Complex Engineering Problem:
Problem Statement:
To design a 100 W, DC-DC Buck converter with input voltage of 60 V and output voltage equal to the Class Number.

Course Title: Power Electronics
Course Code: ELE-331
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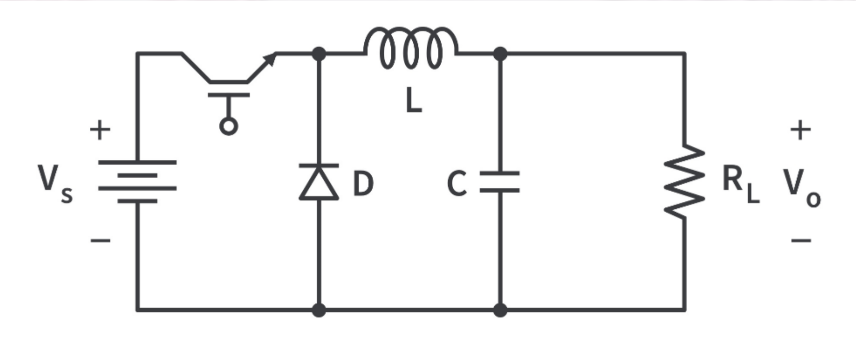
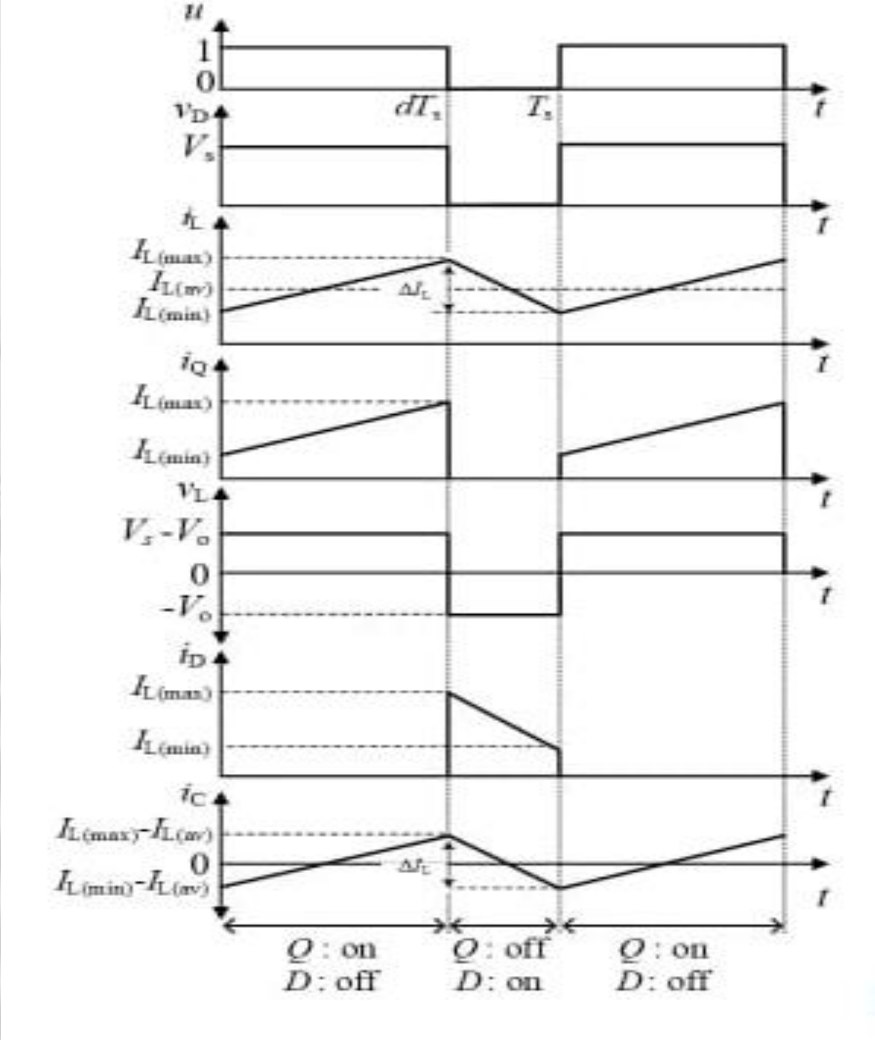
Buck Converter Introduction:

A buck converter, also known as a step-down converter, is a type of DC-DC power converter that efficiently reduces a higher input voltage to a lower output voltage. It operates by intermittently storing energy in an inductor during the on state and releasing it to the load during the off state. This process allows for voltage reduction, making buck converters commonly used in electronic devices to regulate power supply voltages.





Phase A - Design in periodic steady-state

Design Requirements:

Conversion of 60 V DC to 4 V DC.

