Industrial Motors

Commercial & Appliance Motors

Automation

Digital & Systems

Energy

Transmission & Distribution

Coatings

Energy Saving Opportunities When Starting and Running Induction Motors

A comparative guide of torque, current and energy consumption

Driving efficiency and sustainability

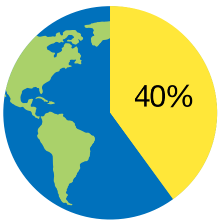
SUMMARY

Introduction

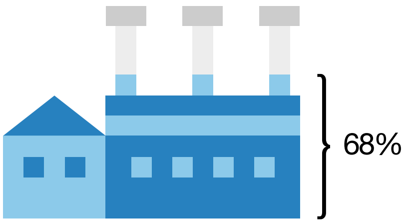
Electric consumption refers to how much electricity a facility uses in an hourly, daily, monthly or yearly basis. This consumption is commonly measured and charged per kilowatt-hours (kWh).

In the industry, energy efficiency improvements can reduce the energy consumption to manufacture a product or provide a service, thereby reducing process/production costs, besides providing other social and environmental benefits.

Savings are obtained when unnecessary energy consumption is eliminated. In industries, it can be achieved by more efficient equipment, or through automation of processes.



It is estimated that around 40% of the energy consumed in the world is directly related to industry.



Breaking that down to the industry sector, electric motors are responsible for about 68% of the energy consumption.

It is also estimated that 90% of the electric motors in industry are 3-phase induction motors.

Considering these estimations, and the relevance of the induction motors power demand on the overall world electricity consumption, this white paper highlights energy savings possibilities when using electric motors, combined with WEG Automation equipment. This document will emphasize possible savings in two different operation points:

- Motor start
- Motor duty cycle

Motor current x rotation speed curve

Induction motors have a defined Current x Rotation Speed curve, when fed with nominal (rated) voltage and frequency. The typical curve is illustrated on the following chart:

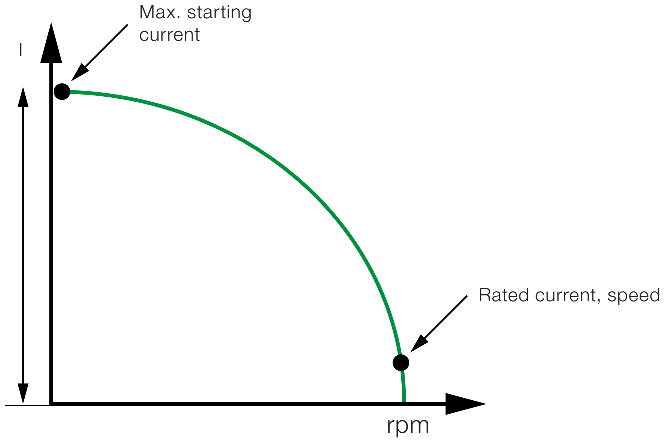


Figure 1 – Current Diagram for Typical Squirrel Cage Motor

Although each induction motor would carry its own characteristic curve, in general they all present similar current x speed responses. You can find the specific curve and further WEG Motor information on the WEG Motor datasheet.

The graph shows that when starting an induction motor (from zero speed) with rated voltage and frequency, high current level is expected while the motor is accelerating to the rated speed. This starting current is many times greater (5 to 8 times) than the motor's rated current. The ratio between starting current and rated current is specified on the WEG Motor Datasheet.

Motor torque x rotation speed curve

Induction motors also present a typical Torque x Rotation Speed curve, when fed with nominal voltage and frequency:

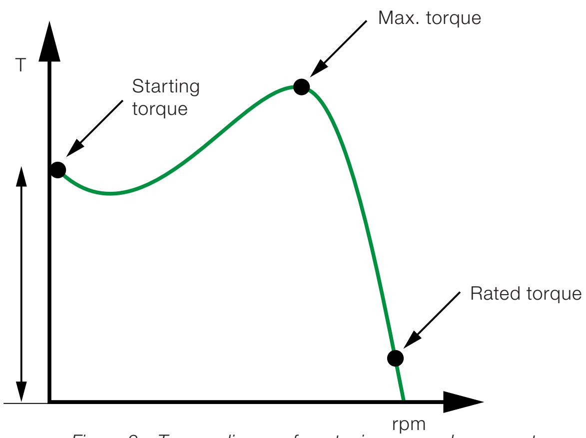


Figure 2 – Torque diagram for a typical squirrel cage motor

Torque is the measure of the energy required to rotate a shaft. When mechanical energy is applied in the form of a rotating movement, the developed power output depends on the torque and on the rotational speed. The ratio is as follows:

$$P = \frac{T.n}{9555}$$

Where:
P is the power [kW];
T is the torque [N.m];
n is the rotor rotational speed [rpm].

The Torque x Speed curve is related to the power available at the motor shaft to be supplied to the driven load. WEG can supply the precise Torque x Speed curve of WEG Motors.

Each type of load finds its own demanding torque curve. If the motor attached to the load supplies it with a torque greater than what is requested, the demand is fulfilled and the motor accelerates. If the delivered torque is not greater than the demanded, the application cannot be driven and the motor won't accelerate.

Assuming a random load torque curve called Cr, and a motor torque curve called C:

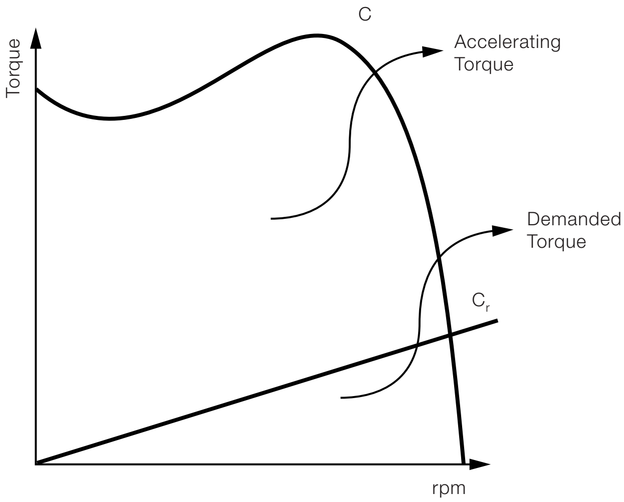


Figure 3 – Motor Torque and Load Demanding Torque

The graph shows the available torque "C" which is delivered by the motor shaft and the load demanding torque "Cr". While the motor torque is greater than the load torque, the motor accelerates. This surplus torque is called accelerating torque. In the moment when Cr equals to C, the application no longer accelerates and the speed remains fixed at that point.

Motor starting methods

Now that the induction motor characteristic curves were introduced, some motor starting methods and their own responses in terms of torque and current are presented.

Direct online (DOL)

Figure 4 –WEG DOL Starter most used options

The Direct Online start is a starting method that consists of purely feeding an electric motor with its rated voltage and frequency. The motor is connected to the power supply via a contactor/breaker/switch. The voltage level and frequency on the power supply is fixed, and will be the power grid voltage and frequency. Figures 1 and 2 illustrate the typical induction motor response to the DOL start.

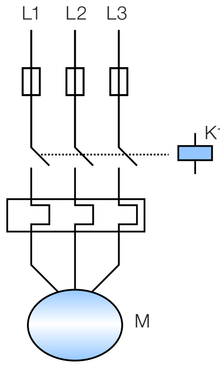


Figure 5 – DOL Power Circuit Illustration

WEG has several solutions for direct online starters, from the sale of separate components, which can be assembled in electric panels, to the sale of the complete package inside plastic or metal enclosures.

Referring to Figure 6, the accelerating torque is illustrated, which, although necessary, represents an "energy waste" when it is too high. The higher the available torque, the greater the mechanical power delivered, and therefore the greater the electrical power consumed. An excess of available torque (accelerating torque) may also stress the couplings and other mechanical parts of the driven machine.

