AKD: Operating Induction machines through closed-loop field oriented control

Firmware version: M-01-12-01-000

This article explains how to set an AKD for driving an asynchronous machine, using a closed-loop field oriented control (FOC) strategy. The article contains:

- Introduction
- Initial settings
- Parameters
- Field weakening
- Calculation of motor parameters
- Vector current limiting
- Commutation angle settings
- Variables for analysis
- Further information
- Examples

Introduction

A Field Oriented Control (FOC) strategy to control an asynchronous machine is implemented in AKD. A separate control of flux and torque is possible, similar to a DC-machine. Fig 1 shows the implemented scheme.

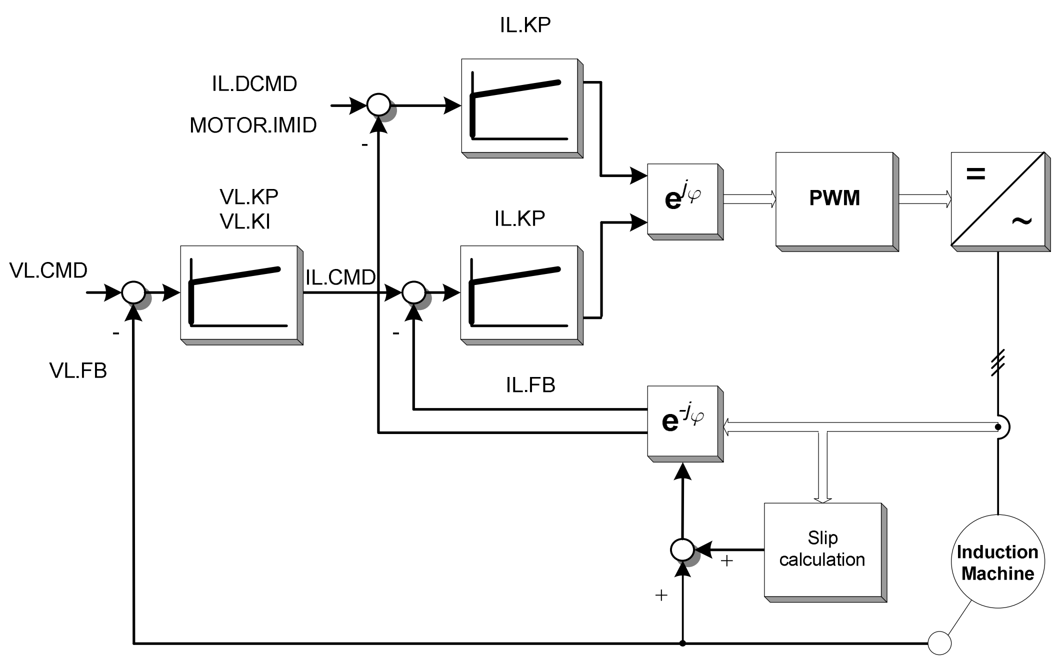

Figure 1: Field Oriented Control of an ASM

The velocity command can be obtained from three different sources, depending on DRV.CMDSOURCE

- 0: Service
- 1: Field bus
- 3: Analog

Initial settings

DRV.OPMODE = 1	Velocity mode
MOTOR.TYPE = 4	V/Hz speed control
FB1.SELECT = XX	Select according to your feedback
DRV.ACC & DRV.DEC	Set according to induction machine mechanical dynamics

Parameters

The following table shows which MOTOR parameters should be also configured for driving induction machines under FOC closed-loop operation:

Keyword	Induction Motor Closed Loop	Description
MOTOR.NAME	Yes	Set a name for customer motor
MOTOR.TYPE	Yes	Set to motor type. For V/Hz, MOTOR.TYPE = 4
MOTOR.AUTOSET	Yes	Available for FOC
MOTOR.IPEAK	Yes	Set to motor peak current (A). 150% of continuous current for NEMA motors
MOTOR.ICONT	Yes	Set to motor continuous current (A)
MOTOR.INERTIA	Yes	Set the motor inertia in kg cm^2
MOTOR.KT	No	No necessary for Induction Motor
MOTOR.LQLL	Yes	Set the stator inductance in mH. For further information see below section "calculation of machine parameters".
MOTOR.POLES	Yes	Set to motor poles
MOTOR.VMAX	Yes	This is the maximum mechanical speed of the motor in RPM
MOTOR.R	Yes	Set the stator winding resistance phase-to-phase in Ohms. For further information see below section "calculation of machine parameters".
MOTOR.VOLTMAX	Yes	Motor max winding voltage. Ex: 230 VAC or 460VAC

