Design and Simulation of a DC Motor Drive System

Comprehensive Analysis of Rectifiers, H-Bridge Control, and Auxiliary Power Supply

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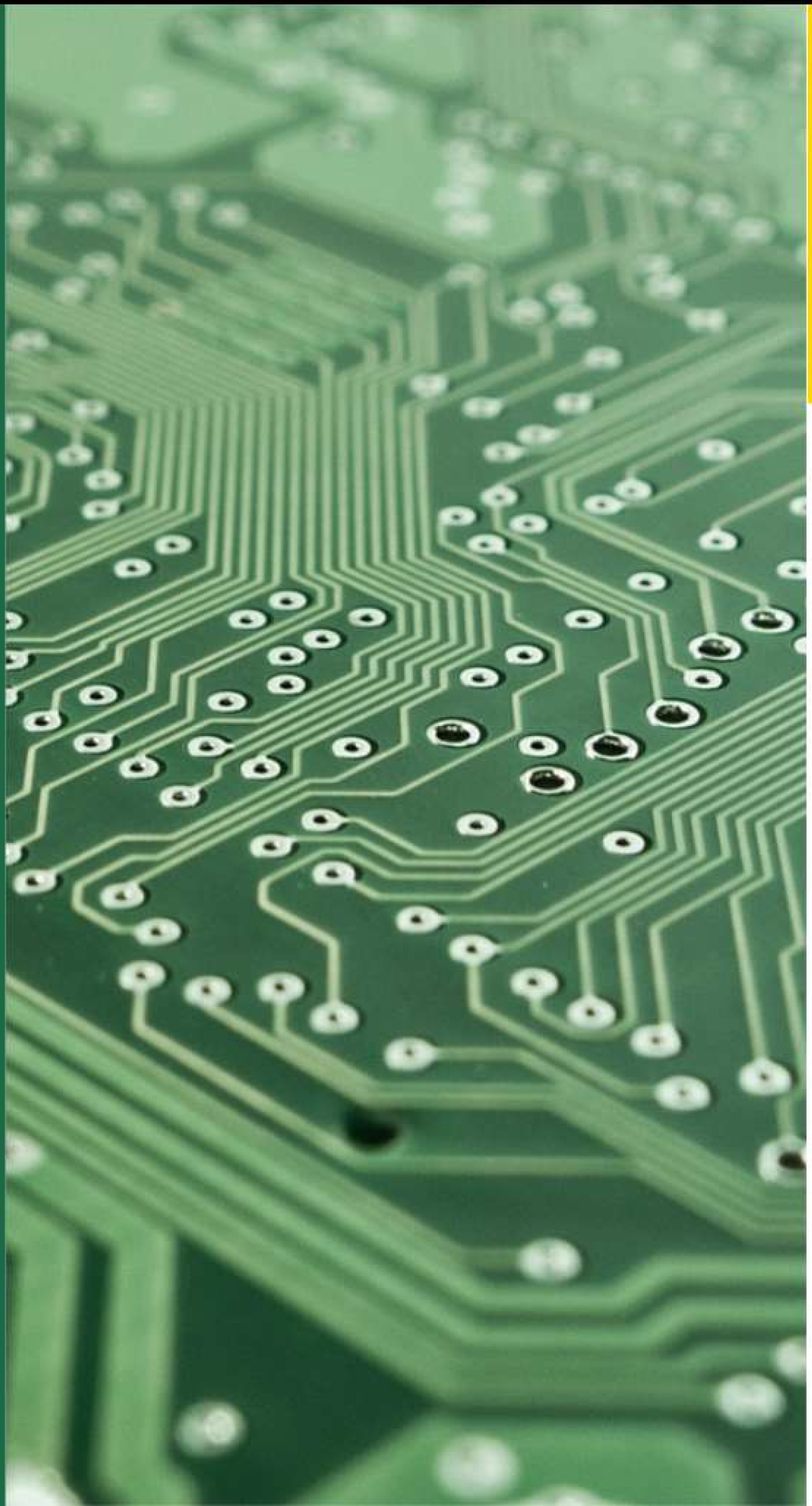


Introduction to DC Motor Drive Project

Project Objective

This project focuses on designing a DC motor starter circuit for a single-phase AC grid with an adjustable DC output voltage up to 180V.

