e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

DC – DC BUCK CONVERTER FOR BATTERY ELECTRIC VEHICLE IN SIMSCAPE

Naveenkumar K*1, Barath R*2, Dinesh Kumar A*3, Jason Prasad W*4

*1,2,3,4Pre-Final Year Students, Department Of Electrical And Electronics Engineering, Sri Ramakrishna Engineering College, Coimbatore, Tamil Nadu, India.

DOI: https://www.doi.org/10.56726/IRJMETS63600

ABSTRACT

This paper presents the modeling and simulation of a DC-DC Buck Converter using MATLAB Simscape, aimed at achieving efficient voltage step-down conversion for various power electronics applications. The Buck Converter, widely employed in power supplies, provides a stable output voltage by converting a higher DC input voltage to a lower one with minimal losses. Using Simscape, an environment that allows for physical modeling of electrical systems, the paper demonstrates the design of the converter circuit, including key components such as the inductor, capacitor, switch, and diode, along with the control strategy for regulating the output voltage.

The converter's performance is evaluated under varying load and input conditions, focusing on critical parameters such as output voltage ripple, efficiency, and transient response. The simulation utilizes Pulse Width Modulation (PWM) control for regulating the switch operation, ensuring output stability despite load fluctuations. The paper also explores the impact of component selection and system parameters on the overall performance. The results from the Simscape model are compared with theoretical calculations to verify the accuracy of the simulation and demonstrate the converter's reliability. This work highlights the effectiveness of using Simscape for rapid prototyping and performance evaluation in the design and optimization of DC-DC converters for a wide range of power electronics applications.

Keywords: DC-DC Buck Converter, Simscape, PWM Control, Voltage Regulation, Efficiency, Power Electronics, Simulation, Transient Response, Load Regulation, Voltage Ripple.

I. INTRODUCTION

A DC-DC Buck Converter is a widely used power electronic device that efficiently steps down a higher input DC voltage to a lower output voltage. It is essential in applications such as power supplies for electronic circuits, battery charging, and renewable energy systems, where stable voltage regulation is crucial. The primary advantage of a Buck Converter lies in its ability to maintain high efficiency by minimizing power losses, which is achieved through the use of energy-storing components like inductors and capacitors, along with an active switching element (usually a transistor) controlled by Pulse Width Modulation (PWM). Modeling and simulation of such converters are key to optimizing their design, ensuring that they operate within desired parameters under various load and input conditions. MATLAB Simscape provides an intuitive environment for simulating power electronic systems using a physical modeling approach, which simplifies the design process and offers insights into system behavior. This tool allows for the accurate modeling of both the electrical and mechanical components, providing a comprehensive platform for analyzing critical performance metrics such as efficiency, transient response, and voltage regulation. This paper explores the design and simulation of a DC-DC Buck Converter in Simscape, focusing on performance evaluation and optimization for practical applications.

II. METHODOLOGY

The methodology for modeling and simulating a DC-DC Buck Converter in Simscape follows a systematic approach, combining theoretical design with practical simulation to evaluate the converter's performance under various conditions. The process is broken down into the following steps:

1. CIRCUIT DESIGN AND COMPONENT SELECTION

The first step involves designing the basic Buck Converter circuit. The key components include:

- **Switch (Transistor)**: Typically, a MOSFET is used to control the on/off switching of the converter.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

- **Inductor (L)**: Used to store energy during the ON phase of the switch.
- **Capacitor (C)**: Filters out voltage ripple and smooths the output.
- **Diode (D)**: Ensures current continuity during the OFF phase of the switch.
- **Load (R)**: Represents the consumer of the converted DC voltage.

These components are chosen based on the required input and output voltage, current ratings, and operating frequency.

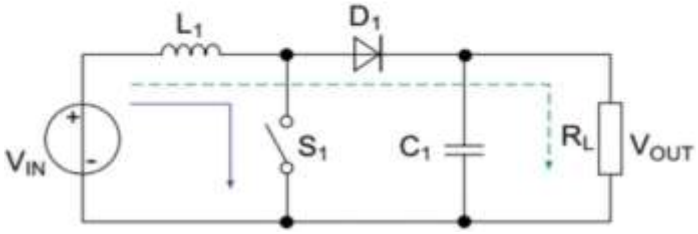

Figure 1: Diagram.

