D3 – D8: Electrical power supply & components

Length: 145 minutes

Theory

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

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Learning outcomes

- Learn about AC and DC electricity
- Know the advantages of alternating current
- Know the theory of electromagnetic induction
- Understand how transformers work
- Know how transformers are rated
- Understand the way a capacitor is built
- Understand the purpose of a capacitor
- Understand their potential hazards
- Know about capacitor sizing
- Know about manual discharging of a capacitor
- Understand the purpose of a rectifier
- Understand the different types of rectifier
- Know about smooth DC
- Understand the construction of a three-phase motor
- Be able to describe the different parts of three phase motors
- Know the purposes of a three-phase motor
- Know how a three-phase motor. works
- Know how to alter the speed of a three-phase motor
- Know the difference between synchronous speed and actual speed
- Understand the construction of a single-phase motor
- Be able to describe the different parts of single-phase motors
- Know the purposes of a single-phase motor
- Know how a single-phase motor. works
- Know the various starting methods for single phase motors

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Types of power supply
Electromagnetic induction
Capacitors
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Single phase AC motors

Types of power supply

The two types of power supply are:

- alternating current (known as AC) and
- direct current (known as DC).

Alternating current is the type of electricity generated in power stations and then supplied to domestic, commercial and industrial premises by the local electricity distributor.

Direct current is the type of electricity you get from a battery or from rectifiers used to convert AC to DC.

Alternating Current (AC) theory

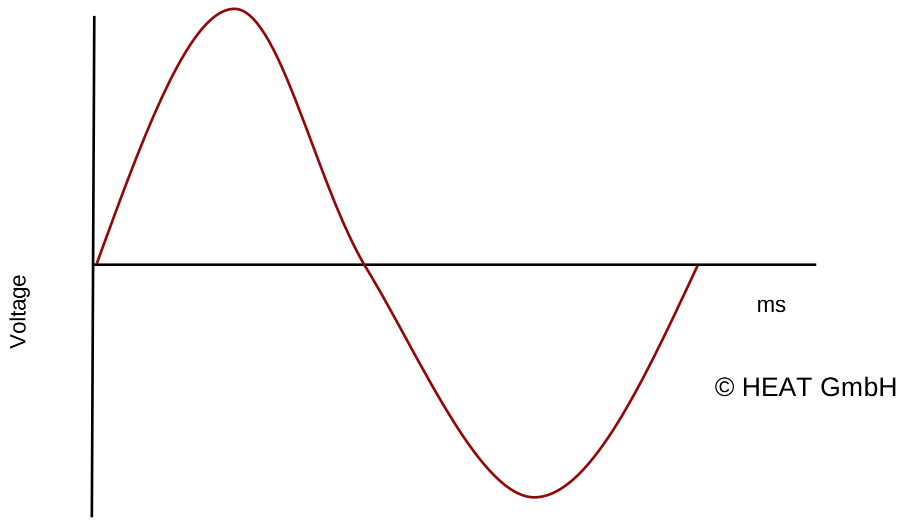
Up to this point, we have only considered current which flows in the same direction all the time.

When we consider AC current in a circuit, however, the current flows one way and then back again in the opposite direction. So it flows in both directions, essentially taking turns in which way it flows.

Types of power supply

Alternating current

- The number of cycles of current flow which occurs in one second is called the frequency of the alternating current.
- A frequency of 50 Hz is standard for electricity supplies throughout the EU.



Types of power supply

Alternating current

Advantages of alternating current

1) Motors designed to operate from AC supplies are much simpler and easier to maintain than similar apparatus designed to work from DC supplies.

2) AC voltages can be changed very easily both to higher and lower voltages by means of a transformer.

3) Transmitting higher voltages is more efficient, since they carry less current for a given amount of power and, consequently, the loss or volt drop is reduced.

Types of power supply

Root Mean Square (RMS) current and voltage

- The root mean square (RMS) value is the value most commonly used when expressing mains voltage as a value of 230V.
- The RMS is essentially the average voltage being supplied by the system.
- When power is generated, the mains waveform reaches a peak value, maximum current and hence maximum power is developed in the load.
- Following that, when the sine wave voltage reaches zero, no current and therefore no power is generated.
- Because the frequency of the mains is 50 Hz, the fact that the power drops to zero 100 times per second is not noticed, as 100 times per second maximum power is generated when the waveform reaches its peak values.
- The power is effectively averaged out during each cycle.
- To produce the same average power in the load, the peak value must be higher than the RMS value.

