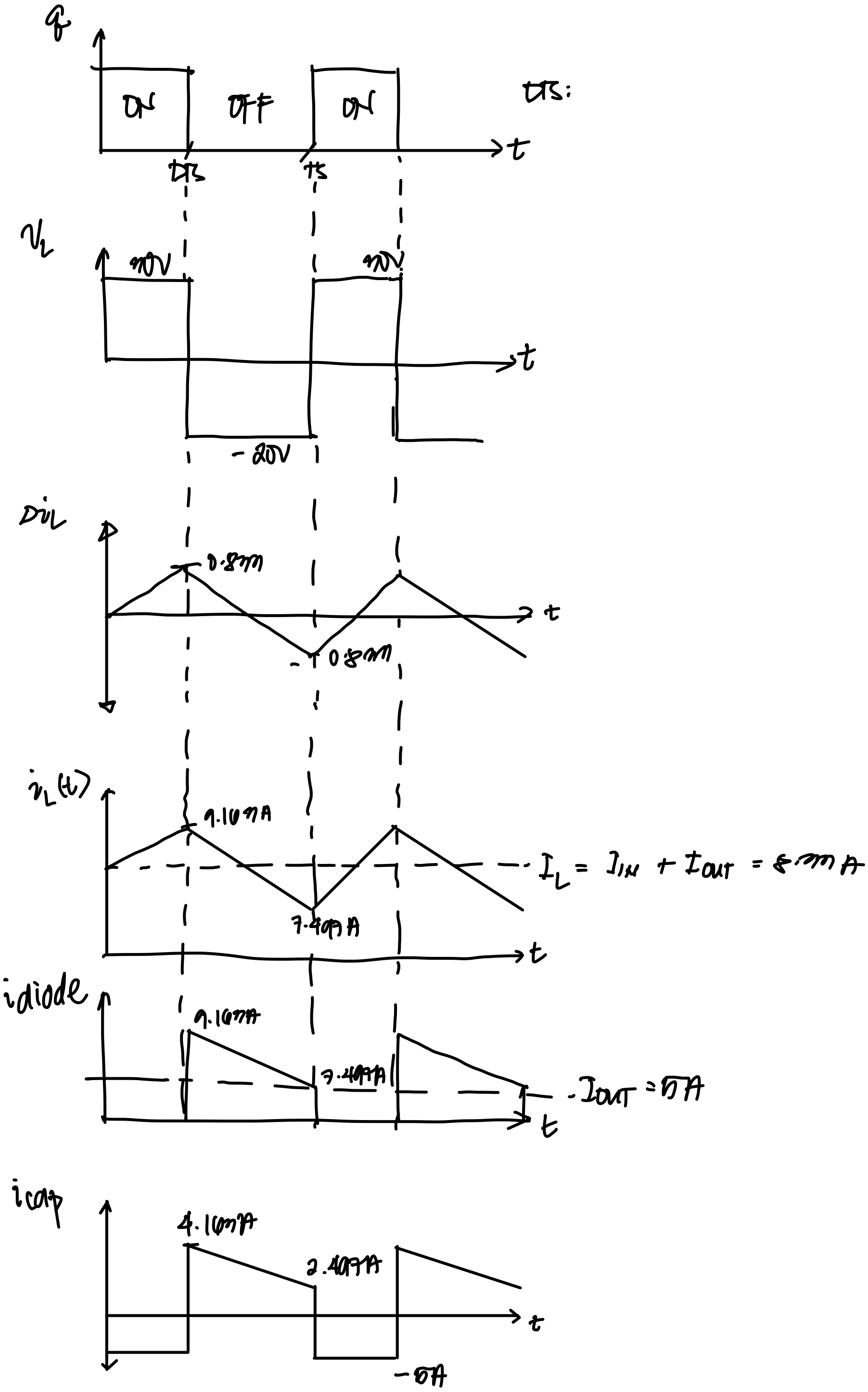
$$\frac{\frac{1}{2}(30V)(0.4)(\frac{1}{40KHz})}{(0.1)(8.33A)} = L = 1.8\times10^{-4} H = \underline{180\mu H}$$

③ voltage ripple : peak output voltage is 0.1V

sol) $\Delta V_C = \frac{\int_0^{DT_S} i_{out}\,dt}{C} = 2(0.1V)$

$$\Rightarrow \frac{(5A)(0.4)(\frac{1}{40KHz})}{2(0.1)} = \underline{2.5\times10^{-4}F}$$

④ Sketch the waveforms. * NOT TO SCALE *



LTSPICE Simulation Results

The Buck-Boost Converter LTSPICE simulation schematic is shown below in figure 1.

