LAB2 - Indirect Field-Oriented Control (IFOC) of an Induction Motor

1. Objective

The goal of this laboratory exercise is to:

1. Study the principles and structure of indirect field-oriented control (IFOC) for induction motors.
2. Observe the dynamic behavior of torque, flux, and current in dq-coordinates.
3. Learn how PI controller parameters affect stability and transient response.
4. Use an optimization algorithm to tune PI regulators for best performance.

2. Description of the System

The system consists of several interconnected subsystems, as illustrated in the Simulink diagram:

1. **Flux and Torque Reference Generation**
   Provides the desired rotor flux and electromagnetic torque for control purposes.
2. **Field-Oriented Control (FOC) Unit**
   Includes transformation of measured currents into dq-coordinates, and computation of reference voltages $U_d^*, U_q^*$for decoupled control of torque and flux.
3. **PI Regulators with Cross-Coupling Compensation**
   Used to minimize flux and torque errors. Their optimal proportional (K_p) and integral (K_i) coefficients are found through a search algorithm in SEARCH.m.
4. **PWM Inverter and dq→abc Transformations**
   Convert dq voltages to three-phase voltages and apply them to the induction motor model.
5. **Induction Motor Model**
   Implemented with inverse inductance function, modeling electromagnetic torque M_{em}, rotor flux Ψ_r, and currents I_a, I_b, I_c.
6. **Mechanical Subsystem**
   Simulates the rotor's angular speed and position under the applied torque.
7. **Measurement and Signal Conditioning**
   Includes A/D converters, low-pass filters, and workspace outputs for recording variables (torque, flux, voltage, and current).

3. Simulation Tasks

Students must perform the following steps:

A. Initialization

Run the file init.m to load all motor and simulation parameters.
Understand how catalog parameters (rated power, voltage, current, etc.) are normalized to per-unit (p.u.) values.

B. Controller Optimization

Study the algorithm in SEARCH.m, which:

- Iteratively adjusts PI controller gains K_p, K_i,
- Evaluates system poles using rootscalc.m,
- Calculates the performance index using performance.m.

Observe how the algorithm minimizes instability by penalizing:

- Poles on the positive real axis,
- Poles close to the unit circle,
- Poor damping ratios (< 0.4).

C. System Simulation

Run the Simulink model and record the following signals:

- Electromagnetic torque $M_{em}(t)$,
- Rotor flux $\Psi_r(t)$,
- Phase voltages U_a, U_b, U_c,
- Phase currents I_a, I_b, I_c.

D. Visualization

Use the provided MATLAB plotting script to visualize and analyze results

4. Tasks

Task 1 – Initialization

Study the init.m script and identify the following parameters:

Rated Power P_{nom}: __________ kW
Rated Torque M_{nom}: __________ Nm
Rated Slip: __________
DC-Link Voltage U_{dc}: __________ V
Sampling Period T_s: __________ s

Task 2 – PI Controller Optimization

1. Open and examine the files performance.m, rootscalc.m, and SEARCH.m.
2. Explain in your own words how the optimization algorithm works:

After running SEARCH.m, record the obtained optimal parameters:

$K_p =$__________
$K_i =$__________

Comment on how the performance criterion penalizes unstable poles or poor damping:

Task 3 – Simulation

1. Run the Simulink model.
2. Observe waveforms of:
   Electromagnetic torque $M_{em}(t)$
   Rotor flux $\Psi_r(t)$
   Phase voltages U_a, U_b, U_c
   Phase currents I_a, I_b, I_c
3. Export all signals to workspace and visualize

5. Discussion Questions

1. What are the advantages of vector control over scalar (V/f) control?

2. What physical quantities do I_d and I_q correspond to?

3. How does the dq-transformation simplify control of AC motors?

4. What happens if PI gains are too high or too low?

5. Why is it useful to express parameters in per-unit values?

6. Report Structure

Your final lab report must include:

Title Page – HDU number, Lab #, Student, Date.
Objective – 2–3 sentences.
Theoretical Background – dq-control, flux–torque decoupling, PI tuning.
Model Description – Annotated diagram with explanation.
Simulation Results – Plots and brief interpretation.
Optimization Results – Final K_p, K_i, damping discussion.
Conclusion – Evaluate control quality and system stability.

7. Conclusion

After completing this lab, students should be able to:

- Describe the principle of indirect field-oriented control (IFOC).
- Tune PI controllers using performance-based criteria.
- Analyze dynamic responses of torque, flux, and current.
- Relate simulation results to theoretical motor control concepts.