POWER SUPPLY FOR
ASYNCHRONOUS MOTORS

Author: Franck Weinbissinger
Three-phase asynchronous motors are very robust and low-maintenance electrical machines widely used in industry. Their application is very varied, such as in ventilator, pumps, complex modular machinery, machines running at very low speed torque and precision, sophisticated dynamic machines or very high power machines.

Due to the developments in energy electronics and the falling cost of asynchronous motors, many areas of application where continuous current motors were once used, are now managed by using an asynchronous motor linked to a speed regulator.

The asynchronous motors may need an UPS protection because of the process they driving: a sudden power interruption could damage the machinery and compromise the product quality.

Asynchronous motors are typically powered at the stator and the current is induced in the rotor. That's why they are also known as induction motors or induction machines.

An asynchronous machine is generally used as a motor but sometimes as a generator. As the asynchronous machine does not suffer the problems with coupling, speed control and voltage that synchronous machines do, the asynchronous generator is used to produce electricity in small installations without the need for human surveillance. It is also used in brake systems, by absorbing energy when the machine is connected to a constant frequency network (e.g. absorbing the power of a slowing down load).

Braking by recuperating at varying brake speeds requires a variable frequency power supply to the machine, in other words the use of regulators. In the same vein, due to power electronics, the induction motors are increasingly being used in applications as a generator. A good example of this are wind turbines.

Aim of this paper is to give a non exhaustive overview of the problems occurring during the UPS sizing for induction motors supply, with or without Variable Speed Drives. Such paper can not be used to design the plant or chose the UPS system.

Motors not linked to a regulator

An asynchronous machine is often used today as a motor with a power scale ranging from a few Watts to several hundreds kW. For power applications exceeding several kW, asynchronous motors run solely on three-phase AC power supplies.

Owing to the sensitivity of a process or the critical nature of certain applications, the network may be supported with an Uninterruptible Power Supply.

During the start-up process the inrush currents can reach rms values between 4 and 7 the nominal current ones, whereas the torque increases up to 1.5 to 2.4 times the nominal torque. The starting times depend on the inertia of the moving mass, the final rotational speed and the accelerating torque of the motor.
Peak current values are even higher and they can reach 10 times the nominal rms value. High inrush currents together with the line impedance cause a voltage drop in the distribution line especially for those loads close to the motor. There are many ways to limit the starting currents, the most common are: Y/Δ starting; Autotransformer; Soft starter. For some very special applications the rotor rheostat is also a solution. The choice depends on a compromise between application and costs.

**Table 1 - Starting currents and torques depending on the starting methods**

<table>
<thead>
<tr>
<th>Starting Method</th>
<th>Starting Line Current</th>
<th>Starting Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct On Line (D.O.L.)</td>
<td>4-7 Iₙ</td>
<td>1.5-2.4 Tₙ</td>
</tr>
<tr>
<td>Y/Δ</td>
<td>1.6-2.8 Iₙ</td>
<td>0.5-0.8 Tₙ</td>
</tr>
<tr>
<td>Autotransformer</td>
<td>4-7 (Vₛ/Vₙ) Iₙ</td>
<td>1.5-2.4 (Vₛ/Vₙ)² Tₙ</td>
</tr>
<tr>
<td>Soft starter</td>
<td>4-7 (Vₛ/Vₙ) Iₙ</td>
<td>1.5-2.4 (Vₛ/Vₙ)² Tₙ</td>
</tr>
<tr>
<td>Speed Drive</td>
<td>1-1.5 Iₙ</td>
<td>1-1.5 Tₙ</td>
</tr>
</tbody>
</table>

Where $Vₛ$ is the Voltage applied to the motor terminals during starting, $Vₙ, Iₙ$ and $Tₙ$ are respectively the nominal voltage, current and torque.

The starting process causes a thermal stress to the electric motor therefore long or frequent startings could cause its damage. Reducing the starting current could reduce the torque too much, risking to increase the starting time.

With regards to the **Power Factor**, it is 0.1 in no load condition and from 0.5 to 0.9 or more (often 0.75 to 0.85), in its nominal function. The value varies considerably due to the motor’s characteristics (number of poles and power).

