Basic Buck-Boost Converter — Step-Up/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 examines the operation of a non-isolated Buck-Boost Converter capable of both step-up and step-down DC voltage conversion.
Using PSIM simulation, a 25 V input was applied while the duty cycle was varied between 0.3 and 0.7.
At low duty (0.3), the converter produced approximately −11 V, demonstrating buck behavior;
at high duty (0.7), it reached around −58 V, demonstrating boost behavior.
The goal of this study is to compare transient response, overshoot characteristics, and the influence of inductance and capacitance values in both modes.

Introduction

The Buck-Boost converter combines the functionality of Buck and Boost converters in a single circuit.
It can generate an output voltage either higher or lower than the input, but its polarity is inverted relative to the input ground.
This makes it suitable for applications requiring flexible voltage regulation from a single supply, such as portable and automotive systems.

In this study, the converter was implemented in PSIM using open-loop PWM gating.
A fixed input of 25 V was used, and the duty ratio was varied from 0.3 to 0.7 to observe both step-down and step-up operation.
By analyzing voltage and current waveforms, the experiment aimed to understand how the same LC configuration behaves differently in each region.

Operating Principle

When the MOSFET switch is **ON**, current flows from the input through the inductor, storing energy in its magnetic field:

$$V_L = V_{in}$$

When the switch turns **OFF**, the inductor reverses polarity and releases energy through the diode into the output capacitor and load:

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

The steady-state voltage relationship is given by:

$$V_{out} = -\frac{D}{1-D} V_{in}$$

where D is the duty cycle.
The negative sign represents inversion of output polarity relative to the input ground.

Circuit Parameters

PARAMETER	SYMBOL	VALUE	DESCRIPTION
INPUT VOLTAGE	(Vin)	25 V	Constant DC source
LOAD RESISTANCE	(R)	5 Ω	Represents load
INDUCTANCE	(L)	5mH	Controls current ramp
CAPACITANCE	(C)	200 μF	Smooths voltage ripple
SWITCHING FREQUENCY	(fs)	20 kHz	Determines ripple and response
DUTY CYCLE	(D)	0.3 / 0.7	Buck and boost test points

These parameters ensured continuous conduction and allowed both buck and boost behavior to be observed under identical hardware conditions.

Circuit Diagram

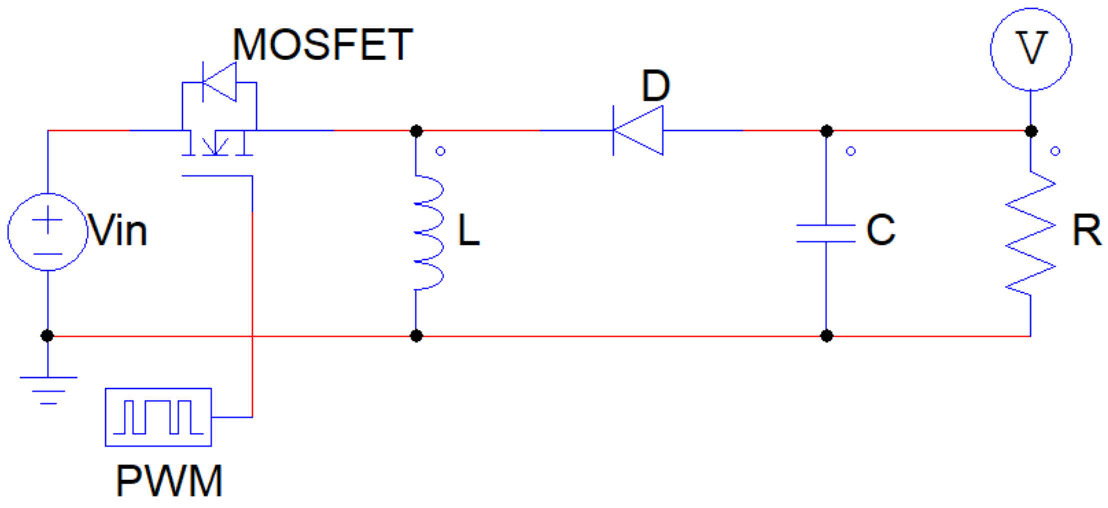

Figure 1

Simulation Results

(a) Step-Down Operation — D = 0.3

At $D = 0.3$, the converter output stabilized near −11 V, corresponding to the theoretical value

$$V_{out} = -\frac{0.3}{1-0.3} \times 25 \approx -10.7V.$$

The voltage rise was fast, but the waveform exhibited a short overshoot before settling. The inductor current averaged around 3 A as shown below in Figure 2.

The overshoot resulted from stored magnetic energy continuing to charge the output capacitor even after reaching the target voltage.
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(b) Step-Up Operation — D = 0.7

At $D = 0.7$, the converter output reached approximately −58 V, also consistent with theory:

$$V_{out} = -\frac{0.7}{1-0.7} \times 25 \approx -58.3V.$$

The output voltage rose smoothly without overshoot, and ripple was minimal as shown below in Figure 3.
Average inductor current was around 38 A, confirming that higher duty requires proportionally higher current flow to maintain power balance between input and output.