2. MODELING THE CONVERTER IN SIMSCAPE

In Simscape, the circuit is built using pre-built blocks representing the physical components:

- **Inductors** and **capacitors** are modeled as electrical components.
- The **MOSFET** is controlled by a PWM signal, which is generated using a Pulse Generator or a controller block.
- A **diode** block is used to represent the flyback diode in the converter.
- **Voltage sources** are used to supply the input, and the **load** is simulated by a resistive element.

Simscape allows for the detailed representation of these components and the connections between them.

3. CONTROL STRATEGY (PWM CONTROL)

The output voltage regulation is achieved through Pulse Width Modulation (PWM)**,** which adjusts the duty cycle of the MOSFET's switching operation. A feedback loop (e.g., a Proportional-Integral-Derivative (PID) controller or a simple comparator) is used to compare the actual output voltage to the reference voltage. The error is used to modulate the duty cycle, ensuring that the output voltage remains constant despite changes in input or load conditions.

- The PWM signal is generated in Simscape using a PWM generator block**.**
- The switching frequency is selected based on the desired trade-off between efficiency and ripple.

4. PERFORMANCE METRICS AND ANALYSIS

Key performance metrics are analyzed to evaluate the converter's behavior:

- **Output Voltage Ripple**: This is measured to evaluate the smoothness of the output voltage.
- **Efficiency**: The efficiency of the converter is calculated by comparing the output power to the input power.
- **Transient Response**: The response of the output voltage to sudden changes in load or input voltage is analyzed.
- **Duty Cycle**: The variation in duty cycle is monitored to understand the switching behavior under different load conditions.

5. OPTIMIZATION AND TUNING

Based on the simulation results, the system is optimized by adjusting key parameters such as the switching frequency, control loop gains, and component values (inductance, capacitance, etc.). The goal is to achieve the desired output voltage regulation while maximizing efficiency and minimizing ripple.

III. MODELING AND ANALYSIS

This is a DC-DC boost converter circuit, which steps up a lower DC input voltage to a higher DC output voltage. Here is a breakdown of the components, their specifications, and the theoretical background of the circuit operation.

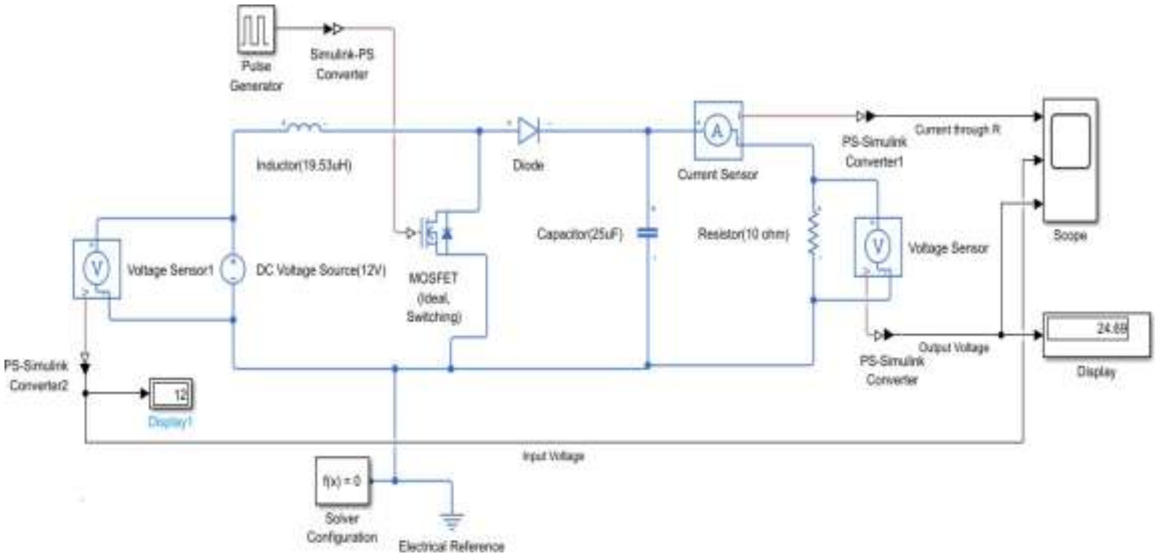

Figure 2: Boost Converter.