Project Aim

The aim is to develop a hardware solution aligned with the course requirements (EE 463 – Hardware Project).

Implementation Approach

We will implement the design by analyzing topologies, running simulations, and selecting appropriate components, providing a practical approach to power electronics in motor drives.

Topology Selection Overview

01

Full Bridge Rectifier

Full Bridge Rectifier for AC to DC conversion of the 230V/50Hz grid voltage

02

H-Bridge Motor Drive

H-Bridge Motor Drive for controlling the DC motor including bidirectional and braking capabilities

03

Centre-Tap Rectifier

Centre-Tap Rectifier, mainly for the auxiliary power supply to provide low voltage rails

Full Bridge Rectifier: Main Power Stage

Advantages of a Single-Phase Full-Wave Diode Bridge Rectifier

- **Simple, robust design**
- **Output voltage ≈ 0.9 × Vs (230V), sufficient for our motor drive**
- **Uses diodes with lower voltage rating and voltage drop than center-tap alternatives**

Disadvantages of a Single-Phase Full-Wave Diode Bridge Rectifier

- **Higher conduction losses (~1.4V total drop due to diodes in series)**
- **Non-linear loading with current drawn near voltage peaks causes harmonic distortions on AC mains**

H-Bridge DC Motor Drive

1

H-Bridge MOSFET Configuration

The H-Bridge uses four MOSFET switches for full 4-quadrant control

2

Motor Drive Capabilities

Forward and reverse motor drive (motoring quadrants I and III)

3

Braking and Energy Recovery

Dynamic braking and regenerative energy recovery (quadrants II and IV)

4

Advantages of H-Bridge

Controlled braking, bidirectional operation

5

Disadvantages: Complex Gate Driving

Complex gate driving setup with bootstrap circuits for high-side MOSFETs

6

Disadvantages: Safety and Component Count

Shoot-through risk requires dead-time insertion in switching signals

Higher component count compared to simpler buck converters

Centre-Tap Rectifier for Auxiliary Power

Advantages of Centre-Tap Rectifier

- Lower diode drop (0.7V) compared to full bridge (1.4V)
- Fewer diodes needed
- Simplifies buck converter implementation with easily available modules

Disadvantages of Centre-Tap Rectifier

- Inefficient transformer utilization (half-secondary used at a time)
- Transformers heavier and costlier
- Higher reverse voltage stress on diodes compared to bridge rectifier

Gate Driving & Control Strategy

PWM Signal Generation with Dead-Time Insertion

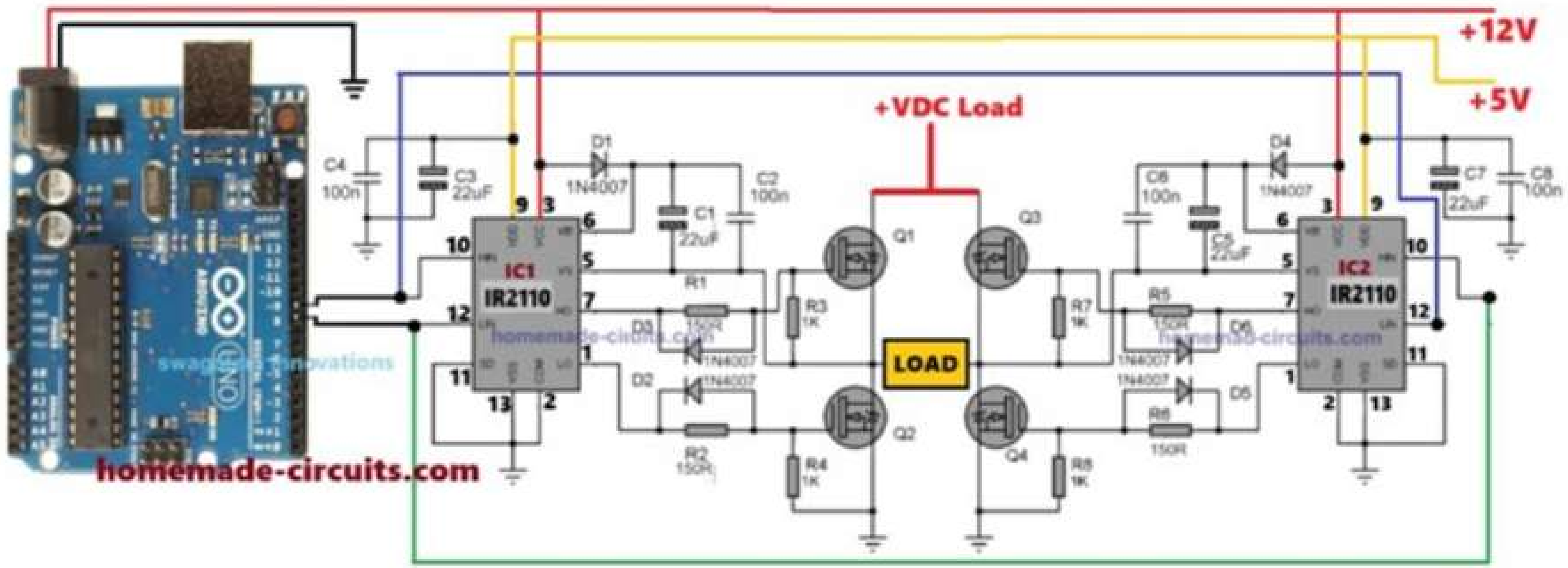
Microcontroller generates complementary PWM signals for H-Bridge switches with dead-time insertion (500ns–1μs) to avoid shoot-through short circuits.

