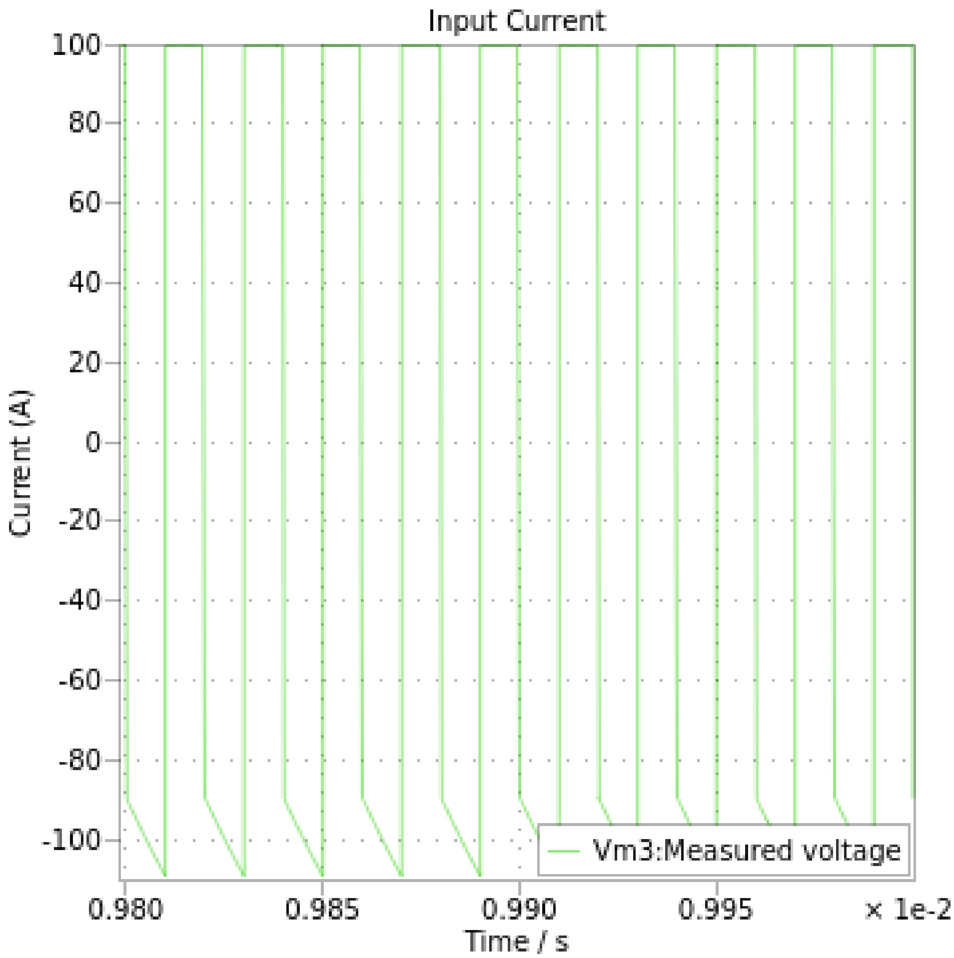
lab1

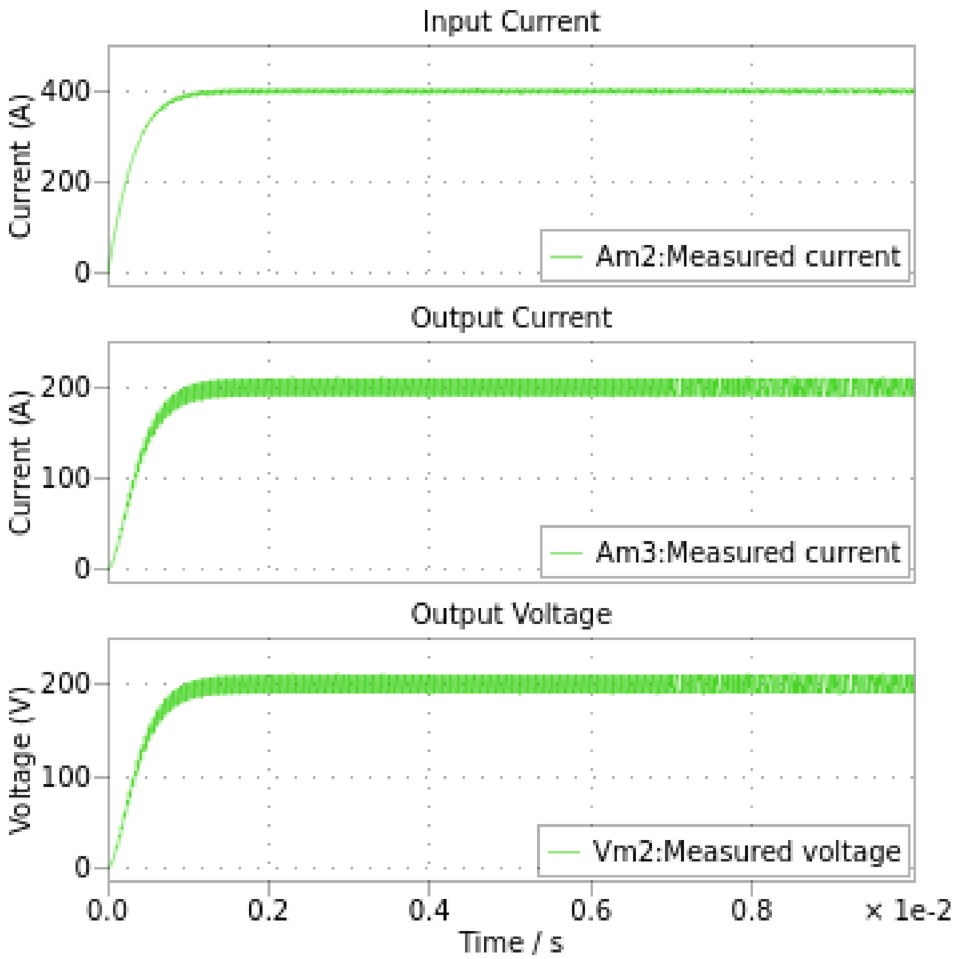
January 30, 2024

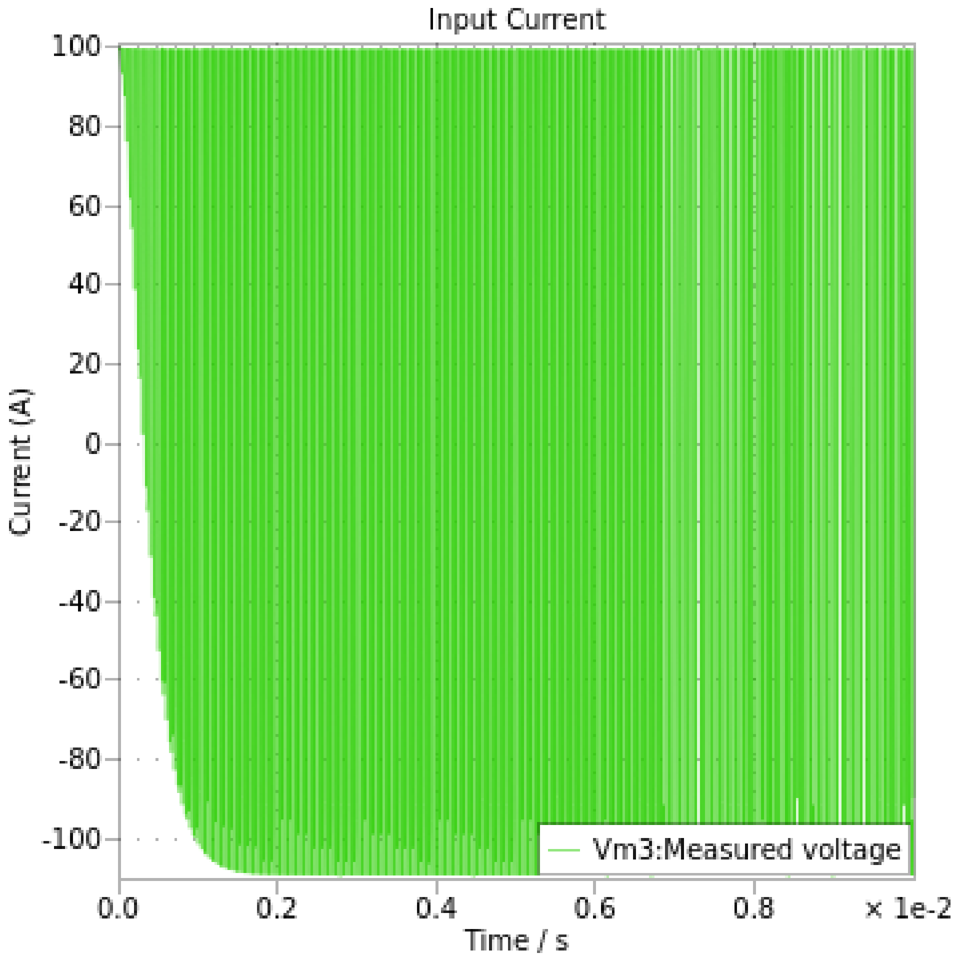
0.1 Lab 1 - Power Converter Circuit Simulation



Lila Smith - January 25th, 2023 Q1. For each waveform determine the peaks and average.