Design Equations:

Duty Cycle: $D = \frac{V_o}{V_s} = \frac{4}{60} \Rightarrow \mathbf{0.067}$

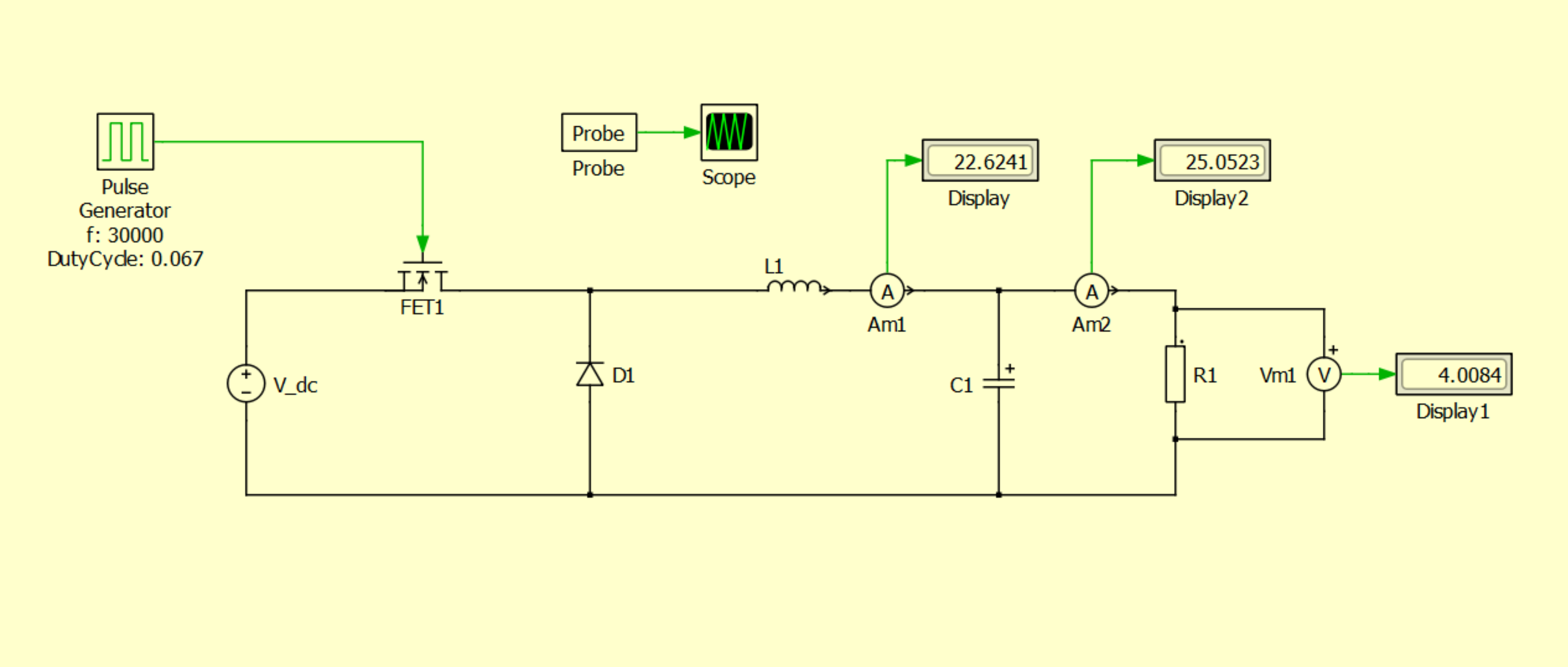
$\Delta I_L = 0.2(I_{out}) = 0.2(25) = \mathbf{5A}$

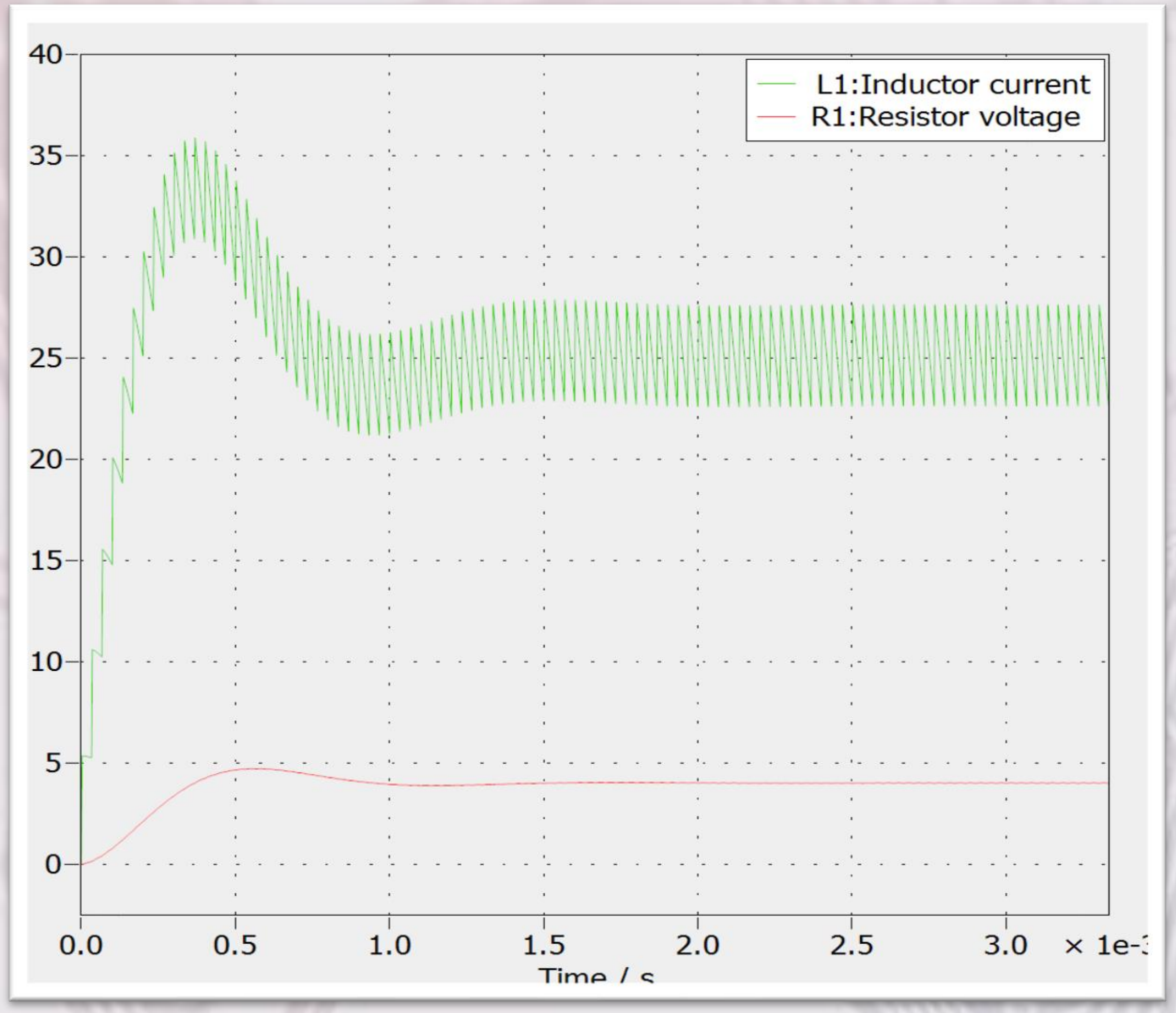
Inductance: $L = \frac{D(V_s - V_o)}{\Delta I_L f_s} = \frac{0.067 * 56}{5(300000)} \Rightarrow \mathbf{25.01\mu H}$

