POWER ELECTRONICS · MOTOR-DRIVE DESIGN

Three-Phase IGBT-Controlled Induction Motor Drive

Design, modelling and validation of a Field-Oriented Control (FOC) drive in the MATLAB/Simulink environment.

Power Electronics | IGBT | FOC | SVPWM | PWM | MATLAB/Simulink | Induction Motor

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Technical Project Documentation

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1. Project Summary

Induction motors are indispensable components of many sectors — heavy industry, transport, agriculture and industrial production. This work addresses the design, analysis and validation of a drive circuit that precisely manages the speed, direction and torque of such motors. The system was first modelled in MATLAB/Simulink and optimized by anticipating possible design faults before physical production. Thanks to its Pulse-Width-Modulation (PWM) control and 6-IGBT switching topology, the drive can dynamically control current, frequency and phase order.

Original Contribution
Stable management of high current/voltage parameters with a microprocessor-based architecture
Generation of high-frequency PWM signals for IGBT switching via embedded software
An FOC architecture that lets the induction motor be controlled with the flexibility of a DC motor

2. Aim & Scope

The aim is to design a stable, efficiency-focused induction-motor drive circuit based on the IGBT semiconductor widely used in power electronics. The circuit converts the three-phase mains voltage from AC to DC in the rectifier stage, smooths the DC-bus voltage with a filter stage, and — in the inverter stage — switches the IGBTs with PWM signals from the control unit to produce the variable-amplitude, variable-frequency three-phase voltage the motor needs. Feedback-sensor data at the motor output is relayed to the control layer for closed-loop operation.

3. Theoretical Background — Field-Oriented Control (FOC)

Induction motors are non-linear and hard to control because their torque and flux components are strongly coupled. Traditional scalar (V/f) control is adequate in steady state but falls short under sudden load changes and for precise torque control. FOC separates the stator currents into two independent DC components through mathematical coordinate transforms, allowing the induction motor to be controlled like a DC motor:

- **I_d (flux component):** forms the magnetic field along the d-axis; held constant at the nominal level.
- **I_q (torque component):** directly produces the electromagnetic torque along the q-axis; manipulated independently of the flux.

This decoupling delivers a high-dynamic speed/torque response, minimal settling time, overshoot suppression, robustness against disturbances, and smooth four-quadrant operation.

4. System Architecture

The system has a cascade (double-loop) closed-loop structure that begins at the speed reference and extends to the voltage applied to the motor and the current feedback from the lines. The control chain consists of Clarke → Park → PI → inverse transforms → SVPWM blocks.

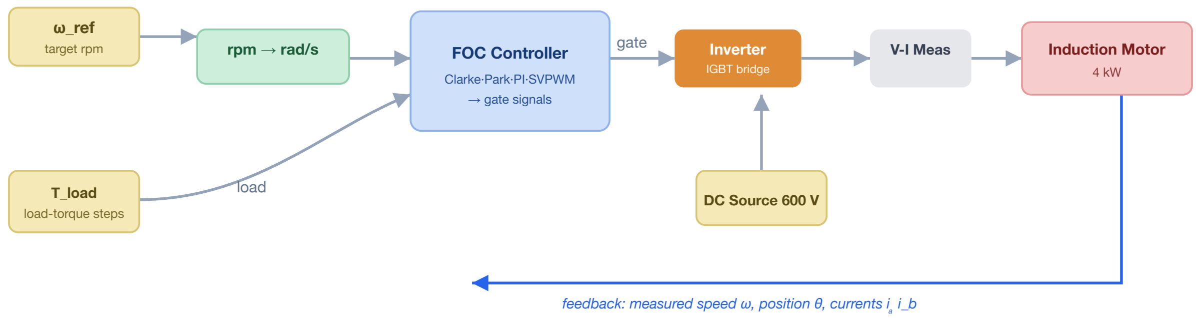

Figure 1. Overview of the FOC induction-motor drive: target speed → FOC controller (Clarke-Park-PI-SVPWM) → IGBT inverter → 4 kW induction motor; the measured values are fed back to the controller.