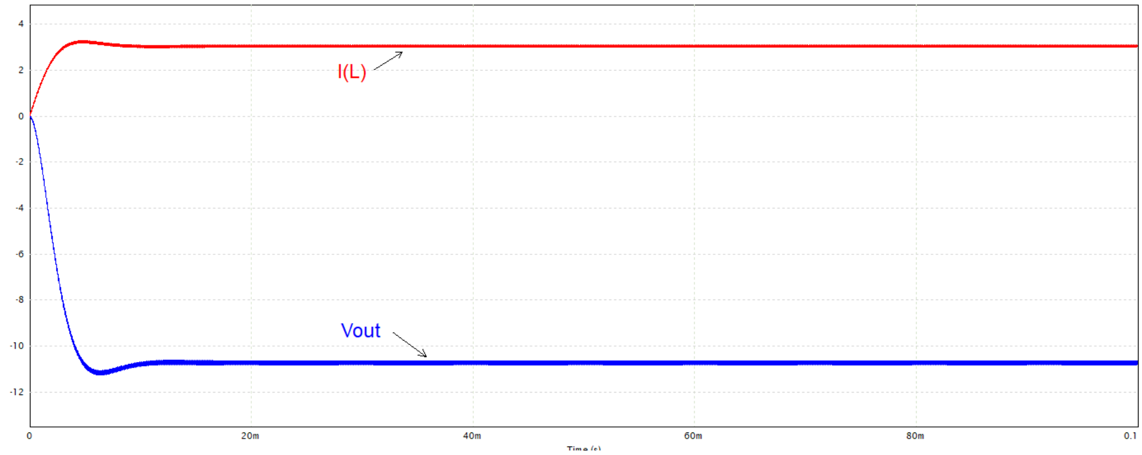

Figure 2 Step-Down Operation

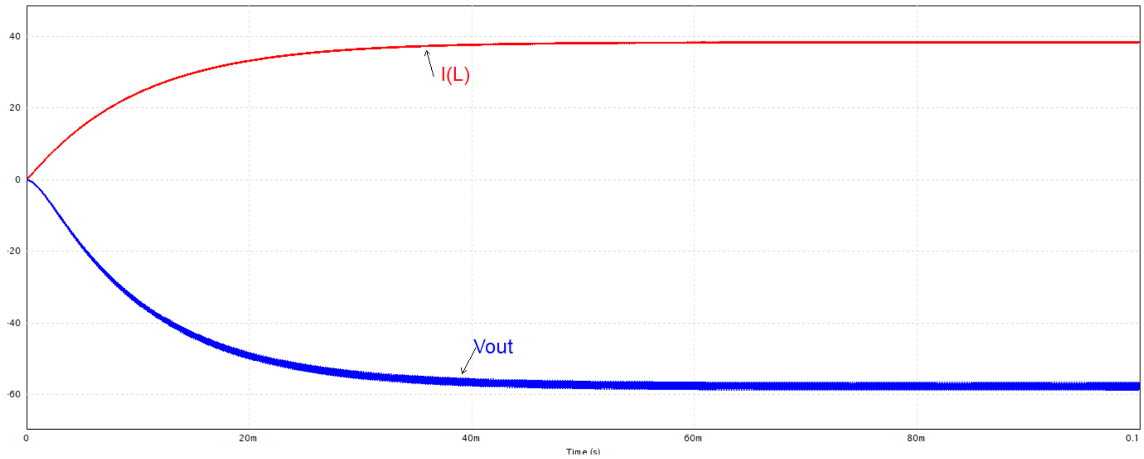

Figure 3 Step-Up Operation

Discussion

Using identical components for both modes revealed a clear trade-off between rise speed and damping.
In the step-down (buck) region, the converter's direct energy transfer from the input to the capacitor caused a brief overshoot during startup.

In the step-up (boost) region, the energy transfer was indirect, through the inductor and diode, which introduced natural damping and produced a smooth, stable rise.

This difference demonstrates that large energy-storage elements (L and C) benefit boost operation but can make buck operation under-damped.
A single passive design therefore cannot perfectly optimize both modes.
To achieve consistent transient performance, active control such as a voltage-mode feedback loop with soft-start is required to shape the duty ratio during startup.

Conclusion

The PSIM simulation confirmed the dual functionality of the Buck-Boost converter and the impact of duty cycle on both output polarity and magnitude.
At $D = 0.3$, the output dropped to approximately -11 V with slight overshoot, while at $D = 0.7$, it increased to -58 V with a clean, monotonic response.
The results highlight that parameter selection alone cannot guarantee identical stability for both directions of operation.

Future work will implement a feedback-controlled soft-start circuit to automatically regulate the duty ratio, minimizing overshoot in buck operation without slowing down boost response.
This improvement will form the foundation of the next mini paper, which will transition from open-loop to closed-loop control design in the Power Electronics Learning Portfolio.