Capacitance: $C = \frac{\Delta I_L}{8 \Delta V_o f_s} = \frac{5}{(4800)} \Rightarrow \mathbf{1.042\ mF}$

Resistance: $R = \frac{\mathrm{V}^2}{P} = \frac{16}{100} \Rightarrow \mathbf{0.16\Omega}$

Phase B - Simulation of Buck converter in CCM

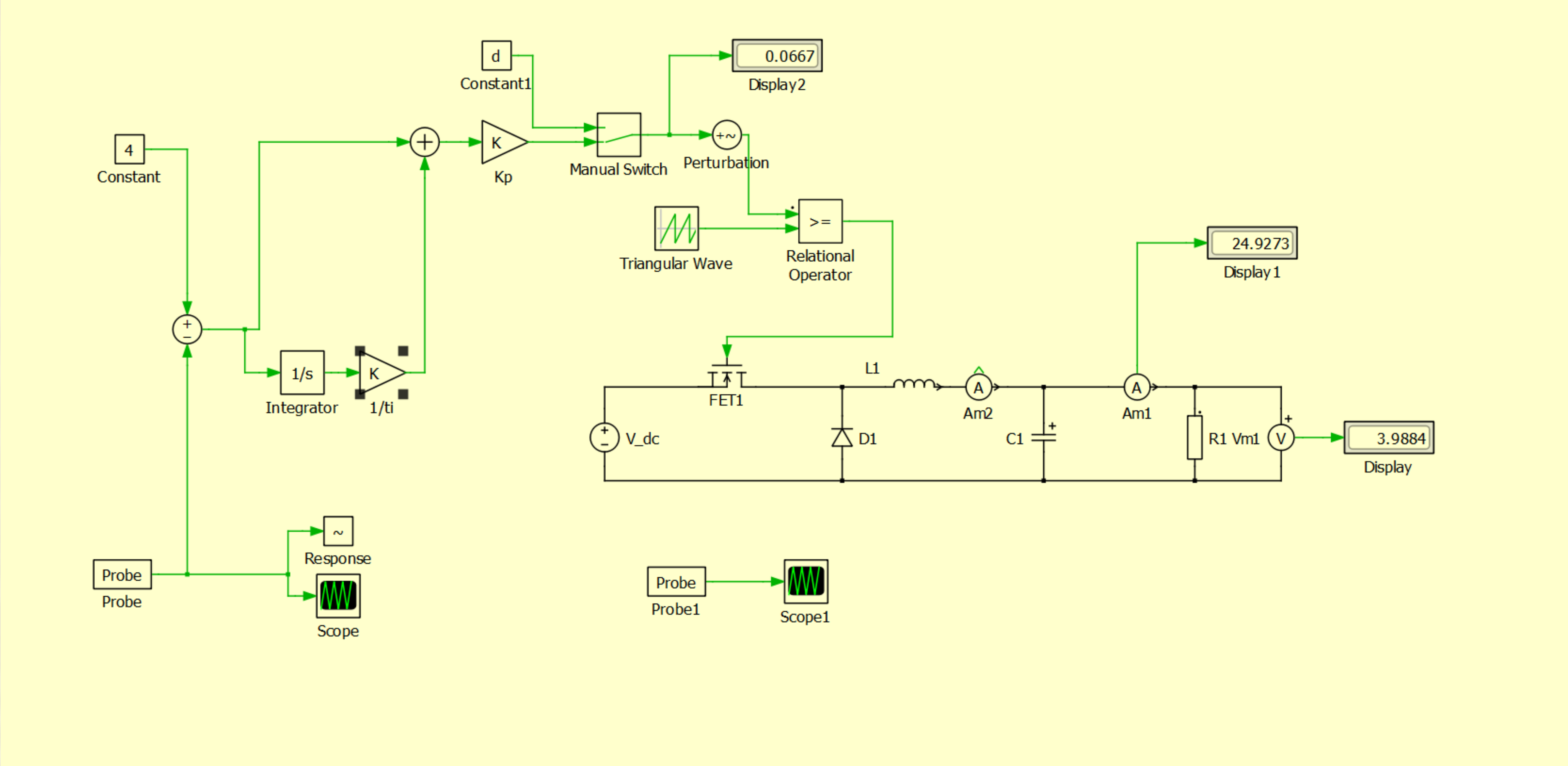


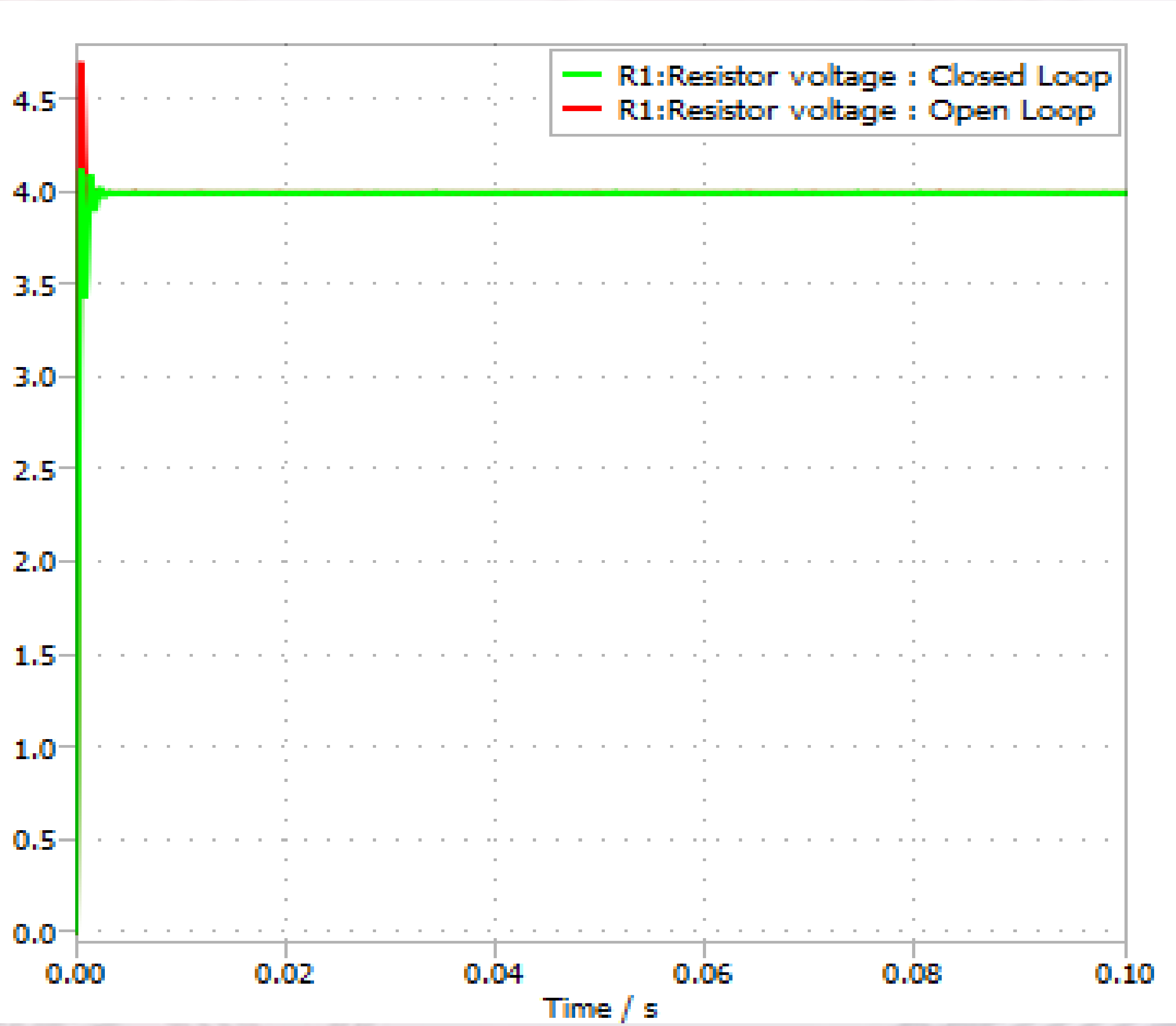


The buck converter designed, steps down a 60V input to an output voltage of approximately 4V, sustaining a constant output thereafter. The output current is 25A, yielding a power output of 100W. The circuit employs a 25µH inductor, 1.40mF capacitor, and 0.16-ohm resistance. During the initial 1-micro-second period, a ripple occurs in the output waveform, possibly due to transient effects or charging/discharging of the capacitor. Once stabilized, the capacitor maintains a steady voltage, and the inductor regulates current flow, ensuring a smooth and regulated 4V output.

