

Run, and stop(over there!)

Introduction to FOC Algorithm

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Introduction

Brief Overview of FOC

Field-Oriented Control (FOC) is a method for precisely controlling the torque and speed of three-phase AC motors, such as brushless DC and permanent magnet synchronous motors. It achieves this by transforming motor currents into two components in a rotating reference frame, allowing for independent control of the motor's magnetic flux and torque. This results in smooth, efficient motor operation with fast response to changes.

Importance in Motor Control

Field-Oriented Control (FOC) is crucial in motor control because it allows for precise, smooth regulation of motor speed and torque. This precision is essential for applications requiring accurate positioning, smooth operation at low speeds, and efficient energy use. FOC's ability to independently control the magnetic flux and torque-producing currents improves motor performance and responsiveness, making it ideal for high-performance applications like electric vehicles, robotics, and industrial automation.

Core Concepts

Vector Control: Basic idea of controlling magnetic flux and torque

Vector Control involves the separation of motor control into two main components: magnetic flux and torque. The fundamental idea is to manage these components independently by transforming the three-phase motor currents into a two-axis coordinate system known as the d-q frame. In this frame, the direct axis (d-axis) component represents the magnetic flux, while the quadrature axis (q-axis) component represents the torque-producing current. By controlling these components separately, vector control can maintain the desired magnetic flux while adjusting the torque as needed. This separation simplifies the control of AC motors, making them behave similarly to DC motors, where the field and armature currents are independently controlled. As a result, vector control provides precise and dynamic regulation of motor speed and torque, leading to smoother operation, better efficiency, and improved performance across a wide range of operating conditions. This control method is especially beneficial in applications requiring quick and accurate adjustments, such as in electric vehicles, robotics, and industrial automation systems.

Core Concepts

D-Q Transformation: Decoupling of torque and flux components

D-Q Transformation is a crucial technique in the Field-Oriented Control (FOC) algorithm, enabling the decoupling of torque and flux components in an AC motor. This process involves two key mathematical transformations: the **Clarke Transformation** and the **Park Transformation**.

The Clarke Transformation converts the three-phase stator currents into two orthogonal components, known as the α and β components, in a stationary reference frame. Following this, the Park Transformation takes these α and β components and translates them into a rotating reference frame, resulting in the d (direct) and q (quadrature) components.

In this d-q frame, the d-axis component corresponds to the magnetic flux, while the q-axis component corresponds to the torque-producing current. By separating these components, the FOC algorithm can independently control the motor's flux and torque. This decoupling is essential for precise and efficient motor control, as it allows for rapid and accurate adjustments to the motor's operating conditions.

FOC Algorithm Steps

Sensing and Measurement

Current Sensors (Phase Currents)

These sensors measure the currents flowing through the motor's three phases. Accurate measurement of phase currents is essential for determining the correct d-q components through the Clarke and Park transformations. These sensors typically provide analog or digital signals corresponding to the current levels, allowing the control system to regulate the motor's magnetic flux and torque effectively.

Position Sensors (Rotor Angle)

To achieve precise control, the FOC algorithm requires knowledge of the rotor's position relative to the stator. Position sensors, such as encoders or resolvers, provide the rotor angle information. This data is crucial for the Park Transformation, which aligns the d-axis with the rotor's magnetic field. By knowing the rotor's position, the control system can accurately calculate the d and q components, ensuring the correct application of current to produce the desired torque and flux.

FOC Algorithm Steps

Transformation to D-Q Frame

Clarke Transformation

Clarke Transformation is a mathematical process that converts three-phase stator currents into two orthogonal components (α and β) in a stationary reference frame, simplifying the analysis and control of AC motors.

$$\begin{pmatrix} i_{\alpha} \\ i_{\beta} \end{pmatrix} = \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix}$$

FOC Algorithm Steps

Transformation to D-Q Frame

Park Transformation

Park Transformation is a mathematical technique that converts the two-phase stationary reference frame (α - β) into a rotating reference frame (d-q), aligning with the rotor's magnetic field, which simplifies the control of AC motor currents for torque and flux control.

$$\begin{pmatrix} i_d \\ i_q \end{pmatrix} = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix}$$

θ is the angle of the rotor's magnetic field.

Why Rotate?