- Input current (avg 1A, peaks 0V to 10V)
- Output current (avg 10A, peaks 10A to 10A)
- Output voltage (avg 10V, peaks 10V to 10V)
- Voltage across current source (avg 0V, -10V to 90V)


Input Current
Current (A)
400
200
0
Am2:Measured current
Output Current
Current (A)
200
100
0
Am3:Measured current
Output Voltage
Voltage (V)
200
100
0
Vm2:Measured voltage
0.0
0.2
0.4
0.6
0.8
× 1e-2
Time / s



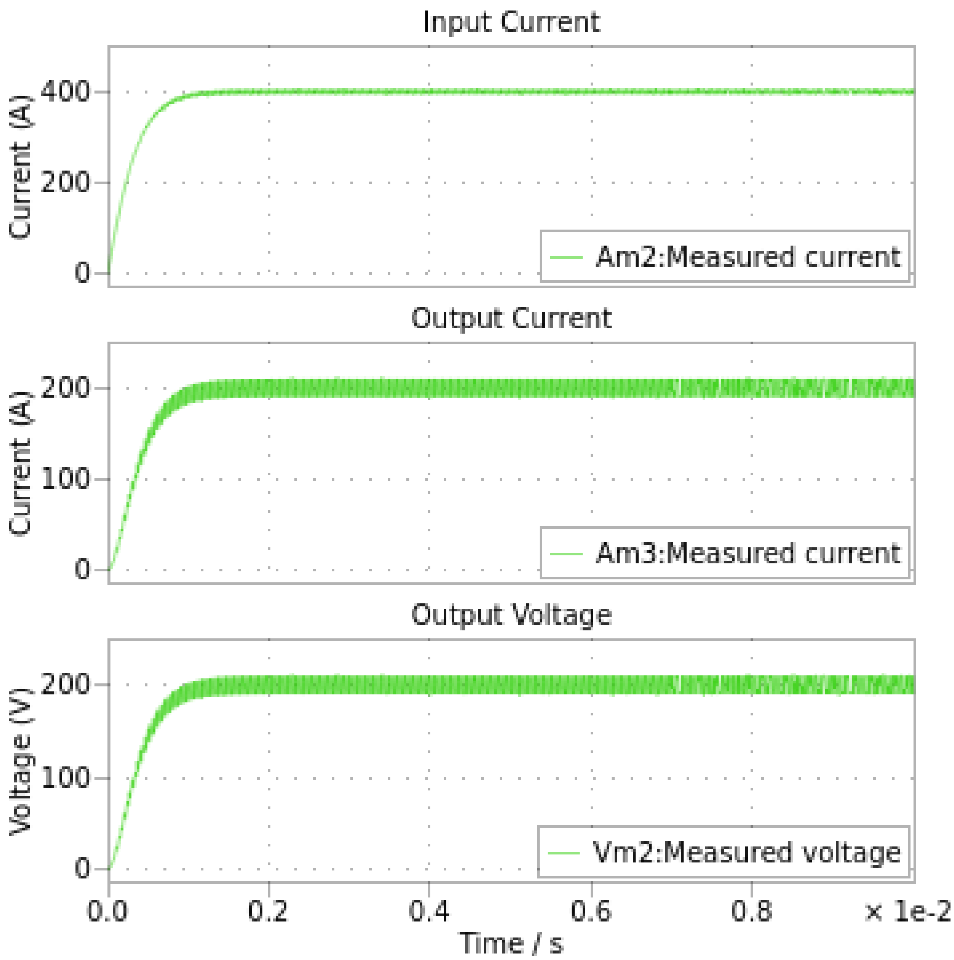
Q2: Which waveforms have a small (or no) ripple versus large ripple?

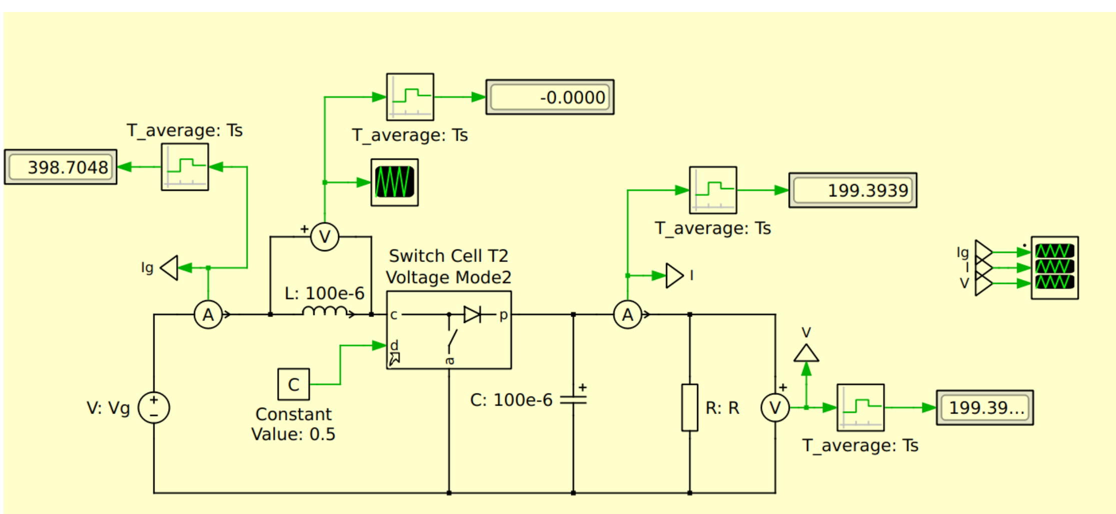
The output current and voltage have no ripple. Input current and voltage don't have ripple, just their duty cycle.

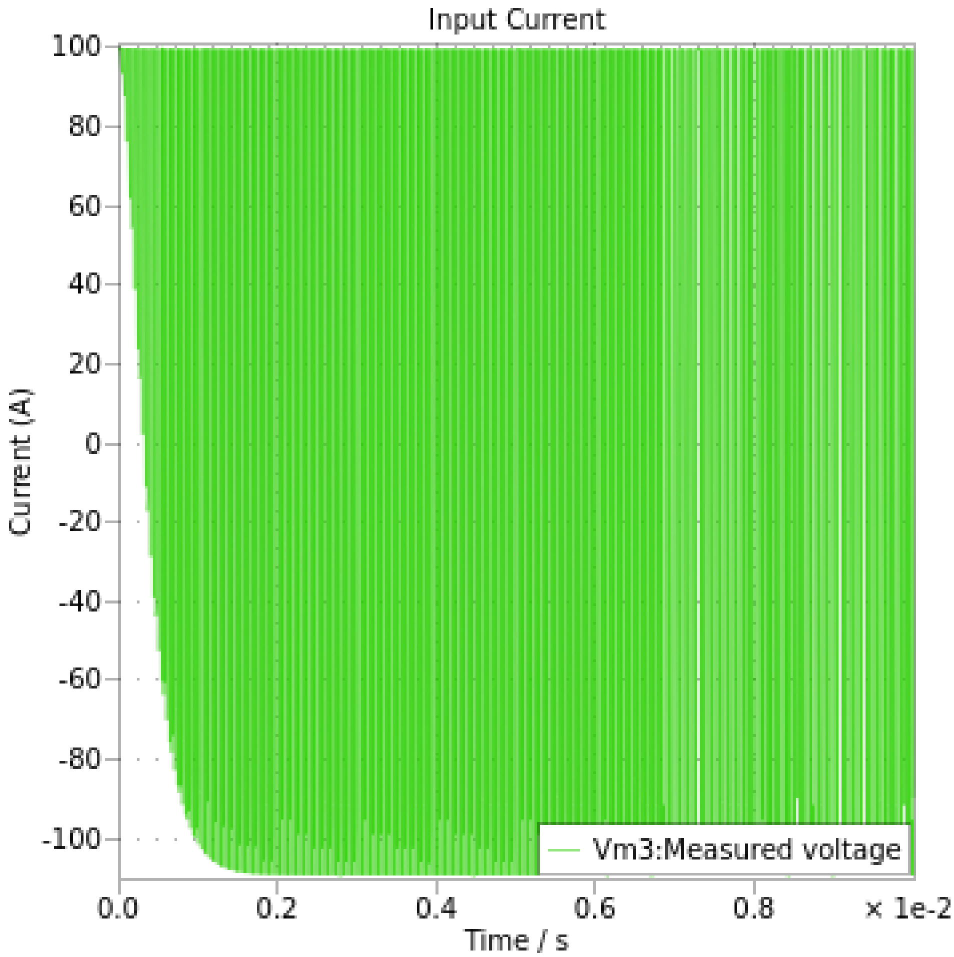
Q3: Which components supply power and which dissipate power?