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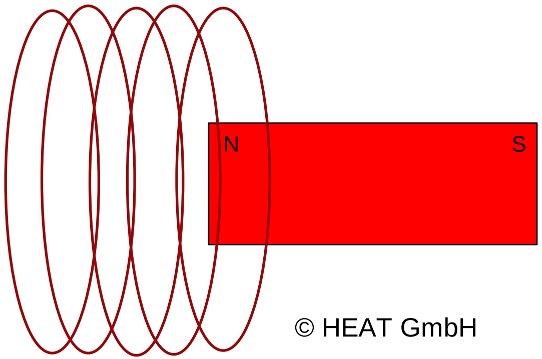
Electromagnetic induction

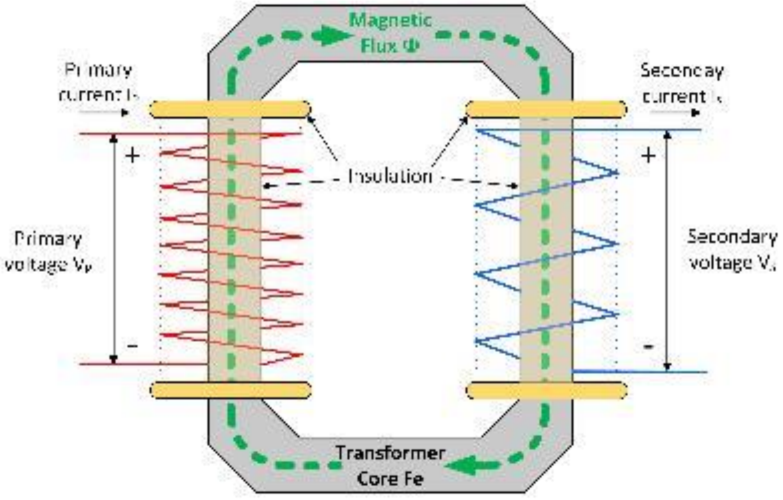
- Electrical energy is produced in a conductor (usually copper wires) by the magneto-electric effect.
- This is created when a conductor is moved in a magnetic field.
- The creation of a voltage in a conductor by this means is termed 'induction'.
- We say that a current is induced in a conductor, provided that the conductor forms part of an overall circuit.



Electromagnetic induction

Mutual induction and transformers

- Mutual induction is where a current in one coil induces a current in another adjacent coil.
- Transformers are inductive devices which work on the basis of mutual induction.
- They only work when there is a continually changing primary flux to permit an induced voltage to be developed across the secondary set of windings.
- Therefore, they can only be used to transform AC voltages; they cannot work at all in pure DC circuits where the primary current is kept constant.



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Electromagnetic induction

Uses of transformers

- Transformers are used to convert voltage - they change the level of one AC voltage to another, either upwards or downwards.
- Alternatively, they can be used as isolation devices, allowing two circuits to be coupled without there being a direct electrical connection, as in the case of bathroom shaver units (this is referred to as electrical separation and is used to reduce the risk of electric shock).
- When the number of turns on the primary winding equals the number of turns on the secondary, then the induced secondary voltage will equal the applied primary voltage.
- The transformer is then said to have a 1:1 turns ratio.
- In practice, losses within the transformer mean that the turns ratio only gives an approximate guide to the primary secondary voltage relationship.
- A turns ratio of 20:1 would produce a voltage across the secondary coil of one twentieth of the input voltage (i.e. a 230 V input would produce an 11.5 V output).
- Transformers can also be used to increase the voltage.
- A turns ratio of 1:3 would produce 690 V output from normal mains input (if we ignore any losses).

Example of Isolating Transformer
150 VA 230 V_S / 12 V_P

Electromagnetic induction

Uses of transformers

- Secondary windings often have a number of connection points which provide a variety of outputs.
- Some transformers include a centre tap in the secondary coil, which is usually earthed.
- This is a safety measure and effectively halves the maximum output voltage relative to Earth.
- In most cases the soft iron core and outer casing are bonded to Earth.
- This type of transformer is used to supply 110 V portable tools on construction sites.