COMPONENTS AND SPECIFICATIONS

1. **DC Voltage Source (Input)**:
- Input Voltage: 12V DC
- This is the low-voltage source that the boost converter will step up.
2. **Inductor (19.53 µH)**:
- An inductor stores energy when current flows through it and releases it when the current path is interrupted.
- Inductance value: 19.53 µH.
3. **MOSFET (Ideal, Switching)**:
- Acts as a switch to periodically connect and disconnect the inductor from the input voltage.
- When the MOSFET is ON, the inductor stores energy; when it is OFF, the stored energy is released to the load through the diode and capacitor.
4. **Diode**:
- Allows current to flow in only one direction, from the inductor to the capacitor and load, preventing backflow of current to the MOSFET.
- This ensures that the stored energy in the inductor is directed to the output.
5. **Capacitor (25 µF)**:
- Smooths the output voltage by filtering the ripples created by the switching action.
- Capacitance value: 25 µF.
6. **Resistor (Load)**:
- Resistance value: 10 Ω.
- Acts as the load for the boost converter.
7. **Pulse Generator**:
- Generates a PWM signal to control the MOSFET switching.
- Controls the duty cycle (D) of the MOSFET, which determines the output voltage.
8. **Voltage and Current Sensors**:
- Used to monitor the input and output voltages, and the current through the resistor (load).

Circuit Operation

The boost converter works in two main phases: the ON phase (MOSFET conducting) and the OFF phase (MOSFET not conducting).

1. **ON Phase (MOSFET is ON)**:

- The MOSFET is turned on by the PWM signal.
- The input voltage source supplies current to the inductor, which stores energy as a magnetic field.
- During this phase, the diode is reverse-biased and does not conduct, so the capacitor supplies the load.

2. **OFF Phase (MOSFET is OFF)**:

- The MOSFET is turned off, interrupting the current flow through the inductor.
- The inductor, now discharging its stored energy, reverses its polarity and pushes current through the diode to the capacitor and the load.
- The energy stored in the inductor, along with the input voltage, charges the capacitor to a higher voltage.

DERIVATION

The boost converter's output voltage V_{out} depends on the input voltage V_{in} and the duty cycle D of the PWM signal controlling the MOSFET.

Voltage Boost Equation

For a boost converter, the output voltage V_{out} is given by:

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

where:

- V_{in} is the input voltage.
- D is the duty cycle, which is the fraction of the time the MOSFET is ON in each cycle.

Explanation of Duty Cycle

- The duty cycle D ranges from 0 to 1.
- If D is close to 0, $V_{\text{out}} \approx V_{\text{in}}$.
- As D approaches 1, V_{out} increases significantly.

Example Calculation

Given:

- $V_{\text{in}} = 12$ V,
- Duty cycle $D \approx 0.5$.

Then:

$$V_{\text{out}} = \frac{12}{1 - 0.5} = \frac{12}{0.5} = 24 \text{ V}$$

This matches the displayed output voltage of 24.69 V in the simulation.

Design Considerations:

1. **Inductor Selection**:

- The inductance value affects the ripple current and should be chosen based on desired ripple and switching frequency.

2. **Capacitor Selection**:

- A larger capacitance reduces the output voltage ripple, but it also increases the response time.

3. **Duty Cycle Control**:

- The duty cycle needs to be carefully controlled through the PWM signal to maintain a stable output voltage.

4. **Diode Selection**:

- The diode should have a fast recovery time and a voltage rating higher than the output voltage to prevent reverse breakdown.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

5. Switching Frequency:

- A higher switching frequency reduces the inductor and capacitor size but increases switching losses.

This circuit, as shown, is a straightforward boost converter design suitable for stepping up a 12V input to approximately 24V, depending on the duty cycle of the MOSFET switching signal.

IV. RESULTS AND DISCUSSION

The graphs represent the performance of the DC-DC boost converter over time, showing the current through the load resistor RRR, the input voltage, and the output voltage. Let's analyze each graph in detail:

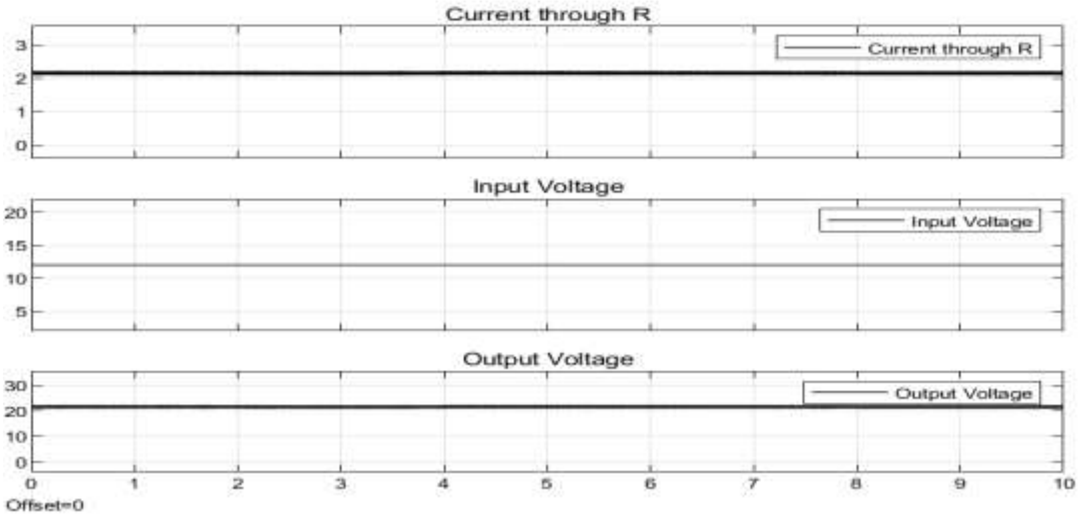

Figure 3: Output Waveform

1. Current through R

- **Graph Description**: The top plot shows the current through the resistor (load) over time. It appears steady at around 2.4 A.
- **Explanation**:
  - In a steady-state DC-DC boost converter, the current through the load should remain relatively constant if the load resistance and input conditions do not change.
  - The steady current indicates that the converter is operating in continuous conduction mode (CCM), where the inductor current never falls to zero. This is expected for a properly designed boost converter under a constant load.

Derivation for Load Current:

The load current I_{load} can be derived from Ohm's Law:

$$I_{\text{load}} = \frac{V_{\text{out}}}{R}$$

Given:

- $V_{\text{out}} \approx 24$ V (from the output voltage graph).
- $R = 10\,\Omega$.

Then:

$$I_{\text{load}} = \frac{24}{10} = 2.4\text{ A}$$

This matches the observed steady current in the graph.

2. Input Voltage

- **Graph Description**: The middle plot shows the input voltage, which remains steady at around 12 V.
- **Explanation**:
  - The input voltage being steady is expected, as the input DC source (12 V) is designed to remain constant.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

- The stability of the input voltage indicates that the power source is not being significantly affected by the converter operation.

3. Output Voltage

- **Graph Description**: The bottom plot shows the output voltage, which remains steady around 24 V with minor ripple.
- **Explanation**:
  - The boost converter steps up the input voltage from 12 V to approximately 24 V, as expected from the converter's duty cycle setting.
  - The minor ripple in the output voltage is due to the switching nature of the boost converter. The capacitor smooth's out most of this ripple, but a small fluctuation is typical.

Derivation for Output Voltage:

The output voltage V_{out} of a boost converter can be derived using the formula:

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

where:

- $V_{\text{in}} = 12\,\text{V}$,
- D is the duty cycle of the PWM controlling the MOSFET.

Assuming the duty cycle $D \approx 0.5$ (50%), the output voltage calculation is:

$$V_{\text{out}} = \frac{12}{1 - 0.5} = \frac{12}{0.5} = 24\,\text{V}$$

This matches the observed output voltage in the graph.

Summary of Analysis:

- **Current through R**: Steady at around 2.4 A, consistent with a 24 V output and a 10 Ω load.
- **Input Voltage**: Steady at 12 V, which matches the input source setting.
- **Output Voltage**: Steady around 24 V, indicating effective boosting by the converter with minor ripple, which is typical due to switching.

Derivation for Output Voltage:

The output voltage V_{out} of a boost converter can be derived using the formula:

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

where:

- $V_{\text{in}} = 12\,\text{V}$,
- D is the duty cycle of the PWM controlling the MOSFET.

Assuming the duty cycle $D \approx 0.5$ (50%), the output voltage calculation is:

$$V_{\text{out}} = \frac{12}{1 - 0.5} = \frac{12}{0.5} = 24\,\text{V}$$

This matches the observed output voltage in the graph.

