Basic Buck Converter — Step-Down DC–DC Conversion

This paper is part of the Power Electronics Learning Portfolio, a self-study documentation series.

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Abstract

This paper explains the basic operation of a Buck Converter, a DC–DC converter used to step down voltage efficiently. Using PSIM simulation, a 50V input is converted to 25V output under open-loop PWM control. The goal is to observe how switching, inductor, and capacitor values influence output voltage, ripple, and transient response.

Introduction

A Buck Converter is one of the most fundamental DC–DC converter topologies. It efficiently converts a higher DC voltage into a lower DC voltage using high frequency switching and energy storage components. In this study, a Buck Converter was simulated using PSIM to understand how duty ratio, inductance, and capacitance determine the output stability.

Basic Principle

Operating Modes

When the switch is ON:
The input voltage is applied to the inductor, and energy is stored in its magnetic field.

$$V_L = V_{in} - V_{out}$$

When the switch is OFF:
The inductor releases stored energy through the diode into the load, maintaining continuous current flow.

$$V_L = -V_{out}$$

The average output voltage is given by:

$$V_{out} = D * V_{in}$$

where D is the duty cycle.

Example: For $V_{in} = 50V$ and $D = 0.5, V_{out} \approx 25V$.

Circuit Parameters

PARAMETER	SYMBOL	VALUE	DESCRIPTION
INPUT VOLTAGE	(Vin)	50 V	Supply voltage
LOAD RESISTANCE	(R)	5Ω	Represents load
INDUCTOR	(L)	1 mH	Controls current ripple
CAPACITOR	(C)	100 µF	Smooths voltage ripple
SWITCHING FREQUENCY	(fs)	5 kHz	Determines ripple and loss
DUTY CYCLE	(D)	0.5	Target ratio

The parameters were selected to keep output voltage ripple below 10 % while ensuring stable operation and visible waveform characteristics.

Simulation Results

The PSIM simulation circuit is shown in Figure 1 The output voltage and inductor current are shown in Figure 2

- Average output voltage stabilized around 25V.
- Initial overshoot reached approximately 34V.
- Inductor current displayed triangular waveform.