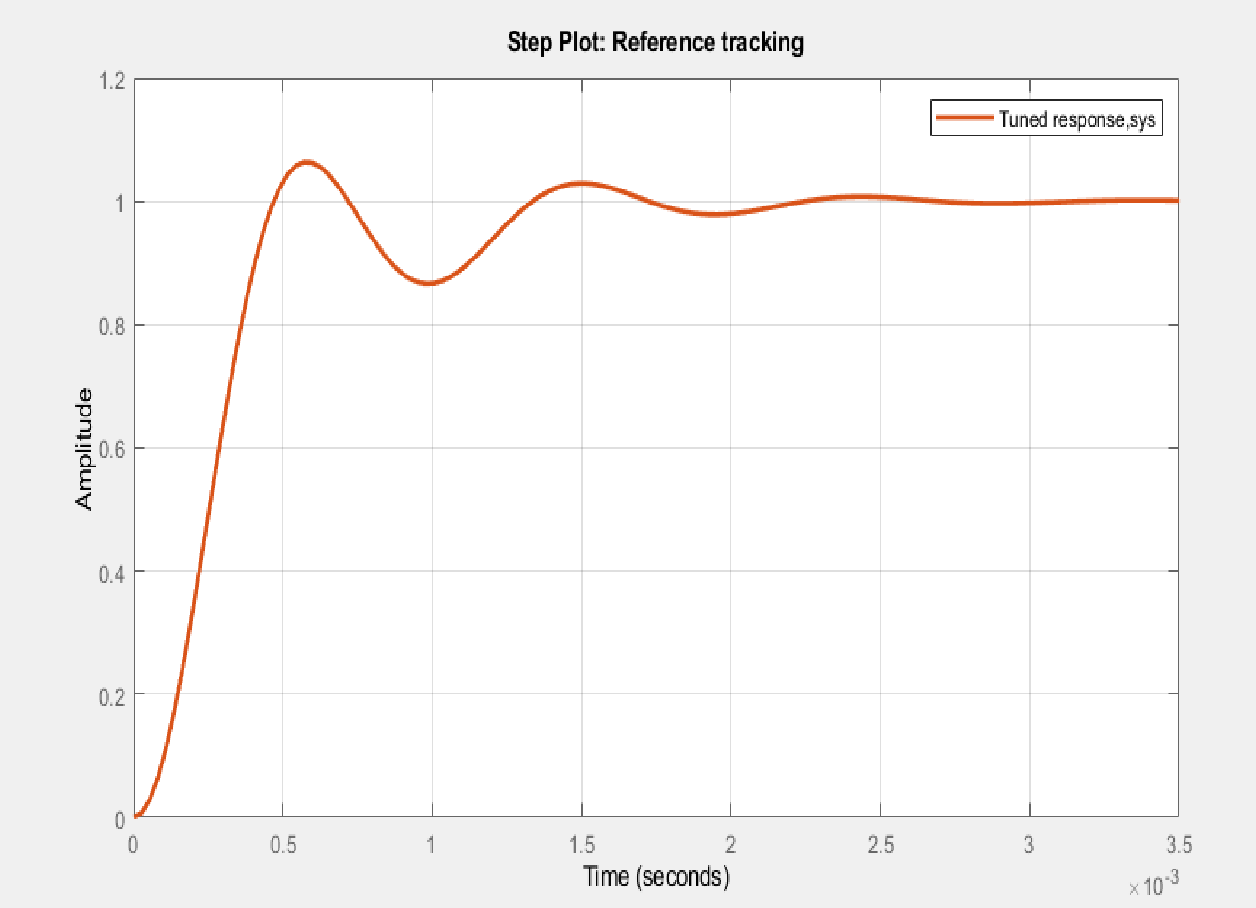
The inductor stores energy during the switching on phase, creating a magnetic field. As the switch turns off, this energy transfers to the capacitor and load, causing the initial ripple. The capacitor smoothens the output voltage by minimizing fluctuations. The inductance helps in regulating current flow, and the capacitor ensures effective filtering. The resistance might contribute to voltage drop and power loss. The stable 4V output, reached after the initial transient period, signifies the successful regulation of voltage, making the buck converter suitable for providing a reliable power supply in electronic applications.

