Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 31: Electrical Systems and Fault Finding

Unit Workbook 2

in a series of 4 for this unit

Learning Outcome 2

Electrical Motors and Generators

Topics Covered: -

Applications, construction, characteristics, and testing

Types of electric motors and generators

Practical applications

Generation methods

Starting methods

Voltages, power, speed, torque, inertia

EMI, efficiency

Cooling and protection devices

Applications, construction, characteristics, and testing

Applications

The purpose of an electrical motor is to convert electrical energy into mechanical energy. Some common uses of electrical motors are;

- Electric car
- Washing machine
- Cooling fan
- Refrigerator or freezer
- Microwave oven
- Drive for a conveyor belt
- Robotics

The purpose of an electrical generator is the opposite to that of a motor i.e. to convert mechanical energy into electrical energy. Some common uses of generators are;

- Dynamo on a bicycle
- Power station turbines
- Fossil fuelled cars
- Diesel trains
- Vessels
- Roadworks tool power

An illustration of the motor and generator concepts is shown in figure 1.

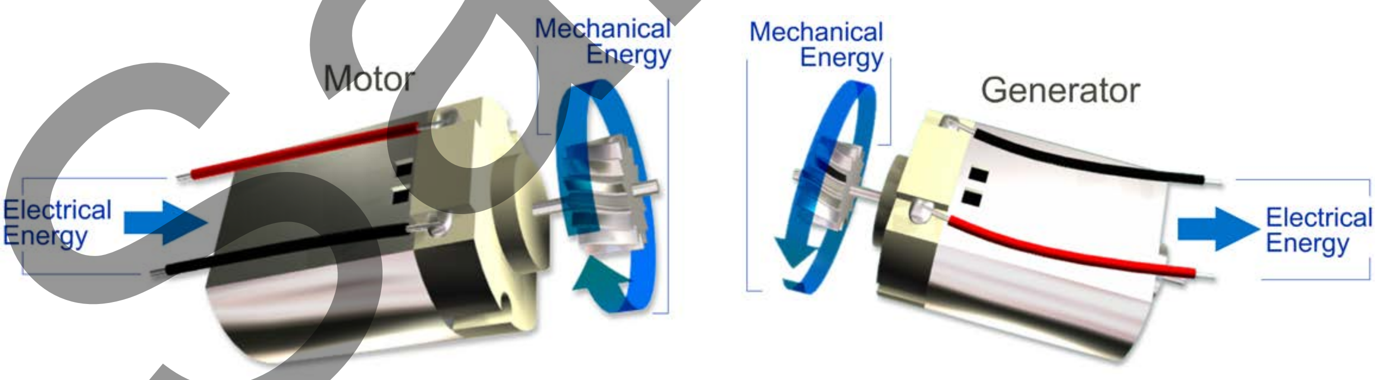

Figure 1 *The motor and generator concepts*

Construction

The two basic components common to both motors and generators are;

- Rotor – the spinning part at the centre
- Stator – fixed part which surrounds the rotor

Other components of motors and generators are;

- Bearings – these provide physical support for the rotor
- Air gap – the space between the rotor and stator
- Windings – usually copper coil placed around both the stator and rotor
- Magnets – these can be found in either or both the stator and rotor
- Slip rings and brushes – present on some types

The overall construction principle for a generator and motor is shown in figure 2.

