JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

BUCK-BOOST CONVERTER APPLICATION

[1]Pallavi Pandit, [2]Sandhya Kulkarni

[1]M.Tech. EPS Student, [2]Associate Professor
[1,2]Department of Electrical Engineering, Government Engineering College, Chhatrapati Sambhajinagar, Maharashtra, India.

Abstract : A buck-boost converter is a versatile DC-DC converter capable of stepping up or down the input voltage to provide a regulated output. This flexibility makes it ideal for applications where input voltage varies but a stable output is required. Common applications include battery-powered devices, renewable energy systems, electric vehicles, and portable electronics. The buck-boost converter operates using components like inductors, capacitors, and switches (typically MOSFETs) controlled by pulse-width modulation (PWM) to adjust to changing input conditions, ensuring efficient energy conversion. This paper explores the working principles, key components, and applications of buck-boost converters, providing an analysis of their performance in various scenarios.

***Index Terms* - DC-DC converter, PWM, CCM, DCM, buck-boost converter.**

I. INTRODUCTION

A buck-boost converter is a type of DC-DC converter that can either step up (boost) or step down (buck) the input voltage to produce a regulated output voltage. The output voltage can be higher, lower, or even inverted compared to the input voltage, making it versatile in situations where the input voltage fluctuates but a stable output is required. The buck-boost converter plays a crucial role in power electronics because of its ability to efficiently convert varying input voltages to a stable output. This makes it highly valuable in a wide range of applications, including battery-powered devices, renewable energy systems, electric vehicles, and portable electronics. Its control systems, typically based on pulse-width modulation (PWM), ensure that the converter adjusts dynamically to changing input conditions, optimizing energy efficiency and maintaining stable operation. Objectives of the Paper: To explore the fundamental working principles of buck-boost converters. To understand the role of each component in the converter's operation. To discuss the practical applications and significance of buck-boost converters in modern electronics. To provide a comparative analysis of different modes of operation and their performance in various scenarios. A boost converter operates by storing energy in an inductor during one phase of the switching cycle and then releasing it at a higher voltage during another phase. This capability is especially valuable in applications where the power source provides a voltage lower than what is needed for efficient operation.

II. WORKING PRINCIPLE OF BUCK-BOOST CONVERTERS

A typical buck-boost converter consists of the following key components:

- Inductor: Stores energy during one phase of the switching cycle and releases it during the other.
- Switch (usually a MOSFET): Controls the flow of current through the inductor by turning on and off at high frequency.
- Diode: Provides a path for current when the switch is off, preventing reverse current flow.
- Capacitor: Smooths out the output voltage by reducing voltage ripple.

OPERATION MODES:

The converter operates in two primary modes:

1. **Continuous Conduction Mode (CCM)**: The inductor current never falls to zero during a switching cycle. In this mode:
   - When the switch is ON, current flows through the inductor, storing energy.
   - When the switch is OFF, the inductor releases the stored energy through the diode to the load, stepping the voltage up (boost) or down (buck), depending on the input and output voltage levels.

2. **Discontinuous Conduction Mode (DCM)**: The inductor current falls to zero during the switching cycle. This typically happens at light loads. In this mode:
   - Energy stored in the inductor is fully discharged before the next switching cycle begins, leading to different dynamic behaviors compared to CCM.

III. SIMULATION RESULT

The three-phase programmable voltage source supplies AC power. As shown in figure 1, this is rectified using a diode bridge, converting AC into DC. The circuit uses Pulse Width Modulation (PWM) control signals generated by controllers (P11, P12, P13) to regulate the switching of IGBTs (Insulated-Gate Bipolar Transistors). The PWM signals control the switching of the DC-DC converter, ensuring proper buck (voltage reduction) and boost (voltage elevation) operations. These are used for energy storage and smoothing out voltage fluctuations. The inductor (L) stores energy when the IGBT is on and releases it when the IGBT is off. Capacitors help filter out the voltage ripple and maintain a steady output voltage. The current and voltage measurement components in the circuit monitor the performance of the buck-boost converter, capturing data used for analysis. The system has a battery connected through a buck-boost stage, indicating that this is likely designed for energy storage applications. The battery may be charged or discharged depending on the buck-boost operation. These switches control the conversion of energy, directing it either towards boosting or bucking the voltage depending on the control signals provided by the PWM generator.