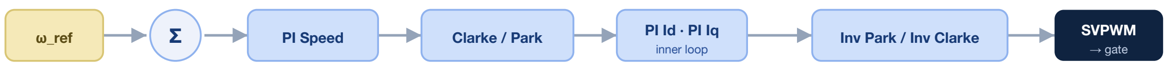

Figure 2. Controller internals (vector-control chain): ω_ref → Σ → PI Speed → Clarke/Park → PI Id and PI Iq → Inverse Park/Inverse Clarke → SVPWM → gate signals.

Subsystem Functions	
Speed reference / Σ (error)	Converts the rpm input to rad/s; compares with the measured speed to produce the error.
Outer PI loop (speed)	5 Hz bandwidth; produces the torque-current reference ($I_{q,ref}$).
Clarke (abc→αβ)	Reduces the three-phase stator currents to a two-axis stationary frame.
Park (αβ→dq)	Moves to the rotating dq frame referenced to rotor position (θ_e).
Inner PI loop (I_d, I_q)	100 Hz bandwidth; produces the V_d and V_q commands.
SVPWM	Uses the DC bus ~15% more efficiently than classic PWM.
PWM gate layer	Generates the on/off signals of 6 IGBTs with a 10 kHz triangular carrier.
6-IGBT bridge	Switches the 600 V DC bus to produce variable AC (power stage).
Induction motor (4 kW)	Squirrel-cage dynamic motor model.

5. Method — How It Was Done

The work followed a scientific-source-based virtual system design-and-test methodology in four phases:

5.1. Literature Review

National/international studies on induction-motor drives, PWM techniques, IGBT-based inverter structures and motor-control methods were reviewed; circuit topologies, control algorithms and chronic production problems were evaluated to determine the most suitable drive structure.

5.2. Virtual Modelling (MATLAB/Simulink)

The chosen topology was ported to Simulink; the inverter, PWM-generation block and induction-motor model were run together to examine current, voltage, speed and torque characteristics under different load conditions.

5.3. Model Tests & Validation

The model was tested with Simscape Power/Motors components to represent real operating conditions; accuracy and stability were assessed and the validations needed to proceed to PCB production were completed.

6. Simulation Scenarios & Results

The drive's robustness was tested in Multi-Step Speed Tracking, Step Loading and Direction Reversal scenarios.

6.1. Speed-Tracking Performance

- Response to reference changes within ~0.2 s; no appreciable overshoot.
- Linear, stable tracking through 500 / 1000 / 1500 / 800 rpm steps.
- Only a 15–20 rpm instantaneous dip under sudden loads at 1000 rpm, with fast recovery.
- Smooth four-quadrant operation with regenerative braking on the +1000 → –1000 rpm transition at 1.0 s.

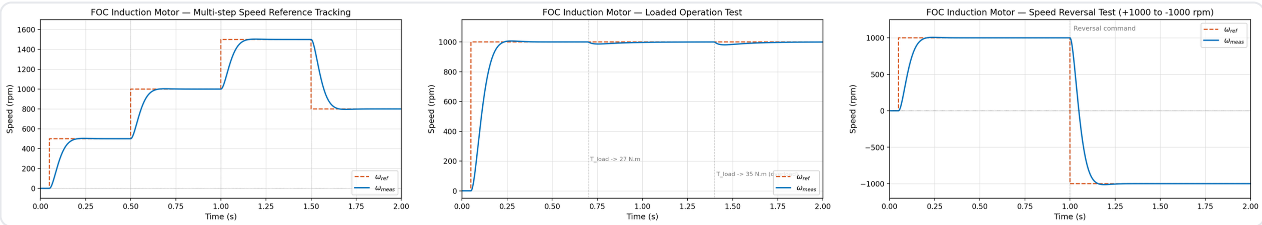

Figure 3. Speed plots — (a) multi-step, (b) loaded operation, (c) direction reversal. The blue (measured) curve catches the red dashed target in ~0.2 s with near-zero overshoot in every scenario.