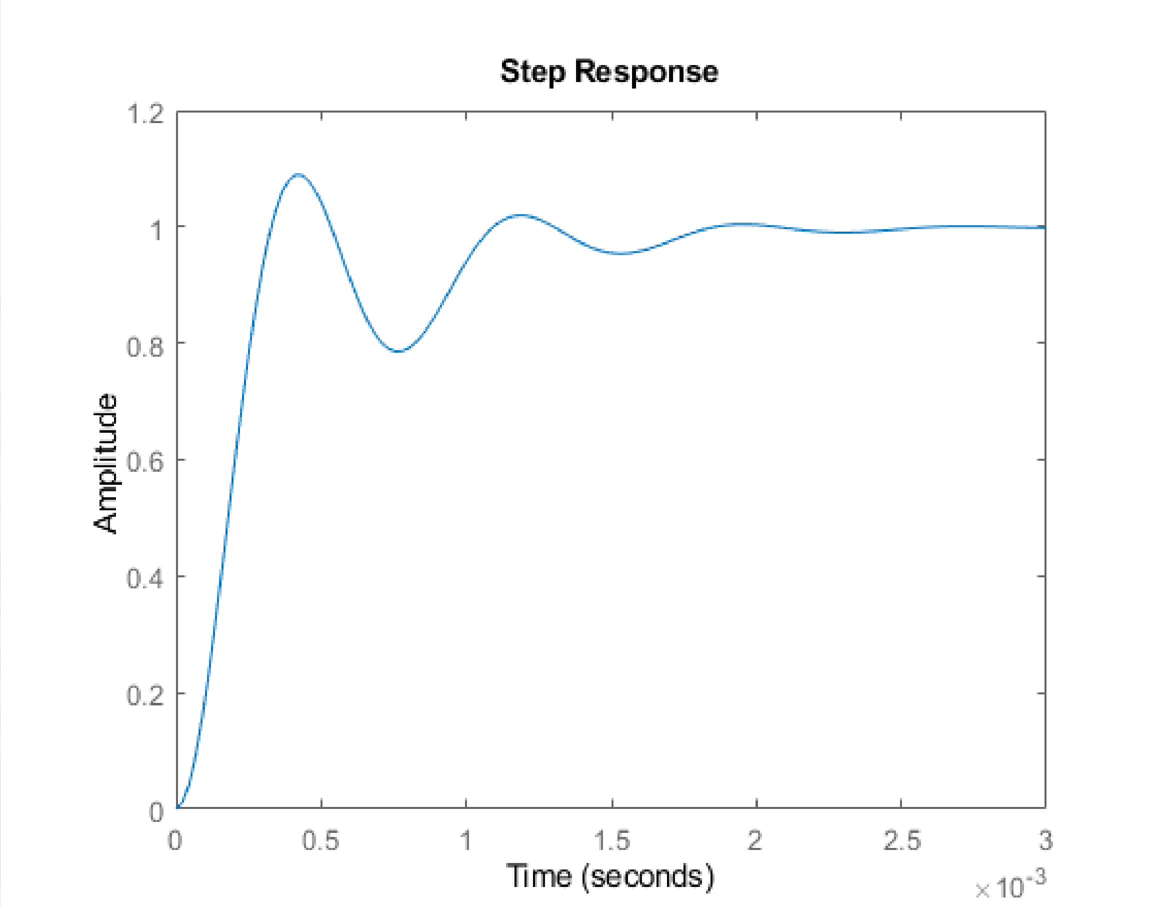
Phase C - Simulation of Feedback controlled Buck converter