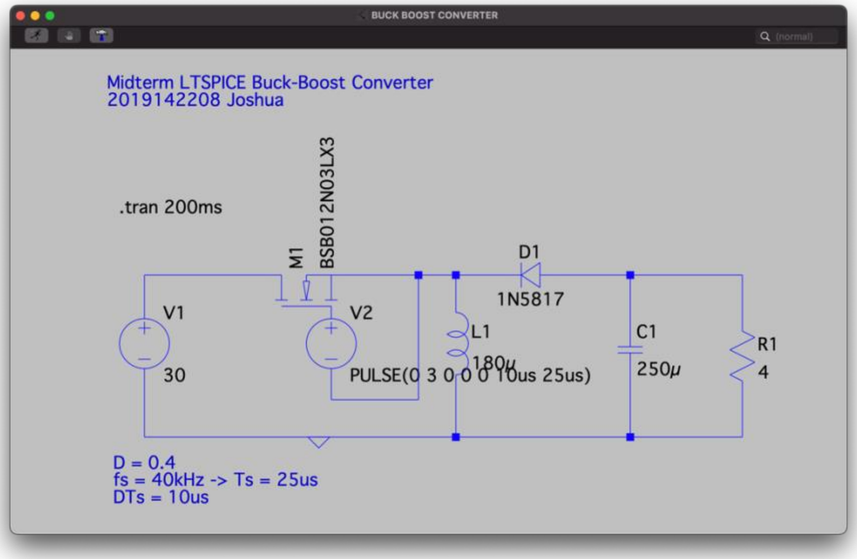


Figure 1Buck Boost Converter Schematic

1. By plugging in the values calculated for the duty cycle D in LTSPICE, we can see that the output voltage is at -19.646V (positive polarity on the top) and that the average inductor current is 8.336 A. Both values closely resemble the calculated theoretical values of -20V and 8.33A respectively. The results are shown below in figures 2 and 3.

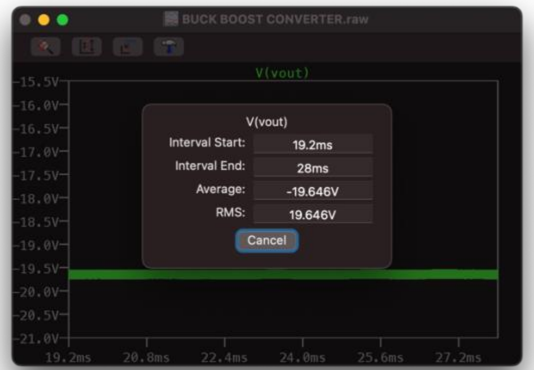


Figure 2: Output Voltage with D = 0.4

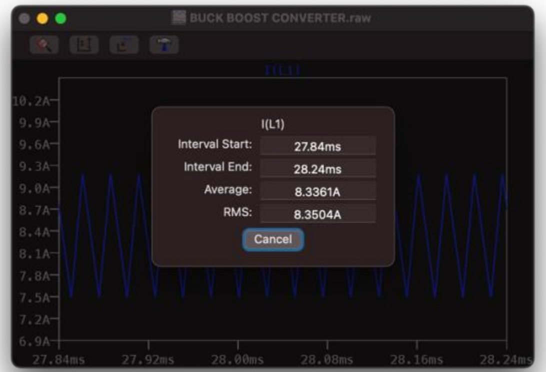


Figure 3: Average Inductor Current

2. The target ripple current on the inductor is to have a peak value equal to 10% of average inductor current. This means that the peak-to-peak ripple must be 20% of average inductor current. Based on the calculations, we have 180μH. Based on the simulation results, the peak-to-peak ripple is around 1.663A which corresponds to 20% of the average inductor current as shown below in figure 4.