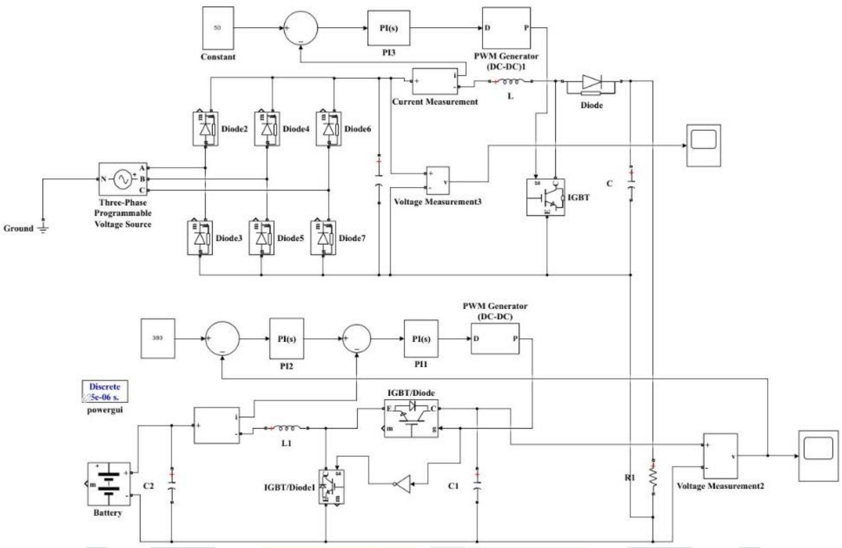

Fig.1: Dual buck boost simulation model

When the voltage needs to be reduced, the converter operates in buck mode. The IGBT switches are controlled to ensure that the inductor stores energy and releases it at a lower voltage. This mode might be used to charge a battery or supply a lower voltage to a load. In boost mode, the inductor stores energy when the switch is on and releases it when the switch is off, effectively increasing the voltage. This is useful when the output voltage needs to be higher than the input voltage, such as in renewable energy systems where voltage from solar panels or other sources needs to be stepped up.

- **Initial Overshoot**:

  - In the very beginning, we see a spike in the output voltage (a quick rise and fall). This overshoot is typical in converters during the start up phase. When the circuit first begins operation, the control system takes a brief period to stabilize the output voltage, causing an initial fluctuation.
  - This overshoot is often a result of the control loop taking time to respond and dampen the excess energy stored in the inductors and capacitors.

- **Oscillatory Behaviour (Ripple)**:

  - After the initial overshoot, you observe oscillations in the voltage. These oscillations represent voltage ripple caused by the switching operation of the IGBT switches.
  - In a typical buck-boost converter, energy is transferred from the input to the output in discrete pulses, which results in ripple. The inductor and capacitor work to smooth out this ripple, but due to the nature of high-frequency switching, some oscillations remain.

  - **Damping:** Over time, the oscillations reduce in magnitude. This damping is a result of the converter's control system working to bring the output voltage into steady operation. The controller (PI controllers connected to PWM generators in the circuit) adjusts the duty cycle of the PWM signals to reduce the oscillations and stabilize the voltage.

- **Steady-State:**

  - Toward the end of the graph, the voltage oscillations have largely been damped, and the converter reaches a steady state. In this state, the output voltage has stabilized at around 551 V (as seen in the graph), with only minor ripple due to switching. This indicates that the control system is functioning as intended, maintaining a constant output voltage despite the ripple.
  - After some settling time, the system stabilizes to a nearly constant voltage, showing the effectiveness of the control system in maintaining a steady output.

