Induction and Synchronous Motor Fundamentals

An Online Continuing Education Course for Engineers

Course Number: E-1005

Credit: 1 Hour / 1 PDH / 1 CPD

Induction and Synchronous Motor Fundamentals (1 PDH)

Introduction

Motors are electromagnetic devices that are used to convert electrical energy into mechanical work. There are three classes of AC motors – synchronous motors, induction motors and series wound motors. The most common motor classes are synchronous and induction.

NEMA MG 1-2003 has the following definitions:

An induction machine is an asynchronous machine that has a magnetic circuit interlinked with two electric circuits, or sets of circuits, rotating with respect to each other. Power is transferred from one circuit to another by electromagnetic induction.

A synchronous machine is an alternating-current machine in which the average speed of normal operation is exactly proportional to the frequency of the system to which it is connected.

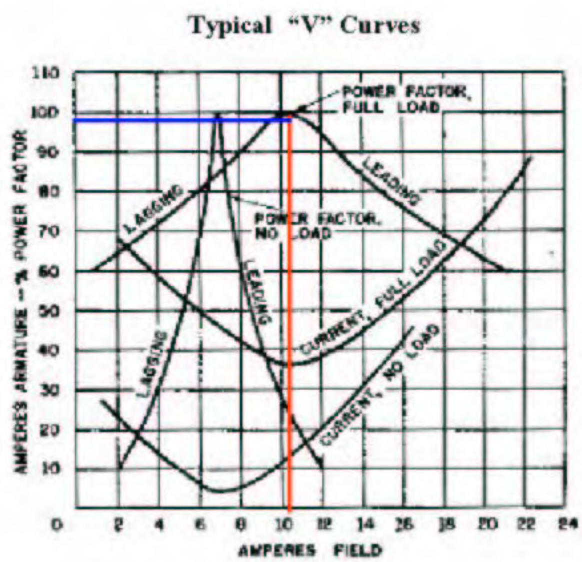
Synchronous motors

A synchronous motor is a synchronous machine used for a motor. A synchronous motor cannot start without being driven. They need a separate starting means.

There are several types of synchronous motors. These include direct current excited synchronous motor (field poles are excited by direct current), a permanent magnet synchronous motor (field excitation is provided by permanent magnets) and a reluctance synchronous motor (starts as an induction motor, is normally provided with a squirrel-cage winding, but operates at synchronous speed).

Synchronous motors have fixed stator windings electrically connected to the AC supply with a separate source of excitation connected to a field winding on the rotating shaft. A three-phase stator is similar to that of an induction motor. The rotating field has the same number of poles as the stator, and is supplied by an external source of DC. Magnetic flux links the rotor and stator windings causing the motor to operate at synchronous speed. A synchronous motor starts as an induction motor, until the rotor speed is near synchronous speed where it is locked in step with the stator by application of a field excitation. When the synchronous motor is operating at synchronous speed, it is possible to alter the power factor by varying the excitation supplied to the motor field.

An important advantage of a synchronous motor is that the motor power factor can be controlled by adjusting the excitation of the rotating DC field. Unlike AC induction motors which run at a lagging power factor, a synchronous motor can run at unity or even at a leading power factor. This will improve the overall electrical system power factor, voltage drop and also improve the voltage drop at the terminals of the motor. Synchronous motors can supply reactive power to counteract lagging power factor cause by inductive loads. As the DC field excitation is increased, the power factor (as measured at the motor terminals) becomes more leading. If the excitation is decreased, the power factor of the motor becomes more lagging.



Refer to the above graph. The curves on the graph show the effect of excitation (field amps) on the stator and on the system power factor. There are separate V curves for No-Load and Full Load cases. A manufacturer may also have curves for other percentages of full load (25%, 50%, 75%). From this particular curve, to determine the field excitation that will produce a unity power factor at full load: Go up the Y-axis to unity power factor (100%). Come across the X-axis to the peak of the Power Factor V curve for full load operation. Come back down the Y-axis from that point to determine the field amps. In this case, the field amps is just over 10 amps. Notice that at unity power factor, the stator full load amps is at the minimum value. As the field amps increases above what is required for unity power factor, the motor becomes more leading. As the amps decrease below what is required for unity power factor, the motor becomes more lagging. In either case, the stator amps increases above that required for unity power factor.

Synchronous motors can be classified as brush excitation or brushless excitation. Brush excitation consists of cast-brass brushholders mounted on insulated steel rods and supported from the bearing pedestal. The number of brushes for a particular size and rating depends on the field current. Sufficient brushes are supplied to limit the current density to a low value. The output of a separate DC exciter is applied to the slip rings of the rotor. A brushless excitation system utilizes an integral exciter and rotating rectifier assembly that eliminates the need for brushes and slip rings.