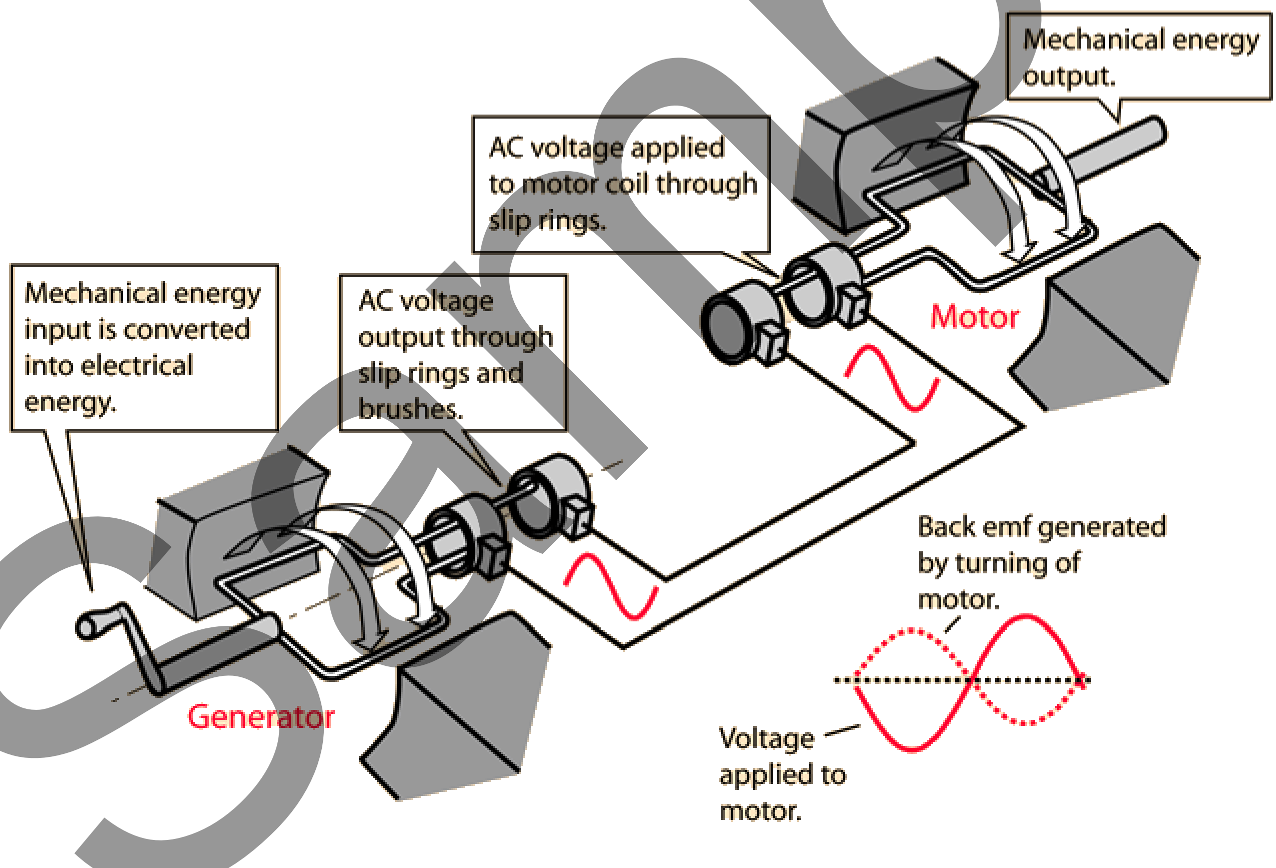

Figure 2 *An AC generator powering an AC motor*

Characteristics

Motors and generators can be made to operate on an AC or DC principle. The basic idea behind any motor or generator is that current-carrying coils which move within magnetic fields will experience a force, as shown in figure 3.

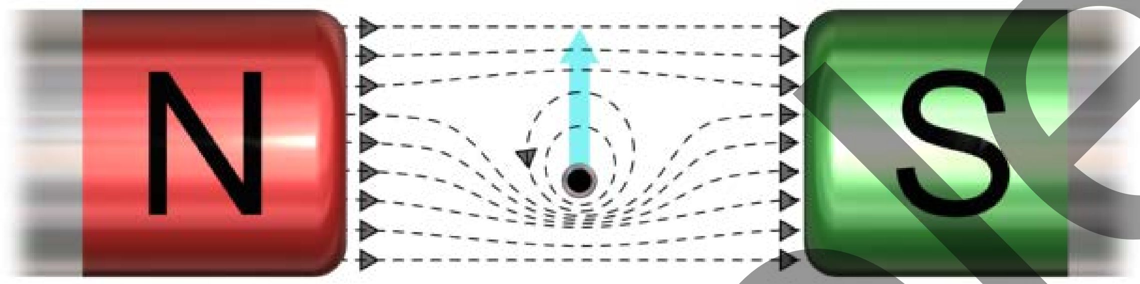

Figure 3 *Force on a current-carrying conductor within a magnetic field*

Any conductor which carries current will radiate a magnetic field. Placing such a conductor inside a larger magnetic field, perhaps constructed from permanent magnets, as shown in figure 3, will result in the conductor experiencing a force and thus movement.

