PL 4 – AC Motors – Main components

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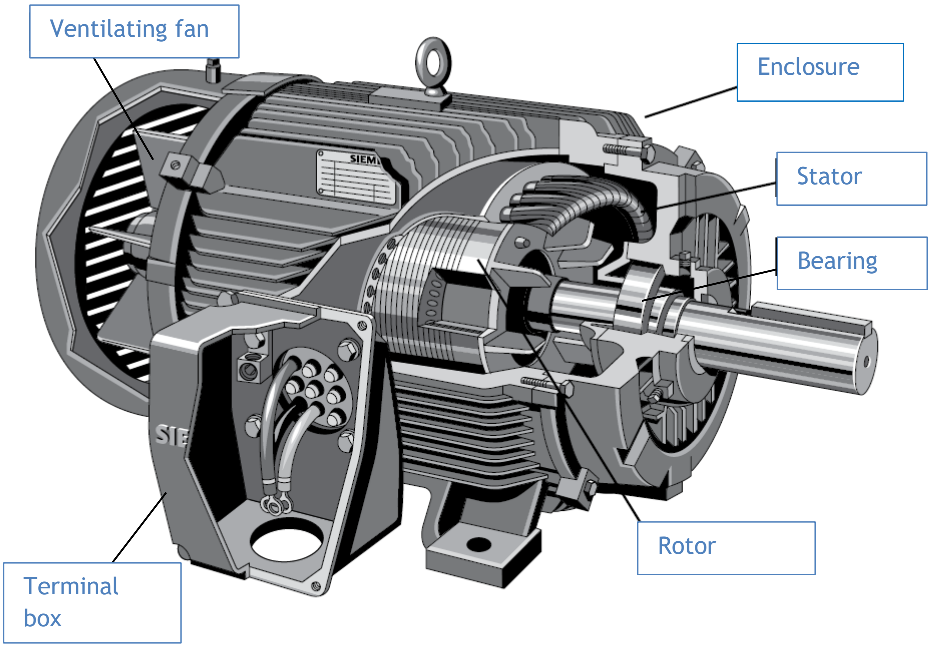
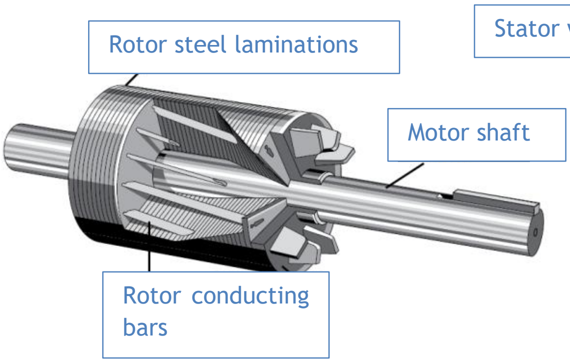
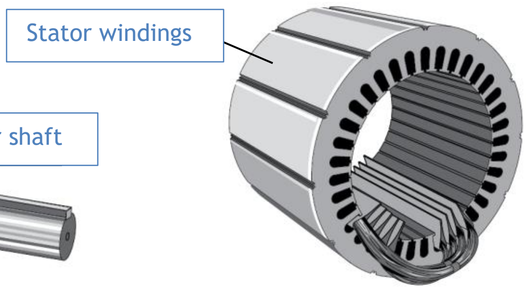
Objectives: Identification of the main components and demonstration of the working principle of induction (AC) motors (three phases and one phase). Characteristic curves (ex. Torque-speed). Three phases balanced electrical power, star (Y) and delta (Δ) connections.

Documents available
PL classes: 1) Catalogue carpanelli-M71b4.pdf
Web sites: [www.carpanelli.net](http://www.carpanelli.net)
[www.marellimotori.com](http://www.marellimotori.com)

**1.** Identification of the main components of AC motors: fill in the following figures the designation of the respective component.

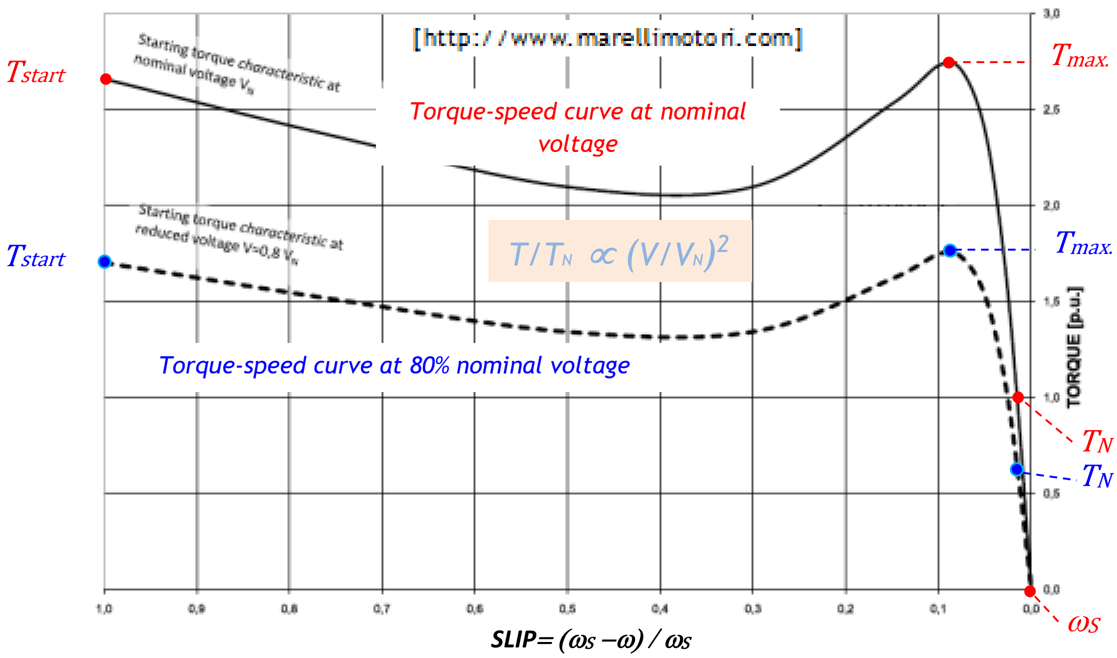


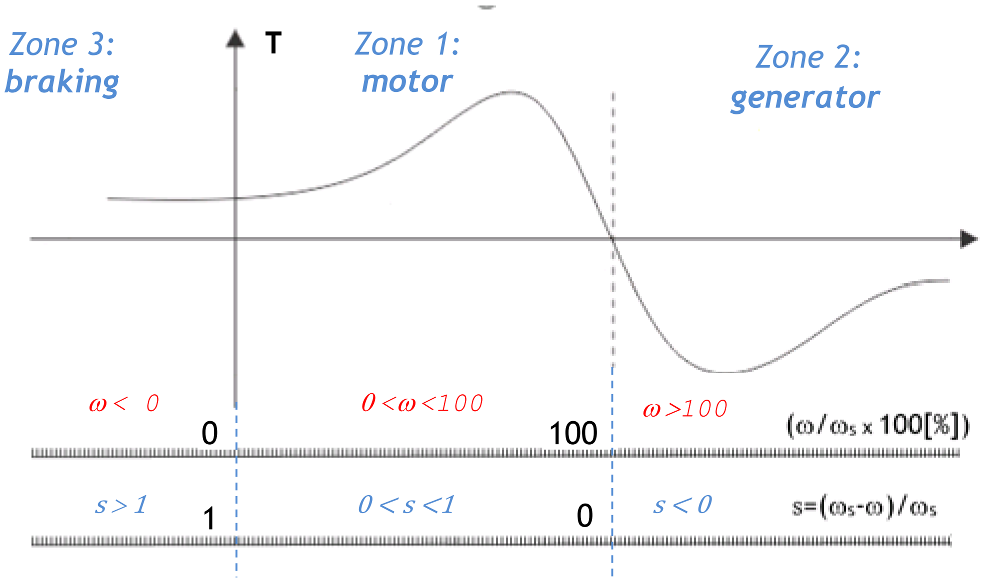



**2.** Characteristic curves Torque-speed (T,ω)

*a.* Identify in the graph below the following (T,ω) working points: nominal, starting, maximum torque and synchronous speed.

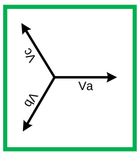



*b.* In the figure below, it is possible to distinguish three working regions, or zones, of a three-phase induction machine. Considering the different scales for speed (angular speed, ω, percent of synchronous speed, $\%\omega_s$, slip, s) in the horizontal axis, identify these three working zones (1: motor zone; 2: generator zone; 3: braking zone).



**3.** Consider a three-phase power system for an electric motor with a positive, or abc sequence: $\boldsymbol{V_a = V_{rms}\angle 0^o}$, $\boldsymbol{V_b = V_{rms}\angle -120^o}$, $\boldsymbol{V_c = V_{rms}\angle 120^o}$. Indicate in the space below the respective: phase and line-to-line voltages, in both the time domain and phasor notation (i.e. $v_a(t)=V\cos(\omega t+\phi)$, and $\boldsymbol{V_a(jw)}$), considering that $V_{rms} = 230V$, $f=50Hz$, $V_a = V_{L1}$, $V_b = V_{L2}$, $V_c = V_{L3}$.

***Phase voltages (using rms values in phasors representation)***



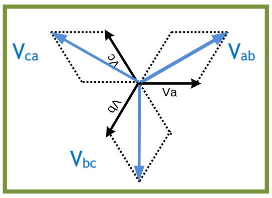

$V_{L1}(jw) = V_a(jw) = 230\angle 0^o$ [V] $V_{L2}(jw) = V_b(jw) = 230\angle -120^o$ [V] $V_{L3}(jw) = V_c(jw) = 230\angle +120^o$ [V]

*Or, more correctly using angle units coherence:*

$V_{L1}(jw) = V_a(jw) = 230\angle(0^o\pi/180^o)$ [V] $V_{L2}(jw) = V_b(jw) = 230\angle(-120^o\pi/180^o)$ [V] $V_{L3}(jw) = V_c(jw) = 230\angle(+120^o\pi/180^o)$ [V]

$v_{L1}(t) = 230\sqrt{2}\cos(100\pi t + 0^o\pi/180^o)$[V] $v_{L2}(t) = 230\sqrt{2}\cos(100\pi t - 120^o\pi/180^o)$[V] $v_{L3}(t) = 230\sqrt{2}\cos(100\pi t + 120^o\pi/180^o)$[V]

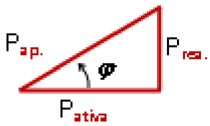
***Line to line, or compund voltages (using rms values in phasors rep.):***




$V_{12}(jw) = V_{L1}(jw) - V_{L2}(jw) = 398{,}4\angle(30^o\pi/180^o)$ [V] $v_{12}(t) = 398{,}4\sqrt{2}\cos(100\pi t + 30^o\pi/180^o)$ [V]
$V_{23}(jw) = V_{L2}(jw) - V_{L3}(jw) = 398{,}4\angle(-90^o\pi/180^o)$ [V] $v_{23}(t) = 398{,}4\sqrt{2}\cos(100\pi t - 90^o\pi/180^o)$ [V]
$V_{31}(jw) = V_{L3}(jw) - V_{L1}(jw) = 398{,}4\angle(+150^o\pi/180^o)$ [V] $v_{31}(t) = 398{,}4\sqrt{2}\cos(100\pi t + 150^o\pi/180^o)$ [V]

***Complex AC power, phasor notation:*** $\boldsymbol{P}(jw) = \frac{1}{2}\boldsymbol{V}(jw)\cdot\boldsymbol{I}^*(jw) = \boldsymbol{V_{rms}}(jw)\cdot\boldsymbol{I^*_{rms}}(jw)$

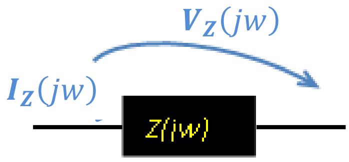
$P_{average,\ i.e.\ real} = |\boldsymbol{V_{rms}}(jw)|\cdot|\boldsymbol{I^*_{rms}}(jw)|\cdot\cos\varphi = V_{rms}\cdot I_{rms}\cdot\cos\varphi$




$P_{reactive} = |\boldsymbol{V_{rms}}(jw)|\cdot|\boldsymbol{I^*_{rms}}(jw)|\cdot\sin\varphi = V_{rms}\cdot I_{rms}\cdot\sin\varphi$

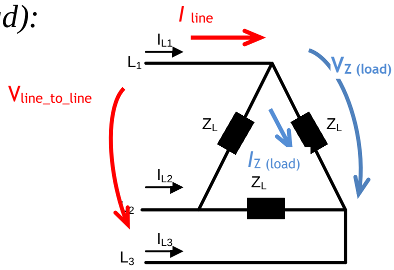
$P_{apparent} = |\boldsymbol{V_{rms}}(jw)|\cdot|\boldsymbol{I^*_{rms}}(jw)| = V_{rms}\cdot I_{rms}$

*Power factor:* $\cos\varphi$




*Phasor impedance:* $\boldsymbol{Z}(jw) = \frac{\boldsymbol{V_Z}(jw)}{\boldsymbol{I_Z}(jw)}$; $|\boldsymbol{Z}(jw)| = \frac{|\boldsymbol{V_Z}(jw)|}{|\boldsymbol{I_Z}(jw)|} = \frac{\boldsymbol{V_Z}}{\boldsymbol{I_Z}}$

***Star (Y) and delta (Δ) connections:*** *$V_{phase}$, $V_{line}$, $I_{line}$, $I_z(load)$, $V_z(load)$:*



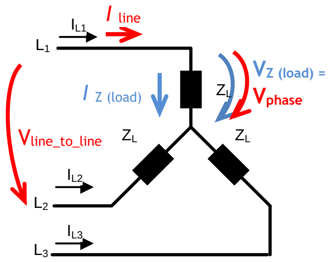

*Delta, Δ:* $I_z = I_{line}/\sqrt{3}$ ; $V_z = V_{line\text{-}to\text{-}line} = V_{phase}\cdot\sqrt{3}$

*Star, ⅄:* $I_z = I_{line}$ ; $V_z = V_{phase}$

*Power (real or average)* $= 3\cdot P_z = 3\cdot V_z\cdot I_z\cdot\cos\varphi$

*Impedance:* $Z_1 = Z_2 = Z_3 = Z_L$ *, balanced three-phase system*

***Calculate the following values, as a function of load ($Z_L$):***



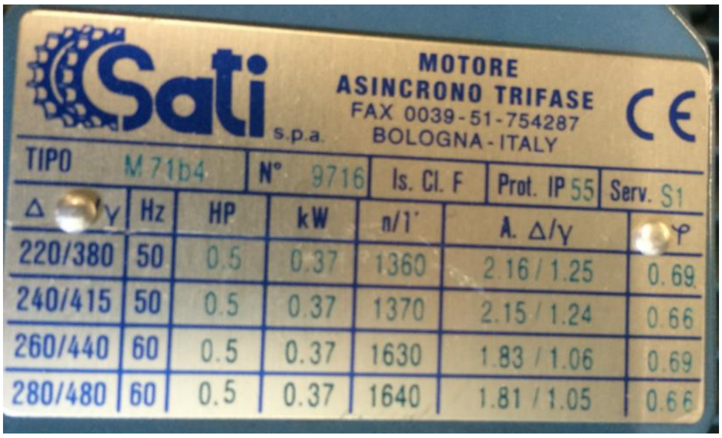

$|\boldsymbol{I_{line\Delta}}| = \sqrt{3}\cdot\boldsymbol{I_z} = \sqrt{3}\cdot V_{line\_to\_line} / \boldsymbol{Z_L}$

$|\boldsymbol{I_{line\,⅄}}| = \boldsymbol{I_z} = V_{phase} / \boldsymbol{Z_L}$

$\boldsymbol{P_\Delta} = 3\cdot\boldsymbol{P_z} = 3\cdot\boldsymbol{V_z}\cdot\boldsymbol{I_z}\cdot\boldsymbol{\cos\varphi} = 3\cdot(V_{line\_to\_line})^2\cdot\boldsymbol{\cos\varphi} / \boldsymbol{Z_L}$ [W]

$\boldsymbol{P_⅄} = 3\cdot\boldsymbol{P_z} = 3\cdot\boldsymbol{V_z}\cdot\boldsymbol{I_z}\cdot\boldsymbol{\cos\varphi} = 3\cdot(V_{line\_to\_line}/\sqrt{3})^2\cdot\boldsymbol{\cos\varphi} / \boldsymbol{Z_L} = \boldsymbol{P_\Delta} / 3$ [W]

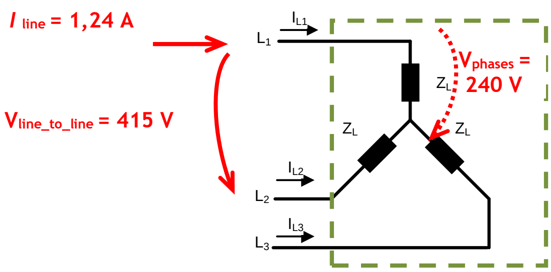
**4.** Analyze the information included in the plate identification of a three-phase AC induction motor.

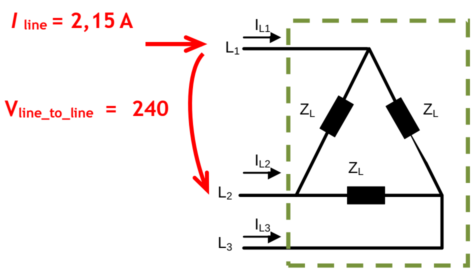



*a.* Identify from the information of the plate identification the following motor characteristics at 240*Δ*/415⅄ and 50Hz/:

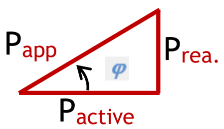
- frequency /voltage /current: 50 Hz, 240*Δ* *or 415*⅄ [V], 2.15*Δ* *and 1.24*⅄ [A]
- nominal values of: power 370[W], torque: P/ω = 370/143,5 = 2,58 Nm speed:1370 rpm = 143,5 rad/s
- synchronous speed: $n_s$ = 1500 rpm, i.e. the one closest to nominal speed (1370 rpm)
- nº of poles per phase: P = 4, nº of pairs of poles/phase: p = freq (cycles/min)/ $n_s$ = 3000/1500 = 2

*b.* Represent in the figures below the values for supply voltage and current when the motor is connected in star (a) and delta (b) configurations:




*c.* Considering f = 50 Hz, calculate:




(⅄) $P_{active} = 3 \cdot V_{phase} \cdot I_{line} \cdot cos\varphi = 3 \cdot 240 \cdot 1,24 \cdot 0,66 = 589\ [W] \cong \sqrt{3} \cdot V_{line\_to\_line} \cdot I_{line} \cdot cos\varphi = \sqrt{3} \cdot 415 \cdot 1.24 \cdot 0,66 = 588\ [W]$

(*Δ*) $P_{active} = \sqrt{3} \cdot V_{line\_to\_line} \cdot I_{line} \cdot cos\varphi = \sqrt{3} \cdot 240 \cdot 2.15 \cdot 0,66 = 589\ [W]$

(⅄) $P_{reactive} = 3 \cdot V_{phase} \cdot I_{line} \cdot sin\varphi = 3 \cdot 240 \cdot 1,24 \cdot 0,75 = 670\ [VAR]$

(*Δ*) $P_{reactive} = \sqrt{3} \cdot V_{line\_to\_line} \cdot I_{line} \cdot sin\varphi = \sqrt{3} \cdot 240 \cdot 2.15 \cdot 0,75 = 670\ [VAR]$

$P_{apparent} = P_{active} / cos\varphi = 589/cos\varphi = 892\ [VA]$

*d.* Estimate the efficiency of the motor and compare the value with an equivalent motor (i.e. M71B4 da Carpanelli, in the available pdf documents: $\eta_{motor}$ = 65 %)

*e.* What motor connection ( *Δ* *or* ⅄) to use if the motor is to be powered directly (DOL) from the AI laboratory electric installation? __star (⅄).