Electromagnetic induction

Rating of Transformers

- As with all electrical equipment we must always consider the maximum current that can be carried without exceeding the rating of the transformer.
- They are limited in the amount of current they can supply from their secondary windings.
- If you try to draw too much current, the windings will get hot, which could melt the winding's insulation and thus burn it out.
- Transformers may get hot when they are being used and if it gets too hot the insulation on the windings will burn off and the transformer will then develop a short circuit.
- Transformers are power-rated in volt-amps (VA).
- Watts cannot be used to represent power dissipation in a transformer because the voltage and current are not in phase with each other as they are in a pure resistance.
- By using a volt-amps figure (which is essentially the same, arithmetically speaking), it is relatively simple to calculate the current that can be drawn from a transformer.

Electromagnetic induction

Rating of transformers

If a transformer has a particular VA rating, that is the maximum power that can be drawn from the secondary winding or windings.

Consider a mains step-down transformer that has a VA rating of 12 kVA and a single secondary winding of 110 V.

What maximum current can safely be drawn from the secondary winding ?

VA	=	Volts x Amps
12,000	=	110 x Amps
12,000 / 110	=	Amps
Amps	=	109.1 A

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Electromagnetic induction

Cooling of transformers

- Small transformers (e.g. 120V primary windings – 24V secondary windings) are cooled by the surrounding air.
- Some even have fans to assist with the dissipation of the heat.
- High voltage transformers however will need more than air to cool them.
- They will contain an oil to absorb the heat when they are in use and the oil then carries the heat to the casing which then gives up the heat to the surrounding air.
- Casings are often ribbed, to provide a larger surface area so as to loose heat more efficiently.

WARNING

- Older transformers may contain a potentially dangerous coolant fluid, PCB (polychlorinated biphenyl).
- Any sign of a thick and heavy fluid coming from the casing, it may well be PCB.
- Do not touch it.
- Ensure it is disposed of by an approved waste disposal company.

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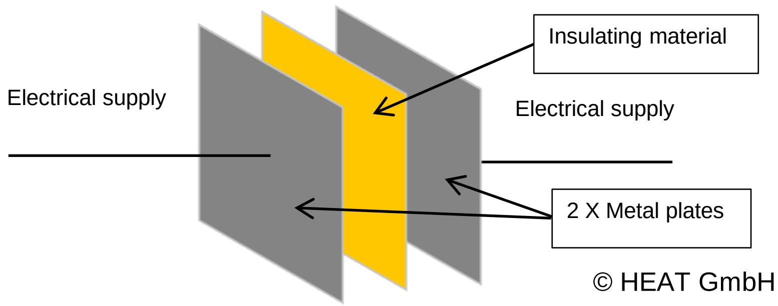
Capacitors

- A capacitor (formerly called a condenser), is a simple device for the temporary storage of electrical energy.
- It comprises two parallel metal plates, insulated from each other.
- If a DC voltage is connected across them, one of the plates becomes rich in electrons; the other plate becomes correspondingly poor.
- In acquiring this charge, a current flows – but it does so only for an instant.
- No sustained direct current can flow between the plates, since they are insulated from each other.
- **If the DC source is removed, the capacitor will retain its charge until it is discharged through an external circuit.**



Capacitors

- However, If an alternating current is fed to a capacitor it will commence to charge on one half-cycle but, as the voltage falls from its peak, it will attempt to discharge and to charge again (in the opposite direction) on the next half-cycle, and so on.
- As a result, a capacitor appears to pass current when connected to an AC source, but prevents the passage of DC, current.
- The larger the area of the plates in a capacitor, the greater the capacitance.
- In practice a capacitor is made from two thin sheets of metal foil, insulated by a dielectric, often made from waxed paper, mica or a similar material.
- The dielectric is simply the insulation between the two metal plates.
- Capacitors are rated in farads, however practically this is far too big, and the micro-farad (one millionth of a farad) is the unit in common use.
- This will be written as µF.