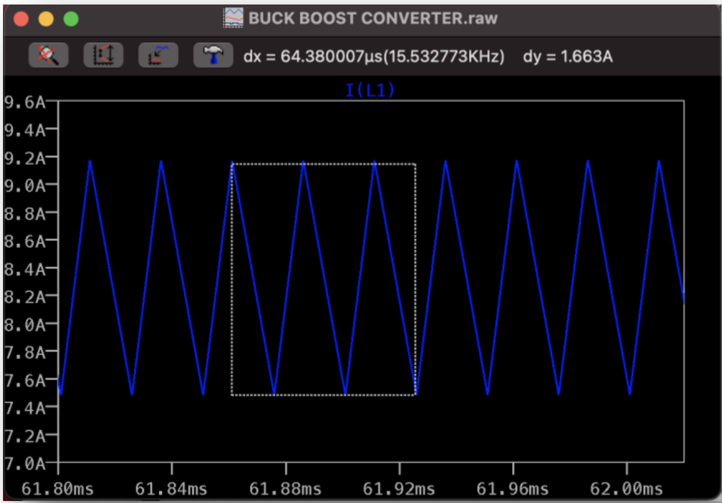


Figure 4: Inductor Ripple

3. For a voltage ripple of 0.1V at the output, we have calculated the required capacitance to be 250μF. Figure 5 below shows the result of the simulation, wherein the peak-to-peak voltage ripple is around 0.2 V which corresponds to 0.1 peak voltage ripple.