The Role of Park Transformation

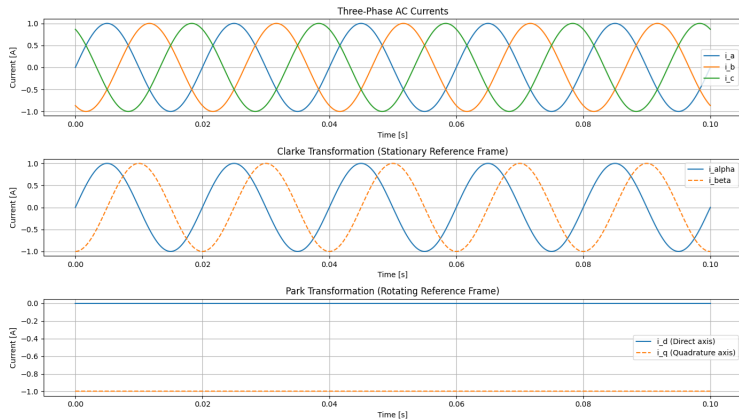
Clarke Transformation's Limitation

Though the Clarke Transformation simplifies the three-phase system by converting the currents into the i_α and i_β components in a stationary reference frame, these components still vary sinusoidally over time due to their dependence on the alternating nature of the three-phase currents. This variability can complicate control processes because the control system must continuously track these time-varying signals.

In the rotating reference frame, the i_d and i_q components are effectively DC quantities in steady-state conditions, meaning they do not vary with time if the motor is running at a constant speed and load. This transformation aligns the reference frame with the rotor's magnetic field, thereby "removing" the time dependence associated with the sinusoidal variations in the i_α and i_β components.

Why Rotate?

The Role of Park Transformation



VVVF vs. FOC: Control Strategies Compared

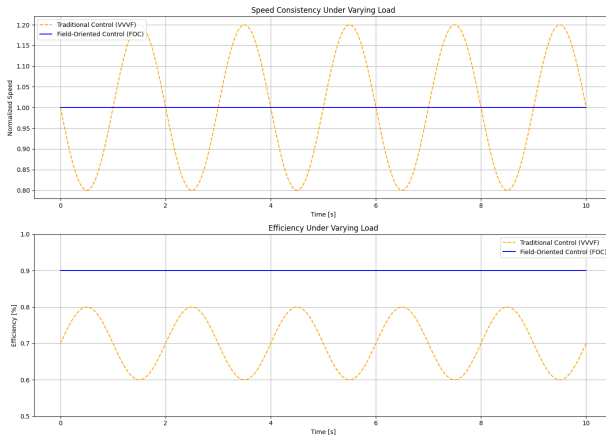
Understanding the Differences in Motor Control Approaches

VVVF: The primary cause of the differences in performance is VVVF's inability to decouple torque and flux control. This results in speed fluctuations and inefficiencies when the load changes.

FOC: FOC's superior performance comes from its ability to decouple and independently control torque and flux, leading to stable speed and consistent efficiency under varying load conditions. This precise control is what makes FOC a more advanced and effective motor control strategy compared to VVVF.

VVVF vs. FOC: Control Strategies Compared

Understanding the Differences in Motor Control Approaches



Why VVVF Gets Unstable?

Understanding the Core Limitations

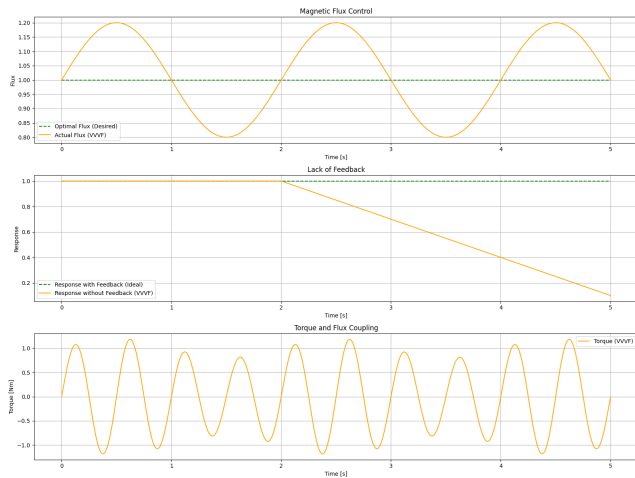
Flux Fluctuations: The inability to maintain stable flux due to the interdependence of voltage and frequency leads to unstable motor operation, especially under varying load conditions.

No Real-Time Adjustment: Without feedback, VVVF cannot quickly adjust to changes in load or speed, causing delays and errors that manifest as instability.

Coupled Torque and Flux: The lack of independent control over torque and flux means that any change in load or speed affects both, leading to instability in motor performance.

Why VVVF Gets Unstable?

Understanding the Core Limitations



Why VVVF Gets Unstable?

Understanding the Core Limitations

