Abstract

In this project AC-DC converter has been proposed for the application of speed control of a DC motor. The converter comprises two stages. The first stage is the diode bridge rectifier and the second stage is DC-DC buck converter. The two stages are coupled by a capacitor which also eliminate the ripple present in the output of the rectifier. For DC-DC buck converter, a feedback control system, based on PWM technique, has been designed which regulates its output to control the speed of dc motor. The prototype model has been designed and results obtained with it have a closed resemblance with the simulation results which has been done in LTspice software. The results of the simulation and prototype demonstrate that the output voltage of DC-DC converter and hence the speed of the dc motor can be controlled by controlling the duty cycle of DC-DC converter. The results also demonstrate the faster dynamic response of the converters.

Index Terms—AC-DC Converter, continuous conduction, dc-dc converter, feedback control, pulse width modulation (PWM).

INDEX

Project Report: AC-DC Converter for Speed Control of a DC Motor

Introduction

The objective of this project is to design and implement an AC-DC converter for the speed control of a DC motor. The system consists of two stages: the AC-DC rectification stage and the DC-DC buck converter stage, regulated by a feedback control system based on pulsewidth modulation (PWM). A driver circuit using bipolar junction transistors (BJTs) controls the MOSFET switch in the buck converter, enabling efficient motor speed regulation. This project builds on the design presented in the paper by Anupam Dixit and Bryce Hillam, with practical implementation and simulation using LTspice.

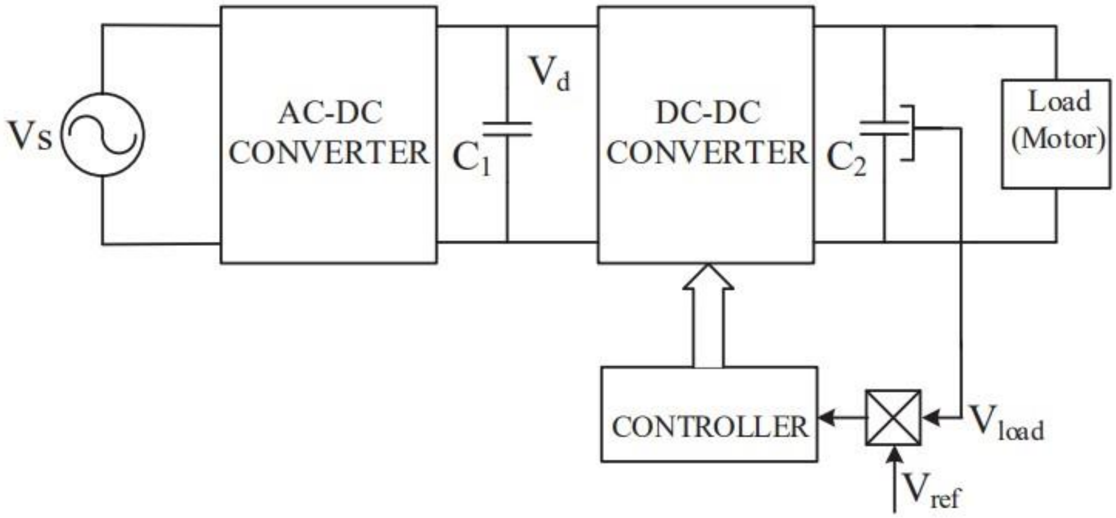
1.1 Background

AC to DC conversion systems are commonly used in applications where DC motors are employed, as they require controlled DC power for precise operation. A well-regulated power supply is crucial for accurate speed control of DC motors, and feedback control systems play a significant role in maintaining this regulation under varying load and input conditions.

1.2 Objective

The goal is to regulate the speed of a DC motor by controlling the output voltage of a DC-DC buck converter using a feedback control system. This control is achieved by adjusting the duty cycle of the converter's switching element (MOSFET), allowing precise speed adjustments.