Example of a capacitor 80 µF

Capacitors
Manual capacitors discharge

If there is a need to discharge a capacitor in order to prevent electric shock or a potential source of ignition (especially when working with HC units), carry out the following procedure:

- With power source disconnected from the unit
- Secure the capacitor(s) and
- Place a 1000 Ω resistor across the terminals for 5 seconds.

- **NOTE: Do not use a wire, screw-driver or pliers to shortcut the terminals of the capacitor and avoiding sparking.**

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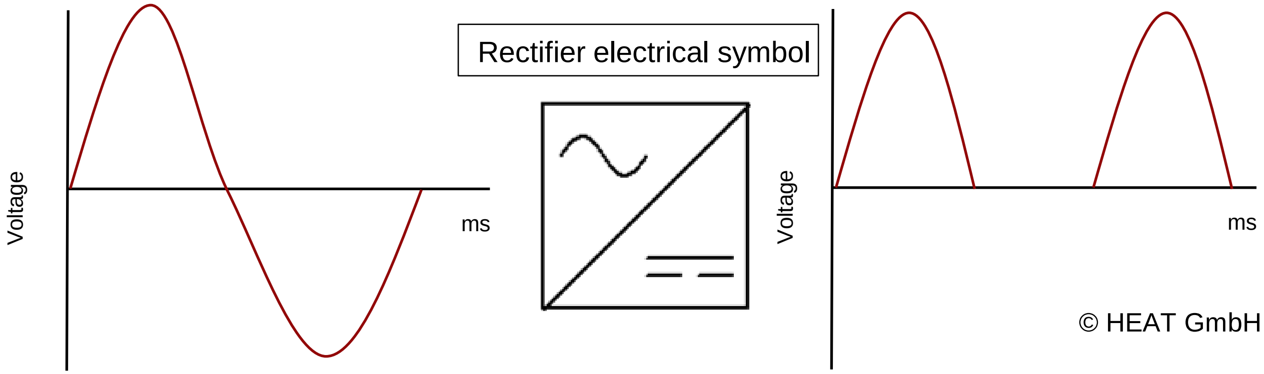
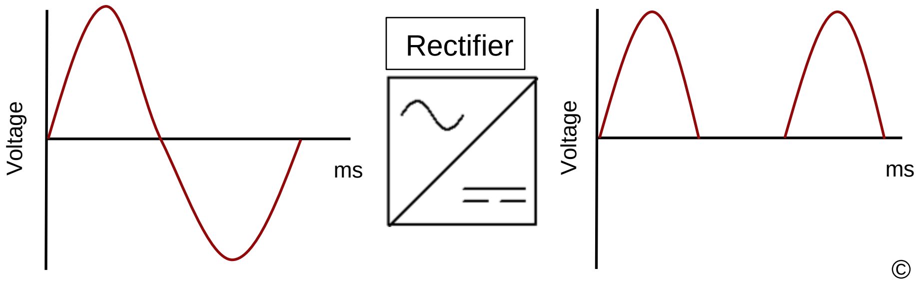
Rectifiers

- It may be necessary to convert an alternating current into a direct current.
- The process of doing this is known as rectification.
- A rectifier is rather like an electrical non-return valve, which permits current to pass freely in one direction, but which prevents current passing in the opposite direction.



Rectifiers

- An alternating current is one which passes through a cycle from a positive peak through zero to a negative peak and then back to zero voltage again.
- A simple rectifier prevents current passing on the negative cycle and only permits the positive element to pass through.
- The output would be a series of positive peak voltages (as shown below).

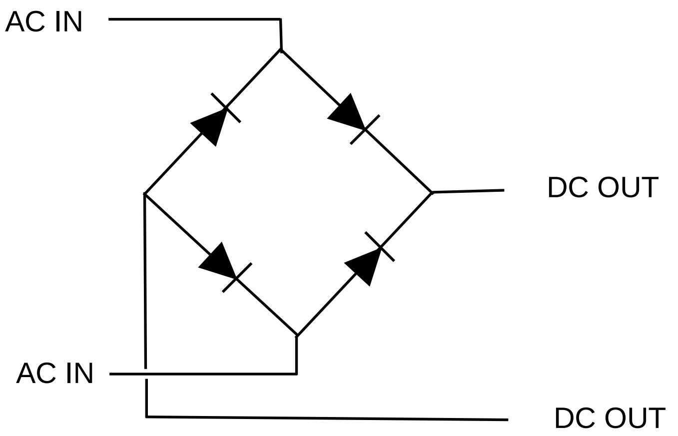


Rectifiers

- Rectifiers can be a single, solid-state diode or a more complex, full-wave or bridge rectifier.
- The bridge rectifier is arranged as to rectify both the positive and negative half-cycles of an alternating current, producing a DC output at twice the original frequency and twice the average voltage.
- This rectified output can then be smoothed to produce a DC output at a stable frequency.