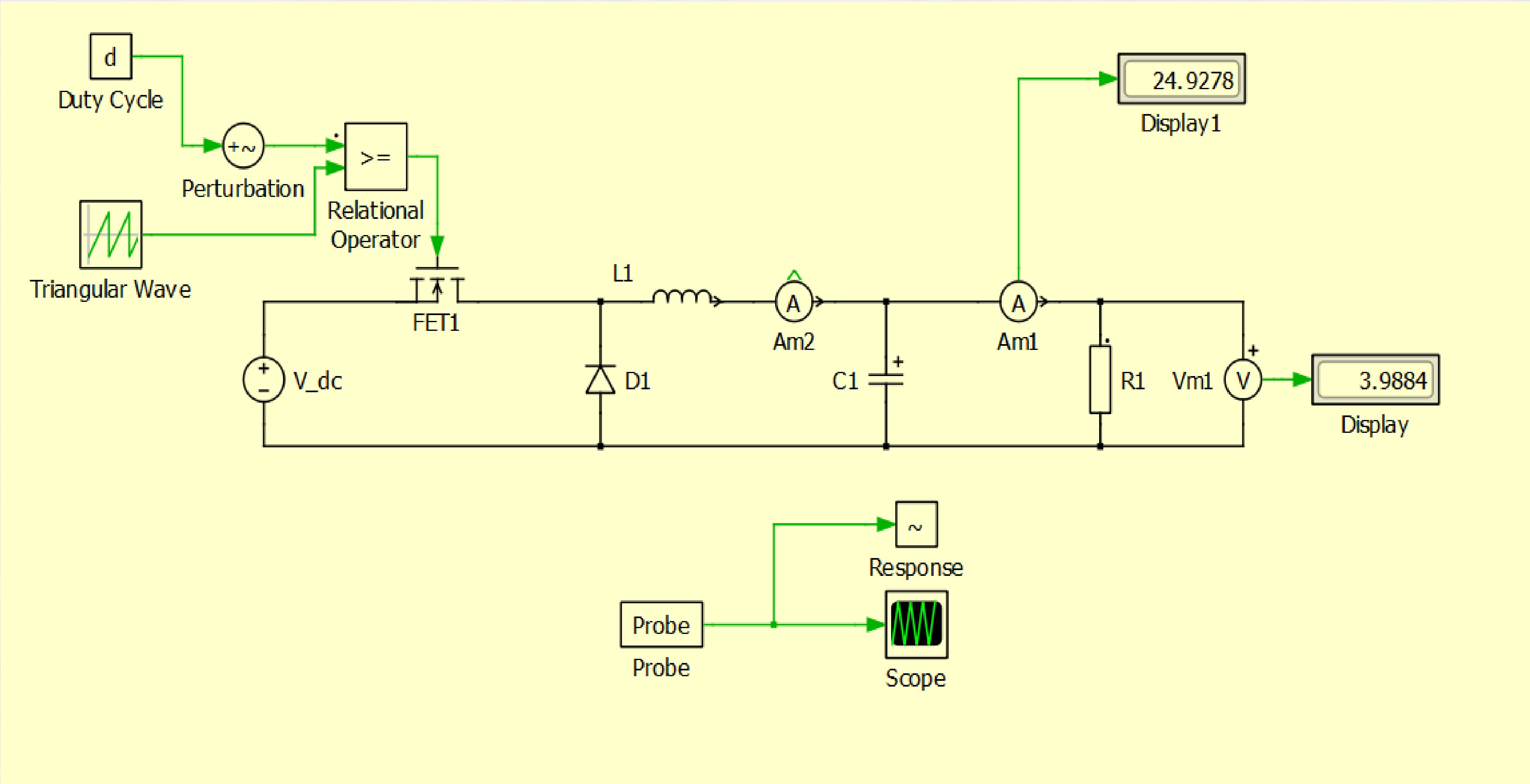


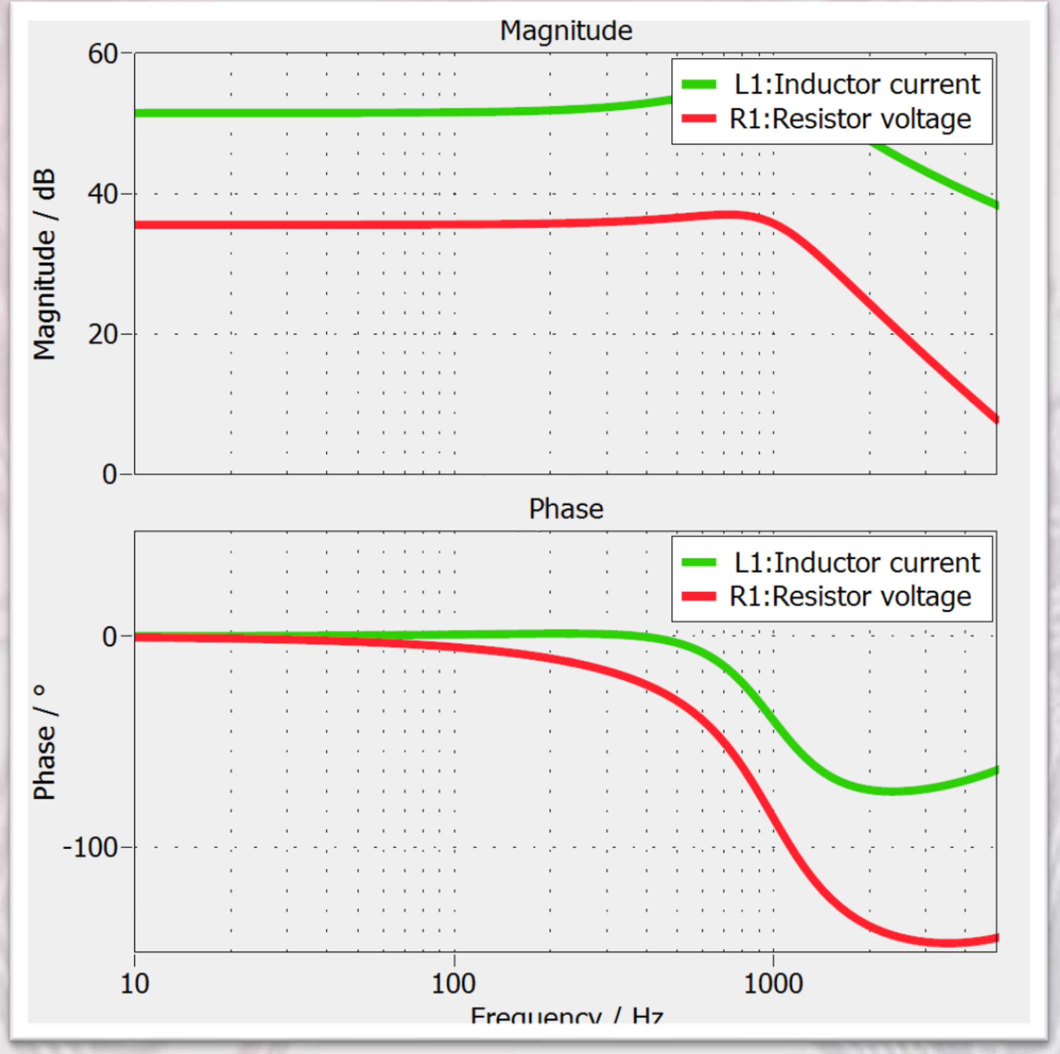
Plexim's PI Compensator is likely employed for closed-loop control in the buck converter circuit. This type of compensator utilizes a Proportional-Integral (PI) controller to enhance system stability and response. The Proportional term adjusts the output based on the current error, while the Integral term helps eliminate any steady-state error. In the steady-state output voltage graph, the PI Compensator ensures that the output settles precisely at 4V, as desired. It achieves this by continuously adjusting the control signal, responding to discrepancies between the reference and actual output. The result is a tightly regulated output voltage with minimal deviation from the set point.