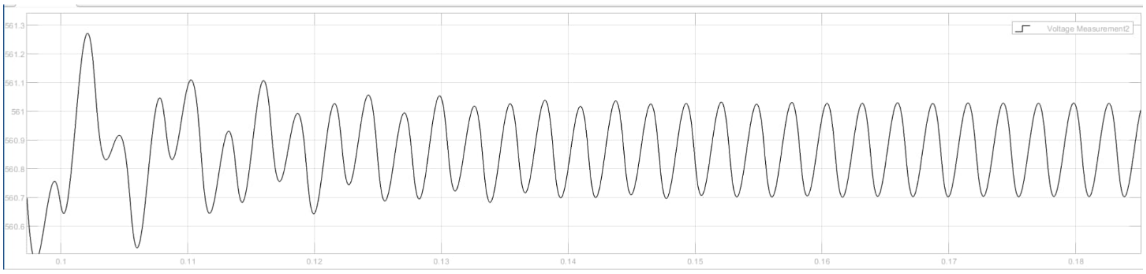

Fig.2: Output voltage over time

This graph shows oscillations in the output voltage over time, eventually stabilizing. The oscillations are a result of switching transients and ripple during the startup phase of the converter.

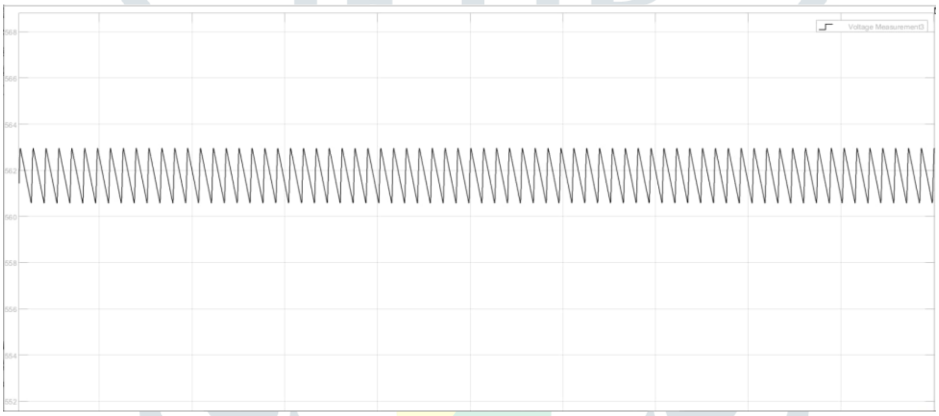

Fig.3: Output transient behavior

This plot shows a more zoomed-in view of the transient behavior during the initial phase of operation. The output voltage starts off with significant fluctuations before settling down.

- **Initial Delay**:

  - The second graph is zoomed in on the early moments of the converter's operation. You can see a brief delay in the output voltage at the very start of the graph, where it begins at 0V. This is normal as it takes a brief moment for the converter to begin switching and for the output to respond.

- **Rapid Voltage Rise**:

  - After the initial delay, there's a steep rise in the voltage from 0V to around 562V. This corresponds to the converter entering its active mode where the energy transfer process has begun, and the output voltage ramps up quickly.

- **Initial Ripple**:

  - Once the voltage rises to 562V, there are distinct, sharp oscillations in the graph. These fluctuations indicate significant voltage ripple right after startup.
  - The ripple is sharp, meaning the switching frequency is relatively high, causing the output voltage to fluctuate quickly. This ripple is caused by the switching of the IGBT transistors in the converter, which momentarily interrupts the current flow, creating oscillations in the voltage.

- **Settling**:

- The graph shows that after some time, the fluctuations begin to reduce, but there are still regular voltage peaks and valleys. The system is still adjusting to reach its final steady state.
- The settling time shown in the graph indicates how long it takes for the converter to stabilize its output. The faster the converter settles, the more efficient and well-tuned the control system is.

- **Steady State Ripple**:

- Even when the converter has mostly stabilized, you can still observe residual ripple. This is a common feature in buck-boost converters. Although the capacitor and inductor smooth out the voltage, switching converters always leave some amount of ripple. The size and frequency of this ripple depend on factors like:
  - The switching frequency of the PWM signal (higher frequencies reduce ripple).
  - The size of the inductor and capacitor (larger components help smooth the ripple more).
  - The load on the converter (higher loads can increase ripple).

The oscillations seen here are likely due to high switching activity and the inductor's response in the buck-boost converter. The system combines a three-phase rectifier and dual buck-boost converter stages controlled via PWM to regulate the output voltage. The IGBT switches ensure proper switching in both buck and boost modes. The waveforms demonstrate the initial transient response followed by a steady-state operation, which is typical in power converters like this.