NOTE: Rectifiers are commonly found in control equipment.

A bridge rectifier



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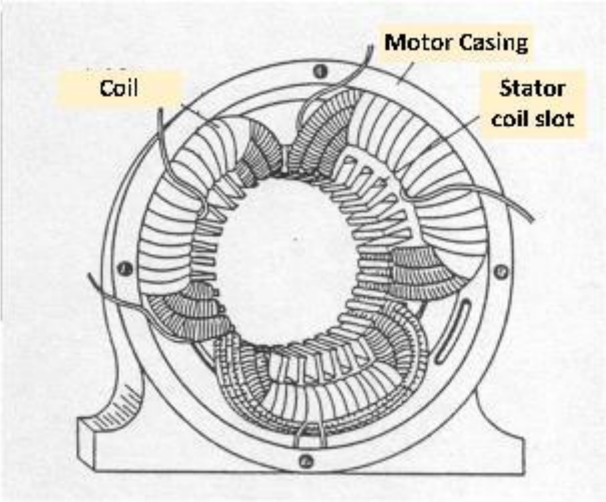
Three-phase induction motor

- Of all electric motors the simplest is the squirrel-cage type of induction motor used with a three-phase supply.
- The stator of the squirrel-cage motor consists of three fixed coils.

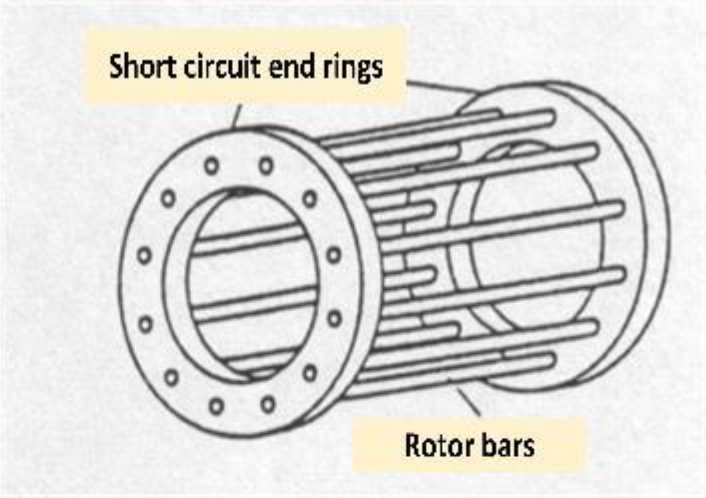


Three Phase Induction Motor Stator

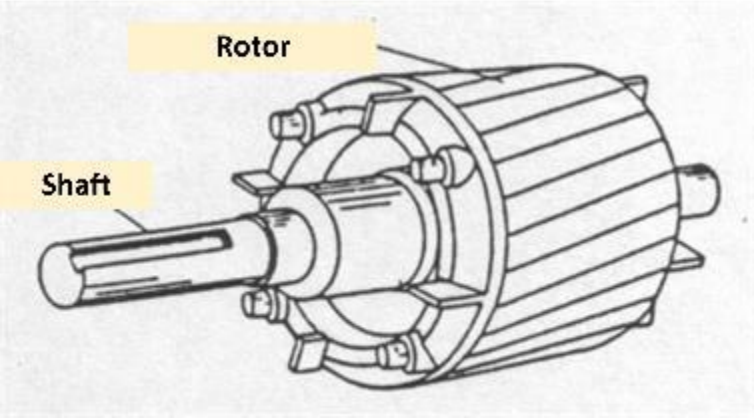
Three-phase induction motor

- The rotor is the part of the motor which rotates and is connected to the piece of equipment which is required to turn.
- Most induction motors contain a rotor in which the conductors are made of either aluminium or copper and are arranged in a cylindrical format resembling a ‘squirrel cage’.
- In squirrel-cage induction motors there is no electrical connection to the rotor, and the rotor is made of solid, un-insulated aluminium or copper bars short-circuited at both ends of the rotor with solid rings of the same metal
- This forms a low-resistance circuit that consists of a number of single-turn coils.
- The rotor is inserted in the space between the field coils which are fitted in to the stator, and any magnetic flux in those windings surrounds the rotor.