Should we twist the conductor into the form of a loop then we have one turn of a coil, as shown in figure 4. Now the current will flow in opposite directions on either side of the coil. The magnetic forces then tend to work in opposite directions, producing a twisting force (torque) on the coil about its centre.

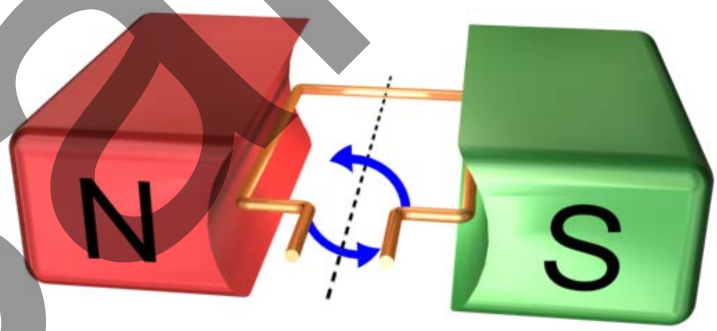

Figure 4 *Force on a current-carrying coil within a magnetic field*

Testing

Testing of motors and generators may be undertaken with a digital or analogue multimeter, clamp meter, temperature sensor, Megger or oscilloscope.

Electric motors can fail to start, run intermittently or become hot. A common cause is a faulty motor controller circuit. The actual load on the motor could be jammed, which may have damaged the motor. If the motor itself is faulty then the cause could be a burnt-out wire, loose or corroded connection, compromised insulation or a faulty bearing. Systematic tests, measurements and observations will usually quickly reveal the cause, as discussed in the previous workbook.

Similar testing will apply to portable generators, but, in either case, adequate personal protection measures should be employed.

Types of electric motors

The various categories and types of electric motor are presented in figure 5.

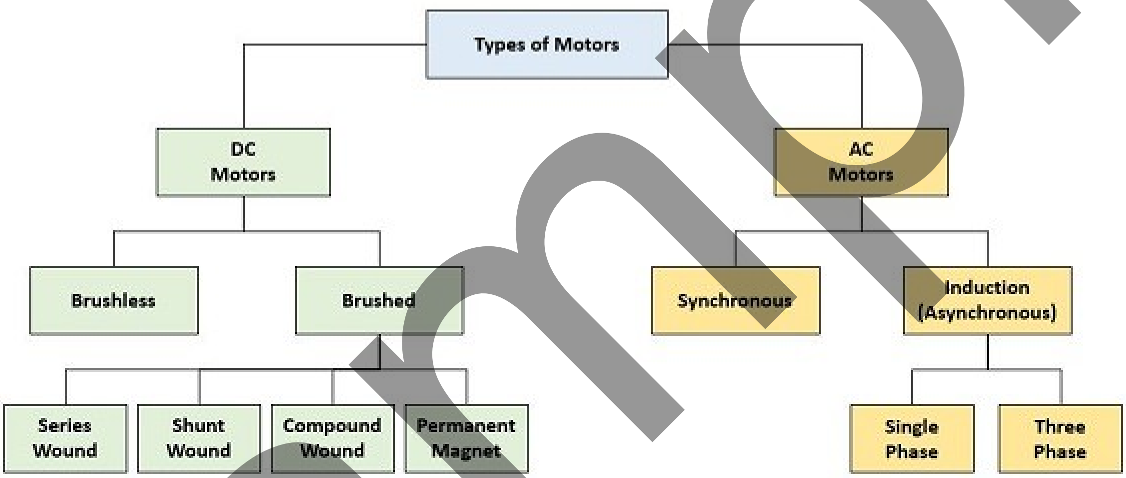

Figure 5 *Various types of electric motor*

DC Motors

Brushed

These are very commonly used and employed in consumer applications and light industry. Brushed motors can be sub-divided into four types, as explained below.

Series wound

The field winding (located in the stator) is connected in series with the rotor winding. Control of the motor speed is achieved by varying the supply voltage.