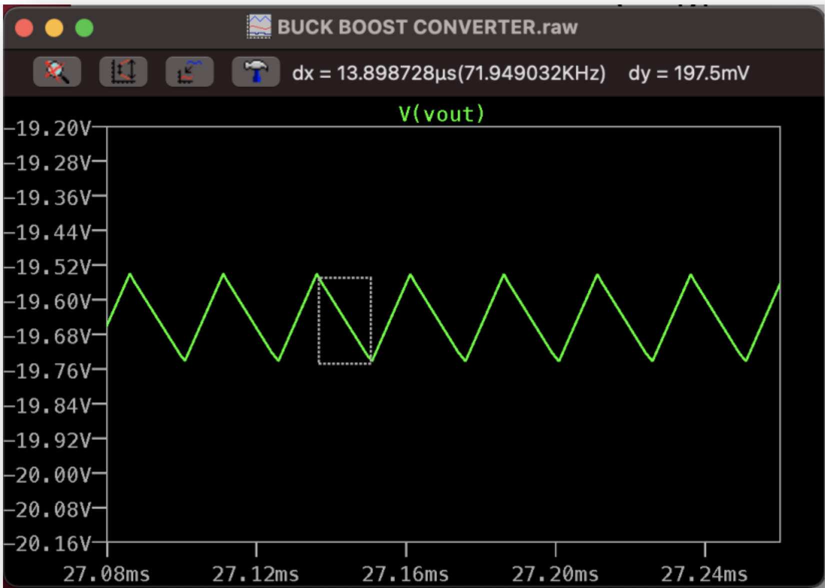


Figure 5: Voltage Ripple

4. The waveforms from LTSPICE are shown below in figure 6.

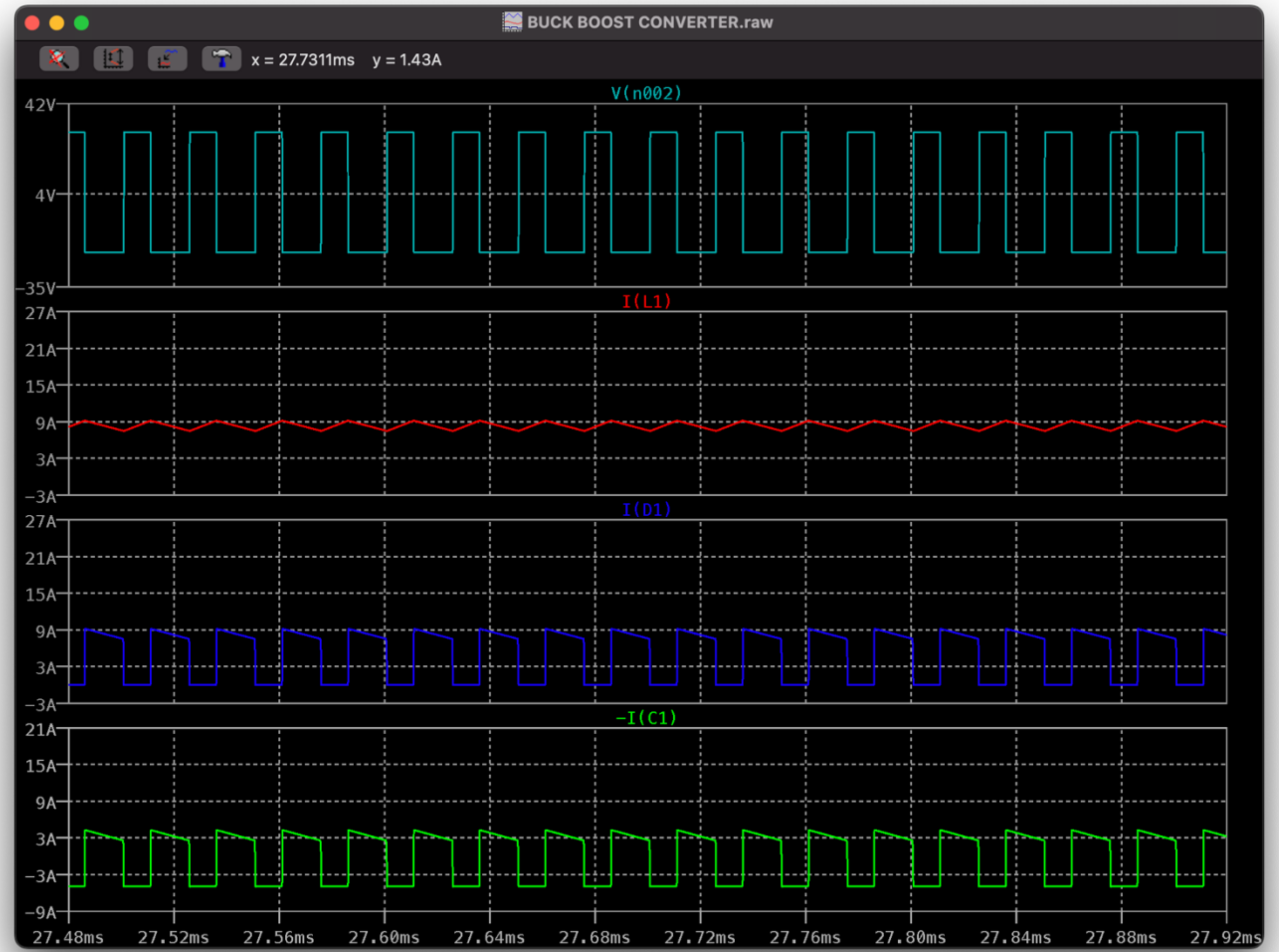


Figure 6: Buck Boost Waveforms

Results from LTSPICE closely resemble the waveforms drawn by hand.

② Analytical Results

a) C: 300 μF , 230 V_{RMS} , 50Hz $\Longrightarrow$ $230\sqrt{2} \cong 325V$

- Power load:

$$\frac{\frac{1}{2}CV_{max}^2 - \frac{1}{2}CV_{min}^2}{\Delta t} = P = \frac{\frac{1}{2}300\mu F\left(325^2 - 300^2\right)}{0.02s} = \underline{\underline{117.1875W}}$$

$$\Delta t = \frac{1}{50Hz} = 0.02s.$$

we model the output as a current source:

$$P = IV \longrightarrow I = \frac{117.1875W}{325V} = \underline{0.36\,A}$$

Ripple: $$\Delta V_{p2p} = \frac{117.1875W}{2(300\mu F)(50)(325)} = \underline{12.01V}$$

b.) Korea: 220 V_{RMS}, 60Hz. $\longrightarrow$ $220\sqrt{2} = 311V$

$P = 117.1875W$

$$\Delta V_{p2p} = \frac{P}{2cfV_{peak}} = \frac{117.1875W}{2(300\mu F)(311V)(60Hz)} = \underline{\underline{10.47V}}$$

LTSPICE Problem

We develop a DBR model for both the Australian setting and the Korean setting. Instead of using a resistor at the output, we use a current source. Figure 7 below shows the schematic while figure 8 shows the waveform result. Note that the results include a 1mH Thevenin source inductance.