V. CONCLUSION

In conclusion, the DC-DC boost converter simulation using Simscape demonstrates a reliable and efficient method for stepping up a lower DC input voltage to a higher DC output voltage. In this simulation, a 12 V input voltage is successfully boosted to approximately 24 V, doubling the initial voltage while maintaining stable output characteristics. Key components like the inductor, MOSFET switch, diode, and capacitor work together in a two-phase process: when the MOSFET is ON, the inductor stores energy from the input, and when the MOSFET is OFF, this stored energy is released through the diode to the output, raising the voltage across the load. The steady-state waveforms in the simulation show a stable output voltage with minimal ripple, indicating efficient energy transfer and good filtering by the capacitor. The current through the load resistor remains stable, which confirms the converter's operation in continuous conduction mode (CCM) under the given load conditions. The consistent input voltage and steady output highlight the boost converter's effectiveness in maintaining output stability despite switching dynamics. By adjusting parameters like the duty cycle of the PWM signal controlling the MOSFET, this design can achieve various output voltages as required by different applications. Overall, this simulation in Simscape provides a clear and insightful visualization of the boost converter's operation, illustrating how it can be applied in real-world power electronics systems that require a step-up in DC voltage, such as battery-powered devices, renewable energy systems, and electric vehicles.

VI. REFERENCES

[1] S. N. Soheli, G. Sarowar, M. A. Hoque and M. S. Hasan, "Design and Analysis of a DC -DC Buck Boost Converter to Achieve High Efficiency and Low Voltage Gain by using Buck Boost Topology into Buck Topology," 2018 International Conference on Advancement in Electrical and Electronic Engineering (ICAEEE), Gazipur, Bangladesh, 2018, pp. 1-4, doi: 10.1109/ICAEEE.2018.8643001.

[2] Lalmalsawmi and P. K. Biswas, "Full-Bridge DC-DC Converter and Boost DC-DC Converter with Resonant Circuit For Plug-in Hybrid Electric Vehicles," 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), Hyderabad, India, 2022, pp. 1-6, doi: 10.1109/ICICCSP53532.2022.9862426.

[3] J. -Y. Lee and J. -H. Jung, "Multi-port DC-DC Converter for Interconnecting Bipolar DC Buses of Bipolar DC Distribution System," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), Vancouver, BC, Canada, 2021, pp. 1191-1196, doi: 10.1109/ECCE47101.2021.9595214.

[4] G. P. Adam, F. Alsokhiry, Y. Al-Turki, M. O. Ajangnay and A. Y. Amogpai, "DC-DC Converters for Medium and High Voltage Applications," IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 2019, pp. 3337-3342, doi: 10.1109/IECON.2019.8926872.

[5] M. D. Bagewadi and S. S. Dambhare, "A Buck-Boost topology based hybrid converter for standalone nanogrid applications," 2017 IEEE Second International Conference on DC Microgrids (ICDCM), Nuremburg, Germany, 2017, pp. 502-506, doi: 10.1109/ICDCM.2017.8001093.

[6] H. Y. Kanaan and K. Al-Haddad, "Modeling and Simulation of DC-DC Power Converters in CCM and DCM Using the Switching Functions Approach: Application to the Buck and C ù k Converters," 2005 International Conference on Power Electronics and Drives Systems, Kuala Lumpur, Malaysia, 2005, pp. 468-473, doi: 10.1109/PEDS.2005.1619732.

[7] B. V. Anuraag, R. Mahalakshmi, S. Likhtih, P. Bhargavi and A. Mohanty, "Design and Comparative Study of DC-DC Quadratic Buck-Boost Converter and Cascaded Buck-Boost Converter," 2021 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT), Bangalore, India, 2021, pp. 642-646, doi: 10.1109/RTEICT52294.2021.9573716.

[8] K. Bendaoud, J. Laassiri, S. -d. Krit and L. El Maimouni, "Design and simulation DC-DC power converters buck and boost for mobile applications using Matlab/Simulink," 2016 International Conference on Engineering & MIS (ICEMIS), Agadir, Morocco, 2016, pp. 1-6, doi: 10.1109/ICEMIS.2016.7745361.

[9] F. Ahmeti, S. Osmanaj and D. Arnaudov, "Comparative Analysis and Optimization Parallel Operation Strategies in DC-DC Converters for Smart DC Grid Integration," 2024 International Conference on Renewable Energies and Smart Technologies (REST), Prishtina, Kosovo (UNMIK), 2024, pp. 1-5, doi: 10.1109/REST59987.2024.10645476.

[10] G. R. Broday, C. B. Nascimento, L. A. C. Lopes and E. Agostini, "Analysis and simulation of a buck-boost operation in a bidirectional ZVS DC-DC converter," 2016 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC), Toulouse, France, 2016, pp. 1-7, doi: 10.1109/ESARS-ITEC.2016.7841431.