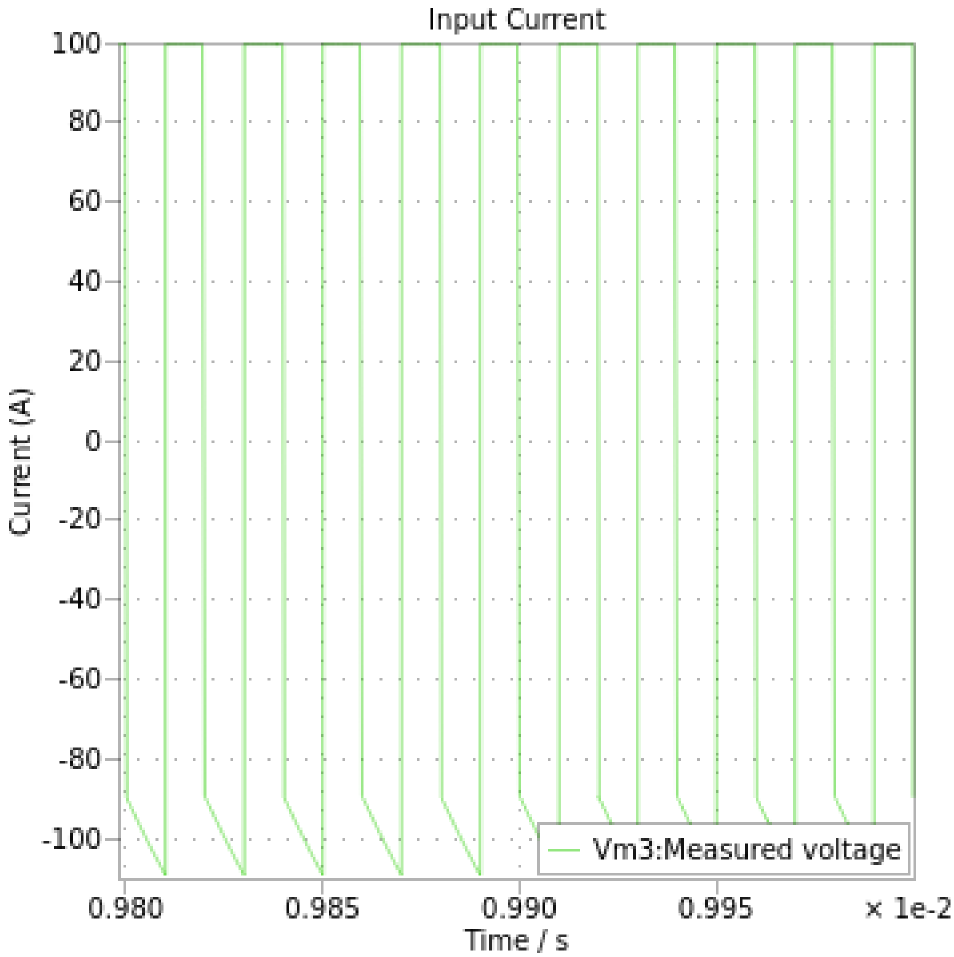
The voltage supply and current supply supply power. The resistor dissipates power.

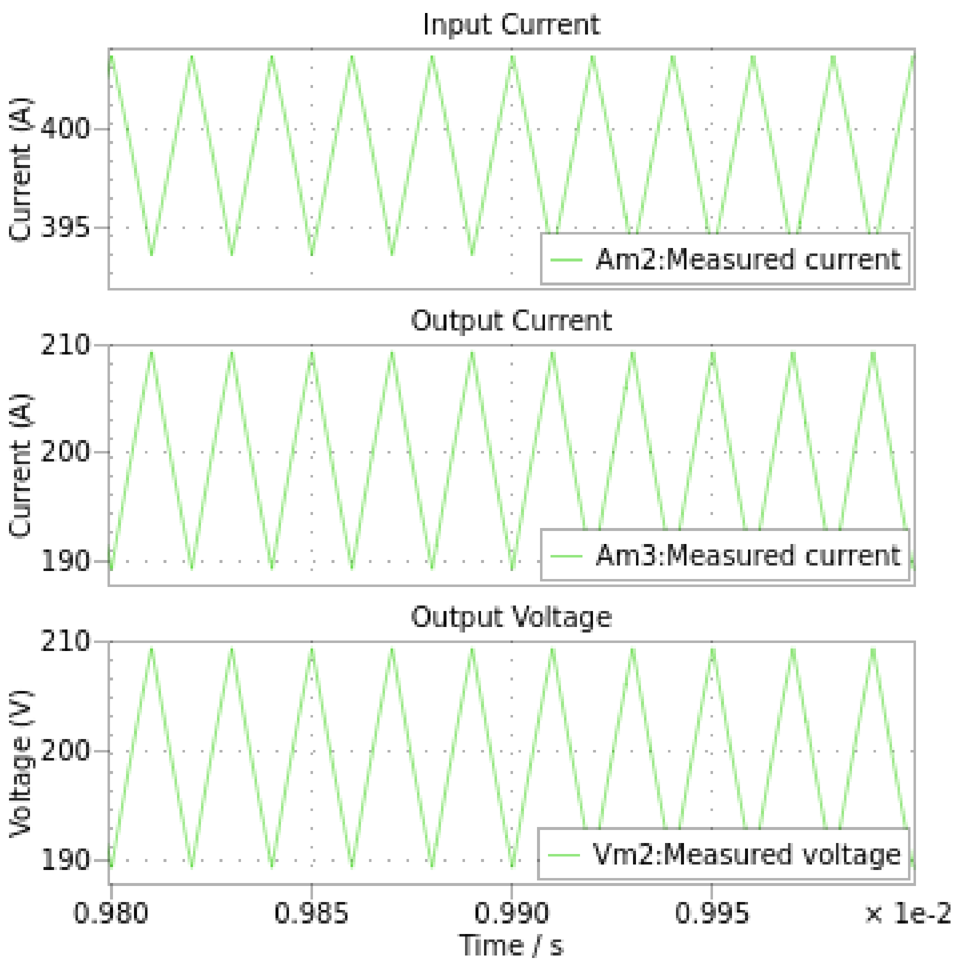
0.1.1 1 mH inductor






Input Current
Current (A)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.0
0.2
0.4
0.6
0.8
× 1e-2
Time / s
Vm3:Measured voltage


Input Current
100
80
60
40
20
0
-20
-40
-60
-80
-100
Current (A)
0.980
0.985
0.990
0.995
× 1e-2
Time / s
Vm3:Measured voltage



Q4: How are the waveforms different? What do they have in common with the prior simulation?

The waveforms are different in that take time to reach steady-state. They also have approximately the same peaks and average values. The input voltage and current are not fully flat on top. The output voltage and current now also have a small ripple.

Q5: After how much time does the circuit reach periodic steady-state?

It takes until about 8 ms to reach period steady-state.

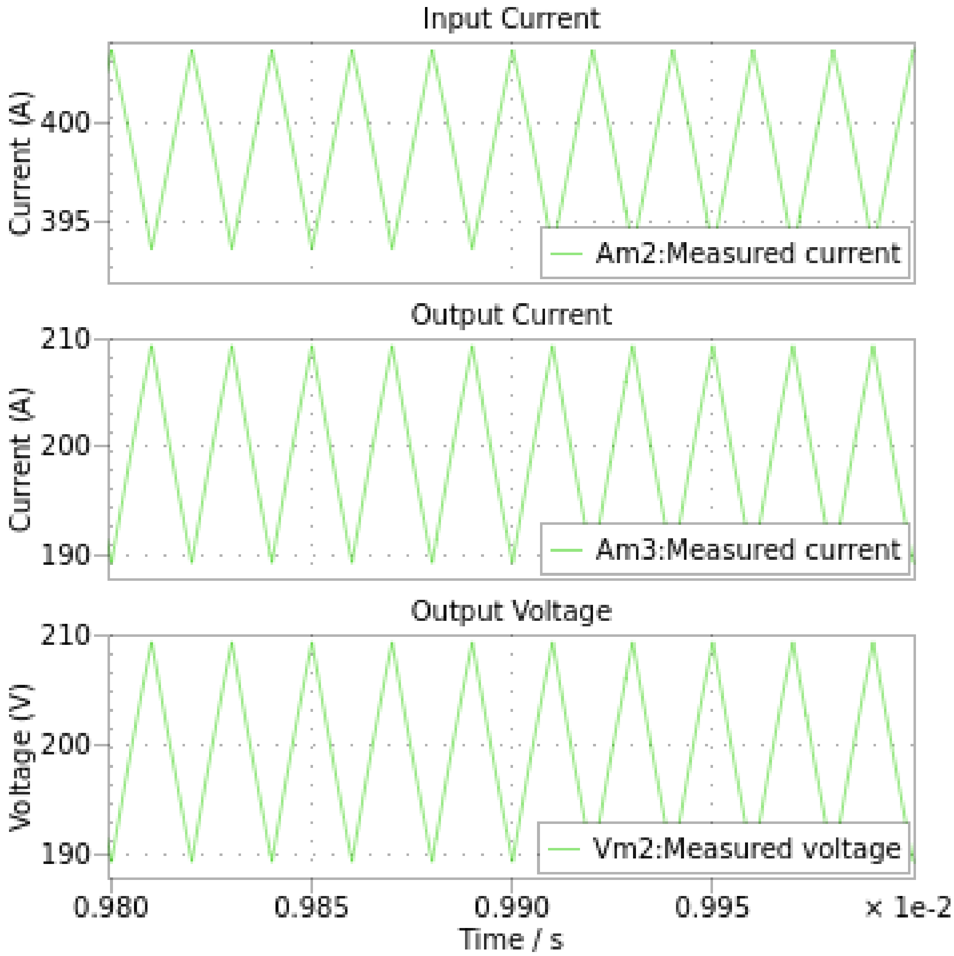
Q6: What is the average voltage across the inductor in periodic steady-state?