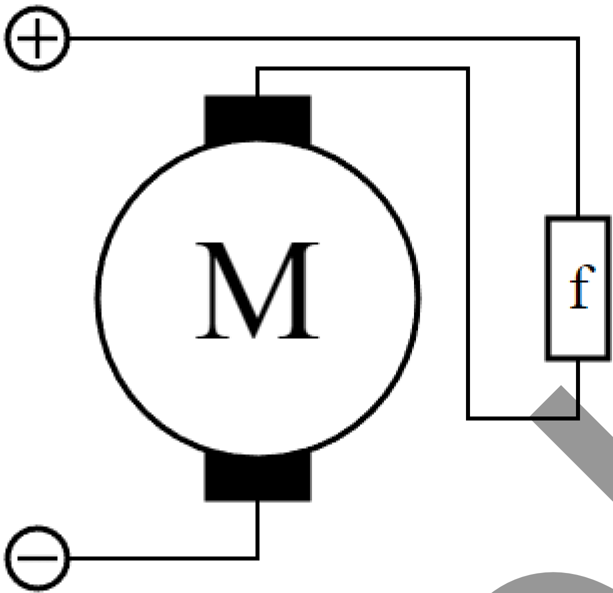

Figure 6 *Series wound brushed motor*

Shunt wound

This type has the field winding connected in parallel with the rotor winding. It can deliver increased torque, without a reduction in speed, by increasing the motor current. This type of motor is suitable for lathes, conveyers, grinders and vacuum cleaners.

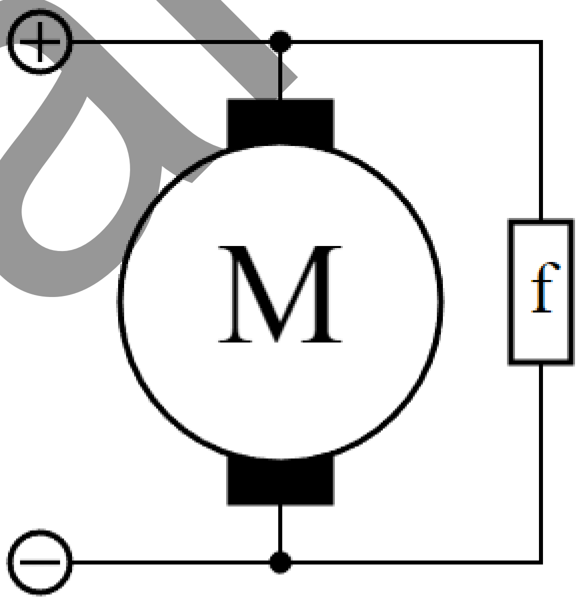

Figure 7 *Shunt wound brushed motor*

Compound wound

Uses a combination of series and shunt windings. The polarity of the shunt winding adds to the series field. This motor has a high starting torque and functions smoothly should the load vary slightly. It is used for compressors, rotary presses and elevators.

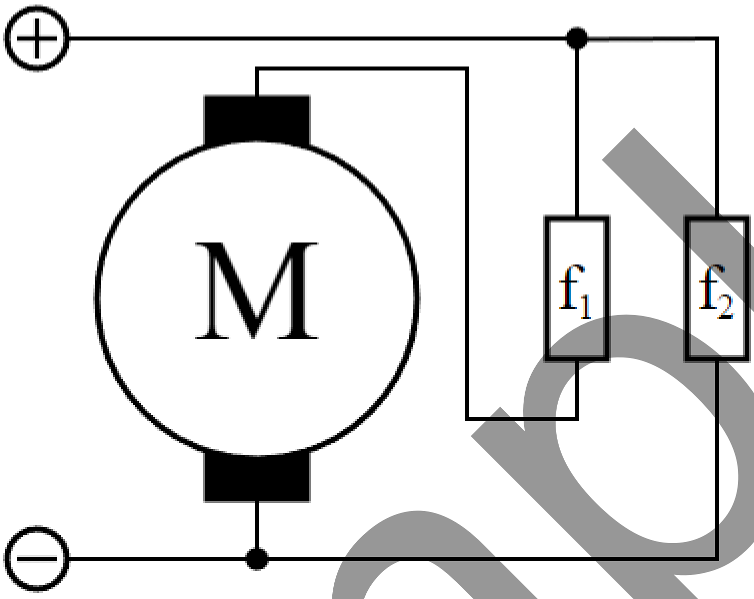

Figure 8 *Compound wound brushed motor*

Permanent magnet

Rather than use an electromagnet, this type uses permanent magnets in the stator, as shown in figure 9. It is used in precise control low-torque applications such as robotics and servo systems.