MOTOR.PHASE	No	No necessary for Induction Motor
MOTOR.CTF0	Yes	This is used to configure the thermal constant of the motor coil
MOTOR.KE	No	No necessary for Induction Motor
MOTOR.IMTR	Yes	Set the rotor time constant in ms. For further information see below section “calculation of machine parameters”.
MOTOR.IMID	Yes	Set the magnetizing current (id) in A. For further information see below section “calculation of machine parameters”.
MOTOR.VOLTRATED	No	No necessary for FOC
MOTOR.VRATED	No	No necessary for FOC
MOTOR.VOLTMIN	No	No necessary for FOC

Field weakening.

So far, the closed-loop control implemented in AKD is not able to drive the ASM in field weakening area.

Calculation of machine parameters

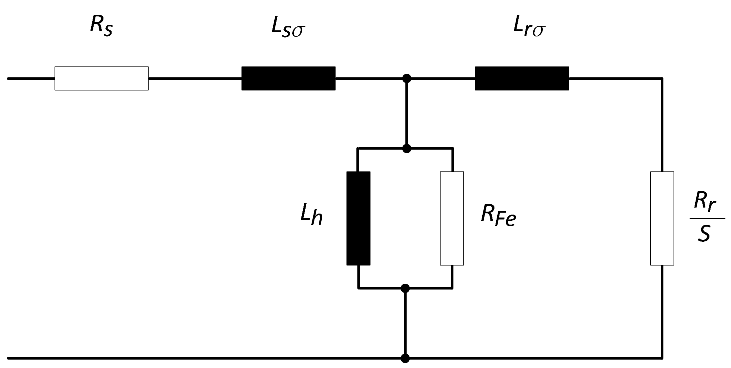

Figure 2: Induction motor equivalent circuit

1. **Determine current set point id = MOTOR.IMID**

The direct-axis (non-torque axis) current I_d is set to a constant value as soon as the drive is enabled. MOTOR.IMID is used to set up and view the magnitude of Id set point.

The appropriate value of MOTOR.IMID can be estimated from the motor name plate information.

A rule of thumb as following can be used (see S300 manual):

$$I_{d,rms} \cong I_R * \sqrt{1-(\cos\varphi)^2} * 0.8 \quad (1)$$

In which I_d is the value for MOTOR.IMID, the preset rotor flux building current. I_R and $cos\varphi$ are the phase current and power factor at rated operation, read from the motor data sheet respectively. And 0.8 is an empirical factor. MOTOR.IMID is in Arms.

2. Rotor resistance

The rotor resistance can be calculated based on the electrical motor losses. This means, based on the difference between ideal mechanical power and real mechanical power, the rotor resistance can be calculated as follows:

$$R_r = \frac{P_a - P_R}{3 * (0.8 * I_R)^2} \quad (2)$$

Where Pa is the ideal mechanical power, N_0 is the synchronous speed and T_{eR} is the nominal electromagnetic torque defined as:

$$P_a = \frac{2\pi}{60} * N_0 * T_{eR} \quad (3)$$

$$N_0 = \frac{60 * f_R}{p} \quad (4)$$

$$T_{eR} = \frac{60 * P_R}{2\pi * N_R} \quad (5)$$

P_R, I_R, f_R and N_R are the nominal values for power, current, frequency and speed, read from motor data sheet, respectively.

3. Rotor inductance

The rotor inductance is defined as $L_r = L_m + L_{r\sigma}$. Since L_m is bigger than $L_{r\sigma}$, we consider that: $L_r = L_m$. The mutual inductance can be calculated as follows:

$$L_m = \frac{1}{2\pi * f_R} * \frac{U_R}{\sqrt{2} * I_d} \quad (6)$$

4. Rotor time constant

Finally, the rotor time constant is calculated as follows:

$$\tau_r = \frac{L_m}{R_r} \quad (7)$$

Vector current limiting

1. **Id limits:**
   - Upper limit: 93.75% fold-back current limit, which is calculated as the smallest of drive current limit, motor current limit, and what fold back algorithm allows.
   - Lower limit: -93.75% fold-back current limit.
2. **Iq limits:**
   - Upper: the lower of
     - Sqrt(Ifold^2 – Id^2)
     - User set Iq positive limit
   - Lower: the higher of
     - Sqrt(Ifold^2 – Id^2)
     - User set Iq negative limit