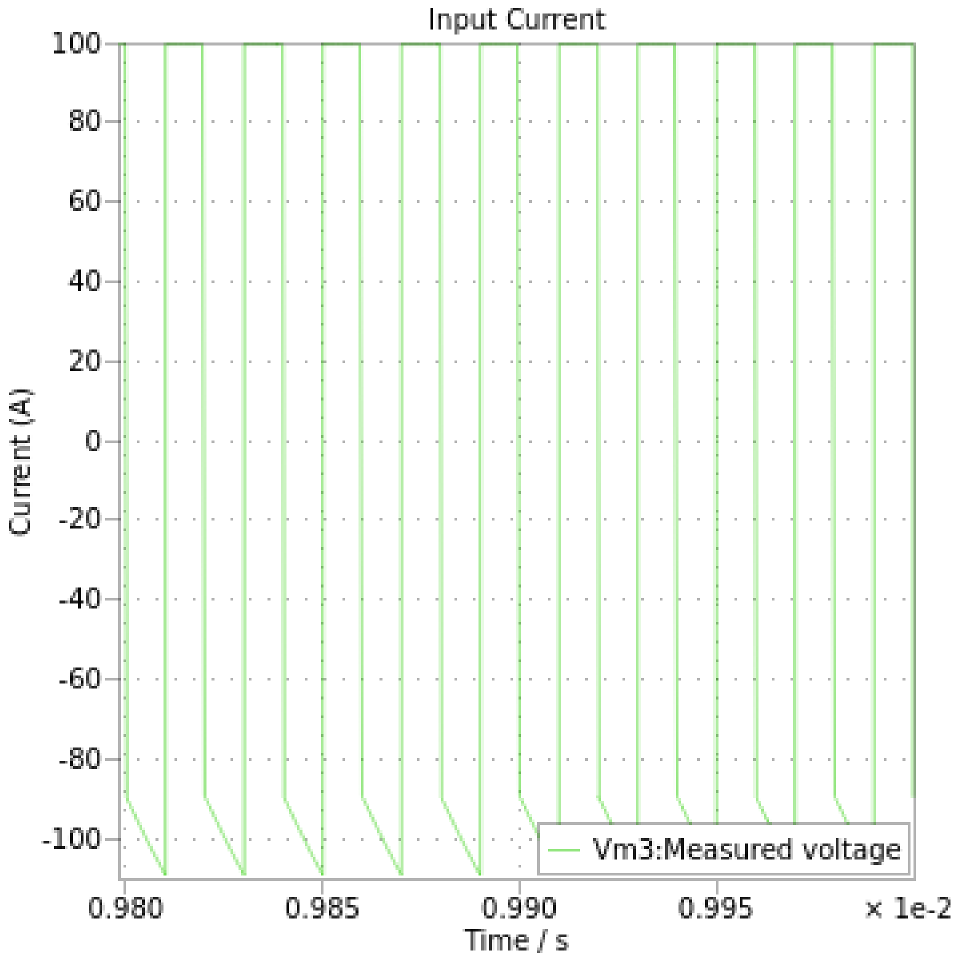
The average voltage is 0.5 mV across the inductor in periodic steady-state.

Q7: What is the voltage conversion ratio for D=10% and D=50%?

For both, the input voltage is 100 V. For D=10%, $\langle V \rangle = 9.9995$ V, so the voltage conversion ratio is 9.9995:100. For D=50%, $\langle V \rangle = 49.9977$ V, so the voltage conversion ratio is 49.9977:100.