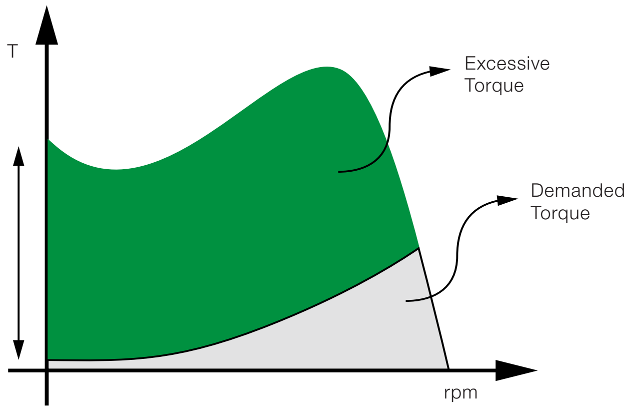


Figure 6 – Torque x Speed curve at a DOL start

Star – Delta

The main principle of the Star-Delta starter is to reduce the voltage on the motor windings during the start. Such method intends to start the motor with its windings connected in Star (or Y) and after the initial acceleration period the winding connection is changed to Delta. When star-connected, the current is reduced to 25-30% of the starting current when delta-connected.

Star connection delivers lower voltage, current and consequently lower starting torque to the motor.