6.2. Electromagnetic Torque Response

- During speed transitions the dynamic torque momentarily rises to a ~19 N·m ceiling, then returns smoothly to the load torque.
- Torque produced under stepped load: 50% → 13.4 N·m, 100% → 26.7 N·m, 130% → 35 N·m (millisecond delay).
- In the deceleration phase the torque goes negative, providing electrical braking (regeneration).

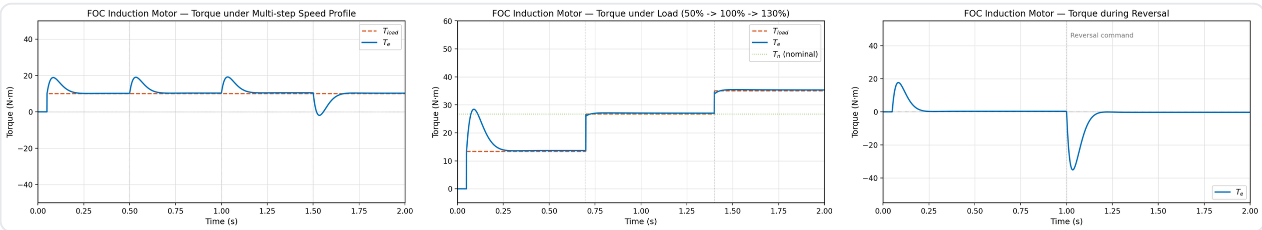

Figure 4. Torque plots — (a) multi-step, (b) loaded, (c) direction reversal. The produced torque (Te) shapes to demand, evidence that the Iq torque current is directly controlled.

6.3. Stator-Current Characteristic

- Ideal sinusoidal currents 120° apart, free of distortion.
- Peak current: ~7.5 A no-load, 10.5 A full-load, 13 A overload (only Iq grows).
- Fundamental electrical frequency ~33 Hz at 1000 rpm; phase order is reversed in software on direction change.

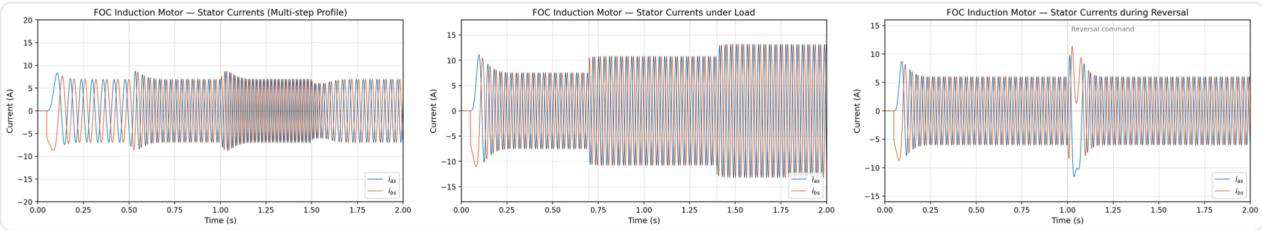

Figure 5. Stator-current plots — (a) multi-step, (b) loaded, (c) direction reversal. Amplitude follows torque (grows with load), frequency follows speed; phase order reverses on direction change.

7. Key Design Parameters

Topology	Rectifier → DC-bus filter → 6-IGBT inverter bridge
Control method	Field-Oriented Control (FOC) + SVPWM
DC-bus voltage	600 V
PWM carrier frequency	10 kHz (triangular carrier)
Speed loop / current loop	5 Hz / 100 Hz bandwidth
Motor	4 kW squirrel-cage induction motor
Development environment	MATLAB / Simulink (Simscape Power/Motors)

8. Conclusion

Simulations across three scenarios confirmed that the designed FOC architecture tracks the speed reference with high dynamism and near-zero overshoot, is highly resistant to disturbances, and successfully decouples the flux and torque components. The numerical and graphical results show that the drive can control the induction motor with the precision of a DC motor, providing a reference-quality study for similar systems.

> *This document is compiled from the power-electronics motor-drive study and the FOC (Vector Control) simulation presentation. Figures 1–2 are Simulink block diagrams and Figures 3–5 are the three-scenario speed/torque/current result plots.*