Commutation angle setting

For induction motor closed loop control the commutation angle is set as shown in the following figure:

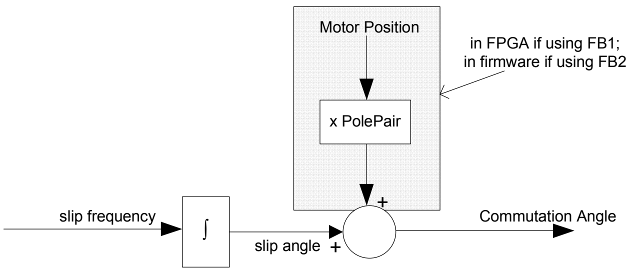

Figure 3. Commutation angle setting in AKD for IM

Induction motor close loop control supports using FB1 or FB2 as commutation feedback source. The shaded calculation, adding motor position feedback to the slip, happens in the FPGA if using FB1 IL.FBSOURCE 0; and in firmware if IL.FBSOURCE is 1

Variables for analysis

Following variables are available for analysis and supervision:

IL.CMD	Currently reference for iq (torque-generation current)
IL.FB	Currently current for iq, at motor terminals
IL.IDCMD	Currently reference for id (flux-generation current)
VL.CMD	Velocity reference
VL.FB	Shaft position, read from the feedback

Further Information.

Such concept is also implemented for our Servostar amplifier. You can find more information in the following links:

KOLLMORGEN Europe Product Wiki: Induction Machine - General

KOLLMORGEN Europe Product WIKI : Sensorless Control for Induction Machines with S300-S700

KOLLMORGEN Europe Product WIKI : Operating Induction Machines S300-S700

Example:

Considering the following ASM:

Nominal voltage = 230/460V	Nominal current = 8.75/5.05A	4 poles
Power: 2.20Kw	Nominal speed = 1395 rpm	
cos ρ = 0.82	Nominal frequency = 50Hz	

With a resolver as feedback

Then, the missed machine parameters are calculated as follows:

1. MOTOR.IMID: based on equation 1:

$$I_{d,rms} \cong I_R * \sqrt{1-(\cos\varphi)^2} * 0.8 = 8.75 * \sqrt{1-(0.82)^2} * 0.8 = 4\ A$$

2. Rotor resistance. The nominal electromagnetic torque is calculated based on eq. 5:

$$T_{eR} = \frac{60 * P_R}{2\pi * N_R} = \frac{60 * 2200}{2\pi * 1395} = 15.05Nm$$

Based on eq. 4, we got the synchronous speed as:

$$N_0 = \frac{60 * f_R}{pp} = \frac{60 * 50}{2} = 1500rpm$$

The ideal mechanical power from eq. 3 is:

$$P_a = \frac{2\pi}{60} * N_0 * T_{eR} = \frac{2\pi}{60} * 1500 * 15.05 = 2360\ watts$$

From eq. 2, the rotor resistance is then calculated as:

$$R_r = R_r = \frac{P_a - P_R}{3 * (0.8 * I_R)^2} = \frac{2360 - 2200}{3 * (0.8 * 8.75)^2} = 1.126\Omega$$

3. Mutual inductance. From eq. 6, we got:

$$L_m = \frac{1}{2\pi * f_R} * \frac{U_R}{\sqrt{2} * I_d} = \frac{1}{2\pi * 50} * \frac{230}{\sqrt{2} * 4} = 129mH$$

4. Rotor time constant. Finally from eq. 7

$$\tau_r = \frac{L_m}{R_r} = \frac{129x10^{-3}}{1.126} = 114ms$$

We set following parameters in AKD

Parameter	Value	Parameter	Value
DRV.ACC & DRV.DEC	10000rpm/s	MOTOR.POLES	4
DRV.OPMODE	1	MOTOR.VMAX	1600 rpm
FB1.SELECT	40	MOTOR.R	1.126 ohm
MOTOR.NAME	NORD-ASM	MOTOR.VOLTMAX	240V
MOTOR.TYPE	4	MOTOR.IMTR	114 ms
MOTOR.IPEAK	13 A	MOTOR.IMID	4 A
MOTOR.ICONT	8.75 A		
MOTOR.INERTIA	6.2 kg cm^2		
MOTOR.LQLL	129 mH		

Speed command: 1395 rpm