The UPS performance in steady state, while supplying an induction motor, is close to standard, as the currents are sinusoidal and balanced. It is important to be aware of the inrush currents and Power Factor before sizing the UPS.
SIZING UPS FOR SUPPLYING INDUCTION MOTORS

A certain number of motor specifications are helpful to size the UPS correctly.

a) Case of:

10 induction motors
maximum two of them starting simultaneously (even without mains)
rated motors’ values:

\[
\begin{align*}
P_n &= 45 \text{ kW} \\
V_n / f_n &= 400 \text{V} \Delta / 50 \text{Hz} \\
P.F. &= 0.87 \\
\text{Efficiency (}\eta\text{)} &= 93.4\% \\
I_s &= 6.5 I_n \\
T_s &= 2.8 T_n
\end{align*}
\]

D.O.L. (Direct On Line) starting

A UPS that should supply the motors only in steady state should be sized for

\[
S_n = \frac{10 \cdot P_n}{P.F. \cdot \eta} = \frac{10 \cdot 45000W}{0.87 \cdot 0.934} = 554 \text{kVA}
\]

Now, considering the starting

\[
I_n = \frac{P_n}{\sqrt{3} \cdot V_n \cdot P.F. \cdot \eta} = \frac{45000W}{1.732 \cdot 400 \cdot 0.87 \cdot 0.934} = 80 \text{A}
\]

\[
I_s = 6.5 \cdot I_n = 520 \text{A}
\]

\[
I_t = (I_s \cdot 2) + (I_n \cdot 8) = (520 \cdot 2) + (80 \cdot 8) = 1680 \text{A}
\]

\[
S_{\text{tot}} = \frac{3 \cdot V_n \cdot I_t}{3} = 1164 \text{kVA}
\]

Taking into account the starting transient we can consider the overload capacity of the UPS (typically 1.5 \( S_n \) per 1 minute at \( V_n \)). The UPS size gets:

\[
S_{\text{UPS}} = \frac{S_{\text{tot}}}{1.5} = 1164/1.5 = 776 \text{kVA} \rightarrow 800 \text{kVA}
\]

The reduced P.F. during starting can be neglected due to its short duration.

An additional verification has to be done to the current peak value if compatible with the peak current that the UPS can supply. Because of transient phenomena the inrush current peak value is approximately 1.7 instead of the usual 1.41 \( I_n \), typical of sinusoidal wave shapes.
\[ \hat{I}_t = (I_s \cdot 2) \cdot 1.7 + (I_n \cdot 8) \cdot 1.41 = 2670A \]

\[ S_{UPS} = \sqrt{3} \cdot V_n \cdot \frac{\hat{I}_t}{3} = 1.732 \cdot 400 \cdot 890 = 616kVA \rightarrow 800kVA \]

The value \( \frac{3}{3} \) that divides \( \hat{I}_t \) in the previous formula is the p.u. phase-phase short circuit current that the UPS can supply. It is different from the phase-neutral, 3.5, and it is used because the motors are supplied without neutral.

In case of there being no need to start up during mains outage, the starting current can be neglected for the choice of the UPS, considering only the rated ones. By the way the starting currents must be considered for the bypass sizing.

b) Same motors of case a) with Y/Δ starting.

\[ I_t = (I_s \cdot 2) \cdot 0.4 + (I_n \cdot 8) = (520 \cdot 2) \cdot 0.4 + (80 \cdot 8) = 1056A \]

\[ S_{tot} = \sqrt{3} \cdot V_n \cdot I_t = 732kVA \]

\[ S_{UPS} = \frac{S_{tot}}{1.5} = 732/1.5 = 488kVA \rightarrow 500kVA \]

\[ \hat{I}_t = (I_s \cdot 2) \cdot 1.7 \cdot 0.4 + (I_n \cdot 8) \cdot 1.41 = 2325A \]

\[ S_{UPS} = \sqrt{3} \cdot V_n \cdot \frac{\hat{I}_t}{3} = 1.732 \cdot 400 \cdot 775 = 536kVA \rightarrow 600kVA \]

In this case the minimum UPS size seems 600 kVA. Such value is compatible with case a) when the apparent power in steady state requested to the UPS was 600 kVA.

