

# Design of a DC-DC Buck Converter with Closed-Loop Control for Low-Power Applications

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**Abstract-** This paper presents the design and implementation of DC-DC buck converter using a digital PI control technique. The system converts a 24V DC input into a regulated 12V DC output. A microcontroller is used to implement closed-loop control and generate PWM signals. The controller continuously monitors the output voltage and adjusts the duty cycle to maintain stable output under different load conditions. The converter achieves an efficiency of around 90% with good voltage regulation. The results show that the proposed system is suitable for low-power embedded applications.

**Keywords-** Buck Converter, PI Control, PWM, DC-DC Converter.

## I. INTRODUCTION

Modern electronic systems depend heavily on efficient and stable power supply units. Applications such as embedded systems, communication devices, battery-powered electronics, and electric vehicles require regulated DC voltage for proper operation. However, these systems often operate at different voltage levels, which makes DC-DC conversion an essential part of power electronics. Among various DC-DC converters, the buck converter is widely used for step-down voltage conversion due to its simple structure, low cost, and high efficiency. It is commonly found in power supplies, chargers, and embedded applications where a stable output voltage is required. Compared to linear regulators, buck converters offer significantly higher efficiency because they use switching techniques instead of dissipating excess energy as heat.

Despite these advantages, maintaining a constant output voltage in practical conditions is not straightforward. Variations in input voltage, load changes, and switching disturbances can affect the output, leading to instability and reduced performance. Therefore, control strategies are necessary to regulate the output and ensure reliable operation. Closed-loop control is commonly used to address these issues. In this approach, the output voltage is continuously monitored and compared with a reference value. Any difference between the two is corrected by adjusting the duty cycle of the switching signal. Among different control methods, the Proportional-Integral (PI) controller is widely preferred because of its simple implementation and ability to reduce steady-state error while

maintaining system stability. With the advancement of digital electronics, microcontroller-based control methods have become popular in power converter applications. Devices such as the microcontroller provide high processing speed, built-in peripherals, and flexibility, making them suitable for real-time control. Digital control allows easy tuning of parameters, integration of protection features, and improved system reliability compared to traditional analog control methods. In this work, a DC-DC buck converter with closed-loop PI control is designed and implemented using a microcontroller. The objective is to achieve stable output voltage, good efficiency, and reliable performance under varying operating conditions. The proposed system demonstrates that a simple digital control approach can provide effective regulation for low-power applications.

## II. DC-DC BUCK CONVERTER WITH DIGITAL PI CONTROL

### A. What is a DC-DC Buck Converter?

A DC-DC buck converter is a power electronic circuit used to convert a higher DC voltage into a lower DC voltage efficiently. It is widely used in regulated power supplies and embedded systems due to its simple structure and reliable operation.

The main components of a buck converter include a switching device (MOSFET), a diode, an inductor, and a capacitor. The operation is based on high-frequency switching. When the switch is turned ON, current flows through the inductor and

energy is stored in the form of a magnetic field. When the switch is turned OFF, the inductor releases the stored energy to the load through the diode, maintaining a continuous current flow.

The output voltage is controlled by adjusting the duty cycle of the switching signal. By varying the duty cycle, the average output voltage can be regulated to the desired level. The capacitor helps in smoothing the output voltage and reducing ripple, ensuring stable performance.

### B. Closed-Loop PI Control

In practical applications, the output voltage of a converter may vary due to changes in input voltage and load conditions. Open-loop systems cannot correct these variations, which can result in unstable output.

To overcome this, a closed-loop control system is used. In this method, the output voltage is continuously measured and compared with a reference value. The difference between these two values is called the error signal.

A PI (Proportional-Integral) controller processes this error signal and adjusts the duty cycle of the switching signal. The proportional part provides a quick response to changes, while the integral part eliminates steady-state error over time. This combination ensures that the output voltage remains stable and close to the desired value even under varying conditions.

### C. Digital Control using Microcontroller

The control of the converter is implemented using a microcontroller, which acts as the central control unit. The microcontroller continuously monitors the output voltage using an Analog-to-Digital Converter (ADC).

The measured voltage is compared with the reference value, and the error is calculated. This error is processed using the PI control algorithm programmed in the controller. Based on the result, the controller generates a Pulse Width Modulation (PWM) signal to control the switching device.

#### The use of a microcontroller provides several advantages:

- Easy implementation of control algorithms
- Fast response to changes
- Flexibility to modify parameters through software
- Integration of sensing and control in a single system

This makes the system more reliable and adaptable for different operating conditions.

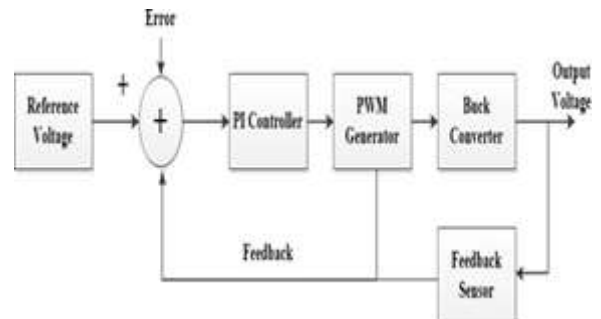


Fig-1: Block Diagram

## III. SYSTEM OVERVIEW

The overall system consists of a DC input source, a buck converter circuit, a microcontroller-based control unit, and sensing components.

The output voltage is continuously monitored and fed back to the controller. The controller processes this feedback and adjusts the duty cycle of the PWM signal accordingly. This closed-loop operation ensures that the output voltage remains stable even when there are variations in input or load. The system is designed to operate efficiently while maintaining proper voltage regulation.

## IV. MATHEMATICAL EQUATIONS

The operation of the buck converter can be understood using simple equations.

The output voltage is related to the duty cycle as:

$$V_{out} = D \times V_{in}$$

where D is the duty cycle.

The efficiency of the converter is given by:

Efficiency = Output Power / Input Power These equations help in understanding the basic behavior of the converter without going into complex analysis.

## V. RESULTS

The converter is tested under different operating conditions to evaluate its performance.

### Voltage Regulation

The system converts a 24V input to a regulated output of approximately 12V. The output voltage remains stable with minimal variation, indicating proper functioning of the control system.

### Duty Cycle Variation

By varying the duty cycle, the output voltage changes accordingly:

- Around 50% duty cycle gives ~12V output
- Lower duty cycle reduces output voltage
- Higher duty cycle increases output voltage This confirms correct operation of the buck converter.

### Efficiency

The measured efficiency of the converter lies in the range of 90%, which is acceptable for low-power applications.

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## VII. COMPARISION

Table 1: Comparative Summary

Parameter	Conventional Method	Proposed System
Control Technique	Open-loop / Analog	Closed-loop Digital PI
Steady-State Error	Present	Very Low
Efficiency	Moderate	High
Implementation	Complex	Microcontroller based
Reliability	Moderate	Improved

## VIII. CONCLUSION

A DC-DC buck converter with closed-loop PI control has been designed and tested. The system successfully provides a regulated output voltage with good efficiency.

The results show that the use of a microcontroller-based control system improves stability, flexibility, and performance. The converter operates reliably under different conditions and can be used in low-power applications.

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