Synchronous motors are started using several reduced voltage methods. The most common is starting across the line with full AC voltage to the windings. As the motor speed increases, the discharge resistor provides the torque required for the motor to reach synchronous speed. Once synchronous speed is reached, the starting resistor is switched out of the field circuit and excitation can be applied to lock the stator and field poles in sync. The DC excitation system is used to apply current to the field winding creating a rotating electromagnet field that couples the rotor field to the rotating AC field in the armature winding when the motor is operating at synchronous speed. If the North and South poles of the rotor and stator are aligned, the rotor will lock in step with the stator and the motor will synchronize. If the rotor poles are 180 degrees out of phase with the stator poles, but the motor is accelerating, it is likely that accelerating torque along with magnetic attraction will combine to pull the rotor rapidly into pole alignment with the stator.

Other starting methods include reduced voltage starting, such as using an autotransformer. Another starting approach is to switch out the starting resistor and apply DC excitation based upon the time after the motor AC supply power is applied. In this approach, the acceleration time of the motor needs to be known and the motor must be able to reach nearly synchronous speed without excitation.

Some applications use a speed signal to apply DC excitation when the motor has accelerated to 90 – 95% of rated speed. The timing for switching out the starting resistor and applying DC excitation is monitored by electronics on the rotating field. Application of the field can be accomplished using solid-state devices instead of mechanical breakers or contactors.

Once the motor’s field poles are in step with the stator frequency, two factors determine the synchronous speed of the motor. The first is the frequency of the applied voltage, and the second is the number of poles in the motor.

$$\text{Speed} = \frac{\text{Freq x 120}}{\text{Poles}}$$

Synchronous motor efficiencies are higher than those of induction motors. Their inrush currents are low. They can be designed with torque characteristics to meet the requirements of the driven load and available power supply. A synchronous motor’s speed/torque characteristics are ideally suited for direct drive of large horsepower, low rpm loads such as reciprocating compressors. Their precise speed regulation makes them an ideal choice for certain industrial processes.

Synchronous motors are used in the pulp, paper processing, water processing treatment, petrochemical and mining industries, to name a few. They are used for chippers, crushers, pumps, and compressor drives to name a few applications.

Synchronous motors are designed to meet NEMA MG1-21.21. Noise tests are performed per IEEE 85 and performance tests per IEEE 115 for machine efficiency, temperature rises, starting characteristics and other parameters.

Induction motors

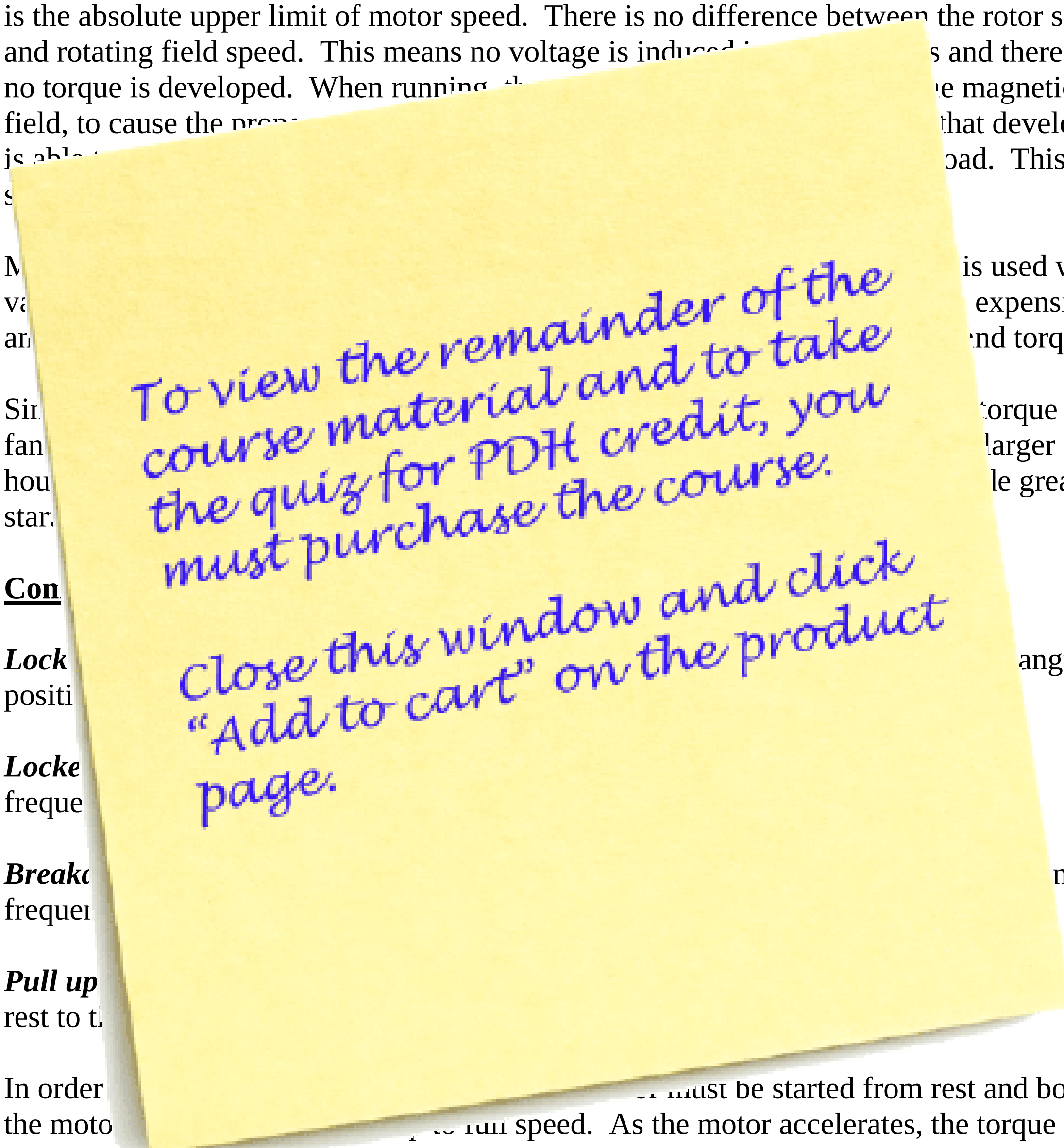
Induction motors are simple and rugged and relatively cheap to construct. They consist of a wound stator and a rotor assembly. They have fixed stator windings that are electrically connected to an AC power source. Current is induced in the rotor circuit. The resulting magnetic field interacts with the stator field for the "induction" to occur. No separate power source is required to provide the rotor field. An induction motor can be started and accelerated to steady state running conditions simply by applying AC power to the fixed stator windings of the motor. They do not rely on brushes like a DC motor does. Induction motors have a longer life than synchronous motors and are common for applications above 1 kW.