Block Diagram

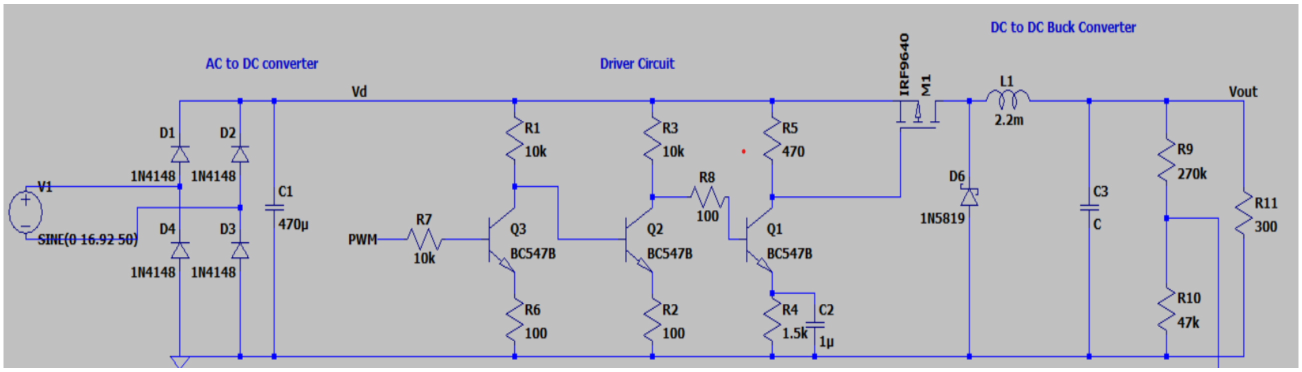


Block Diagram

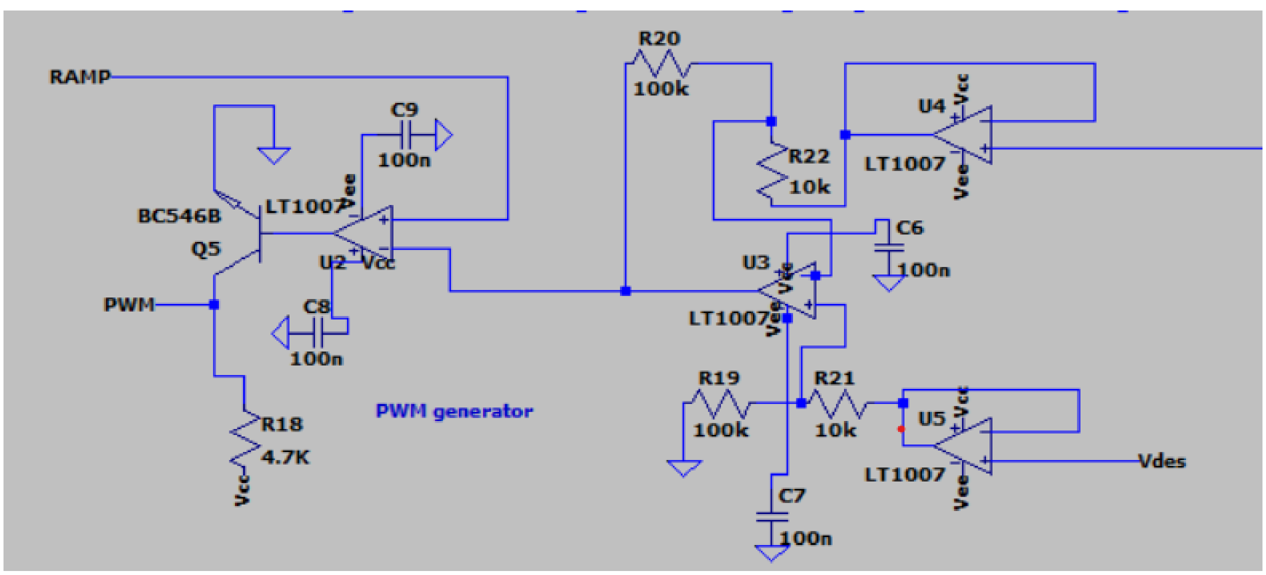
The block diagram consists of:

1. AC-DC Converter: A full-bridge rectifier converts AC to DC.
2. DC-DC Buck Converter: This reduces and regulates the rectified voltage.
3. Driver Circuit: BJT-based driver circuitry ensures efficient control of the MOSFET switch.
4. Feedback Controller: A PWM-based feedback system adjusts the duty cycle based on the reference voltage.