The Customer or his technical reference has to verify if the Y/Δ starting torque of 0.95 T_n is enough to start the load in a compatible time for the induction motor.

Duties

IEC 60034 defines 10 different “ways of using” induction motors in terms of power and time such power can be supplied. They are called services. Below it is possible to find the 3 most used services in the industry. Their impact on the UPS is linked to the current it is requested to supply. S1 means nominal power for indefinite time. The others typically consist in higher requested power for a limited amount of time. The knowledge of the service of the motor to protect is compulsory to verify the thermal stress of the UPS.

The motors can be used in different type of duties. Below the most common:

\[ ^1 0.4I_s=0.4*6.5I_n=2.6 \text{ as shown in Table 1.} \]
Figure 1 - S1: Continuous running duty (N: Operation at constant load; $\theta$: temperature)

Figure 2 - S2: Short time duty (N: Operation at constant load; $\theta$: temperature)
Motors supplied by regulators

For economical and robustness reasons, induction motors are being used more and more frequently in association with electronic regulators.

Soft starter

It consists of two thyristors assembled head to tail (or a triac). By delaying the input of the thyristor at each alternation, we can reduce the rms voltage applied to the motor stator.

Due to its weak speed variation range on a standard cage motor, the soft starter is most commonly used to
start-up on machines with a parabolic resistant torque \( C = f(v) = \alpha \cdot v^2 \)

Examples: Ventilators, pumps.

In these two examples, the speed control can be in a very limited range of speed. Such variable speed capability is usually limited to small units.

The disadvantage consists in heat losses increase both in rotor and stator. This could lead to over size the motor.

Finally, the soft starter is a power generator of harmonics.

Its basic application is in driving pumps with nominal power of the motor from 3 to 630kW. The limitation of the starting current can generally be regulated between 2 and 5 times the nominal current.

**Harmonics generated by the soft starter**

When the voltage shape is not sinusoidal, therefore at partialised voltage conditions, there is always the presence of harmonics. The motor absorption together with the conduction limitation operated by the soft starter cause presence of 3\(^{rd}\), 5\(^{th}\), 7\(^{th}\), 9\(^{th}\), 11\(^{th}\) and more harmonics with consequent impact on the UPS size.

**Power Factor**

Voltage and current shapes are far from being sinusoidal because they are cut to reduce the high inrush currents incompatible with the upstream plant. The Power Factor is also linked to the shape: the same Active Power supplied by non sinusoidal wave shapes have lower P.F. than supplied with sine waves.

It is possible to see from the pictures below, that the current shapes can be closer or farer from the sinusoidal shape depending on the needed rms voltage value.

Examples of wave formats:
Figure 5 – Soft Starter behaviours on resistive load (top) and resistive-inductive (bottom)

Figure 6 - DOL starting at no load (top) Soft Starter starting and its zoom (bottom) The curves above show that with a soft starter
The peak current by the power supply is twice smaller than the DOL start-up.
The start-up current has strong harmonic components 5, 7, 11 and 13.

The 3rd harmonic and multiples are not present on the above example because of star connection.

With the aim of guaranteeing a quality power supply (THD_u < 5%) to the loads in parallel with the soft starter, in general, the UPS must be derated by 20%. So, a UPS of 100 kVA will be suitable to supply a load consisting of soft starter up to a maximum of 80 kVA. The soft starter does not cause any risk of power re-injection into the UPS or mains.

**Inrush currents**
The Soft Starter reduces the inrush current of a ratio (V_s/V_n). It means the start-up could require currents from the UPS higher even than its overload capability and they must be considering at the sizing stage.

**Speed drives**
As well as a UPS, the speed drive is made by an AC/DC and a DC/AC module.
The available devices on the market are different, i.e.:
Stand alone or integrable in PDUs;
An AC/DC centralised for many DC/AC modules (one per motor).

The second solution is typically applied for high power applications such as rolling mills.