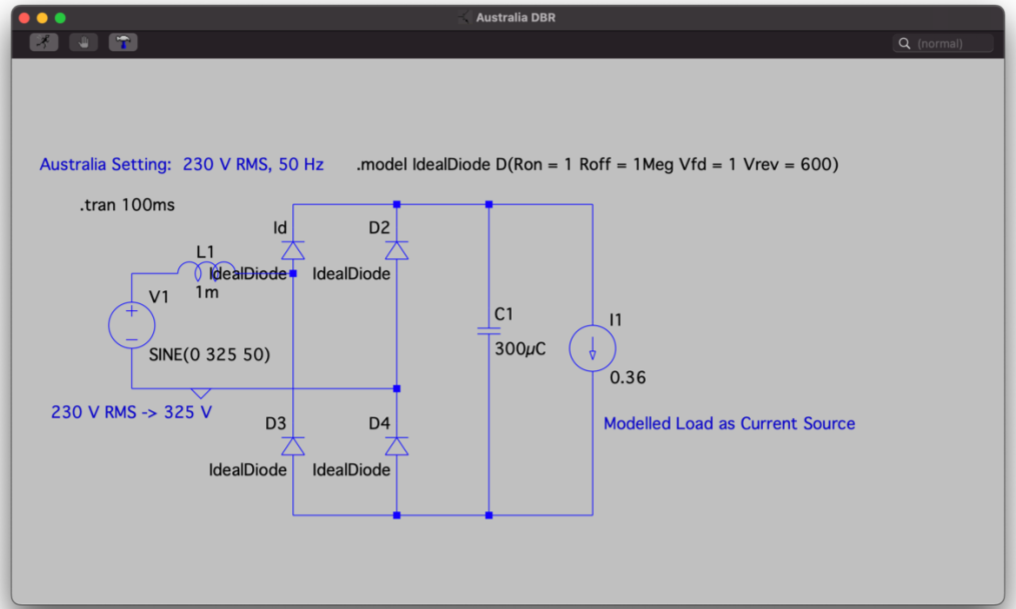


Figure 7: Single Phase DBR Schematic

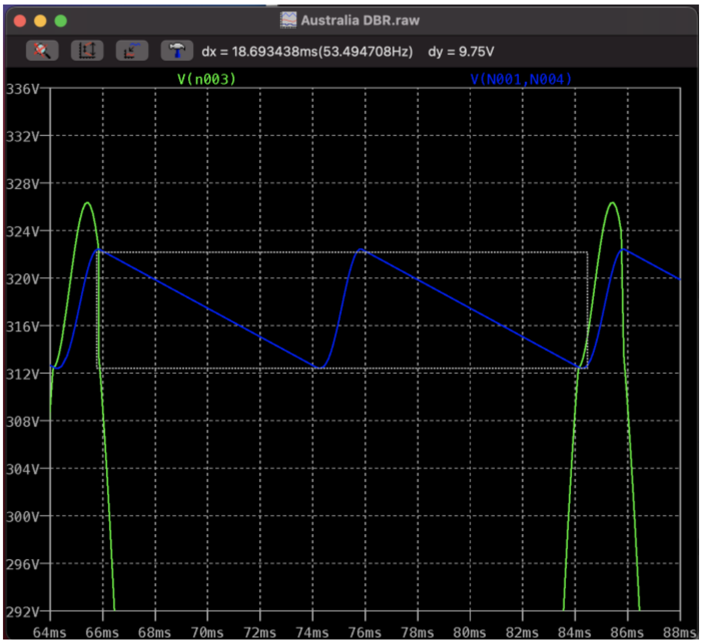


Figure 8: Single Phase DBR Result

From the analytical result, we have the power as 117 watts. If the diodes do not have high forward voltage requirements, the output voltage should also be 325V for the Australian setting hence the current on the output is 0.36 A. As seen in figure 8, this result closely resembles the figure shown initially from the exam paper.