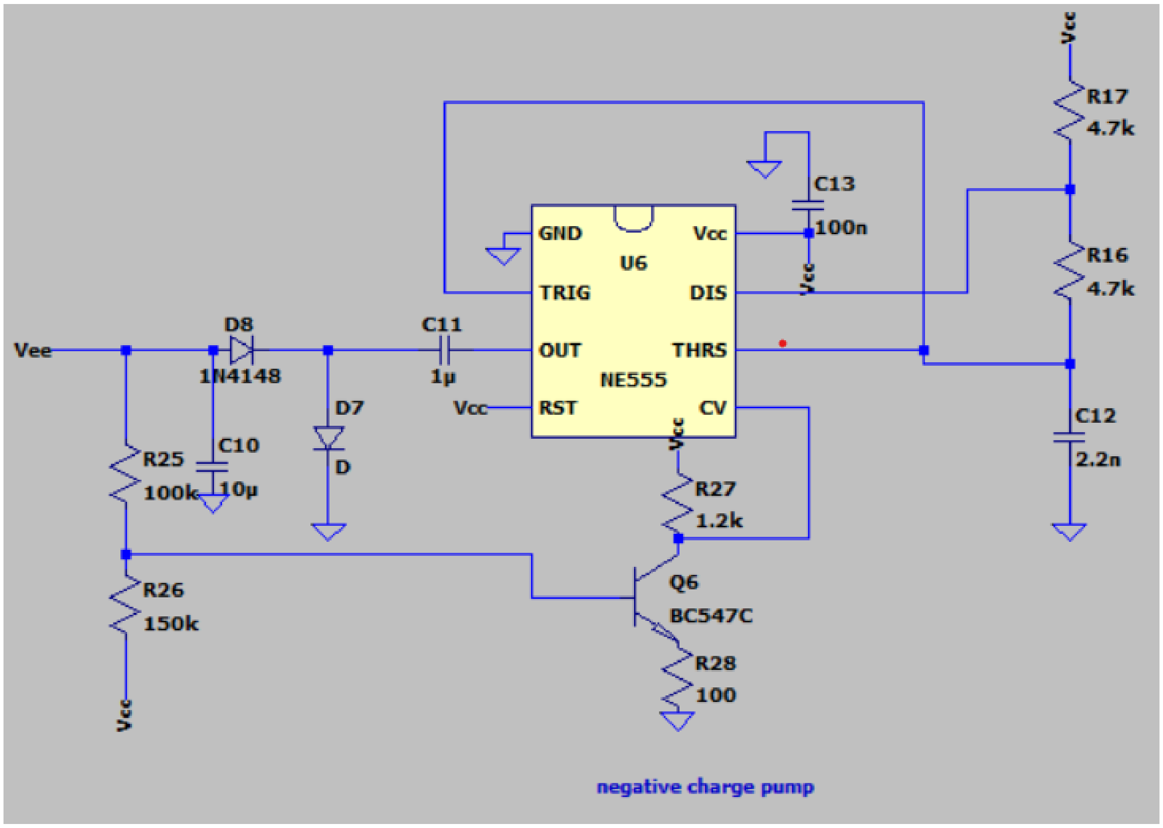
Circuit Diagram



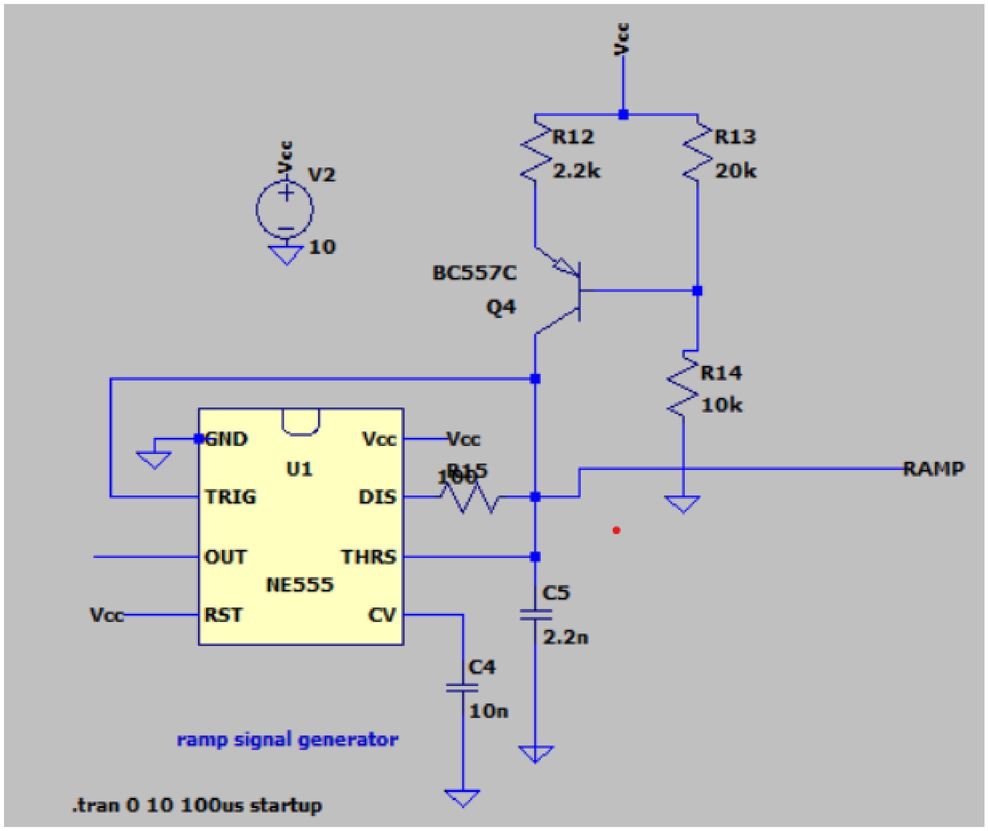
Buck Converter



PWM Generator



Negative Charge Pump



1Ramp Generator

Component Description

- LM317: Used to provide Vcc supply to the voltage comparator.
- LT072: Used as a voltage comparator in the feedback system.
- NE555: Utilized in both the charge pump and ramp signal generator circuits.
- MOSFET (M1): Switch in the buck converter.
- Capacitors and Inductors: Used for filtering and smoothing rectified and converter outputs.
- BJT Driver Circuit: Composed of transistors Q1, Q2, and Q3, responsible for driving the MOSFET gate efficiently.

Driver Circuit

The driver circuit, composed of bipolar junction transistors (BJTs), is responsible for controlling the gate of the MOSFET. The configuration uses:

- Q1 and Q2: Act as level shifters, ensuring the correct voltage level to control Q3.
- Q3: Drives the gate of the MOSFET, ensuring that the MOSFET switches between on and off states rapidly, minimizing switching losses. The gate-source voltage (Vgs) of M1 is controlled to stay within the safe limits (below 20V) using a zener diode.