0.1.2 10 uH inductor

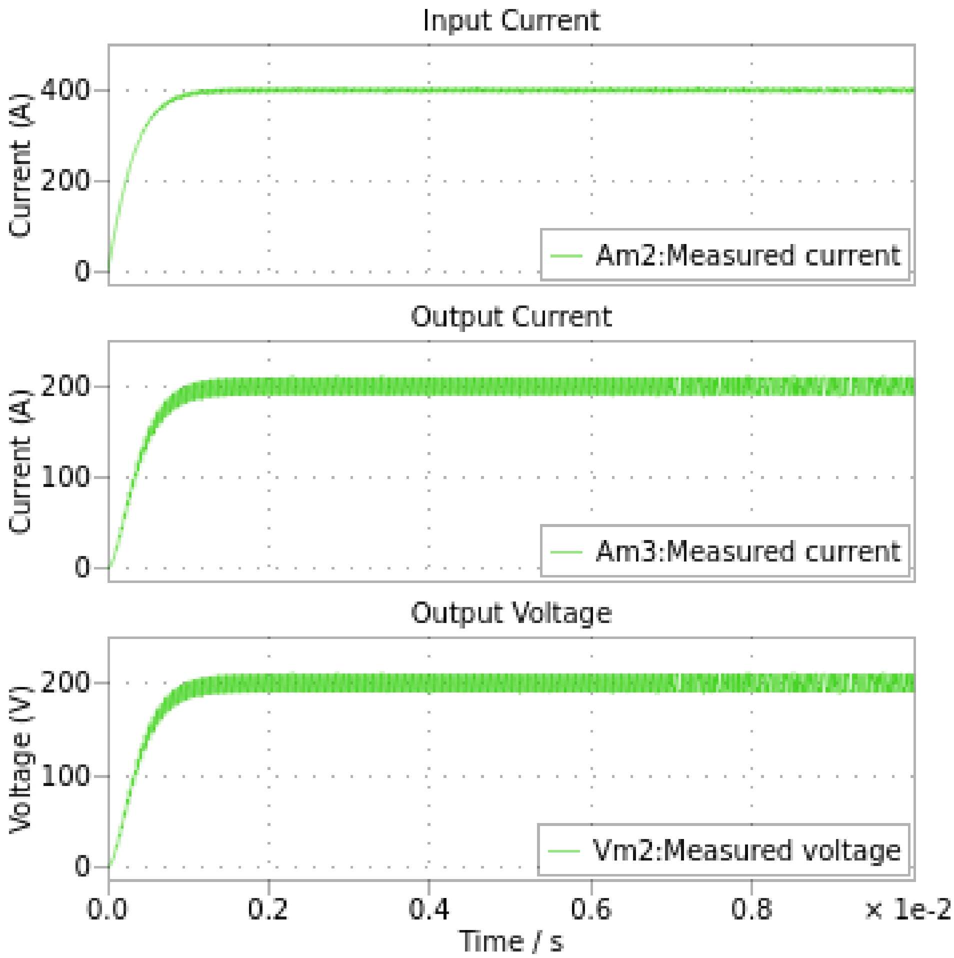


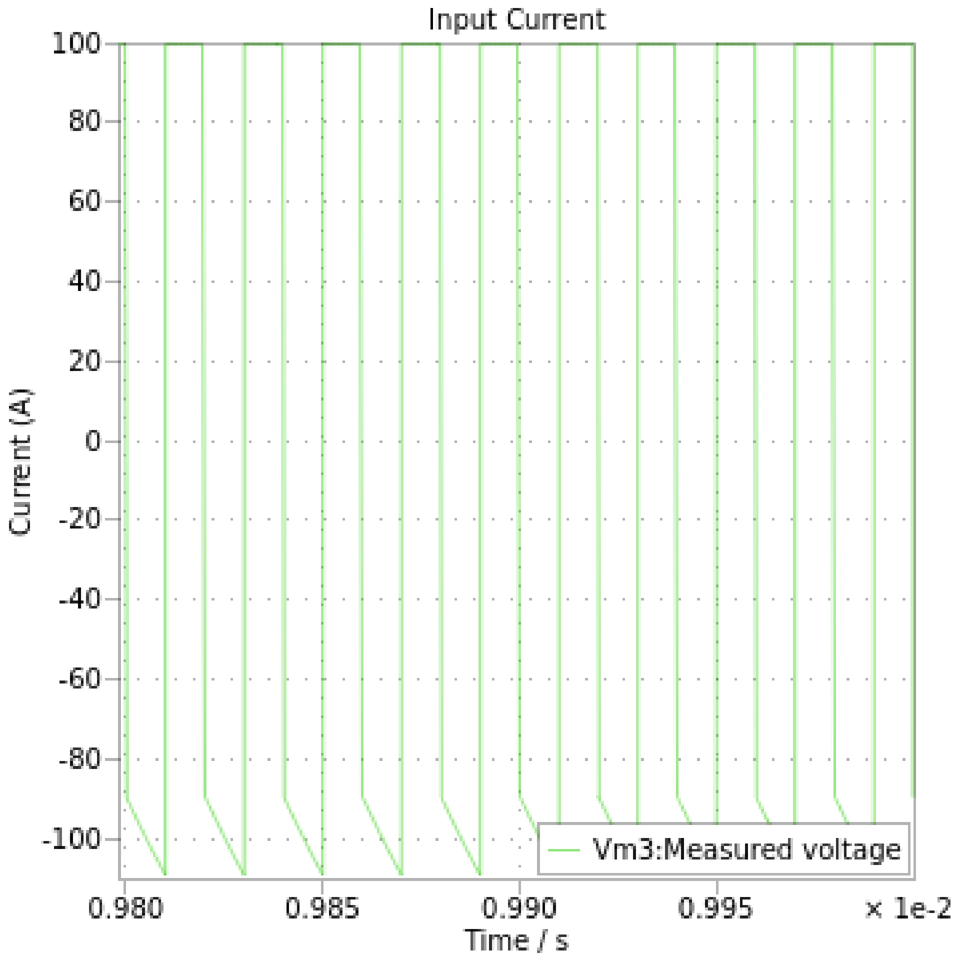


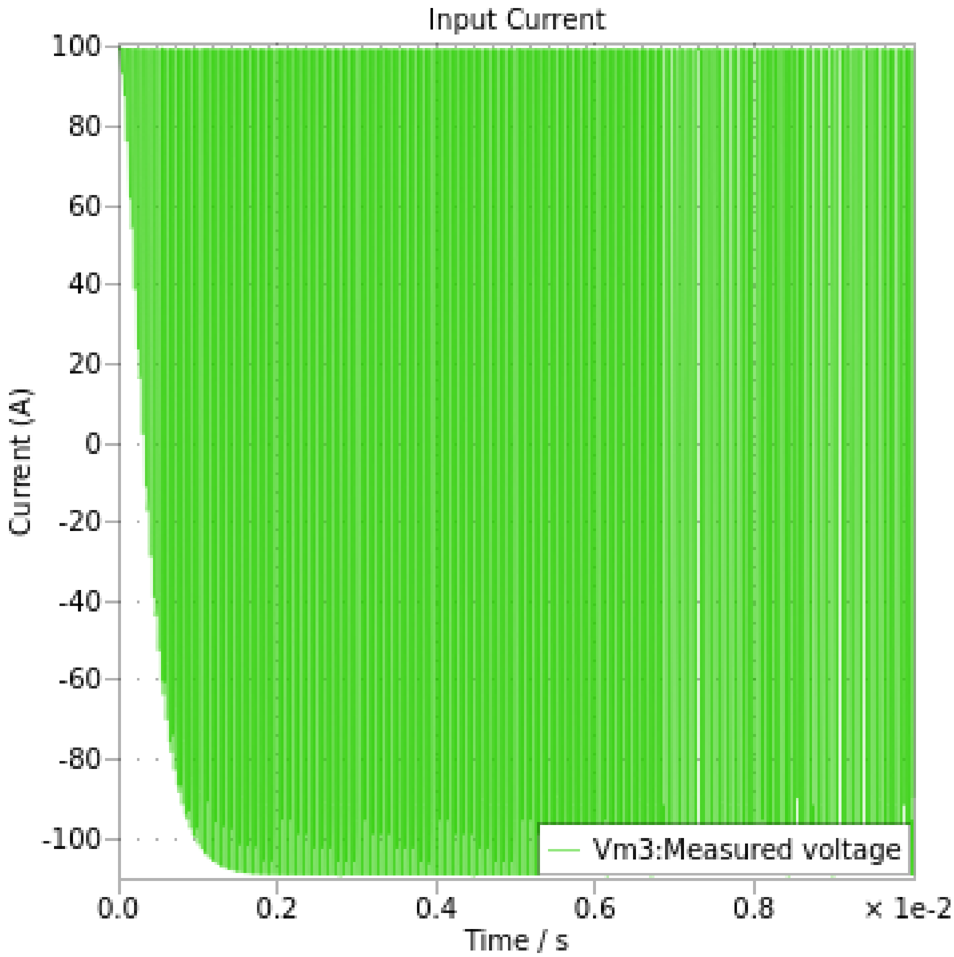
Q8: How are the waveforms changed with 10 uH? Comment thoroughly.

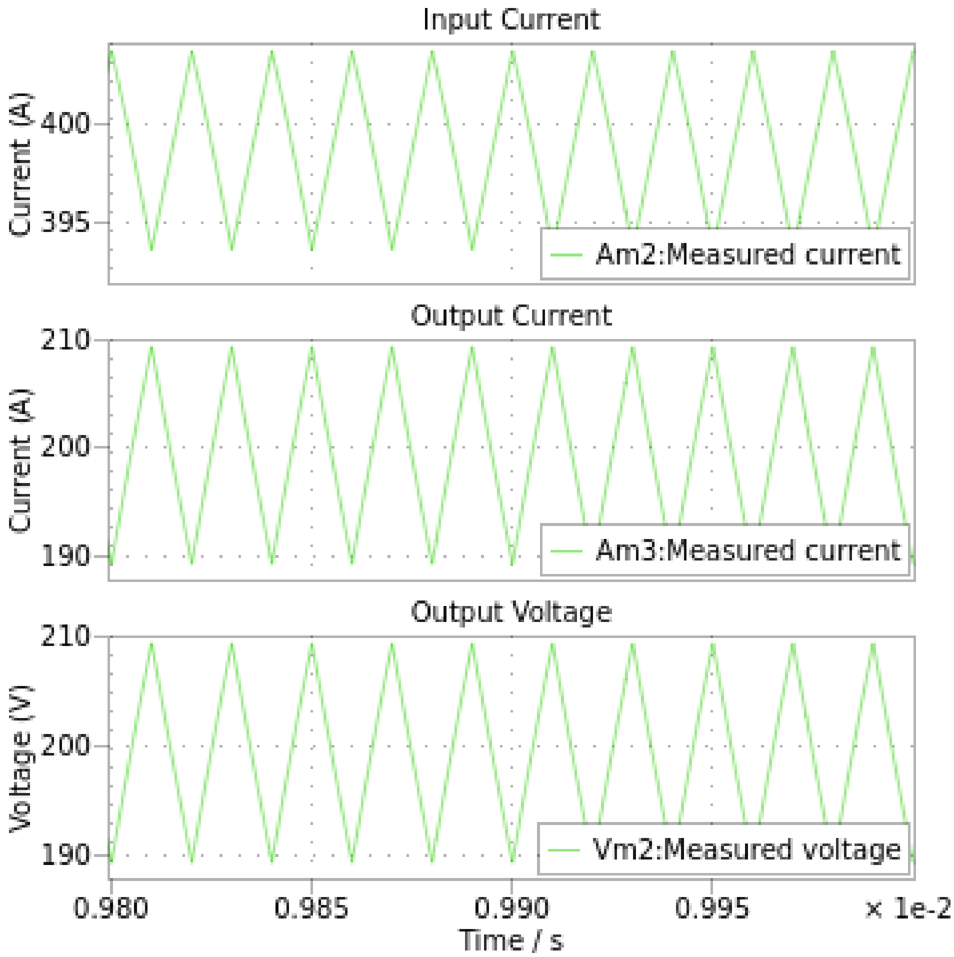
It takes less time to reach periodic steady-state than with the 1 mH inductor. The output current and voltage have very large ripple with an average of 10 V or A but peak of 20 V or A. The input voltage also has larger ripple that goes below -10 V and above 90 V. The input current peak is also 20 A rather than 10 A.

0.1.3 100 uF capacitor




Input Current
Current (A)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.980
0.985
0.990
0.995
× 1e-2
Time / s
Vm3:Measured voltage

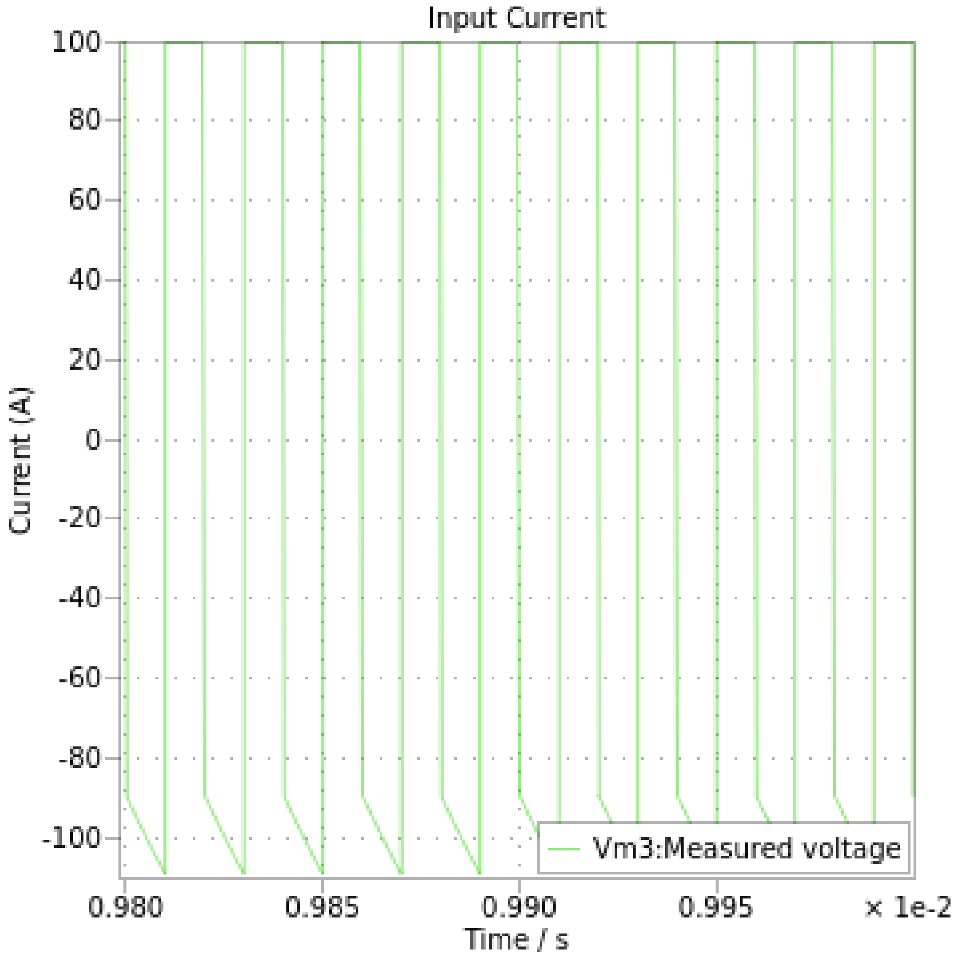

Input Current
Current (A)
Time / s
× 1e-2
Vm3:Measured voltage
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.0
0.2
0.4
0.6
0.8



Q9: How have the waveforms changed? Compare the current before and after the capacitor. Which would you consider to have low-ripple and which large-ripple characteristics? What is effect of the capacitor?