The three most common topologies are as follows, respectively:
2 quadrants (the energy can only flow from mains to motor);
with breaking resistor (energy can flow both to and from motors but in such case it is dissipated over a resistor on the DC bus);
4 quadrants (energy can flow both to and from motors but in such case reinjected into the mains) also called Active Front End (Figure 7).
Impact on the supply

Regulator 1 (6 pulse rectifier as input stage)
The rectifier based on the 6-pulse SCR bridge technology, causes the following on the power network:
Harmonic currents generation;
Input Power Factor 0.8 to 0.9 o 0,7 to 0,8 in case of single phase rectifier;
The presence of switching notches.

Examples:
Three-phase power supply – 6-pulse SCR rectifier input currents:

Single-phase power supply – SCR rectifier input currents:

Regulator 2 (IGBT rectifier as input stage)
This is an example of a sinusoidal regulator and unitary input Power Factor. It injects only high-frequency
and low-amplitude harmonics into the network. In practice, the resulting input current Total Harmonic Distortion (THD) will settle around 5%.

On the other hand, the speed drive standard IEC 61800-3-12 allows a maximum Input THD value up to 48%. To reduce the harmonics a possible strategy can be to clean up the distribution by using a passive, a T (L-C-L) filter can be used to eliminate the harmonics of frequencies close to the kHz value, or active filters. The input bridge uses a Pulse Width Modulation (PWM). Such PWM modulation generates high-frequency disturbances on the network and generally requires the use of a EMC filter This filter does not usually influence the upstream UPS.

If the power is supplied from an UPS, it may be necessary to insert an inductance between the UPS and the speed drive.

The capacity of being reversible can be used and the breaking energy from the motor can therefore be reinjected into the mains. This must be taken into account for the UPS choice.

**Sizing of UPS supplying a speed drive**

We have to take into account the presence of all the harmonics, which may require methods of evaluation. It is critical subject that could affect the UPS performances is the significant presence of harmonic currents which generates voltage distortion at the UPS output.

Due to the common speed drive overload capacity we have to take into account any start-up currents, that typically are maximum 1.5 times the nominal current.

On the market there are transformed based and transformer less UPSs with different performances.

With the aim of guaranteeing a quality power supply (THDU< 5%), in general, the transformer UPS must be derated of 40% in this type of application whereas the transformer less UPS can work at full load. So, a UPS of 100 kVA is capable of supplying a load consisting in the speed drive supplying asynchronous motors up to a maximum of 60kVA. In case of higher accepted THDU value the derating factor can be reduced.

Something also very limiting is the possibility of energy being reinjected in the mains via UPS, as it is not generally designed to manage this situation.

In the case of services, we have to take into account the effects of thermal stress it could have on various UPS components.

**Harmonics**

Almost all regulators produce high rates of input voltage harmonics. These current harmonics generate a distortion in the output voltage of the UPS.
The UPS output voltage regulation has to compensate the effects of those harmonics, and has to maintain the system stability (UPS + Drive + Motor + load). The presence of harmonics, as well as the starting currents, needs a UPS derating. Purpose of this derating is to guarantee a stable operation and a maximum value of 5% output voltage distortion. The common derating factor for industrial applications is around 40%.

The voltage distortion generates strong currents in the UPS output filter capacitors. Purpose of derating is also to protect these components.

Applying harmonic filtering solutions at the speed drive input allows to significantly reduce the derating of the UPS.

**Motor overloads and regulator short circuits**

Today’s speed drives protect the motor against overloads. They generally limit the currents to around 1.5 times the nominal current, for one minute every ten or five. As a result, it is enough that the UPS carries overloads around 150%. The exact duration depends on the application. Given that the speed drives do not generally allow overloads in excess of 150% / 1 minute at 25 °C and 30 s at 30 °C the UPS can work at full load. Higher overload require UPS derating factors.

In case of speed drive short circuit, the UPS limits the current. We therefore need to check the selectivity between the protection of the speed drive and the UPS short circuit current.

**Inrush Currents during start-up**

Speed drives avoid inrush currents. On the other hand needs of fast startings could require temporary overload up to 1.5 times the nominal current.