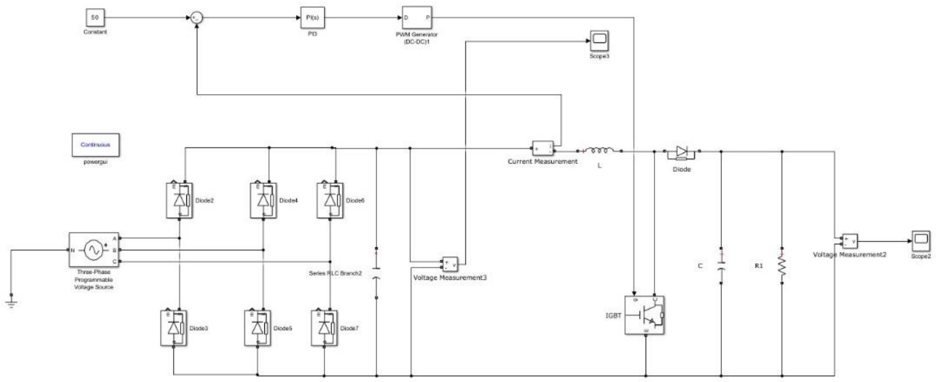

Fig.4: Boost converter simulation result

The diagram represents a boost converter circuit. Three-Phase Programmable Voltage Source is providing input AC voltage. Rectifier (Diodes D2-D7): Converts AC voltage into DC. IGBT: Used as the main switching device to control the boost operation. Inductor (L): Stores energy when the IGBT is switched on and releases it when switched off, boosting the voltage. Capacitor (C): Smooth's the output voltage by reducing ripple. PWM Generator: Provides a pulse-width modulated signal to control the switching of the IGBT.

- **Step 1: IGBT ON:** When the IGBT turns on, current flows through the inductor (L), storing energy in its magnetic field.
- **Step 2: IGBT OFF:** When the IGBT turns off, the energy stored in the inductor is transferred to the output capacitor (C), increasing the output voltage. The diode prevents the backflow of current from the capacitor to the inductor.

The PWM generator controls the duty cycle of the IGBT to regulate the output voltage. The higher the duty cycle, the more energy is stored in the inductor and transferred to the output, leading to a higher boost.

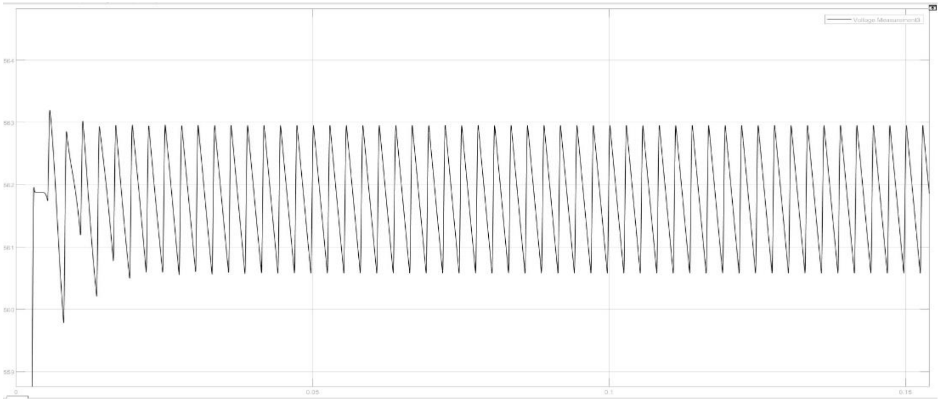

Fig.5: Output Voltage

Graph 1 (Top Graph): Voltage Measurement 2 (Output Voltage)

- The graph shows the output voltage of the boost converter.
- **Initial Spikes:** The initial spikes represent the transient state of the converter when it starts.
- **Steady State:** After the transient, the voltage stabilizes, maintaining a steady waveform with ripple due to switching. The voltage appears to oscillate around a certain level, which is typical for a boost converter with ripple present in the DC output.