Three-phase induction motor



Simple rotor © LUA NRW



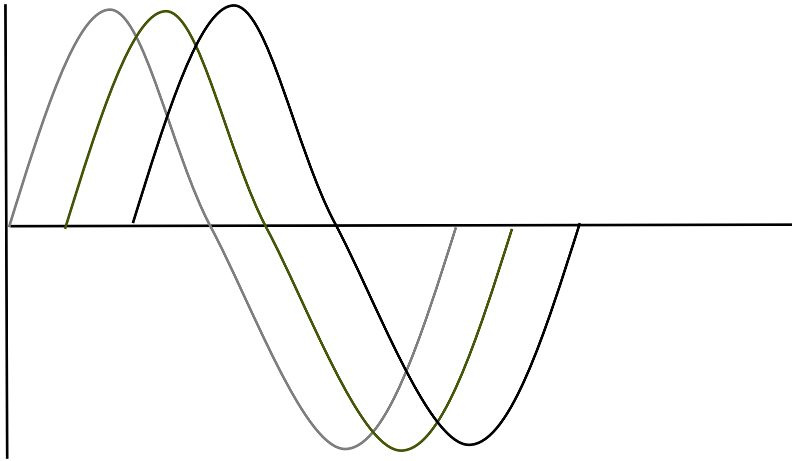
Rotor complete with shaft © LUA NRW

Three-phase induction motor

- Squirrel-cage induction motors are very common and almost 90% of the three-phase AC induction motors are of this type.
- They cost less and can start at heavier loads than their single-phase counterparts.
- Electrical power generated at power stations is AC and, because of this, many motors are designed to operate using AC.
- Power supplies may be single-phase or three-phase, but most larger AC motors operate on a three-phase supply.

Three-phase induction motor

Operation - how they work



- A magnetic field will be produced in each pair of windings, the strength of which will depend upon the voltage in that particular phase at any instant of time.
- When the voltage is zero the magnetic field will be zero, and maximum voltage will produce the strongest magnetic field.

Three-phase induction motor

How they work

- The rotor of a three-phase induction motor turns due to the rotating magnetic fields.
- The coils in the stator connected to the grey phase induce a magnetic field first, and then as the voltage in the grey phase drops to zero, the voltage in the coils connected to the brown phase induce a magnetic field in those coils and so on.
- As the rotating field of the stator cuts the rotor bars of the rotor, an EMF is induced into the conductors which form a closed circuit.
- A magnetic field is set up by the current flowing in the rotor conductors which interacts with the rotating magnetic field, causing the rotor to turn in the direction of the magnetic field.

Three-phase induction motor

- The number of poles (windings) per phase is what determines the speed of the motor.
- A motor with a two-pole winding will complete one revolution in one cycle,
- But if you double that to a four-pole winding, the motor will now complete one revolution for every two cycles of the supply.
- The more the number of poles per winding is increased; the speed of the rotating magnetic field is decreased, so for slower speeds, increase the pairs of windings (poles).

Three-phase induction motor

Rotation speed

The synchronous speed (the speed at which the magnetic field rotates) of AC motors depends upon the frequency of the supply and the number of pairs of poles on the stator.

The synchronous speed can be calculated using the following formula:

$$n_s = \frac{f \times 60}{p}$$

When

n_s=Revolutions per minute (RPM)

N = speed in rpm

f = frequency in cycles/second (hertz)

p = number of pairs of poles

Therefore, a motor wound with two poles per phase and connected to a supply of 50Hz would have a synchronous speed of:

$$n_s = \frac{50\ Hz \times 60}{1p} = 3000\ RPM$$

In reality, synchronous and actual speeds are not achieved. The difference between synchronous and actual speed is called slip.

- Synchronous speed assumes everything is perfect and in any mechanical machine there will always be losses.
- There will be approximately 5% loss under full load conditions.