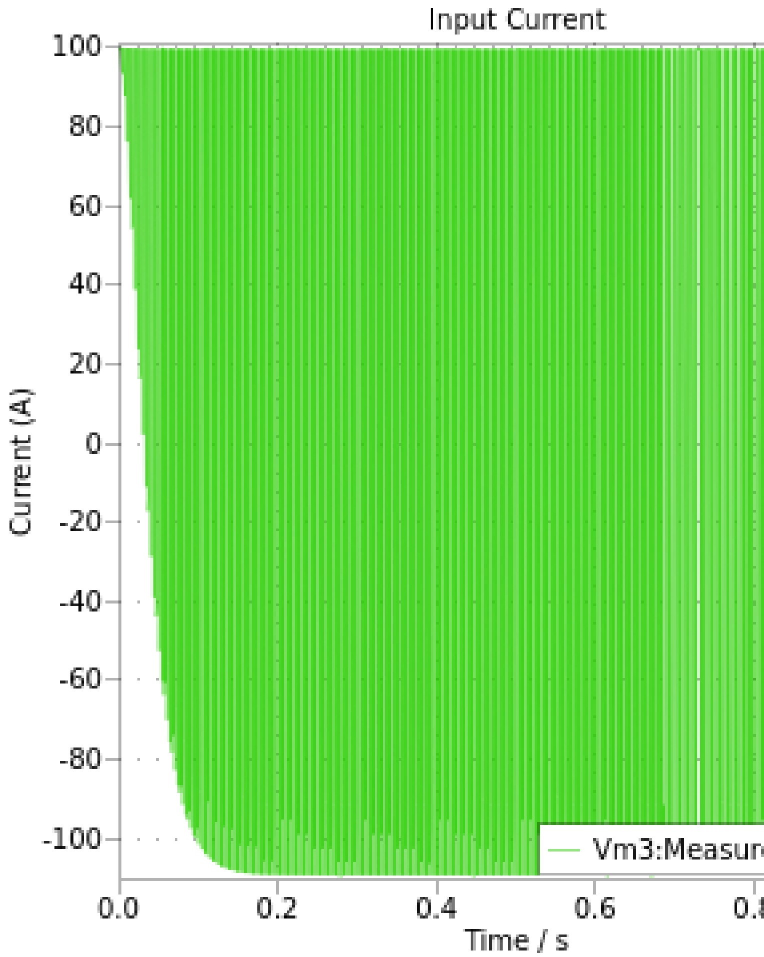
The capacitor resulted in low ripple in the output voltage than before the capacitor where it was high ripple. It also resulted in the output current being much higher than before. The input voltage also stays constant at 0 V for part of the duty cycle rather than constantly changing after adding the capacitor. The input current is much larger with the capacitor than without the capacitor.

0.1.4 Type 1 switch cell

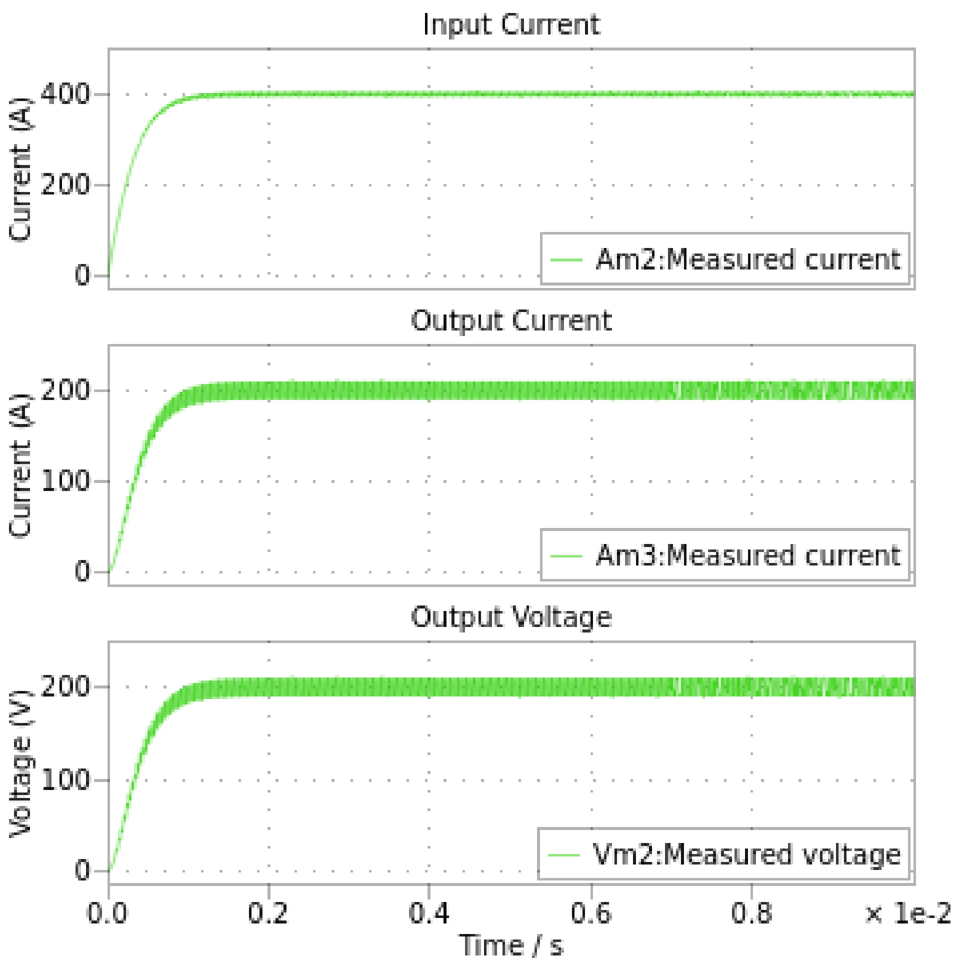


Q10: Explain why the block defined by the brown rectangle can be approximated by an ideal transformer.

The block in the brown rectangle will output an average voltage that is defined by the duty cycle similar to how an ideal transformer is defined by the ratio of coils. Both this model switch and the ideal transformer are lossless.



Run with L=10uH and a second with L=5uH



Q11: Which interesting observations can be made comparing the simulation on results for L=10 uH with the the results for L=5 uH? Use the "Hold trace" feature in the PLECS scope to compare the waveforms. Zoom into the inductor current waveform! Be thorough.

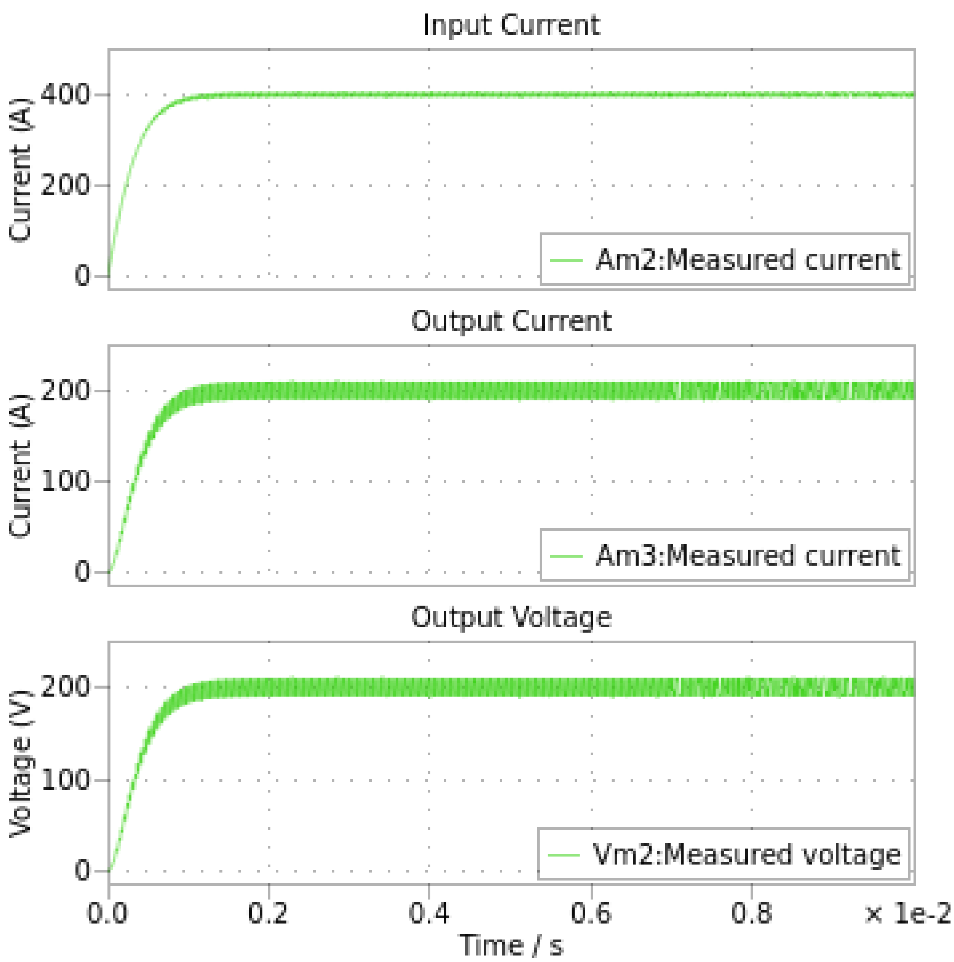
The output voltage is much closer to an average of 10 V with the 10 uH inductor (9.9990 V) than with the 5 uH inductor (13.2132). The average input current for 10 uH is 1.0001 A whereas for 5 uH is 1.7475 A. The peaks for input current of the 5 uH are almost double the 10 uH trace. Similarly, the peak output current for 5 uH is almost double the 10 uH and includes a period of time at 0 A. The input voltage has a strange shape that I cannot explain for 5 uH since it stays at 0 V for a brief amount of time that corresponds to the time that the current for 5 uH is 0 A. 5 uH also does not quite reach 90 V, but 10 uH does.