Feedback for Closed-Loop Control

ADC sampling feeds back DC link voltage and motor current signals for closed-loop control implementation.

Bootstrap Gate Driver for High-Side MOSFETs

Bootstrap gate driver is used for N-Channel high-side MOSFETs, enabling gate voltage above DC bus voltage by charging a bootstrap capacitor during low-side conduction.



Simulation Results: Full Bridge Diode Rectifier

01 **Simulation Parameters**

Input: 215V peak, 50Hz single-phase AC

Load: 60Ω, output capacitor 1500μF

Diode forward voltage: 1.1V

Line impedance modeled as 0.1 + j*0.001 Ω

02 **Output Voltage Ripple**

Output voltage ripple ~15V peak (7% of input voltage)

03 **Diode Voltage Waveforms**

Diode voltage waveforms confirm rectification behavior

04 **Diode Current Waveforms**

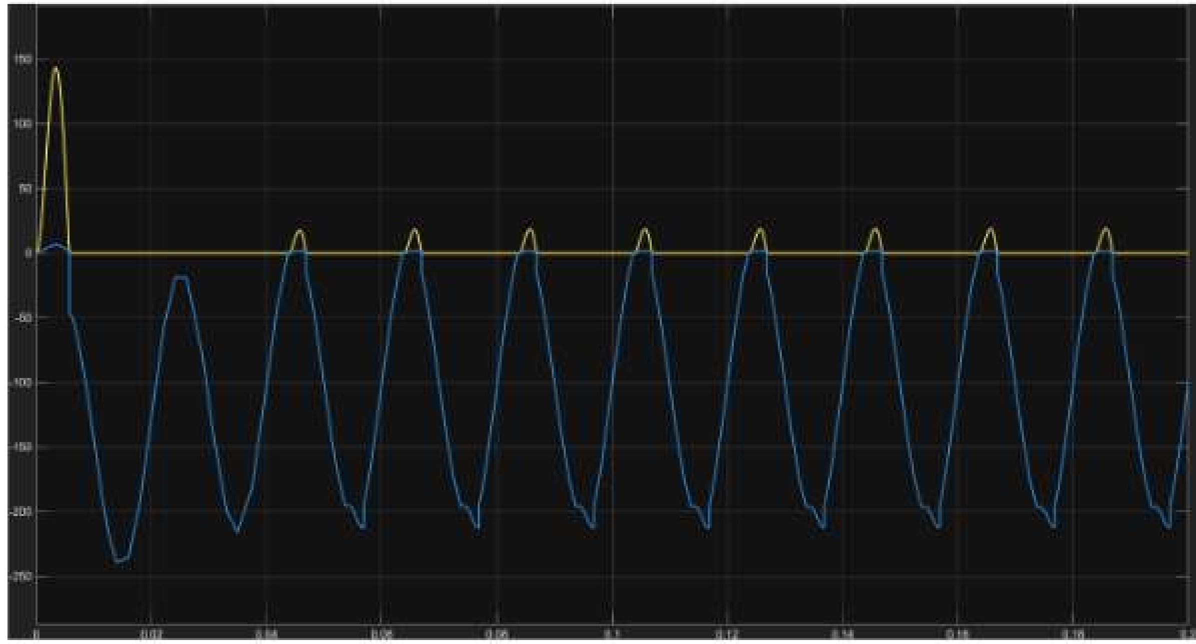
Diode current waveforms confirm rectification behavior