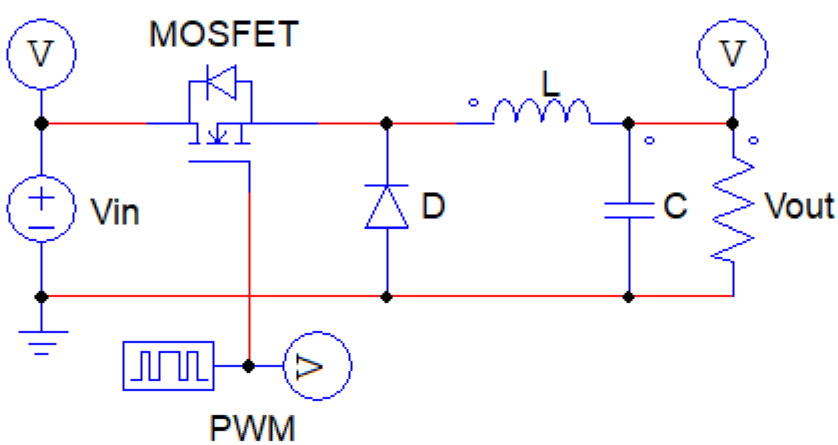

Figure 1

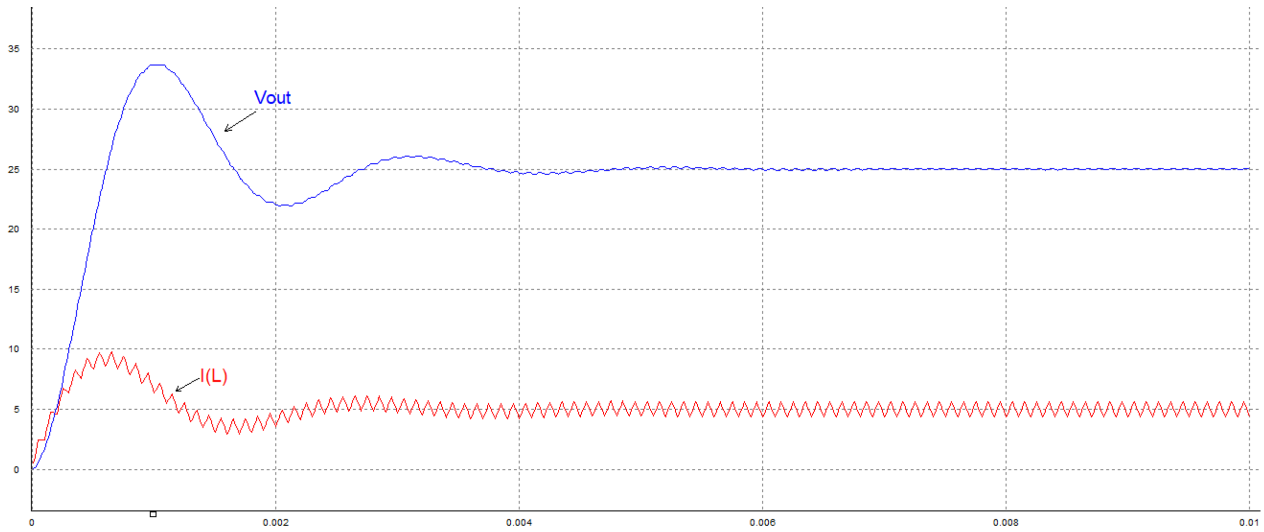

Figure 2

Discussion

In this experiment, the startup response of the Buck Converter showed that the amount of output overshoot is strongly influenced by the values of the inductor (L) and capacitor (C).
When the circuit was initially tested with L = 1 mH and C = 100 µF, the output voltage exhibited a clear overshoot near the input voltage before settling to the expected steady-state of approximately 25 V. This occurred because the inductor current continued to charge the output capacitor even after the output voltage reached its target, leading to an underdamped LC response.

To analyze this effect, the parameters were varied: the inductance was increased from **1 mH to 5 mH**, and the capacitance was reduced from **100 µF to 50 µF and 30 µF**.

As a result, the startup waveform changed from a fast but overshooting rise to a **gradual and monotonic rise** without overshoot as shown below in Figure 3

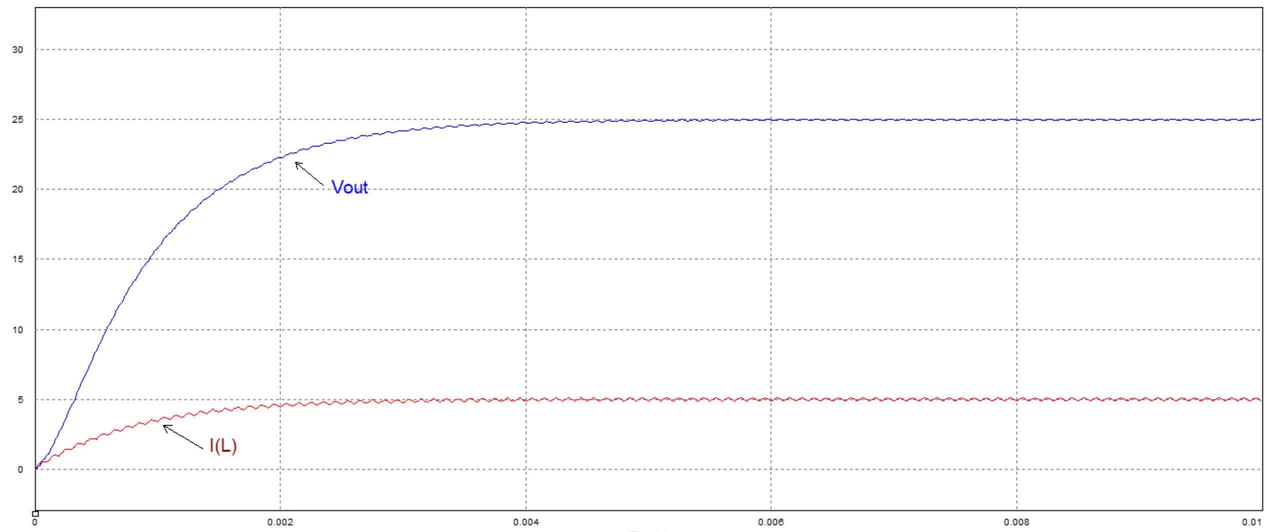

Figure 3

Conclusion

This study confirmed the fundamental operation of a Buck Converter and highlighted how component selection directly affects startup behavior and output stability.
When operated with $V_{in} = 50$ V, $D = 0.5$, $L = 1$ mH, and $C = 100$ µF, the converter produced the correct average output but exhibited a noticeable voltage overshoot during startup.
By increasing the inductance to 5 mH and reducing the capacitance to 30–50 µF, the overshoot was completely eliminated, and the output voltage rose smoothly and monotonically to the steady-state value of approximately 25 V.

These results show that a larger inductor slows the inductor current ramp and reduces excess energy transfer to the capacitor, while a smaller capacitor increases damping and suppresses underdamped oscillation.
Together, they form a well-damped system with improved transient behavior.

Although smaller capacitance can increase steady-state voltage ripple, the effect was minimal due to the larger inductance.
For future work, implementing soft-start control or closed-loop voltage feedback can provide more predictable startup behavior under varying loads and component tolerances.