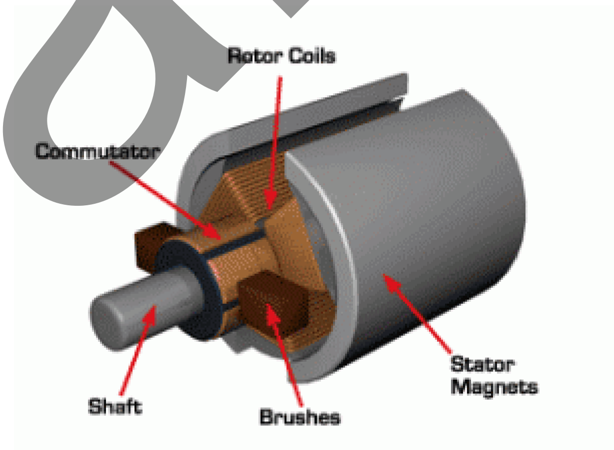

Figure 9 *Permanent magnet DC motor*

AC Motors

Synchronous

These motors have their speed of rotation synchronised with the frequency of the supply current, with the speed remaining constant with changing loads. Constant speed operation means that these motors find uses in robotics and process control.

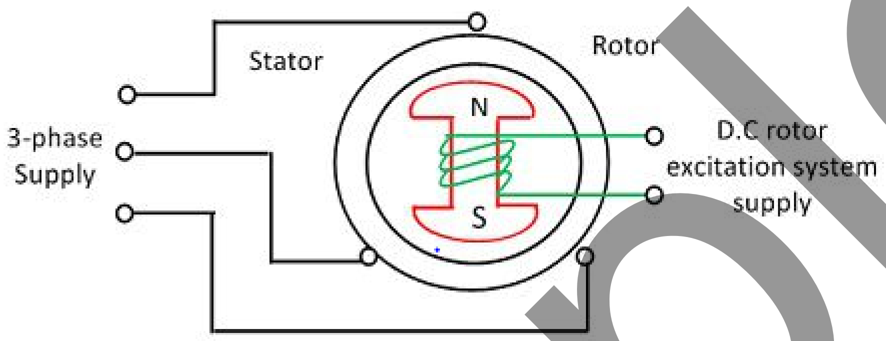

Figure 11 *Synchronous AC motor*

Asynchronous (Induction)

These are the most common types of AC motor. They use the electromagnetic field from the stator winding to induce an electric current in the rotor, and thereby torque.

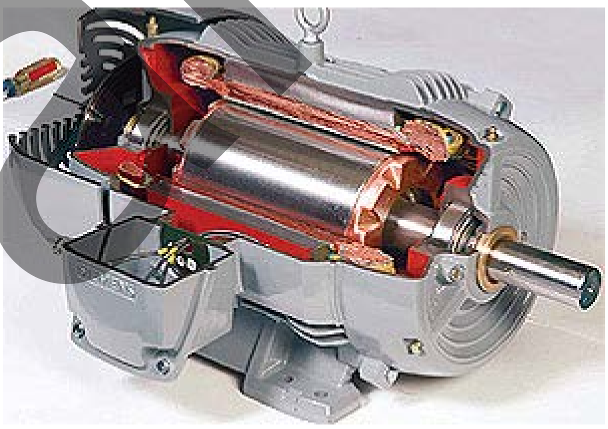

Figure 12 *Induction motor*

Single Phase

Single phase induction motors find uses in low-load applications such as household appliances.

Three Phase

Three phase induction motors find uses in high-load industrial applications such as compressors, pumps, conveyors and hoists.

Types of electric generators

There are two main types of generator; DC and AC.

DC Generators

These can be categorised as either;

- Separately excited
- Self-excited

Separately excited

Here an external DC source is used to energise the field coils.

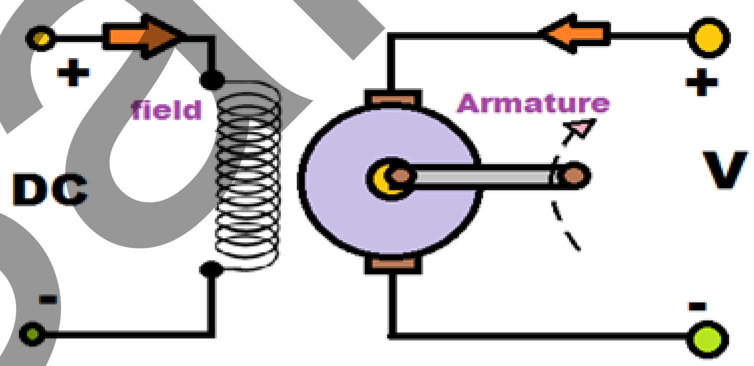

Figure 13 *Separately excited DC generator*

Self-excited

The generator produces its own current to energise the field coils. As for motors, we may have series, shunt and compound arrangement for the field and armature windings.