Q12: Create a plot for the voltage conversion ratio as a function of inductance (D=10%) for L=1 uH to 15 uH, taking 1 uH increments.

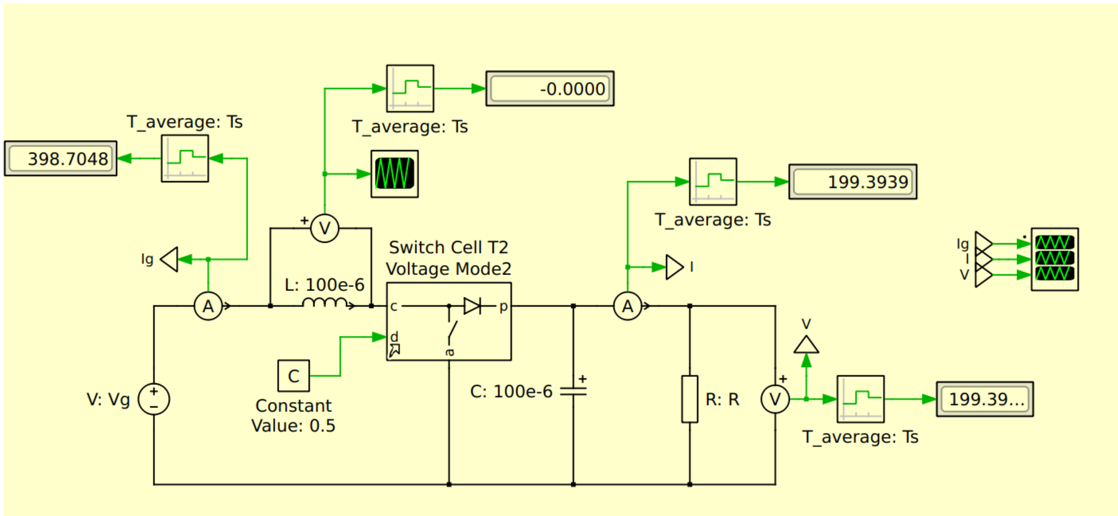
[ ]:
```
import numpy as np
import plotly.express as px
input_voltage = 100 #V
inductance = np.linspace(1,15, 15) # uH
voltage_out = [27.2691, 20.1130, 16.7363, 14.6591, 13.2132,
                12.1309, 11.2808, 10.5899, 10.0137, 9.9990,
```

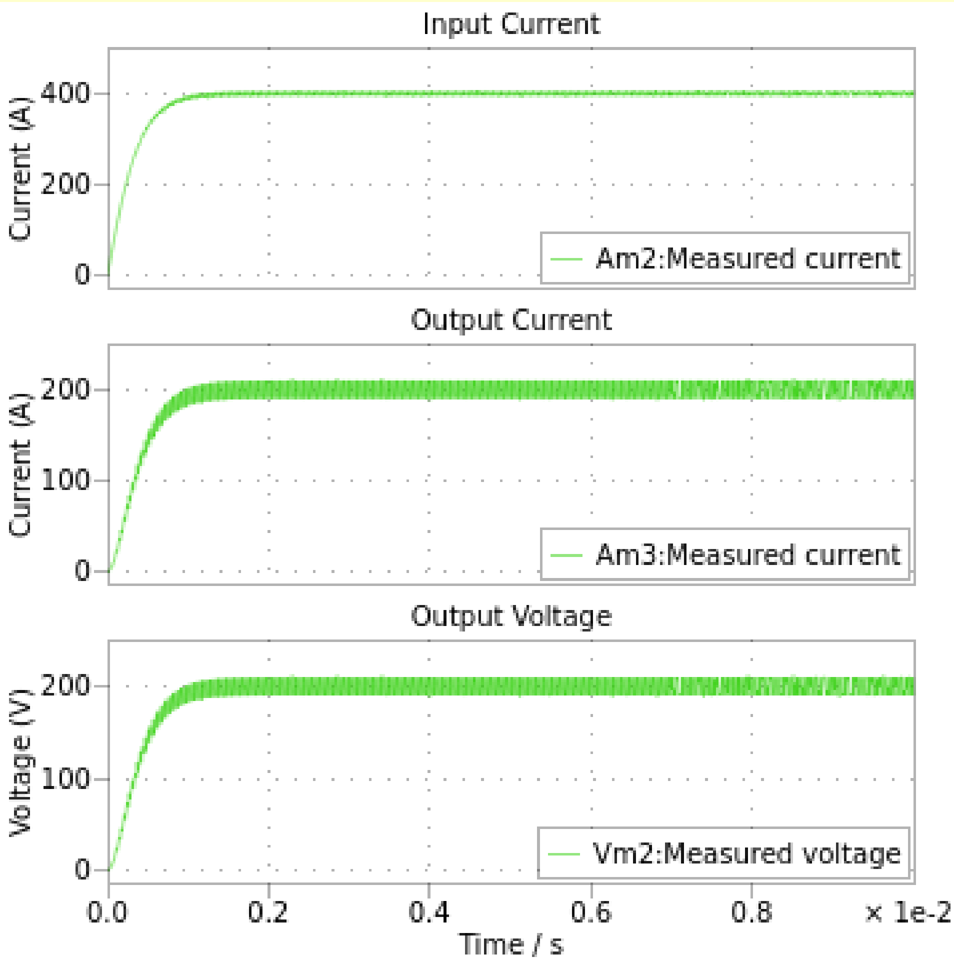
```
                9.9990, 9.9990, 9.9990, 9.9990, 9.9990] #V, average
voltage_conversion = np.array(voltage_out)/input_voltage
fig = px.scatter(x=inductance, y=voltage_conversion, title="Inductance and␣
 ↪Voltage Conversion Ratio")
fig.update_layout(
    xaxis_title="Inductance (mH)",
    yaxis_title="Voltage Conversion Ratio"
)
fig.show()
```

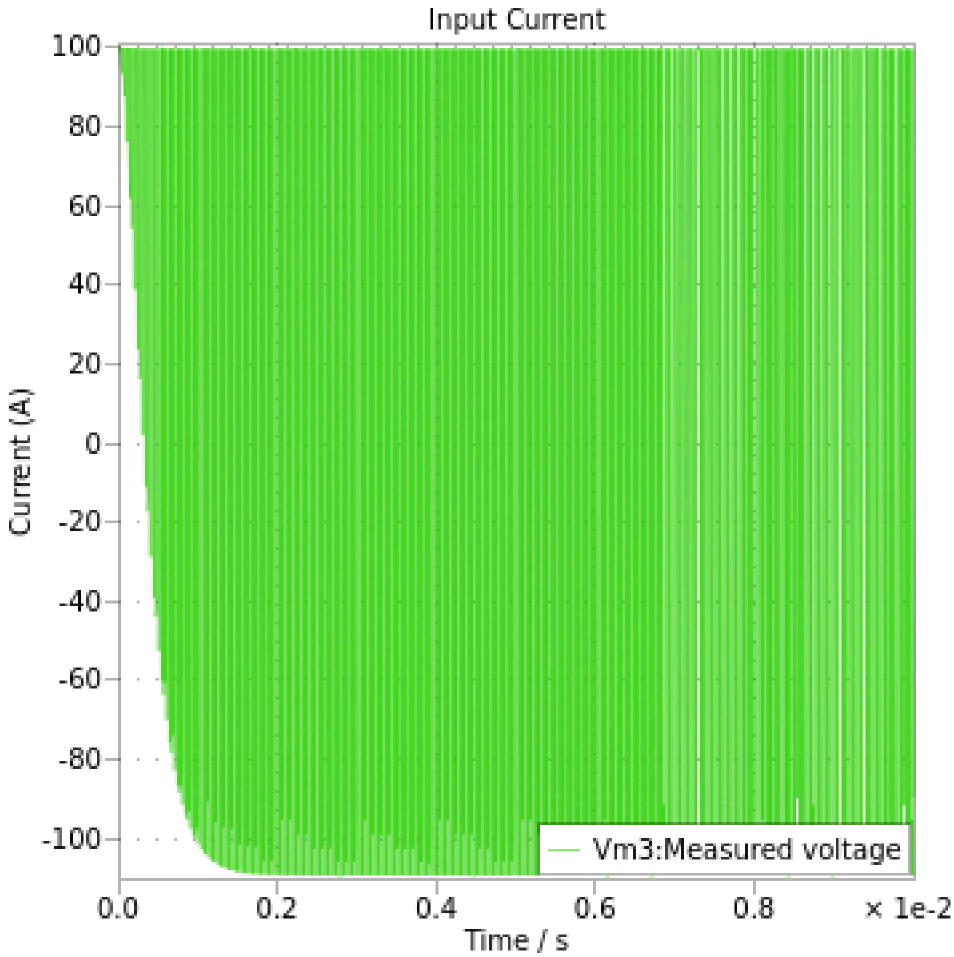
Q13: Create an equivalent buck converter circuit using a Type 2 switch cell. Hint: This circuit will not have a common ground between input and output.



