AC Induction Motor Control

Operation principles

Introduction

This article describes the basic operation principles and control of AC induction motors (ACIMs).

AC induction machines are popular due to their simplicity, reliability and direct operation from an AC line voltage. ACIMs are asynchronous machines and always have a lower mechanical rotor speed than the power line frequency.

Historically, variations to speed requests was a limitation for AC machines, but the development of frequency converters has simplified motor speed changes, and are now widely used.

ACIM Fabrication

ACIM fabrication begins with a three-phase winding placed in the winding slot of the stator. There are two basic types of rotor winding concepts. The first type places the rotor winding placed in the winding slot with a slip ring on the shaft, which historically was used for speed regulation and startup. The more common type consists of a rotor in a squirrel cage form.

Figure 1: Example of ACIM

Operation Principle

The principle of operation for an ACIM is based on the voltage induction from the stator to the rotor. When the stator winding is fed by a three-phase supply voltage, the current flows in the winding and the stator rotating magnetic field is generated. Induced voltage in the rotor windings will create the rotor current and the rotor magnetic field. The interaction between two magnetic fields creates the mechanical torque needed to turn the rotor.

The operational rotor speed is lower than the stator magnetic field speed in order to achieve rotational torque.

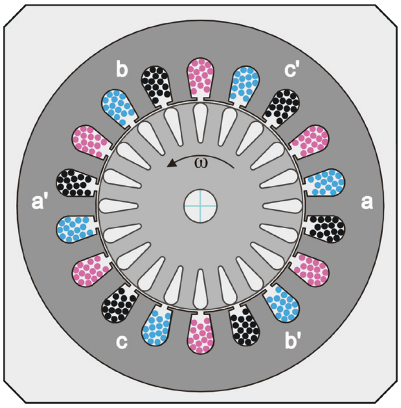
There are three defined operational variables of ACIM: synchronous speed, slip speed and slip.

The synchronous speed is proportional to supply frequency and inversely proportional to the number of paired poles.

$$synch_{speed}[rpm] = \frac{60 \cdot suppy_{frequency}[Hz]}{no\ of pole\ pairs\ [-]}$$

The slip speed is represented in the difference between the synchronous speed and the rated speed. The slip is the ratio between slip speed and synchronous speed and shows how much the rotor speed falls with the load.

Figure 2: ACIM Incision



For example, a 50 Hz, six-pole ACIM with 7 percent slip results in the following:

$$synch\_speed = \frac{60\ \cdot 50Hz}{3} = \mathbf{1000\ rpm}$$

$$slip\_speed = \mathbf{7}\ \% * 1000\ \text{rpm} = \mathbf{70\ rpm}$$

$$\begin{aligned} rated\_speed &= 1000\ rpm - 70\ rpm \\ &= \mathbf{930\ rpm} \end{aligned}$$

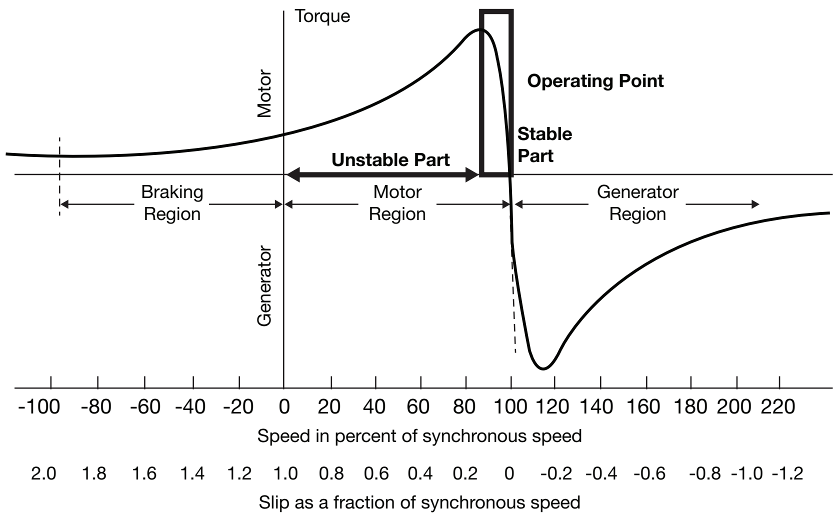
From these results, it is apparent that the motor runs at a lower speed than the supplied voltage frequency and requires regulation for precise speed operation.

Speed Torque Characteristic

The speed torque characteristic shows the ACIM reaction on the load.

The convenient operating point selection is in the middle of the speed torque characteristic of the stable part of the motor region. In this area, the speed falls slightly with the load.

Figure 3: ACIM Speed Torque Characteristic



ACIM can operate as a generator but it is necessary to supply machine reactive energy because there is no source of magnetic field. The generator speed torque characteristic region is central symmetry to torque zero crossing point. On the left there is a braking region. In the case of ACIM in generator mode the slip is a negative value.

It is evident from the characteristic, that the motor start torque is restricted. The full motor start torque can be achieved using an advanced control method.

ACIM Control

ACIM changes speed according to supply frequency and voltage provided by the frequency converter. This is efficient and allows the entire machine speed range to be used.

There are two groups of control methods. First, the simple method is named voltage/frequency control (or scalar control) and refers to applied voltage that is proportional to applied frequency. This method is simple, is not dependent on motor parameters and can use the entire speed range. On the other hand, it does not include current controllers and does not control the machine optimally in transient states. This technique is appropriate for fans, pumps and compressors.

Freescale offers 8-bit MCUs such as the MC9S08P/MP with dedicated peripherals that can easily handle the task.

Second, there are advanced control methods such as field-oriented control (FOC) or direct torque control (DTC). FOC enables independent control of motor torque and magnetic flux. The control is based on the transformation of current/voltage coordinates from stationary to rotation that makes the control similar to DC machine control. The control incorporates fast torque/flux current control loops and slower speed/position control loops. The FOC requires the knowledge of the actual rotor position, which is typically measured by the encoder or resolver. In some cases, the sensor cannot be used and the rotor position is calculated using the sensorless observer from measured machine currents and voltages.

Advanced control techniques provide an excellent dynamic performance, wide speed range from zero speed and excellent efficiency. They can be used for industrial and servo drives but also for advanced appliance applications such as washers.

On the other hand, they require a high-performance MCU with dedicated motor control peripherals. Freescale offers a family of DSCs, the MC56F8xxx based on 56F800E/X cores and ARM® Cortex™-M4 core-based Kinetis MCUs that provide the ideal solution for advance control of AC induction motors.

Reference designs, application notes and software solutions for ACIMs, are available at **freescale.com/motorcontrol**.

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