Calculations

1. Inductor Calculation

The inductor value ensures that the converter operates in continuous conduction mode (CCM). At the boundary between continuous and discontinuous conduction modes, the peak current is given by:

$I_{L,peak} = (V_{in} - V_{out}) / L * t_{on}$

For continuous conduction mode, the inductor value L should satisfy:

$L >= (D * T_s) / 2 * (V_{in} - V_{out}) / I_{L,peak}$ Where:

- D = duty cycle
- T_s = switching period - V_{in} = input voltage
- V_{out} = output voltage
- $I_{L,peak}$ = peak inductor current

2. Capacitor Calculation

The capacitor value is determined by the voltage ripple allowed across the capacitor:

$C = I_{in} * \Delta t / \Delta V$ Where:

- I_{in} = input current
- Δt = discharge time (half the period of the input supply)
- ΔV = allowed voltage ripple

Working of Circuit

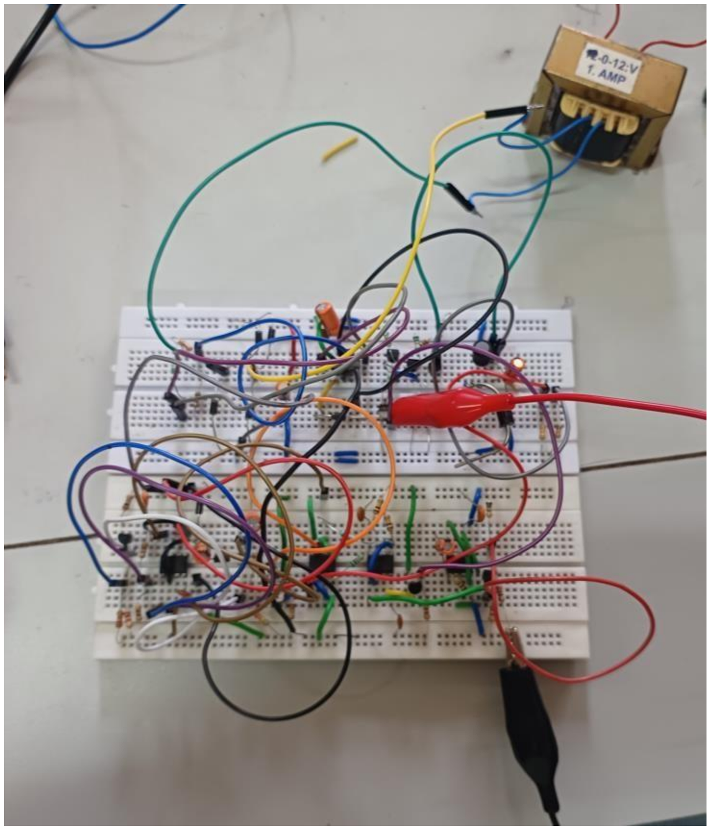
The AC-DC converter follows a two-stage process:

1. Rectification Stage: The AC input is stepped down and rectified by a full-bridge rectifier, generating a DC voltage. A capacitor at the rectifier output reduces ripples.
2. Buck Converter: The buck converter reduces and regulates the voltage based on the PWM feedback. The duty cycle of the PWM signal controls the motor speed by adjusting the voltage supplied to the motor. The driver circuit efficiently controls the switching of the MOSFET to ensure minimal power loss during operation.

Feedback Control System: The error amplifier compares the output voltage to a reference voltage, generating an error signal. This signal is compared with a ramp signal generated by the NE555 timer, creating a PWM signal. The PWM signal regulates the MOSFET's duty cycle and controls the motor speed.

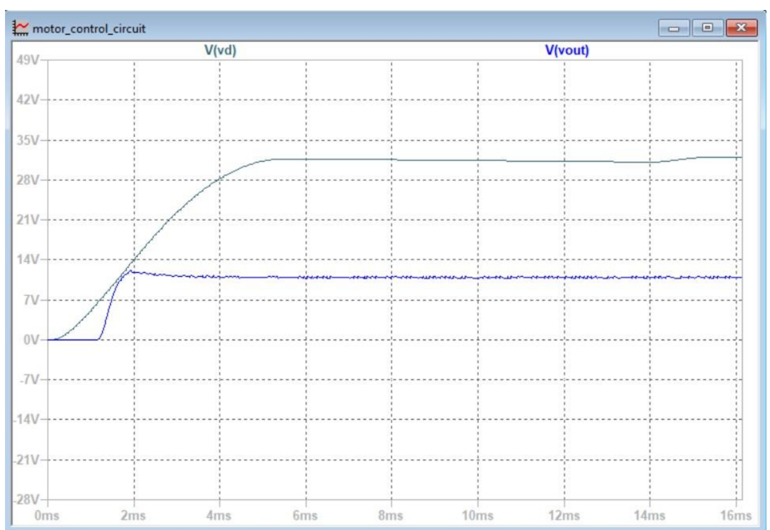
Practical Setup and Troubleshooting

The practical implementation was performed on a breadboard using LM317 for Vcc, LT072 for voltage comparison, and NE555 timers for generating the charge pump and ramp signal. The BJT driver circuit ensured efficient MOSFET control. The setup was tested using a digital storage oscilloscope (DSO) and digital multimeter (DMM). Photos of the test results are included, showing voltage waveforms and PWM signals.

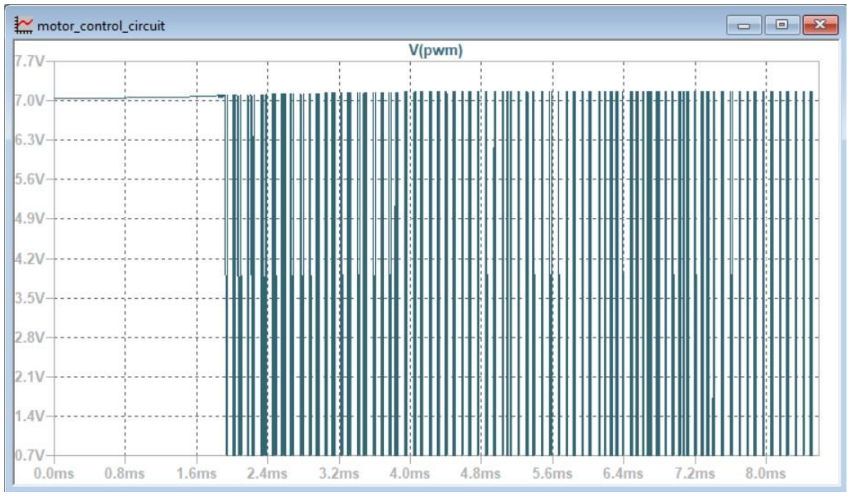


Practical Setup

Simulation Base Results:

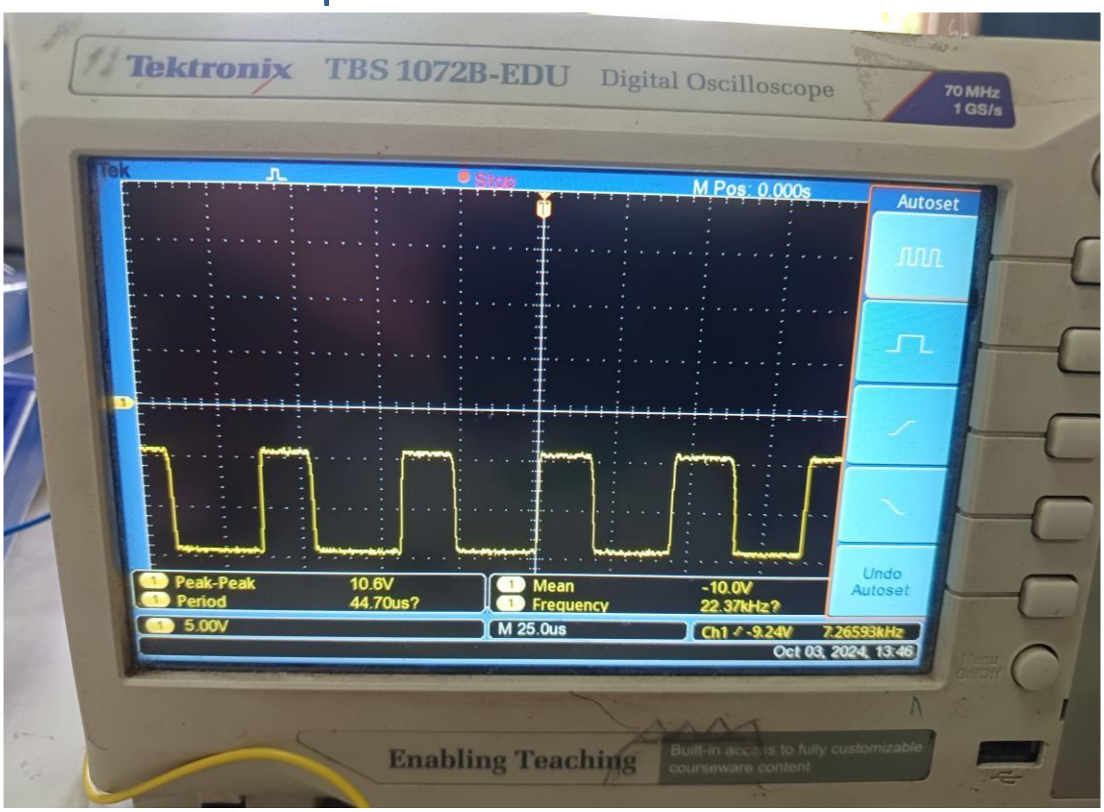


Output Voltage



PWM Generation

Result of Practical Setup:



PWM Generated by Feedback Loop

In the simulation model, an input supply of 33.94V is given to the rectifier. The rectifier output is measured to be 32V dc with very less ripples i.e 680mV because of the filter action. The rectified voltage is given to dc-dc buck converter which, by the controller action, gives the output voltage in the range of 9V to 24V. Also, in the simulation model, instead of motor load, a resistance equivalent to motor load has been used. We observe output voltage which has around 900mV ripple voltage and PWM of 7V peak. Output is very near to expected output.

Limitations of Circuit

- Ripple: The output ripple could not be completely eliminated despite the use of filtering capacitors.
- Response Time: The feedback loop response time is adequate but could be improved with advanced control techniques.

Conclusion

The AC-DC converter successfully regulated the output voltage to control the DC motor speed. The use of a BJT driver circuit for the MOSFET improved efficiency by reducing switching losses. The design demonstrates the ability to accurately control motor speed through a PWM feedback system, with results closely matching the simulations performed in LTspice.

Application and Future Work

The system can be adapted for various motor control applications. Future work could involve improving the feedback system by incorporating adaptive control techniques, or using a more efficient MOSFET driver circuit to further reduce power losses.

References

1. Anupam Dixit, Bryce Hillam, "A Two Stage AC-DC Converter for Speed Control of a DC Motor," The University of Queensland, Australia.
2. Texas Instruments, "Loop stability analysis of voltage mode buck regulator," Application Report SLVA301, 2008.