05 **Input Current Waveforms**

Input current waveforms demonstrate conduction paths and ripple reduction

06 **Output Current Waveforms**

Output current waveforms demonstrate conduction paths and ripple reduction



Simulation Results: H-Bridge Motor Drive

H-Bridge Motor Drive Configuration

H-Bridge with four MOSFETs drives the motor using asymmetric unipolar switching (Slow Decay Mode).

Switching States Overview

Switch S4 (Low-Side Right) held ON continuously; S1 (High-Side Left) PWM switched; S2 and S3 kept OFF.

Operation Cycles Description

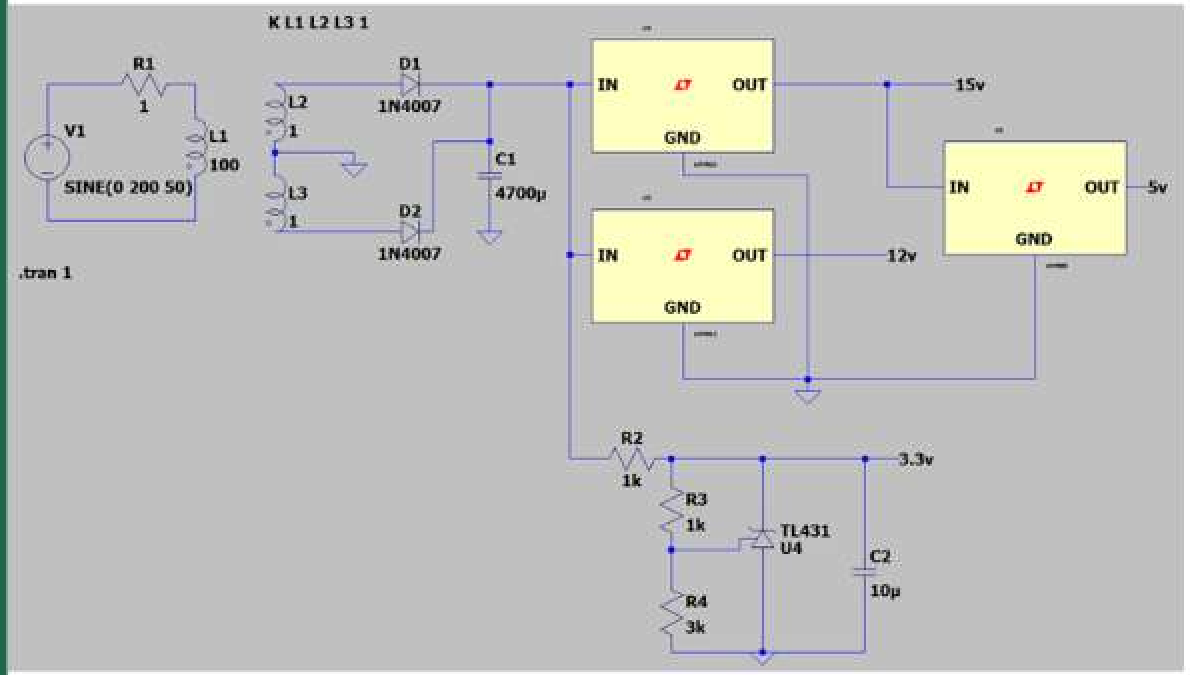
Drive State (S1 and S4 ON): motor sees full DC bus voltage (approx. 200V)

Freewheeling State (S1 OFF, S4 ON): current recirculates via body diodes, maintaining motor current

Performance Waveforms Analysis

Waveforms shown at no load and 20Nm load torque demonstrate current, voltage, and motor speed characteristics.