There are a couple of types of induction motors – a squirrel-cage motor and a wound-rotor motor. A squirrel-cage motor is one where the secondary circuit consists of a number of conducting bars that have their end pieces connected by metal rings or plates at each end. A wound-rotor motor in one where the secondary circuit has a polyphase winding or coils whose terminals are either short circuited or closed through suitable circuits.

The rotor assembly of an induction motor, when looked at from the end, resembles a squirrel cage (or a hamster exerciser). Thus the name squirrel-cage motor refers to an induction motor. The most common rotor type has cast aluminum conductors (bars) and short-circuiting end rings. The position of the bars in relation to the surface of the rotor, the shape, cross sectional area and material of the bars determine the rotor characteristics. A bar with a large cross sectional area will exhibit a low resistance. A copper bar will have a low resistance compared to a brass bar of equal proportions. The rotor design will determine the starting characteristics of the motor. The rotor turns when the moving magnetic field induces a current in the shorted conductors.

The stator of an induction motor is the outer body of the motor. This houses driven windings on an iron core. The standard stator has three windings for a three-phase design. A single-phase motor typically has two windings. The core of the stator is made up of a stack of round pre-punched laminations pressed into a frame that is made of aluminum or cast iron. Laminations are round with a round hole where the rotor is positioned. The inner surface of the stator has slots or grooves where the windings are positioned. The arrangement of the windings determines the number of poles that a motor has. A stator is like an electromagnet and has poles (north and south) in multiples of two (2-pole, 4-pole, etc.). The voltage rating of the motor is determined by the number of turns on the stator. The power rating of the motor is determined by the losses. These include copper loss, iron loss and the ability of the motor to dissipate the heat generated by the losses. The design of the stator determines the rated speed of the motor as well as the full load/full speed characteristics.

The synchronous speed of the motor is the speed where the magnetic field rotates. It is determined by the number of poles in the stator and the frequency of the power supply. It is the absolute upper limit of motor speed. There is no difference between the rotor speed and rotating field speed. This means no voltage is induc... s and therefore no torque is developed. When running ... e magnetic field, to cause the prop... that develops is able ... oad. This s...



M... is used when va... expensive an... nd torque.

Sir... torque like fan... larger hou... le greater star...

Con

Lock ... angular positi...

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Pull up ... m rest to t...

In order ... must be started from rest and both the moto... full speed. As the motor accelerates, the torque and the current ... with rotor speed if a constant voltage is maintained. The starting current of a motor, with a fixed voltage will drop slowly as the motor accelerates and will begin to fall significantly when the motor has reached between 80% and full speed. The general curve for an induction motor indicates a high current until the motor has almost reached full speed. The locked rotor current of a motor typically falls between 550% and 750% of the full load current. Refer to the typical curve below.