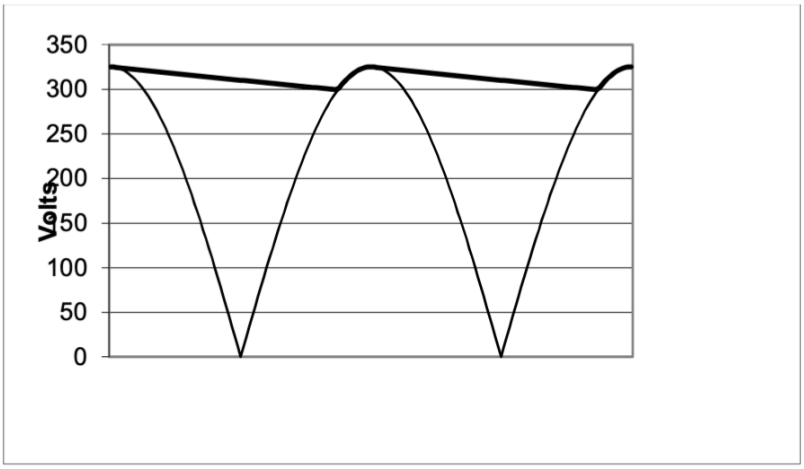


Figure 9: Figure Shown on the Exam

We now check on the case if the converter was used in Korea: 311 V and 60 Hz. Since the output voltage had changed but not the power (as assumed constant power load), the current source value should now change to 0.38 A. The converter schematic and results are shown in figures 10 and 11 respectively.

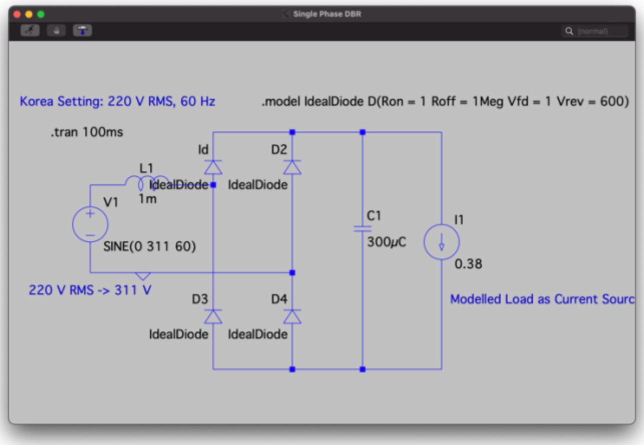


Figure 10: Korea DBR Schematic

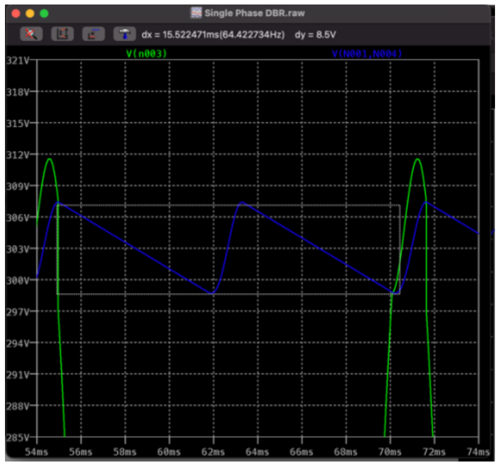


Figure 11: Korea DBR Result

As we can see in the LTSPICE simulation output, the waveform however the ripple values have changed where the Korean setting has less ripple than the Australian setting: around 10 V for Australia and 8.5 V for Korea. This was expected since in 60 Hz Korea, the same capacitor gets charged more often hence the ripple goes down. This can be attributed to the formula that we have for the voltage ripple shown below.

$$\Delta V_{p2p} = \frac{P}{2Cf_sV_{peak}}$$

As seen, the higher the frequency the lower the peak values. However, since in Korea the voltage also dropped, the peak-to-peak voltage must increase as well, compensating for the increase in frequency. Hence, we can see from the graphs that the output does not differ by a huge margin. Based on theoretical calculations, we have a 12.01 V ripple in Australia and 10.47 V ripple in Korea, but simulations show that the ripples are at 9.75 V and 8.5 V respectively.

Suppose that we need to keep the ripple at 3% of the rated voltage. Our DBR would then need the ripple to stay within 9.33 V peak-to-peak (3% of 311 V is 9.33 V). This is slightly over the theoretical values but well within the simulation results. Since the simulation used an ideal component, we cannot accept the current DBR as the ripple can still increase. The ripple can be contained by using a slightly bigger capacitor to guarantee that the voltage ripple can be kept well within the 3%. We choose a capacitor with 350μF.