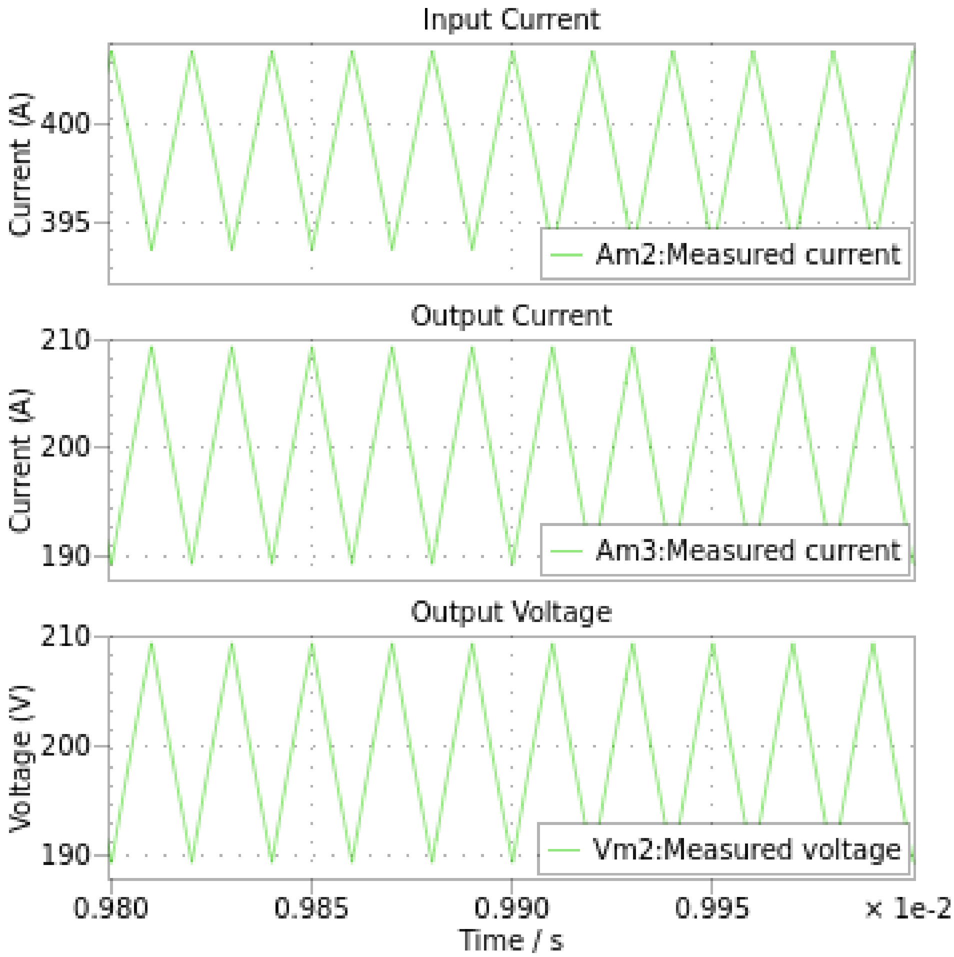
0.2 Boost converter



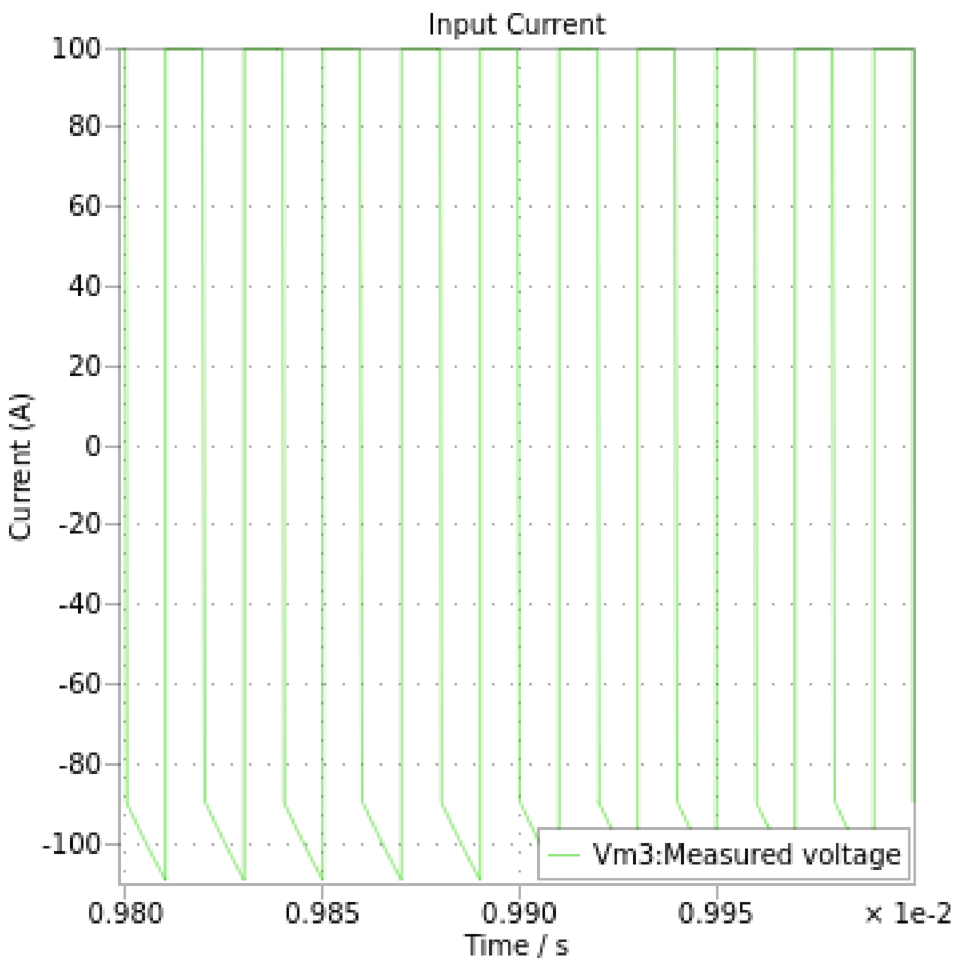




Input Current
Current (A)
Time / s
× 1e-2
Vm3:Measured voltage
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.0
0.2
0.4
0.6
0.8



Input Current
Current (A)
400
395
Am2:Measured current
Output Current
Current (A)
210
200
190
Am3:Measured current
Output Voltage
Voltage (V)
210
200
190
Vm2:Measured voltage
0.980
0.985
0.990
0.995
× 1e-2
Time / s



- Input current (avg 398.7048 A, peak 403.403 A, min 393.642)
- Output current (avg 199.3939 A, peak 209.312 A, min 189.772 A)
- Output voltage (avg 199.3939 V, peak 209.312 V, min 189.772 V)
- Voltage across current source (avg 0 V, peak 909.603 V, min -109.312 V)

Q14: What are some of the fundamental differences compared to the Buck waveforms?

The input current does not switch all the way down to zero but stays high the entire time. It's periodic steady-state value is held within a small range. The shape of the output current and output voltage waves are the same, with the same values, unlike the Buck which had more rounded output voltages.

Q15: What is the voltage conversion ratio for D=50%?

398.7048:100

Q16: Plot the voltage conversion ratio M as a function of the duty cycle, for D=10% to 90% in 10% increments.

[ ]:
```
import numpy as np
import plotly.express as px
input_voltage = 100 #V
duty_cycle = np.linspace(10,90, 9) # %
```

```
voltage_out = [123.4308, 156.1538, 203.8359,
               277.2158, 398.7048, 621.6851,
               1110.3874, 2410.9605, 6113.1515] #V, average
voltage_conversion = np.array(voltage_out)/input_voltage
fig = px.scatter(x=duty_cycle,
                 y=voltage_conversion,
                 title="Inductance and Voltage Conversion Ratio")
fig.update_layout(
    xaxis_title="Duty Cycle (%)",
    yaxis_title="M: Voltage Conversion Ratio"
)
fig.show()
```