DEMec - Dep. of Mechanical Engineering
SAIC- Automation, Instrumentation and Control Section
Master in Mechanical Engineering

Electromechanical Systems

1st Year– 2nd Semester
2025-2026

Support documents to TP classes

Induction motors

Paulo Abreu

2026 Edition

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AC induction motors

Paulo Abreu

March 2026

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Electric Motors classification
Working principle/source of energy

- Electric motors
  - Brushed Motors (*de escovas*)
    - DC motors
    - AC motors
    - Universal motor
  - Synchronous Motors (*síncronos*)
    - Single phase motors
      - Permanent magnets
      - Reluctance
      - Hysteresis motors
    - Three-phase motors
    - BLDC motors (brushless DC motors)
    - Stepper motors
  - Asynchronous Motors (*assíncronos*)
    - Single phase motors
      - Shadow poles
      - Capacitor start induction motors
    - Three-phase induction motors

Induction motors

- Three-phase induction motors
  - Working principle
  - Torque-speed and current-speed curves
  - Motor characteristics
- Single-phase induction motors

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Three-Phase Induction Motors

The Three-Phase Induction Motor (IM) is the "workhorse" of modern industry. Its dominance in the market is due to several key factors:

- **Robustness**: no brushes or commutators, leading to extremely low maintenance.
- **Cost-Efficiency**: the squirrel-cage construction is simple and inexpensive to manufacture.
- **Direct-on-Line (DOL) Capability**: ability to start directly from the AC grid without complex electronics, operating at a constant speed

Note: for variable speed operation, a driver (variable frequency driver- VFD) is necessary, increasing the solution cost and improving the energy efficiency

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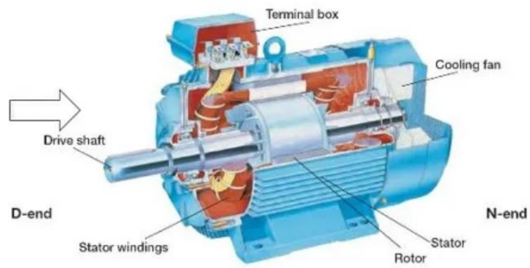
Three-phase induction motor Construction and Architecture

Main components:

- **The Stator**: a stationary frame housing three-phase windings displaced by 120° in space. When powered by a three-phase AC supply, it generates a **Rotating Magnetic Field** (RMF)
- **The Rotor** (Squirrel-Cage): a series of conducting bars short-circuited by end rings. It is not connected to any external power source; its energy is received entirely via **induction**
- **Shaft and Bearings**



Motor WEG

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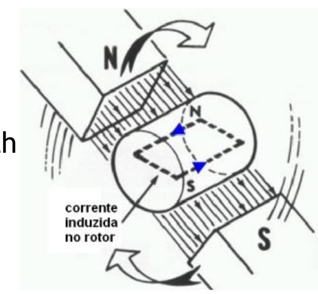
Three-phase induction motor

Working principle

1. **RMF Generation:** creation of a rotating magnetic field in the stator, through the three-phase AC supply, that rotates at the **Synchronous Speed** (n_s)
2. **Induced EMF and current in rotor (Faraday's Law):** as the RMF sweeps across the stationary rotor bars (in squirrel-cage design) it induces a voltage and subsequent current in the rotor
3. **Torque due to interaction of magnetic fields (Lenz's Law):** the rotor current creates its own magnetic field, which interacts with the stator RMF. The rotor tries to "catch up" with the RMF to reduce the rate of flux change, creating torque



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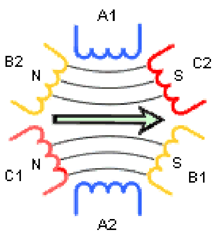
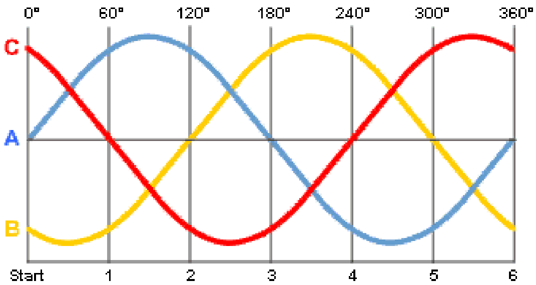
Three-phase induction motor: Stator

Process of generating a **Rotating Magnetic Field** in the stator:

- by the three-phase AC power supply applied to the stator coils



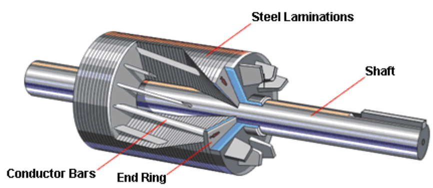


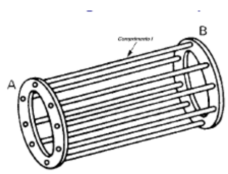
The rotor then follows the rotating field created

www.siemens.com

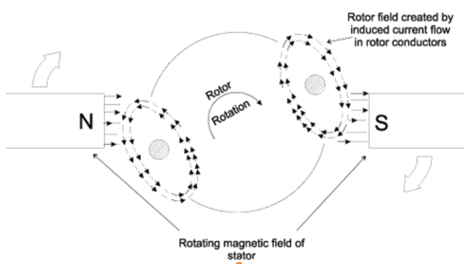
video: Understanding electric motor Windings

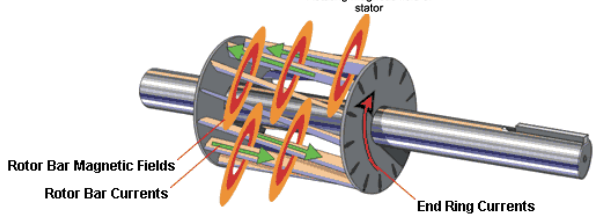
Three-phase induction motor: Rotor



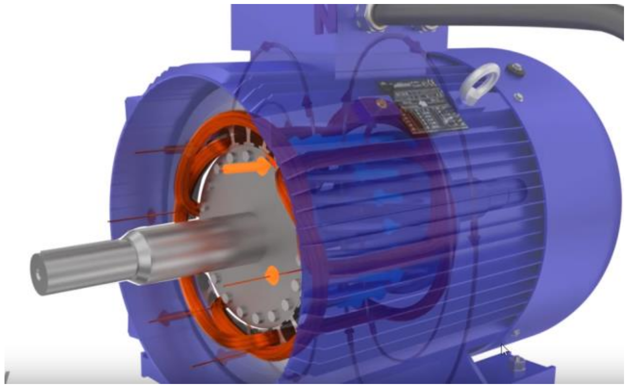


Rotor (squirrel cage)





Three-phase induction motor



https://www.youtube.com/watch?time_continue=9&v=AQqyGNOP_3o

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Three-phase induction motor: Speed

- The **synchronous speed** (n_s) is the speed of rotation of the magnetic field in the stator, defined by:
  - $n_s = 120\, f/p$ with
    - n_s = synchronous speed [rpm]
    - f = frequency of supply voltage [Hz]
    - p = number of stator poles (per phase)

- **Synchronous speed** (n_s) depends on
  - Number of poles (motor built with a given number of poles)
  - Operating frequency of the power supply

  To change synchronous speed: use of a variable frequency driver (VFD) or configuration of nº poles in some specially built motors, using contactors

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Three-phase induction motor: speed

- The **rated speed** (n_n) of an induction motor is typically between 90% and 97% of the **synchronous speed** (n_s), corresponding to a slip of about 3% to 10%
- A fundamental characteristic of **induction (asynchronous) motors** is that the rotor never reaches synchronous speed. If $n_n = n_s$, there is no relative motion; therefore, no flux change ($d\phi/dt = 0$), no induced current, and zero torque
- The **slip** (s) is defined by

$$s = \frac{n_s - n_n}{n_s} \qquad s\,[\%] = 100 \cdot \frac{n_s - n_n}{n_s}$$

- Typical values of **SLIP** depend on motor power
  - Motors with power < 0.25 kW : s = 10%
  - Motors with power >15 kW : s = 3%

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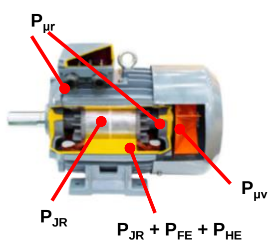
Three-phase induction motor

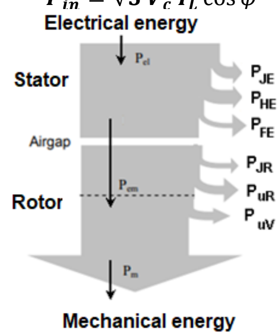
Motor energy balance

Losses of electromagnetic, thermal, and mechanical energy:

- Stator
  - Joule - P_{JE} (I^2R), Hysteresis - P_{HE} e Foucault - P_{FE}
- Rotor
  - Joule - P_{JR} (I^2R), bearings friction - $P_{\mu r}$
- Fan
  - friction - $P_{\mu v}$



$$P_{in} = \sqrt{3}\, V_c\, I_L \cos\varphi$$



$$P_{out} = T_m\, \omega_m$$

Typical efficiencies of 60% up to 98%

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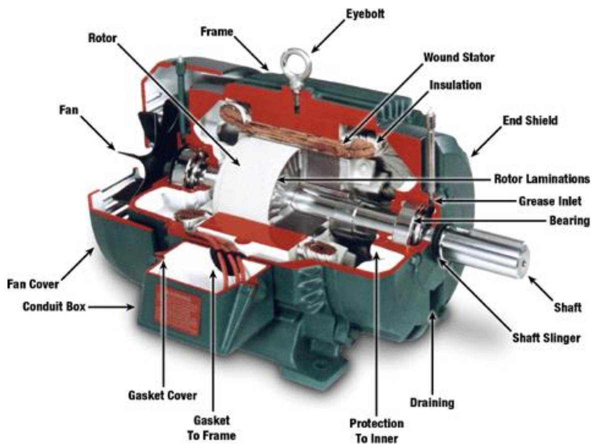
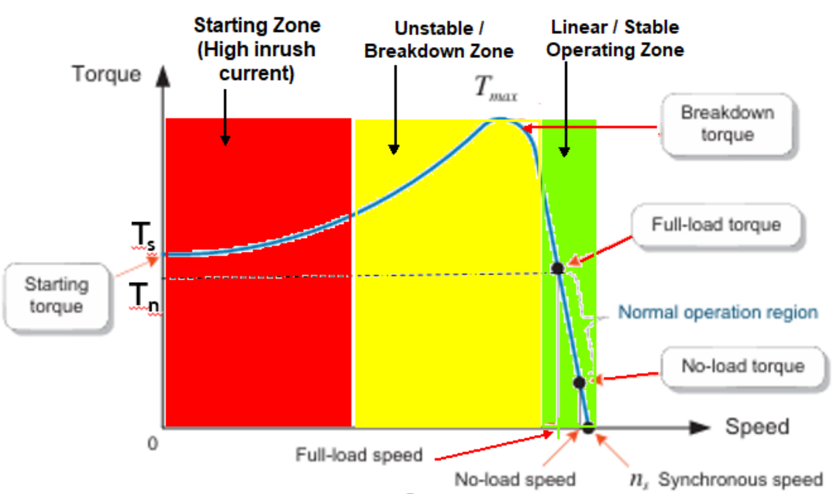
Three-phase induction motor



Three-phase induction motor
Typical Torque–Speed Curve

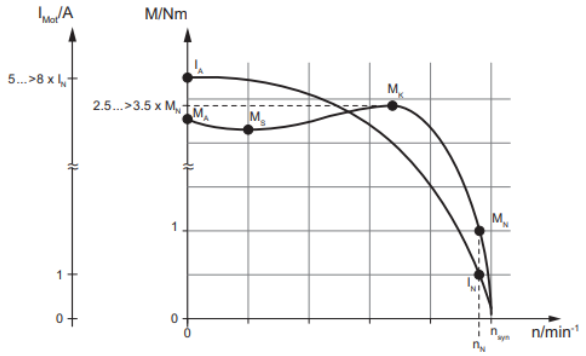


T_s - start torque (1.2 up to 2.5 T_n)

T_n - nominal torque

n_s - synchronous speed

Three-phase induction motor
Typical Torque–Speed Curve and Current–Speed curve

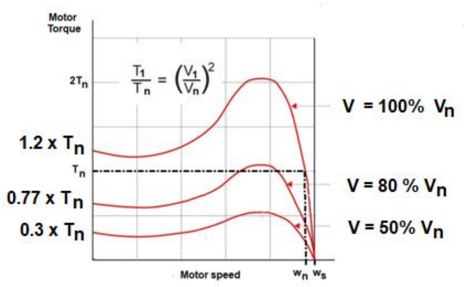


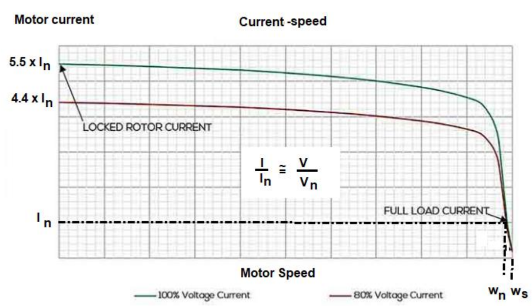
I_{Mot}	Motor current as a function of the rotational speed
M	Motor torque as a function of the rotational speed
I_A	Starting current
M_A	Starting torque
M_S	Pull-up torque
M_K	Breakdown torque
M_N	Rated torque
I_N	Rated motor current
n_N	Rated speed
n_{syn}	Synchronous speed
n	Speed

Start current: typically 5 to 8 x nominal current

Can be a problem! The use of Star-Delta starters, Soft-starters, or Variable Frequency Drives (VFDs) can overcome this problem

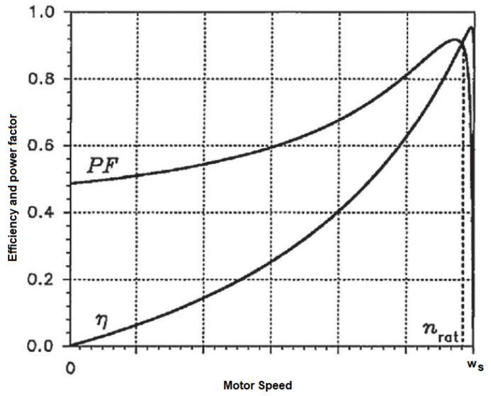
Torque–speed and current-speed curves
Influence of Supply Voltage





- The starting torque and the maximum torque of the motor is almost directly proportional to the square of the feeding voltage: $T/T_n \propto (V/V_n)^2$ **(10% drop in voltage** leads to a **~19% drop in torque)**
- The starting current is almost directly proportional to the feeding voltage: $I/I_n \propto V/V_n$

Three-phase induction motor
Efficiency and power factor curves



- See: Effects of Voltage Quality on Induction Motors' Efficient Energy Usage | IntechOpen

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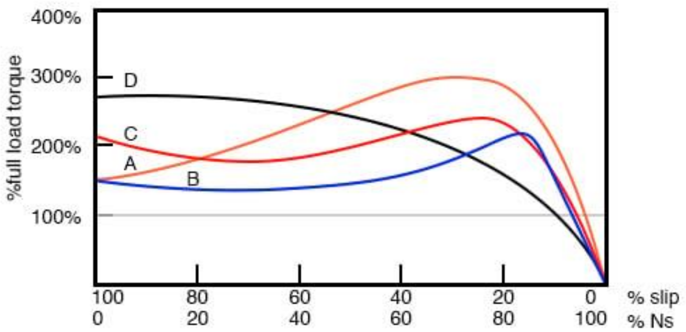
Three-phase induction motor
Torque–speed curves

NEMA motors type A, B, C and D



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Three-Phase Induction Motors: Operational Summary

1. **The Principle of Slip (s)**
   - The rotor must always lag behind the Stator's Rotating Magnetic Field ($n_r < n_s$)
   - Standard Slip: typically 3-10% at rated load
2. **The Starting Paradox:**
   - High Current: 500%-800% of nominal current at t=0
   - Low Torque: starting torque (T_s) is significantly lower than breakdown torque (T_{max})

   Note: for many (squirrel cage) induction motors, $T_s \approx 1.5\, T_n$ *while* $T_{max} \approx 2.5 - 3.5\, T_n$
3. **Control Sensitivity:**
   - Torque is highly sensitive to the supply voltage ($T_n \propto V^2$)
   - Speed is primarily determined by the supply frequency (f) and the number of poles (p)

   $$n_s = 120\, f/p$$
4. **Industrial Application:**
   - Rugged, low-maintenance, and the standard for constant-speed applications. For variable speed, a VFD is mandatory to maintain efficiency and control

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Motor Efficiency Standards (IEC 60034-30)

- The IEC defines **International Efficiency (IE) classes** for AC motors. These apply to motors powered either directly from the grid or via inverters.
- Classification Hierarchy
  - IE1: Standard Efficiency
  - IE2: High Efficiency
  - IE3: Premium Efficiency
  - IE4: Super Premium Efficiency
  - IE5: Ultra Premium Efficiency (covered under part 2 for variable speed)

Feature	IEC 60034-30-1	IEC 60034-30-2
Operation	Fixed speed (Direct-on-line)	Variable speed (Inverter/Driver)
Power Range	0.12 kW to 1000 kW	0.12 kW to 1000 kW
Voltage	50 V to 1000 V	50 V to 1000 V
Classes	IE1 to IE4	IE1 to IE5

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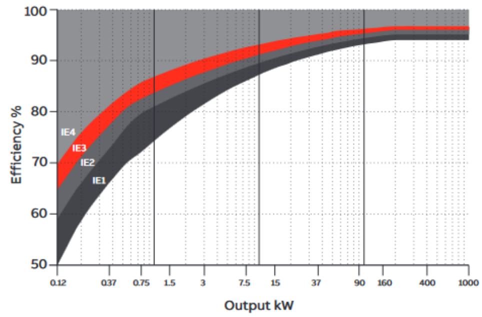
Motor Efficiency Standards (IEC 60034-30) International Efficiency (IE) classes

- IEC 60034-30-1 defines four IE (International Efficiency) efficiency classes for single speed AC electric motors (with power from 0.12 to 1000 kW, with 2, 4, 6 or 8 poles, supply voltage from 50 V up to1000 V)

  - IE1, Standard efficiency
  - IE2, High efficiency
  - IE3, Premium efficiency
  - IE4, Super premium efficiency

Note: IEC 60034-30-2 defines 5 classes:
IE1 up to **IE5**



Ref. image

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Motor Efficiency Standards (IEC 60034-30-2) International Efficiency (IE) classes

- IEC 60034-30-2 defines 5 efficiency classes IE (International Efficiency) for AC motors not operated directly from the power supply, which use a driver (inverter) for variable speed control (classes IE1, IE2, IE3, IE4 e IE5)
- Motors covered:
  - Nominal power P_N from 0,12 kW up to 1 000 kW
  - Nominal voltage, U_N, from 50 V up to1 kV
  - Nominal speed, from 600 rpm up to 6000 rpm, regardless of the number of magnetic poles
  - Motors with cooling methods IC4A1A0 (IC410), IC4A1A1 (IC411), IC4A1A6 (IC416), or IC4A1A8 (IC418), in accordance with IEC
  - Capable of continuous operation at the rated operating point (torque/power, speed) with a temperature rise compatible with the specified insulation class temperature

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EU Eco-design Regulations & Implementation

The EU has introduced mandatory requirements to phase out inefficient motors, significantly impacting industrial energy consumption

- Jan 2017: all motors from 0.75 to 375 kW must meet at least IE3
- July 2021: three-phase motors between 0.75 kW and 1000 kW must reach IE3 level
- July 2021: the Regulation on electric motors and variable speed drivers (EU) 2019/1781 is mandatory, (REGULAMENTO (UE) 2021/341)
- July 2023:
  - three-phase motors between 75 kW and 200 kW must meet IE4
  - single-phase motors (≥0.12 kW) must meet IE2

https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/electric-motors_en

System-Level Efficiency (IEC 61800-9)

Modern engineering focuses on the **Extended Product approach**, looking beyond just the motor to the **entire actuation system**

- **Components of the Power Drive System (PDS)**
  1. **CDM (Complete Drive Module):** includes the feeding section, auxiliaries, and basic drive module (VSD)
  2. **Motor**: the electrical machine
  3. **Transmission & Load**: the driven equipment

System-Level Efficiency (IEC 61800-9)

- **New Efficiency Labels for Systems**
  Unlike motors, **drives and full systems** use **IE** and **IES** labels based on losses relative to a reference value:
  - **Complete Drive Module (CDM)**: rated as **IE0, IE1, or IE2.**
    Class IE1 is the reference; if losses are >25% of the reference, it is **IE0**.
  - **Power Drive System (PDS)**: rated as **IES0, IES1, or IES2.**
    If losses are >20% of the reference, it is **IES0**.

- **Characterization Points**
  - Efficiency is not static. The standard defines (varying speed and torque) to characterize performance under partial loads, allowing for system optimization

System-Level Efficiency (IEC 61800-9)

- The efficiency of electric motors is important, but the combined efficiency of the control system + motor + transmission must also be considered.
- Standard **EN 50598 /** IEC61800-9, **Part 1 and Part 2** specifies energy efficiency indicators for *Eco-design for power drive systems, motor starters, power electronics and their driven applications*

https://www.focusondrives.com/a-new-international-standard-for-energy-efficiency-iec61800-9/

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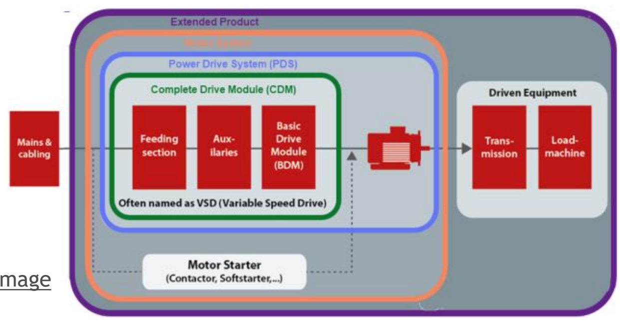


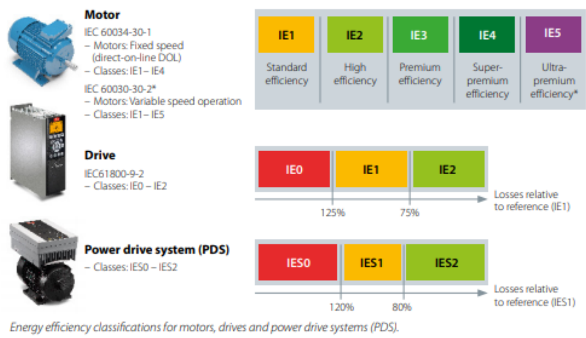
System-Level Efficiency (IEC 61800-9)

For motors from 0.12kW to 1000 kW, not operated directly from the supply
(servo motors are excluded from this standard)

Five efficiency classes for Motor: IE1 up to IE5

Three efficiency classes for Driver
(CDM- *complete drive module*): IE0, IE1 IE2
The rating is determined by taking into account the losses in the drive, including filters, braking resistors. Ratings are rated for 90% frequency and 100% current operating conditions

Three efficiency classes for PDS (*power drive system*- IES0, IES1 and IES2
The classification is determined taking into account the losses in the drive system (CDM-complete drive module) and the losses in the motor for an operating situation corresponding to 100% speed and 100% torque



Energy efficiency classifications for motors, drives and power drive systems (PDS).

Ref image

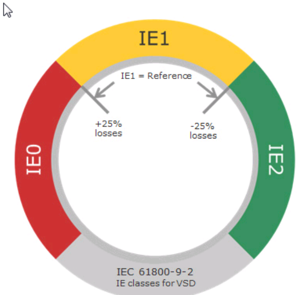
see http://ecosmart.danfoss.com/

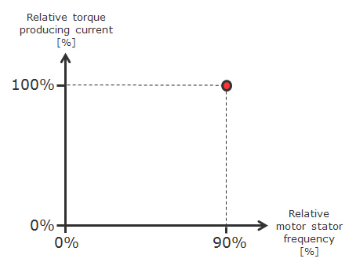
System-Level Efficiency (IEC 61800-9)

Efficiency classes for Drivers: IE0, IE1 and IE2

- A reference value is defined for each power size. This reference value corresponds to the IE1 class. If the drive has losses greater than 25% relative to the reference value, it is categorized in class IE0

The IE class for the drive is evaluated for only one operating point
(100% current and 90% speed)





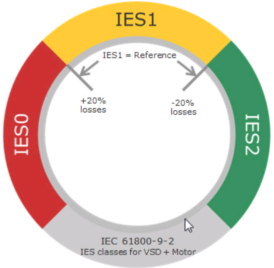
System-Level Efficiency (IEC 61800-9)

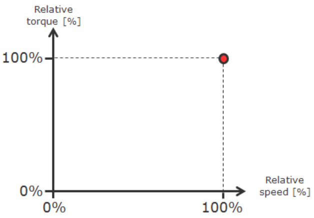
Efficiency classes for *Power Drive System* (PDS): IES0, IES1 and IES2

- There is a reference value for each power size. This reference value corresponds to the IES1 class. If the drive and motor have losses greater than 20% relative to the reference value, it is categorized as class IES0.

The IES class for the Power Drive System(PDM) is evaluated for only one motor operating point (100% current and 100% speed)

Note: PDS includes driver and motor





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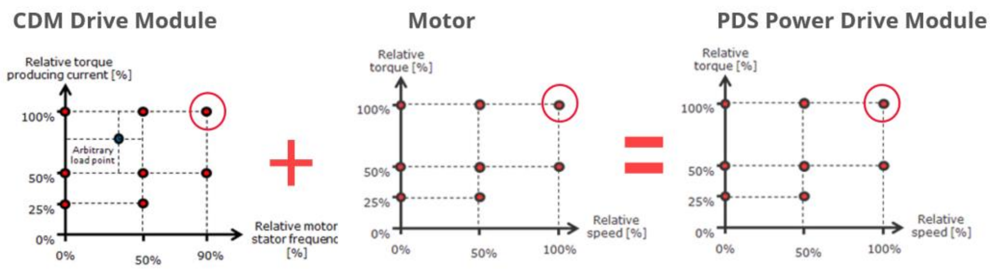
System-Level Efficiency (IEC 61800-9)

- The IEC 61800-9 standard also defines **eight operating points** that can be used to characterize the performance of the driver and motor-drive systems, under partial load situations, which also allows extrapolating values to other operating conditions.



See "bauergears"

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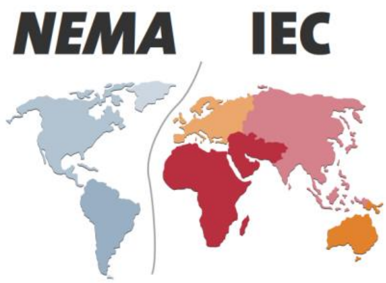
Three-phase induction motor
Global Standardization Framework

Electric motor specifications are governed by two primary international bodies:

- **IEC (**International Electrotechnical Commission**)**: the standard in Europe and Asia
- **NEMA (**National Electrical Manufacturers Association**)**: the standard in the USA and Canada



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Three-phase induction motor
Global Standardization Framework

The specification of the multiple functional and motor construction aspects follows a broad set of parameters that are standardized. The primary standards and directives include:

- IEC 60034 *Rotating electrical machines (3189 pages!)*
- EC 60072-1 *Dimensions and output series for rotating electrical machines - Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1080*
- Directive EU 2019/1781, *eco-design requirements for electric motors and variable speed drives*

- IEC 60529 *Degrees of protection provided by enclosures (IP Code)*
- IEC 60085 *Electrical insulation - Thermal evaluation and designation*
- IEC 60038 *IEC standard voltages*

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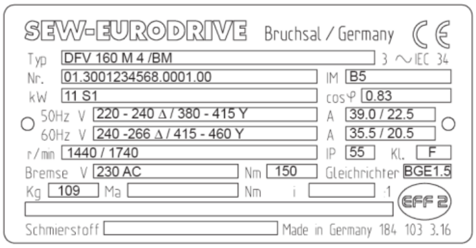
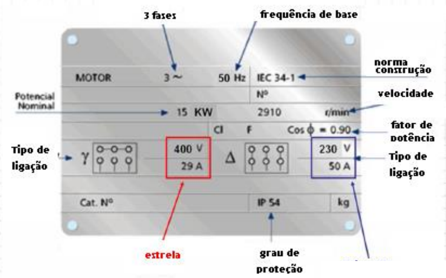
Three-phase induction motor
Rated characteristics – The Nameplate

Constructive and performance characteristics

- Nominal power (mechanical)
- Rated speed
- Rated current
- Rated voltage (Terminal connections-Star/delta)
- Rated frequency
- Power factor
- Degree of protection (IP)
- Insulation class
- Efficiency class





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Three-phase induction motor
Standard Supply Voltage Range

Standard supply voltages: 230 V, 400 V, 500V, 660 V., 50/60 Hz

Direct-on-line start or, with Δ-connection, also Y/Δ-start

Motor size	S		D	
	50 Hz	60 Hz	50 Hz	60 Hz
56-100	220-240 VΔ	-	380-415 VΔ	440-480 VΔ
	380-415 VY	440-480 VY	660-690 VY	-
112-132	220-240 VΔ	-	380-415 VΔ	440-480 VΔ
	380-415 VY	440-480VY	660-690 VY	-
160-450[1]	220, 230 VΔ		380, 400, 415 YΔ	440-480
	380, 400, 415 VY	440 VY	660 VY	-

Motor size	E		F	
	50 Hz	60 Hz	50 Hz	60 Hz
56-100	500 VΔ	[2]	500 VY	[2]
112-132	500 VΔ	[2]	500 VY	[2]
160-450	500 VΔ	[2]	[2]	[2]

Standard supply voltage range (ABB motors, codes S, D, E and F)

Three-phase induction motor
Supply Voltage and the Connection Type

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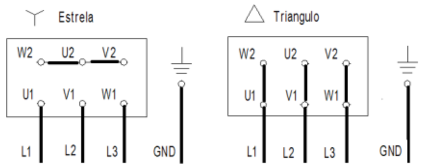
Electrical connections

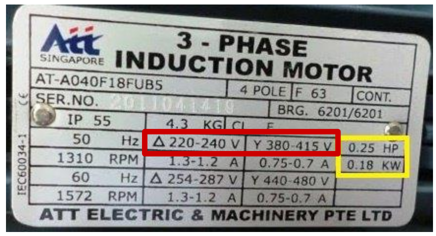
- Observe **Standard Nominal Voltages** and **Connection Type** indications (star/delta)



Motor example

- **Delta connection** for supply voltage (voltage between phases) of 230 V
- **Star connection** for supply voltage (voltage between phases) of 400 V

Note:
This motor must never be connected in delta directly from a typical three-phase electrical network (230/400 V, 50Hz)!



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Three-phase induction motor
Dimensions: IEC 60072-1:2022

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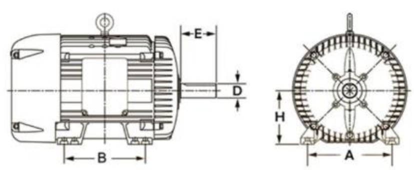
IEC frame size

- **Frame size** is defined by the distance from the motor shaft to the base(H)
- **Frame size** values range from **63** up to **450**



Frame Size	A	B	H	D	E
63	100 mm	80 mm	63 mm	11 mm	23 mm
71	112 mm	90 mm	71 mm	14 mm	30 mm
80	125 mm	100 mm	80 mm	19 mm	40 mm
90S 90L	140 mm	100 mm 125 mm	90 mm	24 mm	50 mm

Frame sizes: 63 - 450,
Power range: 0.12 – 1 000 kW

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Three-phase induction motor
Standard Power Values relative to Frame Size

IEC 60072-1:2022 defines data for standardized output power, and mounting dimensions

Standard output								
Frame size	Shaft extension diameter		Rated output				Flange number	
	2 poles mm	4,6,8 poles mm	2 poles kW	4 poles kW	6 poles kW	8 poles kW	Free holes (FF)	Tapped holes (FT)
56	9	9	0.09 or 0.12	0.06 or 0.09			F100	F65
63	11	11	0.18 or 0.25	0.12 or 0.18			F115	F75
71	14	14	0.37 or 0.55	0.25 or 0.37			F130	F85
80	19	19	0.75 or 1.1	0.55 or 0.75	0.37 or 0.55		F165	F100
90S	24	24	1.5	1.1	0.75	0.37	F165	F115
90L	24	24	2.2	1.5	1.1	0.55	F165	F115

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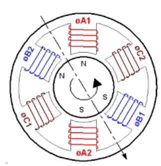
Three-phase induction motor
Number of Poles and Speed

50 Hz (in Europe)	
Poles	Synchronous Speed – RPM
2	3000
4	1500
6	1000
8	750

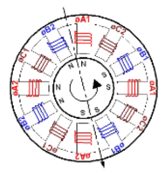
60 Hz (in USA)	
Poles	Synchronous Speed – RPM
2	3600
4	1800
6	1200
8	900
10	720
12	600

$$n_s = 120\, f/p$$

n_s: synchronous speed [rpm]
f: frequency [Hz]
p: n° of poles per phase



Motor with 2 poles per phase



Motor with 4 poles per phase

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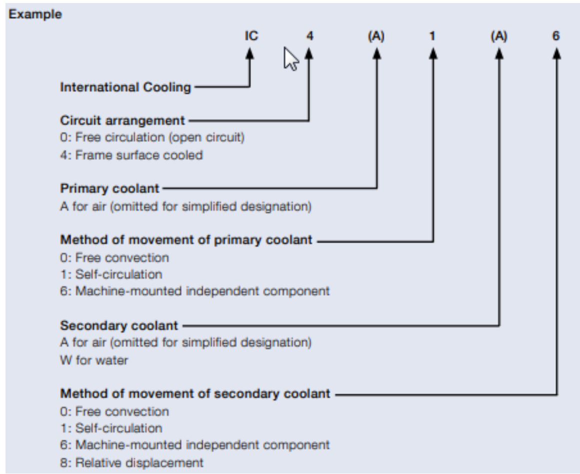
Three-phase induction motor Cooling systems (IC Code): IEC 60034-6

Typical configurations:

- IC 410: totally enclosed motors without a fan
- IC 411: totally enclosed fan cooled motor, TEFC
- IC 416: totally enclosed motors with an auxiliary fan motor
- IC 418: totally enclosed motors, frame -surface cooled without a fan
- IC 31W: inlet and outlet pipe or duct circulated: water-cooled motors



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Degree of Protection (IP code): IEC 60529

IP code XX in accordance with IEC 60529 **Example: IP 5 5**

First digit	Second digit
Protection to persons and to parts of the motors inside the enclosure, against contact and ingress of solid objects	Protection provided by the enclosure with respect to harmful effects due to ingress of water
0 No special protection 1 The motor is protected against solid objects bigger than 55 mm, e.g. a hand 2 The motor is protected against objects bigger than 12 mm, e.g. a finger 3 The motor is protected against solid objects bigger than 2.5 mm, i.e. wires, tools, etc. 4 The motor is protected against solid objects bigger than 1 mm, e.g. wires 5 The motor is protected against the ingress of dust 6 The motor is completely dust-proof	0 No special protection 1 The motor is protected against vertically falling drops of water, such as condensed water 2 The motor is protected against vertically falling drops of water, even if the motor is tilted at an angle of 15° 3 The motor is protected against water spray falling at an angle of 60° from vertical 4 The motor is protected against water splashing from any direction 5 The motor is protected against water being projected from a nozzle from any direction 6 The motor is protected against heavy seas or high-pressure water jets from any direction 7 The motor is protected when submerged from 15 cm to 1 min water for a period specified by the manufacturer 8 The motor is protected against continuous submersion in water under conditions specified by the manufacturer

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Three-phase induction motor
Degree of Protection (IK Code): IEC 62262

- The **IK Code** (International Protection) is the standardized metric for **Impact Protection**.
- While the IP Code (Ingress Protection) deals with dust and water, the IK Code defines the ability of an electrical enclosure to resist **mechanical impact**.

IK Rating	Impact Energy Joules)	Equivalent Impact Scenario
IK00	0 J	No protection
IK01 - IK05	0.14 J - 0.7 J	Low protection; resistant to small objects or accidental hand contact
IK07	2 J	Equivalent to a 0.5 kg mass dropped from 40 cm
IK08	5 J	Standard industrial protection; resistant to a 1.7 kg mass dropped from 30 cm
IK10	20 J	Vandal-resistant; resistant to a 5 kg steel mass dropped from 40 cm

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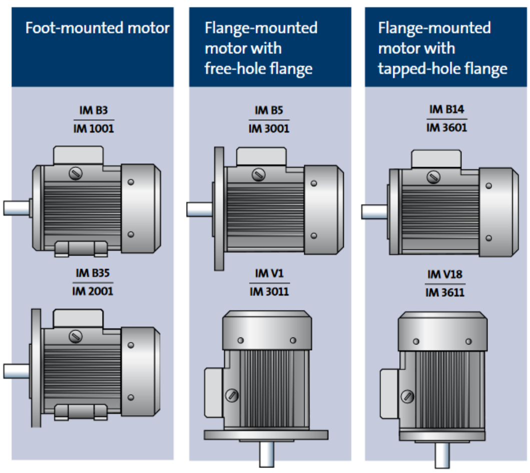
Three-phase induction motor
Mounting Configurations (IM code) IEC 60034-7

- **IM Codes** (International Mounting) specify how the motor is physically attached to the machine or structure it drives. Governed by the **IEC 60034-7** standard, these codes ensure that a motor from one manufacturer will physically fit the mounting bracket of another

The Two Coding Systems

- **Code I (Alpha-numeric):** this is the "short-hand" most commonly seen on motor nameplates or in catalogs (e.g., **IM B3, IM V1**)
- **Code II (Numeric):** a four-digit code used for more complex or non-standard configurations (e.g., **IM 1001**).



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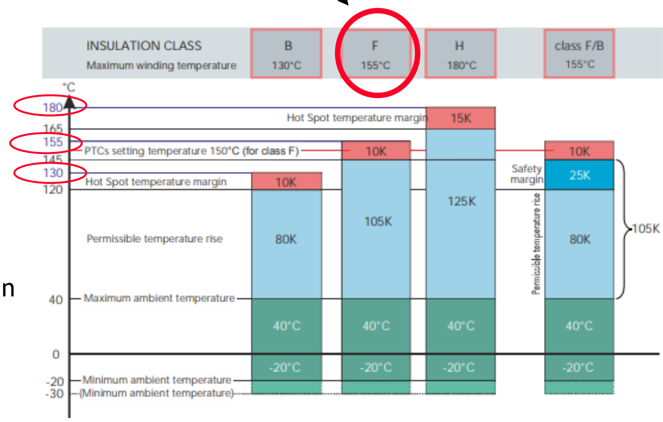
Three-phase induction motor
Insulation Classes IEC 60085

Insulation classes

- The insulation class specifies the maximum temperature that the coils can withstand continuously, without affecting their service life
- It is the primary factor determining the thermal lifespan and reliability of a motor
- **The Rule**: for every 10°C a motor operates above its rated temperature limit, the life expectancy of the insulation is cut in half
- **Failure Mode**: excessive heat causes the resin and enamel on the windings to become brittle and crack, leading to internal short circuits

ABB uses class F insulation



Three-phase induction motor
Terminal Boxes IEC 60034-7

Terminal boxes

IEC		
Lead Location	Special	Standard
Mounting	B-3/L	B-3
Special Features	"Conduit Box on Left Side of Motor Facing Drive End"	None

NEMA		
Lead Location	Standard	Special
Mounting	F-1	F-2
Special Features	None	None

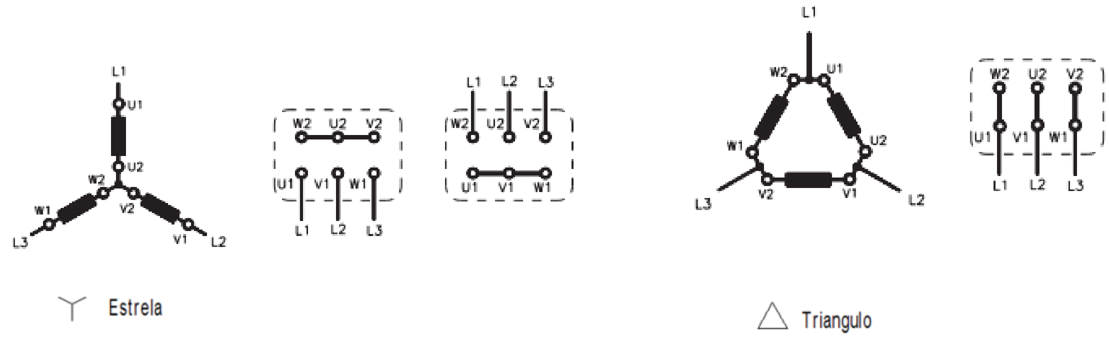
Typical terminal box in motor sizes 71 to 250

Typical terminal box in motor sizes 280 to 315

- Terminal box that can be rotated 4x90°
- The degree of protection of a standard terminal box is IP 55
- Wide range of cable glands

Three-phase induction motor Connection diagram

Terminal Box Configuration: Single speed motors (6 leads)



Star

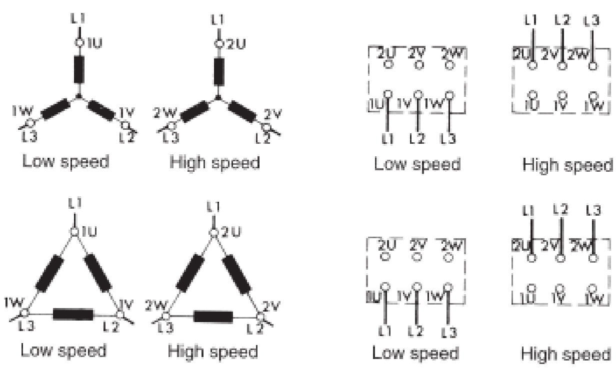
Delta

Three-phase induction motor Connection diagram

Terminal Box Configuration: Dual speed motors (motors with 6 leads)

The motor has **two physically distinct stator windings** (e.g., one for 4-poles and one for 6-poles). You only energize one at a time

- **Two separate coils Y/Y**
- **Two separate coils Δ/ Δ**



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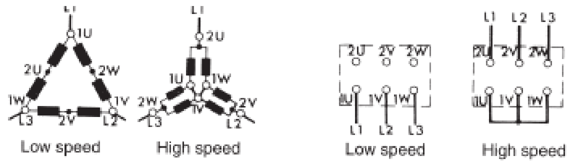
Three-phase induction motor Connection diagram

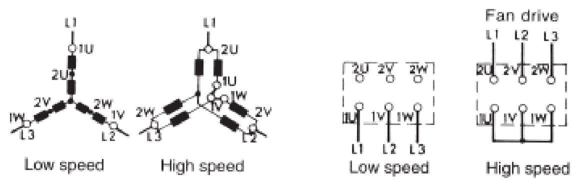
Terminal Box Configuration: Dual speed motors (motors with 6 leads)

The 6 leads are part of a **single winding** that can be reconfigured (e.g., from Delta to Double-Star) to change the number of effective poles by a factor of 2:1 (e.g., 4-pole/2-pole).

- **Dahlander connection Δ /Y Y**



- **Dahlander connection Y/Y Y**



With the rise of Variable Frequency Drives (VFDs), dual-speed Dahlander motors are becoming less common. A VFD allows a standard 1-speed induction motor to operate at any speed, providing better efficiency and smoother control than a fixed 2-speed motor.

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Three-phase induction motor Service Duty IEC 60034-1

- The service duty is the degree of regularity of load to which the motor is submitted. Standard motors are designed for continuous running duty. The load is constant during an indefinite period of time, and it is equal to the rated motor output.
- The service duty takes into account the time of use, the number of starts, the time interval between starts,… .

The Standardized Service Duties are indicated by S1 up to S10

- **Continuous (S1):** thermal equilibrium is reached
- **Intermittent (S3, S6):** the motor never reaches a "steady" temperature; it heats up and cools down in cycles
- **Sequential/Transient (S2, S4, S5, S7-S10):** includes the massive heat generated during starts and braking

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Three-phase induction motor Service Duty IEC 60034-1

S1 and S3 are the most common industrial specs.

- S1 (Continuous Running Duty)
  - Logic: the motor runs long enough to reach a stable temperature (Thermal Equilibrium)
  - Application: Pumps, fans, conveyors

- S3 (Intermittent Periodic Duty)
  - Logic: a sequence of identical cycles: **Run Time (t_{opr}) + Rest Time (t_0)**
  - Key Math: define the $\boldsymbol{Duty\ Cycle}\ \% = (t_{opr} + t_0)/t_{opr} \times 100$
  - Example: if a motor is S3 25%, it can run for 2.5 minutes, but then must rest for 7.5 minutes

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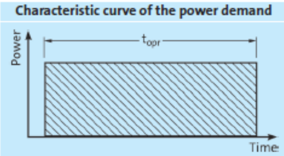
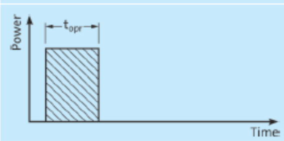
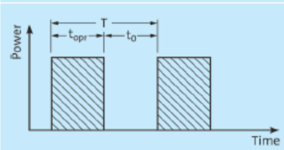
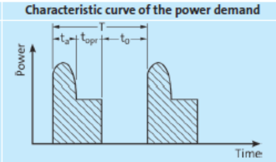
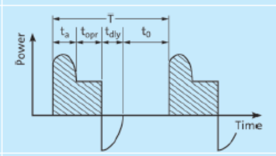
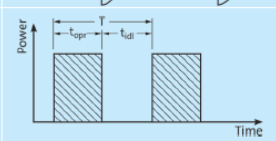
Three-phase induction motor Service Duty IEC 60034-1

Operating mode	Characteristic values	Characteristic curve of the power demand
Continuous operation **S1** ($t_{opr} > (3 \dots 4) \cdot T_{\vartheta}$)	Operating time $t_{opr} = 100\,\%$ Temperature increase time constant T_{ϑ} Cooling time constant $T_{\vartheta,0}$	
Short-time operation **S2** ($t_{opr} < (3 \dots 4) \cdot T_{\vartheta}$ ($t_0 > (3 \dots 4) \cdot T_{\vartheta,0}$)	Operating time t_{opr} Interval time t_0	
Periodic intermittent operation **S3** ($t_{opr} < (3 \dots 4) \cdot T_{\vartheta}$ ($t_0 < (3 \dots 4) \cdot T_{\vartheta,0}$	Operating time t_{opr} Idle time t_0 Load cycle duration T	

Operating mode	Characteristic values	Characteristic curve of the power demand
Periodic intermittent operation with influence of the starting process **S4**	Starting time t_a Operating time t_{opr} Idle time t_0 Load cycle duration T	
Operating mode Periodic intermittent operation with electric braking **S5**	Starting time t_a Operating time t_{opr} Delay time t_{dly} Idle time t_0 Load cycle duration T	
Uninterrupted periodic operation **S6** ($t_{opr} < (3 \dots 4) \cdot T_{\vartheta}$ ($t_{idl} < (3 \dots 4) \cdot T_{\vartheta,0}$)	Operating time t_{opr} Idling time t_{idl} Load cycle duration T	

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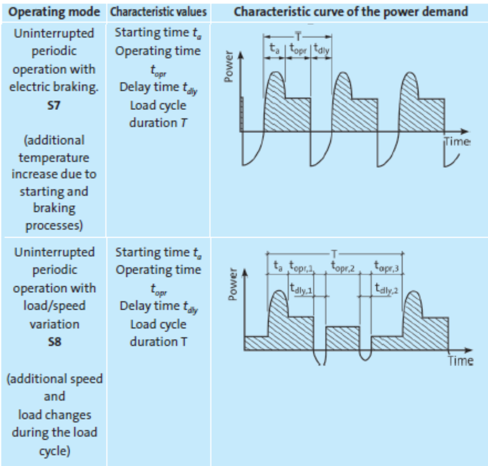
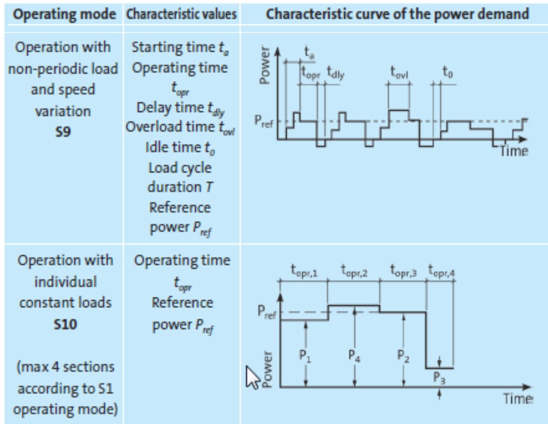
Three-phase induction motor
Service Duty IEC 60034-1



Operating mode	Characteristic values	Characteristic curve of the power demand
Uninterrupted periodic operation with electric braking. **S7** (additional temperature increase due to starting and braking processes)	Starting time t_a Operating time t_{opr} Delay time t_{dly} Load cycle duration T	Power, T, t_a, t_{opr}, t_{dly}, Time
Uninterrupted periodic operation with load/speed variation **S8** (additional speed and load changes during the load cycle)	Starting time t_a Operating time t_{opr} Delay time t_{dly} Load cycle duration T	Power, T, t_a, $t_{opr,1}$, $t_{opr,2}$, $t_{opr,3}$, $t_{dly,1}$, $t_{dly,2}$, Time



Operating mode	Characteristic values	Characteristic curve of the power demand
Operation with non-periodic load and speed variation **S9**	Starting time t_a Operating time t_{opr} Delay time t_{dly} Overload time t_{ovl} Idle time t_0 Load cycle duration T Reference power P_{ref}	Power, t_a, t_{opr}, t_{dly}, t_{ovl}, t_0, P_{ref}, Time
Operation with individual constant loads **S10** (max 4 sections according to S1 operating mode)	Operating time t_{opr} Reference power P_{ref}	$t_{opr,1}$, $t_{opr,2}$, $t_{opr,3}$, $t_{opr,4}$, P_{ref}, P_1, P_4, P_2, P_3, Power, Time

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Drive Solutions pocket book

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Service Duty: Comparison Table

Duty	Description	Key Variable	Common Application
S1	Continuous	Constant Load	Water treatment plants
S2	Short-time	Operating Time (min)	Emergency backup generators
S3	Intermittent	Duty Cycle %	Industrial cranes and hoists
S6	Continuous with Intermittent Load	Loading / Idling	Sawmill blades (spinning but not cutting)

![U.PORTO FEUP logo]

Three-phase induction motor
Direction of Rotation IEC 60034-8

- According to IEC 60034-8, the standard direction of rotation is **Clockwise (CW)** when facing the drive-end (DE) of the shaft
- Connection Logic: this is achieved by connecting the supply phases in their natural sequence (L1,L2,L3) to the corresponding motor terminals (U1,V1,W1)
- Vector Analysis: this sequence creates a **Rotating Magnetic Field (RMF**) that pulls the rotor in a clockwise direction
- Typically, the cooling system is independent of the direction of rotation.