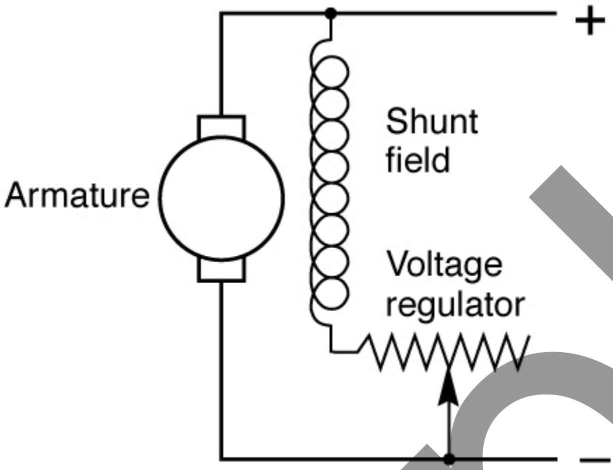

Figure 14 *Self-excited DC generator*

AC Generators

These can be categorised as either;

- Synchronous generator
- Induction generator

Synchronous generator

The coil is connected to slip rings, and the load is connected to brushes which rest on these slip rings. The slip rings are arranged in such a way that every 180 degrees of rotation sees the current direction reversed in the load; hence, an AC current is generated.

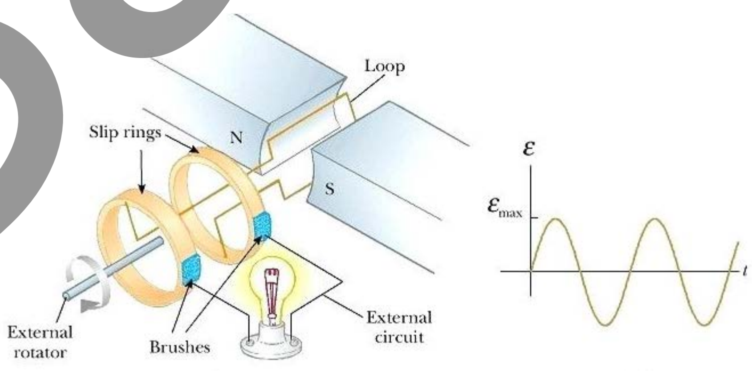

Figure 15 *Synchronous AC generator*

Induction (Asynchronous) Generator

Here, an AC supply to the stator causes a rotating magnetic field which causes the rotor to begin to turn. The rotor is made to turn faster (by a prime mover) than the synchronous speed of the magnetic field produced by the stator. The prime mover is often a petrol engine. The generator then becomes asynchronous.

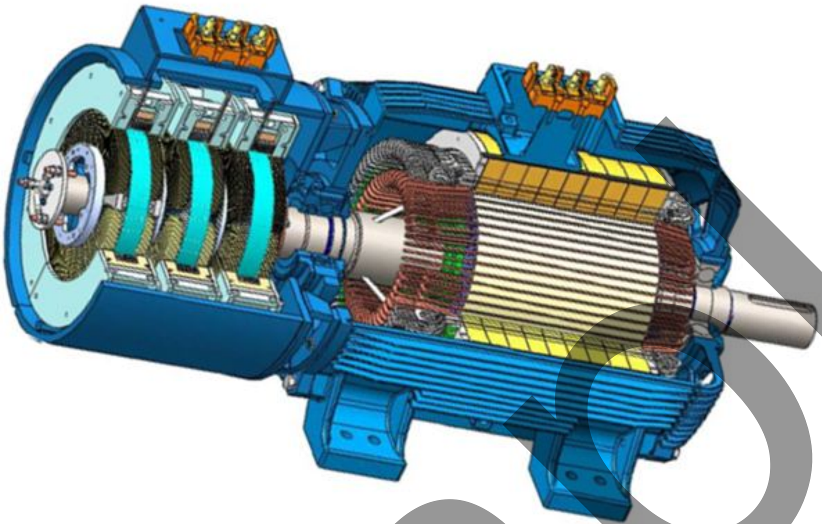

Figure 16 *AC induction generator*

Starting Methods

For motors rated at only a few kilowatts it only necessary to connect the supply and the motor starts by itself. However, where the motor is rated at well more than a few kilowatts we need to ensure that the motor does not affect the general power supply and perhaps dim lights or trigger circuit breakers.