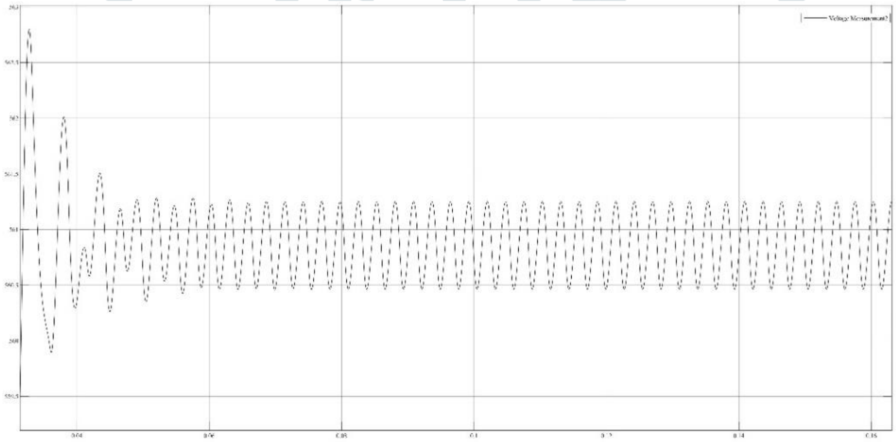

Fig.6: Current Measurement

Graph 2 (Bottom Graph): Current Measurement

- This graph shows the current behavior.
- **Transient State:** Similar to the voltage waveform, the current shows an initial transient spike when the converter is turned on.
- **Steady State:** The current stabilizes after the transient and follows a consistent pattern, indicating the converter's switching behavior. The ripple in the current waveform shows the inductors response to the IGBT's switching.
- The output voltage graph suggests that the boost converter is successfully increasing the voltage from the input to the desired level. The steady oscillation indicates the normal operation of the boost converter.
- The ripple in the output is expected in switching power supplies and can be minimized by optimizing the capacitor and inductor values or using filters.

Table 1: Parameter of Dual Buck-Boost Converter

Input Voltage	Frequency	Output Voltage	Efficiency
400V	60hz	551V	83%

Table 2: Parameter of Boost Converter

Input Voltage	Frequency	Output Voltage	Efficiency
400V	60hz	562V	84%

IV. CONCLUSION

The buck-boost converter is an essential element in modern electronics, offering flexibility in managing varying input voltages. Its ability to efficiently convert energy in both buck and boost modes makes it valuable for a wide range of applications, from renewable energy systems to portable electronics. Simulation results highlight its performance, with typical overshoot, ripple, and damping characteristics seen during startup and steady-state operation.

REFERENCES

[1] M. H. Rashid, Power Electronics: Circuits, Devices and Applications. FL, USA: Prentice Hall/Pearson, 2014.
[2] F. Maloberti, Analog Design for CMOS VLSI Systems. New York: Kluwer Academic Publisher, 2001.
[3] M. Fakhfakh, E. Tlelo-Cuautle, R. Castro-Lopez, Analog/RF and Mixed- ´ Signal Circuit Systematic Design. New York: Springer, 2013.
[4] A. M. Sodagar, Analysis of Bipolar and CMOS Amplifiers. FL, USA: CRC Press, 2007.
[5] B. Razavi, Design of Analog CMOS Integrated Circuits. USA: McGrawHill, 2001.
[6] P. Mattavelli, L. Rossetto, G. Spiazzi, and P. Tenti, "General-purpose sliding-mode controller for dc/dc converter applications," in IEEE Power Electronics Specialists Conf. Rec. (PESC), 1993, pp. 609–615
[7] P. Mattavelli, L. Rossetto, G. Spiazzi, and P. Tenti, "General-purpose sliding-mode controller for dc/dc converter applications," in IEEE Power Electronics Specialists Conf. Rec. (PESC), 1993, pp. 609–615
[8] S. C. Tan, Y. M. Lai, and C. K. Tse, "Adaptive feed forward and feedback control schemes for sliding mode-controlled power converters," IEEE Trans. Power Electron. vol. 21, no. 1, pp. 182–192, Jan.2006.
[9] S.C. Tan, Y. M. Lai, and C. K. Tse, "Adaptive feed forward and feedback control schemes for sliding mode-controlled power converters," IEEE Trans. Power Electron., vol. 21, no. 1, pp. 182–192, Jan.2006
[10] Q. Valter, Pulse Width Modulated (PWM) Power Supplies. New York:Elsevier, 1993