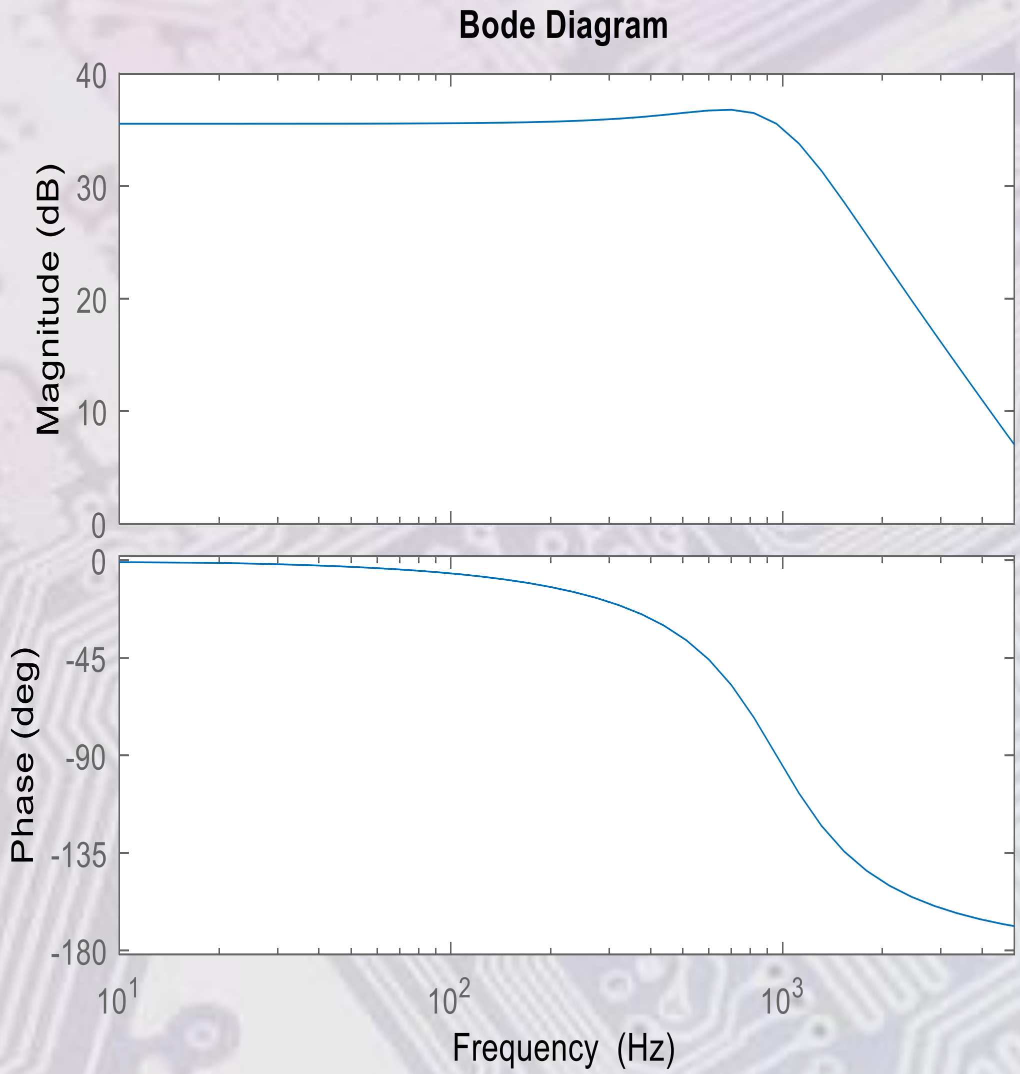

Step Plot: Reference tracking
Tuned response,sys
Amplitude
Time (seconds)
$\times 10^{-3}$


Step Response
Amplitude
Time (seconds)
$\times 10^{-3}$

Frequency Response:




Magnitude
60
40
20
0
Magnitude / dB
L1:Inductor current
R1:Resistor voltage
Phase
0
-100
Phase / °
L1:Inductor current
R1:Resistor voltage
10
100
1000
Frequency / Hz


Bode Diagram
40
30
20
10
0
Magnitude (dB)
0
-45
-90
-135
-180
Phase (deg)
10^1
10^2
10^3
Frequency (Hz)

The frequency response of the buck converter circuit, as indicated by the Bode plots, reveals how the system responds to varying input frequencies. In this case, the initial ripple in the DC output for about 1 micro second suggests a transient response as the system stabilizes. The subsequent constant 4V output indicates a steady-state response. The Bode plots help analyze how the circuit attenuates or amplifies input frequency components, offering insights into the converter's stability and transient behavior during the initial seconds.

Conclusion:

The buck converter design with an input voltage of 60V successfully achieved a stable DC output of 4V after an initial ripple period of approximately 1 microsecond. The output current was maintained at 25A, resulting in a power output of 100W. The inductance of 25 micro-henry and capacitance of 1.40 milli-farad contributed to the smoothing of the output voltage, minimizing fluctuations. The designed converter, with a resistance of 0.16 ohms, demonstrated efficiency in power delivery. The transient ripple during the first microsecond could be attributed to the initial settling of the converter. This behavior is common in practical implementations and is acceptable as long as the output stabilizes within an acceptable timeframe, which was achieved in this case. The chosen parameters appear to be well-suited for the desired output characteristics. However, further considerations, such as thermal performance and component stress, should be evaluated in real-world applications to ensure the reliability and longevity of the buck converter. Overall, the simulation results indicate a successful design meeting the specified requirements.