Three-phase induction motor

Rotation speed

Motor speeds for three-phase machines							
Number of poles		2	4	6	8	10	16
Sync speed	rpm	3,000	1,500	1,000	750	600	375
Approx. FL speed	rpm	2,900	1,440	960	720	570	360

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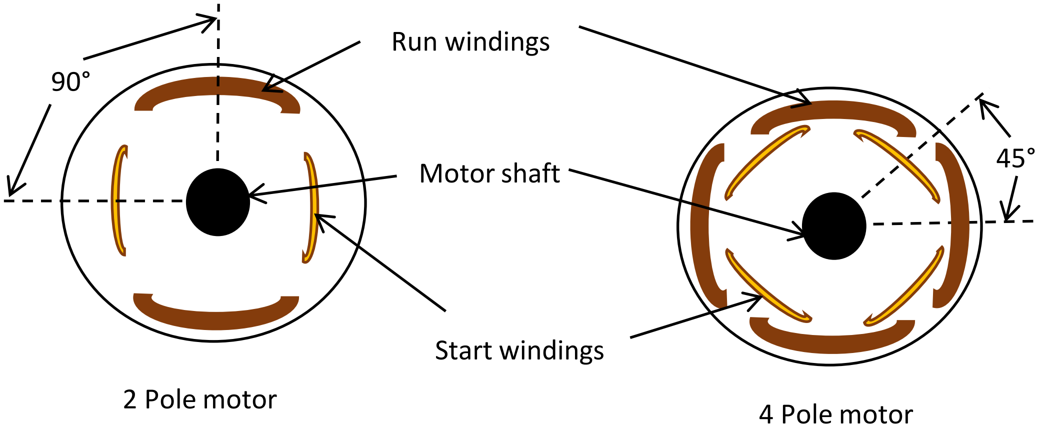
Single-phase AC motor

- A single-phase AC supply will not produce a rotating magnetic field produced by a three-phase supply.
- To start an AC motor a rotating magnetic field is required.
- When there is only a single-phase supply, the magnetic field in the windings rises to maximum, falls to zero and then rises to a maximum in the opposite direction.
- This creates only a 'pulsating' magnetic field which rises and falls with the supply frequency but does not rotate around the stator.
- This pulsating magnetic field in the windings built into the stator will not cause the rotor to rotate.
- To get the rotor to rotate we need to create a rotating magnetic field.
- One way to create a rotating magnetic field in the stator is to introduce a second winding known as a start winding.
- This is displaced on the stator by 90˚ to the main field winding, which is commonly known as the run winding.

Single-phase AC motor



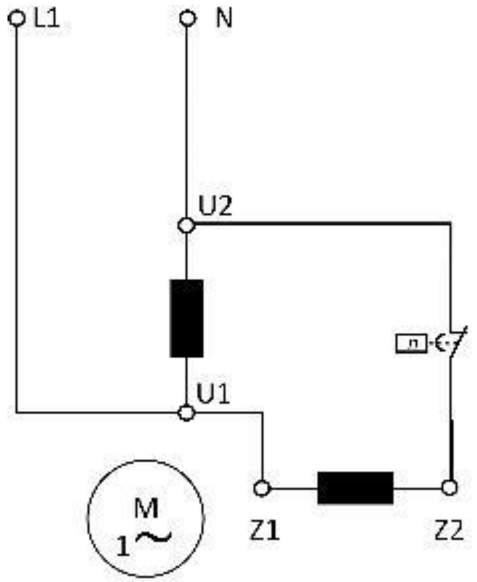
Single-phase AC motor

The split-phase motor (also known as Resistance start motor)

- The split phase motor has two windings built into the stator – a run winding and a start winding (the latter being only used to start the motor, as the name suggests).
- The run winding has low resistance and high reactance (*reactance* is the resistance offered to the AC currents by inductors and capacitors only)
- And the start winding has high resistance and low reactance.
- The start windings will create a magnetic field first followed by a magnetic field in the run windings
- And hence there is now a rotating magnetic field which will cause the motor to rotate.
- The running winding is created with thicker wire than the starting winding and
- Has less resistance than the starting winding, which is made up of very fine wire
- The starting winding is only required for a very short time and is automatically cut out by a centrifugal switch or relay when the motor reaches about 75% full speed.