Simulations show that this will in fact make the ripple even smaller hence guarantees we meet the requirement for the voltage ripple wherein we see that the ripple had dropped to 7.04 V.

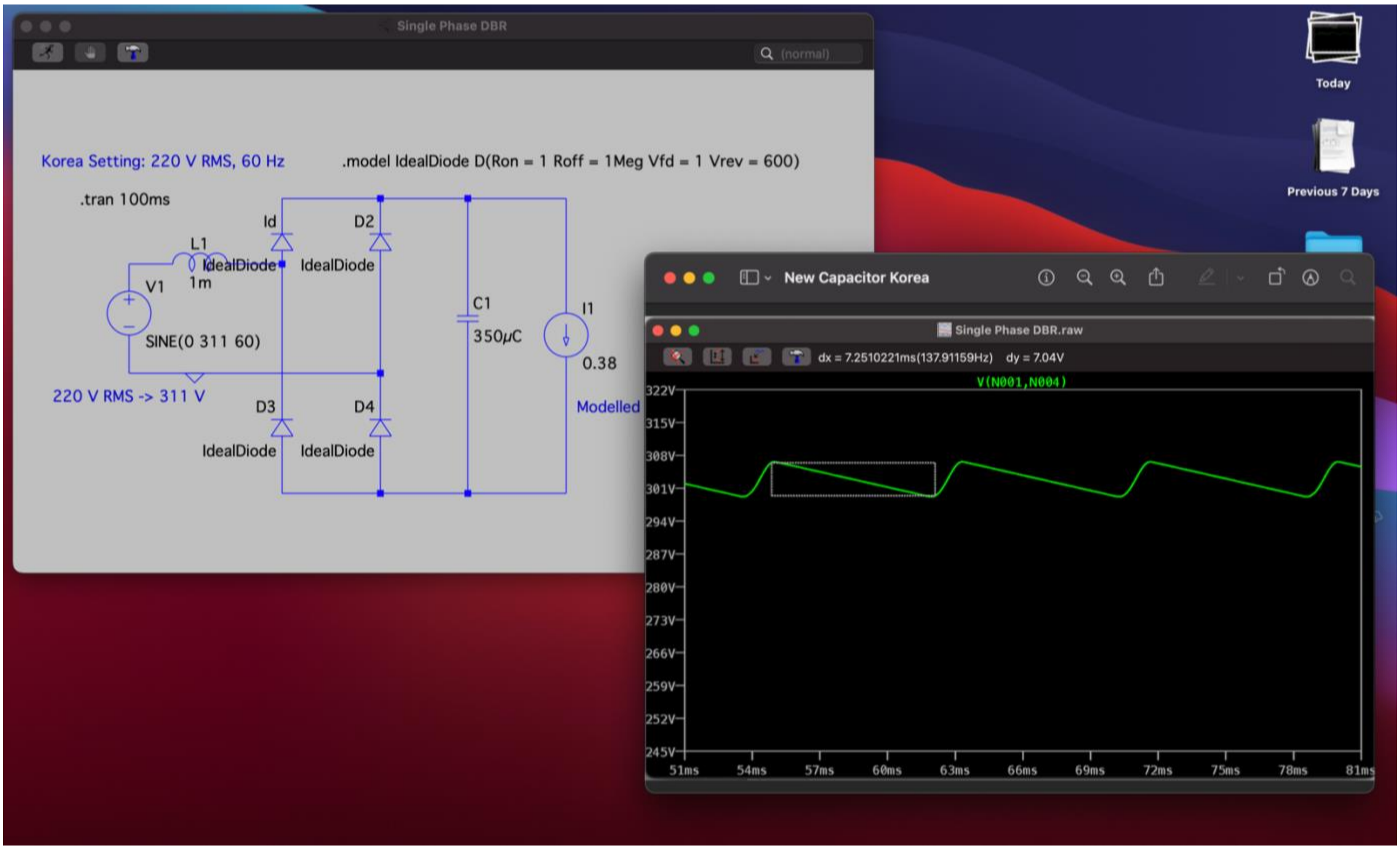


Figure 12: 350μF C for Korea DBR