The formula below does not take into account any derating related to the 150% overload but the permitted permanent overload of 1.1 \( C_n \). In case of non sinusoidal currents the total harmonic distortion must be considered:

\[
I_{ms} = I_1 \sqrt{(1 + \text{THDI}^2)}
\]

with

\[
I_1 = 1,1 \frac{P_{mot}}{\sqrt{3} \cdot U} \cdot \frac{1}{\eta_{motor} \cdot \eta_{drive}}
\]

\(P_{mot}\): Nominal power of the motor

\(U\): Power supply voltage between phases

\(\eta_{motor}\): motor efficiency

\(\eta_{drive}\): speed drive efficiency
The table below shows the calculations and the UPS needed to supply just one motor of the same type of the first example of this paper.

<table>
<thead>
<tr>
<th>6 pulse speed drive</th>
<th>Supposing $\eta_{\text{drive}}=90%$ and the temporary overload of the speed drive is compatible with the UPS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1 = 1.1 \cdot \frac{I_n}{\eta_{\text{drive}}} = 1.1 \cdot \frac{80A}{0.9} = 98A$</td>
<td>It is interesting to note that: a UPS chosen just for the motor nominal current would have been 56 kVA$^2$.</td>
</tr>
<tr>
<td>$I_{\text{rms}} = I_1 \cdot \sqrt{1 + \text{THD}^2} = 98A \cdot \sqrt{1 + 0.32^2} = 103A$</td>
<td>the daily experience suggest to chose the UPS 67% higher than the nominal power of the motor to keep the THD$_{U}$ less than 5%, therefore 93 kVA.</td>
</tr>
<tr>
<td>$S_{\text{drive}} = \sqrt{3}V_n I_{\text{rms}} = 71kVA$</td>
<td></td>
</tr>
</tbody>
</table>

**Speed drive input Power Factor**

The Power Factor can vary greatly, depending on the regulator model. It is advisable to provide the precise regulator model to avoid any useless derating.

**Power reinjection**

Some speed drives have the capability to reinject the energy back to the mains. Particular attention has to be given to this subject, because UPSs are not generally designed to manage it.

The capability of the UPS in absorbing the backwards energy depends on the charge level of the batteries connected directly to the DC bus. The drawback is that the batteries are overly stressed in case of too frequent happenings. This is not a solution, this relieves the situation but does not solve the problem and should be used rarely and wisely.

**Cycles and starting**

The existence of load cycles is even more true for motor supplied by a speed drive. Depending on amplitude, duration and cycle frequency, certain UPS components age prematurely (e.g. battery, IGBT…).

In case of cycling, batteries are generally used by the UPS for trying to compensate the voltage drop of the DC bus. Not taking it into account during the sizing of the UPS could cause progressive discharge and in the long term, premature ageing of the batteries.

A good way to avoid those drawbacks is to use a device that keeps the DC voltage constant and fast reacting to energy requests. These are typical characteristics of high speed flywheel based energy storage systems.

The best way to have long BUT and DC bus voltage stability is to have both, battery and flywheel in parallel.

Similar phenomena are observed during start up, but this procedure is much less frequent. Therefore, up to 10 start-up cycles equally distributed during the day can be accepted.

$^2 P_n / \text{P.F.} = 45 \text{ kW} / 0.9 = 56 \text{ kVA}$
Battery Mode functionality

In case of the above mentioned processes without mains present upstream to the UPS, the stress on the battery is worsened since there is no rectifier supporting the battery by supplying the UPS inverter.
White Paper – 07/2010
Power supply for asynchronous motors
Author: Franck Weinbissinger – Industrial Marketing Manager

Head Office
SOCOMEC UPS Strasbourg
11, route de Strasbourg
B.P. 10050
F-67235 Huttenheim Cedex – France

SOCOMEC UPS Vicentina
Via Silla, 1/3
36033 Isola Vicentina (VI) – Italy

Sales, Marketing and Service Management
SOCOMEC UPS Paris
95, rue Pierre Grange
F-94132 Fontenay-sous-Bois Cedex – France