Single-phase AC motor

The split-phase motor (also known as Resistance start motor)



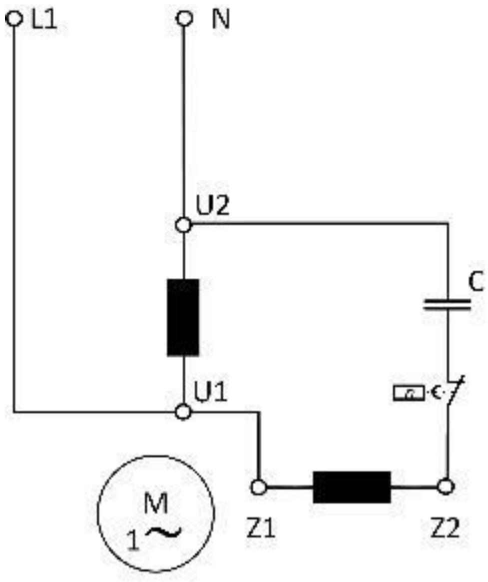
Single-phase AC motor

Capacitor Start Motor

- In capacitor start motors, during the starting sequence, as the capacitor is connected in series with the starter winding, the current through the starter winding *Is* leads the voltage V, which is applied to the circuit
- Whereas the current through the run (or main) winding *Im*, lags the applied voltage V across the circuit.
- The bigger the difference between the *Is* and *Im*, the better the resulting rotating magnetic field.
- The capacitors are usually fixed to the frame of the motor but can be mounted separately nearby.

Single-phase AC motor

Capacitor start motor



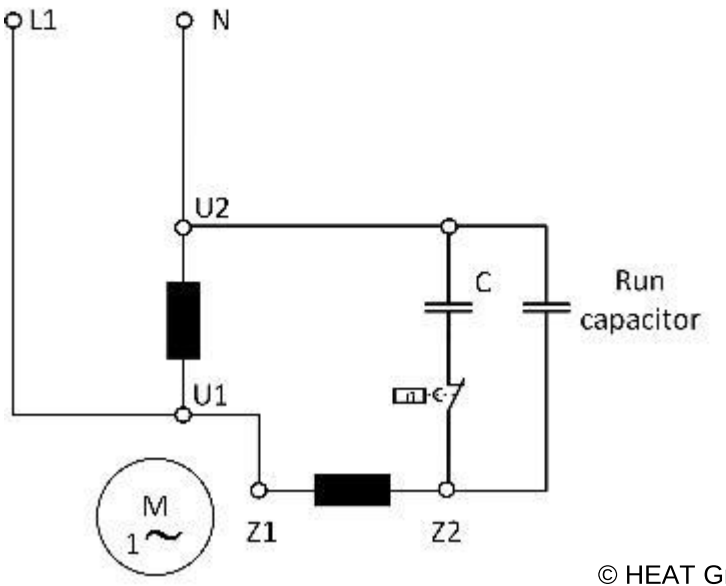
Single-phase AC motor

Capacitor start capacitor run motor

- The capacitor start, capacitor run motor, has two capacitors used to start the motor
- A large and a small capacitor are connected to the start winding during starting
- Once the motor is running a centrifugal switch or relay will disconnect the large capacitor, leaving the small capacitor in circuit.
- The small capacitor is capable of carrying load.
- The overall *effect* is a better running torque and an improved power factor.

Single-phase AC motor

Capacitor start capacitor run motor



Typical Capacitor Start Capacitor Run Motor

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GIZ Proklima

Contact:
Bernhard Siegele
E bernhard.siegele@giz.de
T +49 6196 79-1968
I www.giz.de/proklima

Author:
Anthony Darlow, Rolf Hühren
E anthony.darlow@heat-international.eu; rolf.huehren@heat-international.de
HEAT GmbH, Königstein i. Ts., Germany

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Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Friedrich-Ebert-Allee 36 + 40
53113 Bonn, Germany
T +49 228 44 60 - 0
F +49 228 44 60 - 17 66

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Germany
T +49 61 96 79 - 0
F +49 61 96 79 - 11 15

E info@giz.de
I www.giz.de

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH