The simplest of all types of electric motors is the **squirrel-cage induction motor** that is used with three-phase power. The armor of this type of motor consists of three fixed coils and is similar to that of the synchronous motor. The rotating element consists of a core, which includes a series of large capacity conductors placed in a circle around the tree and parallel to it.

The current flowing through the rotor winding is due to the electromotive force induced in it by the rotating field; for this reason, this type of motors are also referred to as induction motors.

To make an electrical circuit analysis, the equivalent circuit of the following scheme is used.

**Scheme 1**: Equivalent circuit of the asynchronous motor including mechanical losses

In a three-phase asynchronous squirrel-cage machine the terminal box has six terminals, corresponding to the ends of the three phases of the stator (two ends, beginning and end, for each phase), forming two rows of three. In this way it is easy to connect the stator winding in star (Scheme 2a) or in triangle (Scheme 2b).

**Scheme 2**: Terminal box of a three-phase asynchronous squirrel-cage machine:
(In both cases the terminals U1, V1 and W1 are the ones that connect to the phases of the line supply)

This facility to connect the stator winding in star or delta allows an asynchronous machine to work with two different assigned line voltages, which have a relationship between them of $\sqrt{3}$. 
Thus, for example, a 400/230 V motor has an assigned phase voltage of 230 V. For this reason, when you want to use it in a network whose line voltage is 230 V, you will use the triangle connection, because in it the phase and line voltages are equal. If you want to use this machine in a network whose line voltage is 400 V, you must use the star connection, because in it the phase voltage is equal to the phase-neutral voltage, which is \( \sqrt{3} \) times less than the line voltage.

To sum up, the possibility of changing the connection in the stator allows the asynchronous machine to operate with two different assigned line voltages. The minor corresponds to the triangle connection and is also equal to the assigned phase voltage. The largest corresponds to the star connection.

**ASYNCHRONOUS MOTOR POWER THEORY**

In this section we will study the power balance of an asynchronous machine acting as a motor. Consequently, in the following, the signs criterion is considering positive the powers whose meaning is the one corresponding to the operation of the machine as motor is adopted. It will be assumed that the machine works with an industrial way (therefore, the effective value and the frequency of the voltages of the stator phases are constant and equal to their assigned values) and with a small slip.

In an engine power flows from the stator to the rotor and the machine shaft (see Scheme 3), transforming the electrical energy absorbed in the stator P\(_1\) into useful mechanical power P\(_\text{u} \) on the shaft.

The active power absorbed by the stator P\(_1\) as a function of the phase values of the voltage V\(_1\) and the stator current I\(_1\), as well as the power factor \( \cos \rho \) and the number of phases m\(_1\) of the stator is obtained as follows:

\[
P_{\text{in}} = \sqrt{3} \cdot V_L \cdot I_L \cdot \cos \theta
\]

Considering the mechanical losses, air gap, etc... to zero, we would have the following power quotient to obtain the motor performance:

\[
\eta \text{ (performance)} = \frac{P_{\text{out}}}{P_{\text{in}}}
\]
To sum up in terms of power (discarding the mechanical losses that have, air gap, etc... the engine), the squirrel-cage motor, is defined in the following formulas.

\[ P_u = P_1 \times (100\% \text{ Performance}) \]

\[ P_u = \omega M \text{ (angular speed by mechanical output torque)} \]

\[ P_1 = V_L I_L \text{ (current by supply voltage)} \]

Therefore in summary mode and without counting the losses it is:

\[ \omega M = V_L I_L \]

**SPECIAL CONNECTION TRIANGLE INDUCTION MOTORS**

When operating with an engine above its nominal frequency (50/60Hz), there are two options:

1. use the possibility of operating the motor with field weakening (constant power and lower torque)
2. use the motor with the characteristic "87Hz Technique"

In both cases, these techniques are only possible with the use of frequency inverters.

**Field weakening**

Typically, at speeds above the nominal, the output frequency of the inverter is appropriately increased, but there is the disadvantage that it decreases the flux and therefore the motor torque (it is the so-called constant power motor curve zone).

The output frequency of the inverter increases, while the voltage output remains constant, however the torque decreases due to the flux in the motor decreases and the speed increases.

In the constant power zone, the torque decreases inversely proportionally to the increased speed above the nominal speed, as can be seen in Scheme 4.

- It may see the green line (torque curve) as it decreases from the nominal frequency increase (field weakening).
- The curve in red (motor power), remains constant from the nominal frequency increase.
A few years ago, the motor windings are protected with greater insulation to allow the voltage spikes caused by the inverters and PWM switching of the IGBT’s, this has caused new connection ways of the motors to increase their power in smaller equivalent sizes.

This new connection system is known as the "87Hz technique". (This curve of 87Hz is a very interesting variant because it offers a relatively constant flux above the nominal frequency).

**Scheme 5: Motor characteristics curve**

This operation mode is possible for motors that, at nominal frequency, can be connected both in star, and in delta configuration (triangle). With this technique, the triangle configuration has a voltage greater than the nominal one by a factor of \( \sqrt{3} \), which is used to increase the speed by the same factor, that is by \( \sqrt{3} \) up to 87Hz, in a zone of almost constant torque.

\[
87Hz = 50Hz \times \sqrt{3}
\]

The following scheme shows the comparison of the motor curve for work in nominal regime and with the 87Hz technique.

**Scheme 6: Motor curve comparison with 87Hz technique**

It may see the green line (torque curve) remains almost constant in the weakening zone (between 50Hz and 87Hz), allowing the engine to work in a zone of almost constant torque.
For example a 230/400V motor is connected-up in Δ (configuration 50Hz/230V) with a 400V line supply voltage (it is possible by motor insulations reinforcement), so the new nominal characteristics are of 87Hz/400V. For the motor, this means that from the rated motor frequency 50Hz/230V, the voltage is continuously increased up to 87Hz but without field weakening, instead in at constant flux (constant torque).

When an motor is connected in this way and operates above its nominal characteristics, both the motor and the inverter must be selected and appropriately sized for the operation and taking into account the following points:

- The mechanical limit speeds.
- The increased thermal load.
- The increased voltage stress on the motor (the motor insulation)
- The modulation depth of the Inverter.

When making this new type of connection and following the general motor characteristics, we have that the power in this type of “87Hz technique”, also increases in \( \sqrt{3} \), becoming to:

1.- Standard triangle connection motor: 50Hz/230V/0.73Amp/0,12Kw
2.- New 87Hz triangle connection motor: 87Hz/400V/0.73Amp/0,21Kw

\((0,12Kw \sqrt{3} = 0,21Kw)\)

Therefore, the inverter to be used must be dimensioned according to the new electrical indications of the 87Hz technique connection and its final application.

An example of a nameplate with the three types of connections mentioned in this document:

![Motor Nameplate](image)

**Scheme 7**: Motor nameplate with 87Hz technique

**REDUCTORS AND MECHANICS**

It is important that the reductors used, also admits 87Hz speeds, as well as the characteristics of acceleration and deceleration, to avoid breaks when working at these speeds.
FREQUENCY INVERTERS CONSTANT TORQUE AT 87HZ

MOTOR MECHANICAL CURVE

V/f

M/Mn

0.5

1

3 Hz

50 Hz

75 Hz

f

INVERTER SELECTION

Constant torque up to 87Hz

Motor:

- 2,2kW / 400V / 5,4A / 50Hz
- 2,2kW / 230V / 9,4A / 50Hz

87Hz Connection:

- 3,8kW / 400V / 9,4A / 87Hz

Identical motor

Increase the inverter’s power
**Constant torque up to 87Hz**

**Motor:**
- 2,2kW / 400V / 5,4A / 50Hz
- 2,2kW / 230V / 9,4A / 50Hz

**87Hz Connection:**
- 3,8kW / 400V / 9,4A / 87Hz

---

**Calculations**

**Motor:**
- 2,2kW / 400V / 5,4A / 50Hz
- 2,2kW / 230V / 9,4A / 50Hz

\[ f = \sqrt{3} \cdot f_R \]
\[ I \geq I_R \cdot \sqrt{3} \]

**87Hz Connection:**
- 3,8kW / 400V / 9,4A / 87Hz

\[ P_R = \sqrt{3} \cdot U \cdot I \cdot \cos \phi \]
Constant torque up to 87Hz

Autotuning:

1. Choose an inverter greater than the motor (That supplies the current in triangle)

2. Enter the motor data to 230V / triangle.

3. Make auto tuning

Parameters:

1. Modify Voltage (400Vac) and base frequency (87 Hz)