Note: to change the direction of rotation it is just necessary to swap any two phases

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Three-phase induction motor

- Very wide range of motors available on the market from multiple manufacturers
  - Example of Manufacturer ABB, “Low voltage motor” range:
    - Powers 120W to 1000 kW, supply voltage 50V to 1000V, dimensions IEC 53 to 315, speeds (ref. 50 Hz) 750 rpm, 1000 rpm, 1500 rpm and 3000 rpm
    - Possibility of using these motors by direct connection to the network or by using variable frequency drivers (VFD)
- Three important sources of information
  - ABB Low voltage motors: motor guide
  - ABB Low voltage General performance cast iron motors
  - WEG Electric motors – specification guide

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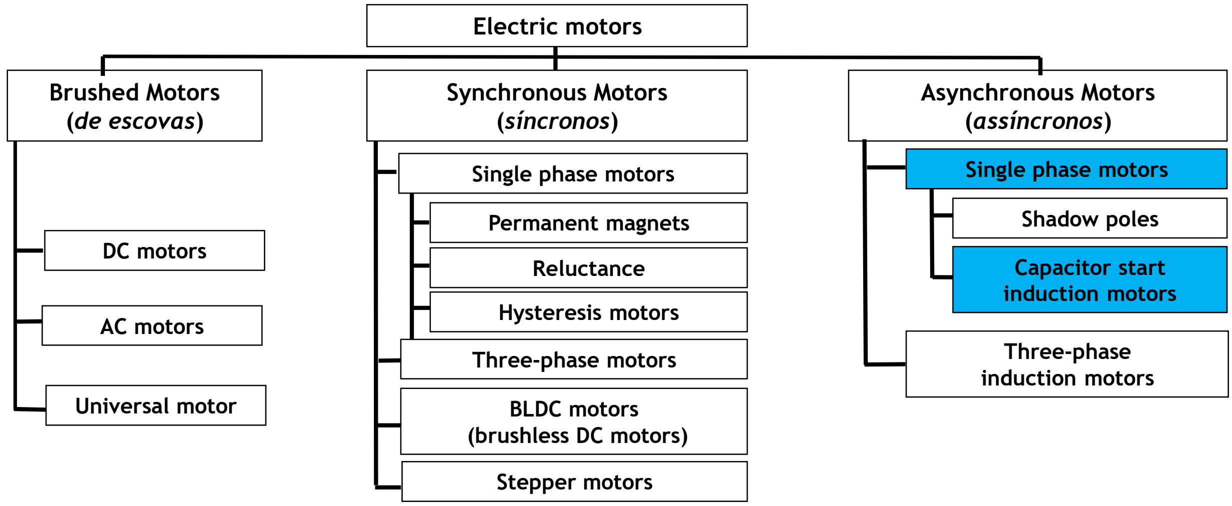
Electric Motors classification
Working principle/source of energy



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Single-phase induction Motor

- **Why a Single-Phase Motor Cannot Start on Its Own**
  - A **single-phase stator winding**, when supplied with AC, produces only a **pulsating magnetic field**
  - Unlike a three-phase supply, this field does not rotate—the magnetic axis stays fixed in space while its magnitude oscillates and reverses polarity sinusoidally
  - **Consequence**: there is **zero net starting torque**. The motor may vibrate or hum, but it will not start
- **The Solution: Auxiliary winding and Capacitor Phase Shifting**
  - A second winding, called the Auxiliary/Start winding, is placed 90° electrically (and physically) apart from the main winding
  - By feeding the auxiliary winding through a capacitor, its current leads the main winding current. The combination of a 90° physical displacement and a ~90° electrical phase shift creates a **Rotating Magnetic Field (RMF)**, similar to a true two-phase system
  - **Three possible options:**
    - Capacitor Start / Centrifugal Switch
    - Permanent Split Capacitor (PSC / Capacitor Run)
    - Two capacitor (Capacitor Start / Capacitor Run) /Centrifugal Switch to remove start capacitor

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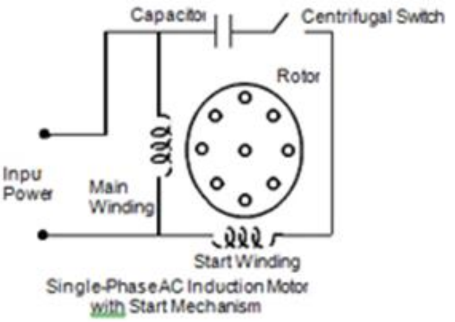
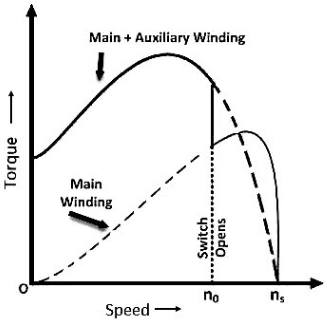
Paulo Abreu ®

Single-phase induction Motor

- Capacitor Start / Centrifugal Switch

The auxiliary winding and capacitor are only rated for "short-time duty." If the switch fails to open, the capacitor or the winding will burn out quickly.





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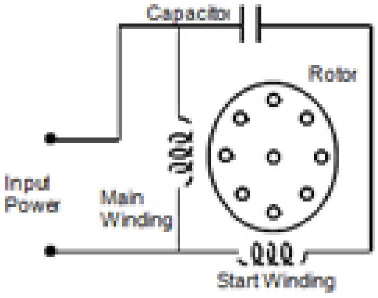
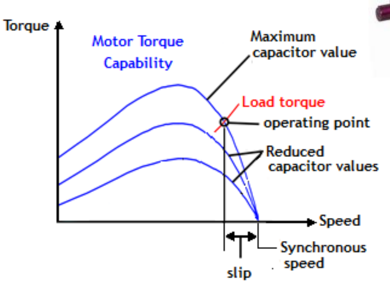
Single-phase induction Motor

- Permanent Split Capacitor (PSC / Capacitor Run)





Note the influence of capacitor value on torque curve

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Single-phase induction Motor Summary Comparison Table

Motor Type	Starting Torque	Efficiency	Mechanical Complexity	Common Use
Capacitor Start / Centrifugal Switch	High	Medium	High (Switch + Cap)	Compressors / Conveyors
Permanent Split Capacitor (PSC / Capacitor Run)	Low	High	Low (No Switch)	Ceiling fans / AC units
Two-Capacitor / Centrifugal Switch	High	High	High (Switch + Two Cap)	Heavy-duty farm machinery

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Single-phase induction Motor

Capacitor Start / Centrifugal Switch

- Example: motor from Zohi, YC series, model YC80C-2, 750W, 230V/50Hz, 2850 rpm, 6.7 A, PF =0.75, eff. 68%, $T_{start}/T_n = 3$, $T_{max}/T_n = 2$, $I_{start}/I_n = 6.5$

www.zozhi.net

IEC Soga motors

See videos: https://youtu.be/awrUxv7B-a8?t=2
https://youtu.be/FDerrQw99KU

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