When a large induction motor is started it can draw five or six times its rated current, and greatly lowers the power factor during the start-up. We therefore need to use starting methods to overcome these problems. Four starting methods are discussed next.

Star/Delta Starter

This is a very common starting method. To begin the starting process the motor windings are connected in a Star (wye) arrangement, causing the voltages applied to each phase to drop by nearly 50%. Once the motor reaches close to its designed running speed the windings are reverted to a Delta (Mesh) arrangement.

Autotransformer Starter

This is used when a star/delta starter will not provide enough starting torque. The autotransformer has just one winding per phase and one or more tapped points on each winding are used in succession, from lower voltage to higher voltage, until the motor reaches its rated speed.

Resistance or Reactance Starter

Placing three appropriately valued resistors or inductors in series with the motor, it is possible to reduce the starting current to any desired value. The downside here is that the starting torque is also reduced. Once the motor has reached full speed the resistors/inductors are shorted out with contactors.

Solid-State Soft Starter

This is a widely used starting method which allows for a smooth increase in both current and torque. The smoothness of starting prevents sudden jerks in the rotor and thereby protecting some sensitive loads. Semiconductor control circuitry and an arrangement of back-to-back thyristors is used to facilitate the smooth starting.

Quantification of Induction Motor Parameters

Rotor Voltage

Let us allocate some letters and subscripts to various quantities…

$E_1 \quad Stator\ e.m.f.(voltage)$

$E_2 \quad Rotor\ e.m.f.(voltage)$

$N_1 \quad Number\ of\ turns\ on\ stator\ winding$

$N_2 \quad Number\ of\ turns\ on\ rotor\ winding$

When the rotor is at a standstill…

$$E_2 = \left(\frac{N_2}{N_1}\right) E_1$$

The rotor e.m.f. when running (E_r) is proportional to the slip, s, therefore…

$$E_r = sE_2$$

$$\therefore \quad \boldsymbol{E_r = s\left(\frac{N_2}{N_1}\right)E_1}$$

Synchronous speed and rotor speed

Let…

$n_s = synchronous\ speed$

$n_r = rotor\ speed$

$$\therefore \quad \boldsymbol{n_r = n_s(1 - s)}$$

Efficiency and Power

Efficiency, η, can be quantified as…

$$\boldsymbol{\eta = \frac{output\ power}{input\ power} \times 100\%}$$

The main losses in an induction motor are;

- Stator losses
- Rotor copper losses
- Friction and winding losses

Torque

Let…

$R_2 = Rotor\ resistance$

$X_2 = Rotor\ reactance$

$m = number\ of\ phases$

$$\therefore \quad Torque, T = \left[\frac{m\left({N_2}/{N_1}\right)^2}{2\pi n_s}\right]\left[\frac{sE_1{}^2R_2}{R_2{}^2 + (sX_2)^2}\right]$$

Inertia

Let…

$T = Torque$

$I = Inertia$

$a = angular\ acceleration$

$$\therefore \quad I = \frac{T}{a}$$

EMI (Electromagnetic Interference)

EMI from an electrical machine (motor or generator) may be radiated and/or inducted. DC motors are a very common source of EMI. When EMI affects digital circuitry it can corrupt data, and therefore damage the operation of communications and computer circuitry. A large part of the the EMI problem results from;

- degradation or faults within the electrical or mechanical components
- arcing
- fast-switching driver circuits

EMC (Electromagnetic compatibility) is the term used to describe efforts to reduce EMI. Most countries have strict standards in terms of new products and the levels of EMI they can radiate.

EMC strategies involve the use of;

- A choke in the power feed
- A ceramic capacitor placed between motor terminals. 10nF is a common capacitor value
- A ceramic capacitor placed from EACH motor terminal to ground/casing
- More complex analogue filters using capacitors, inductors and resistors.