Simulation Results: Centre-Tap Auxiliary Power Stage



Center-Tap Transformer Configuration

Simulation models a center-tap transformer (3 inductors) providing 2x20V outputs.

Voltage Regulation Cascade

Linear voltage regulators LM7815 and LM7805 cascade the voltages to 15V and 5V rails, respectively.

Precision Reference Voltage

TL431 precision shunt regulator used as reference to generate 3.3V for ADC accuracy and logic compatibility.

Output Stability and Smoothing

Large output capacitor smooths the voltage; regulator outputs show stable voltage levels confirming reliable power supply for control electronics.

Component Selection: H-Bridge MOSFETs

Voltage Requirement for H-Bridge MOSFETs

Voltage rating >400V (DC bus peaks ~325V plus margin)

Current Handling Capability

Continuous current rating >22A to handle motor start-up and load

Gate Charge for Efficient Switching

Low total gate charge (<100nC) for efficient 20kHz switching

Selected Device Overview

Selected device: Panjit PJMP120N60EC

Voltage Rating of Selected MOSFET

Voltage rating: 600V for robust margin

Current Rating and Gate Charge of Selected MOSFET

Current rating: 30A, sufficient for motor transients

Gate charge: 42nC, reducing switching losses and gate driver load

Component Selection: Microcontroller and Gate Driver

Microcontroller: ESP32

- **Features dedicated Motor Control PWM hardware for complementary PWM and dead-time insertion**
- **3.3V logic compatible with precision voltage references**
- **Dual-core 240 MHz for high-frequency control and system management**

Gate Driver: Infineon IR2110

- **Supports floating high-side and low-side driving with up to 500V offset tolerance**
- **Provides peak drive current up to 2A for fast MOSFET switching to minimize losses**
- **Compatible with 3.3V logic inputs, simplifying interface with ESP32**

Auxiliary Power Supply Components

01 Transformer Model and Specifications

Transformer: Aslan ASL130101

Inputs 230V/50Hz

Outputs 2x20V center tapped for isolation and voltage regulation margin

02 Voltage Regulator LM7815

LM7815 provides stable 15V supply for gate drivers

03 Voltage Regulator LM7805

LM7805 steps down 15V to 5V for microcontroller logic

04 Precision Shunt Regulator TL431

TL431 precision shunt regulator generates 3.3V reference for ADC sensors and control signals

05 Purpose of Cascading Regulators

Cascading regulators reduces thermal dissipation, improving reliability.

03 Voltage Outputs from Transformer

Outputs 2x20V center tapped for isolation and voltage regulation margin

Simulation Results: Full Bridge Diode Rectifier — Figures

Figure 1: Full Bridge Diode Rectifier Circuit Schematic

Presented figures demonstrate operation and key waveforms: Figure 1 shows the full bridge diode rectifier circuit schematic.

Figure 2: Diode Voltage and Current Waveforms

Figure 2 illustrates diode voltage and current waveforms showing conduction cycles.

Figure 3: Input Current Waveform

Figure 3 presents the input current waveform illustrating non-linear loading.

Figure 4: Output Current Waveform

Figure 4 depicts the output current waveform showing load current flow.

Figure 5: Output Voltage Waveform

Figure 5 displays the output voltage waveform, showing ripple of approximately 7% peak voltage. These validate the design assumptions and performance expectations for main power stage.

Simulation Results: H-Bridge Motor Drive — Figures

Figure 6: Manual Switch Logic

Manual switch logic for control modes

Figure 7: H-Bridge Circuit Setup

H-Bridge circuit with constant DC supply connection

Figures 8-15: Voltage and Current Waveforms

Voltage and current waveforms for switches and motor at no load and 20Nm load torque

Figures 16-17: Switch S4 Waveforms

Voltage and current waveforms of switch S4 under different load conditions

Figures 18-19: Motor Speed Characteristics

Motor speed characteristics showing response at no load and full load

Practical Insights from Figures

These highlight practical switching dynamics and motor control functionality.