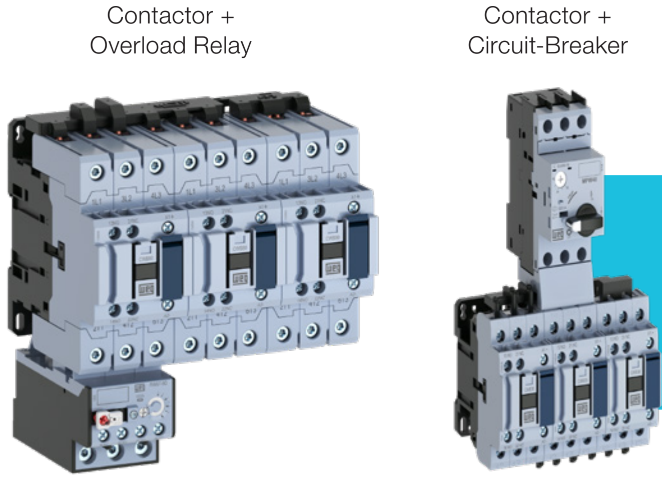


Figure 7 – Some of WEG Star-Delta Starter Options

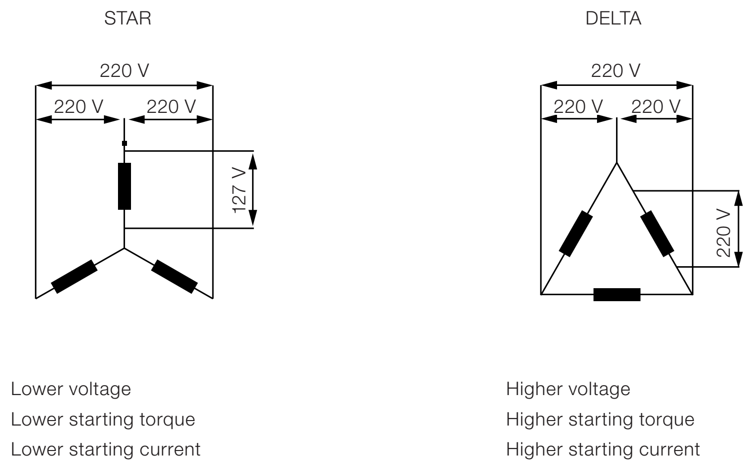


Figure 8 – Star and Delta Connection Comparison

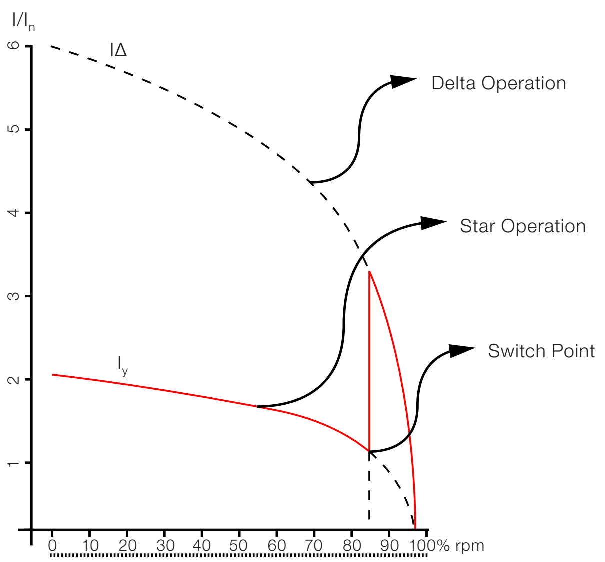


Figure 9 – Star-Delta Current x Speed Curve

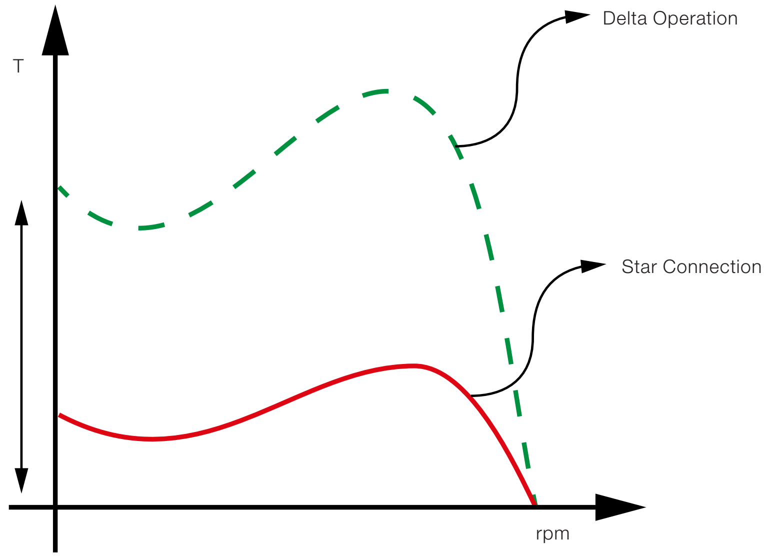


Figure 10 – Torque x Speed Curve at Star and Delta Connections

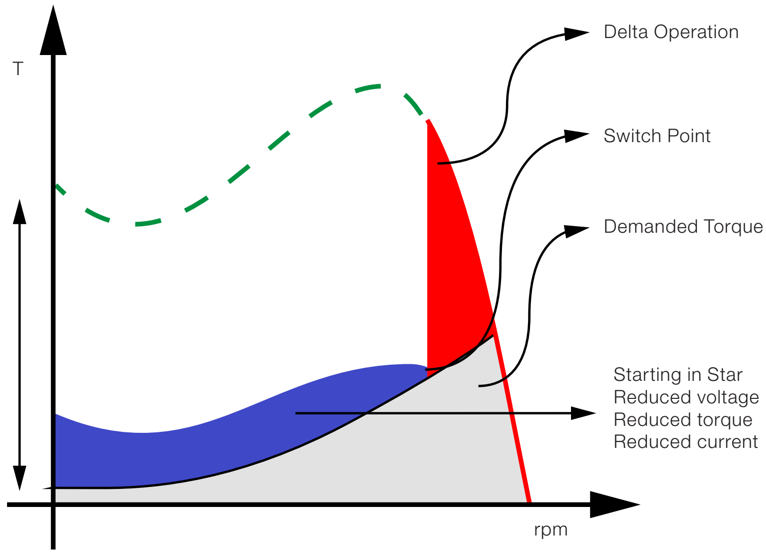


Figure 11 – Torque x Speed curve at Star-Delta Start

As presented over the previous figures, is notable that the Star-Delta Start can be more efficient than the DOL, in terms of energy savings, since the excessive starting torque is smaller.

Soft-starter

Soft-starter is a device designed to start an electric motor smoothly, by controlling the voltage supplied to the motor. The voltage reaches its rated value with a smooth acceleration ramp instead of being submitted to increments or sudden peaks.

WEG Soft-starter allow user to configure acceleration ramps, voltage ramps, current ramps and much more.

The following graphs illustrate comparisons between DOL, Star-Delta and Soft-starter starting methods. The left chart compares the Torque x Speed curves, and the right chart compares the starting currents. For these graphic purposes, the Soft-starter was considered using a voltage ramp starting method.

Figure 12 – WEG Soft-starter SSW900

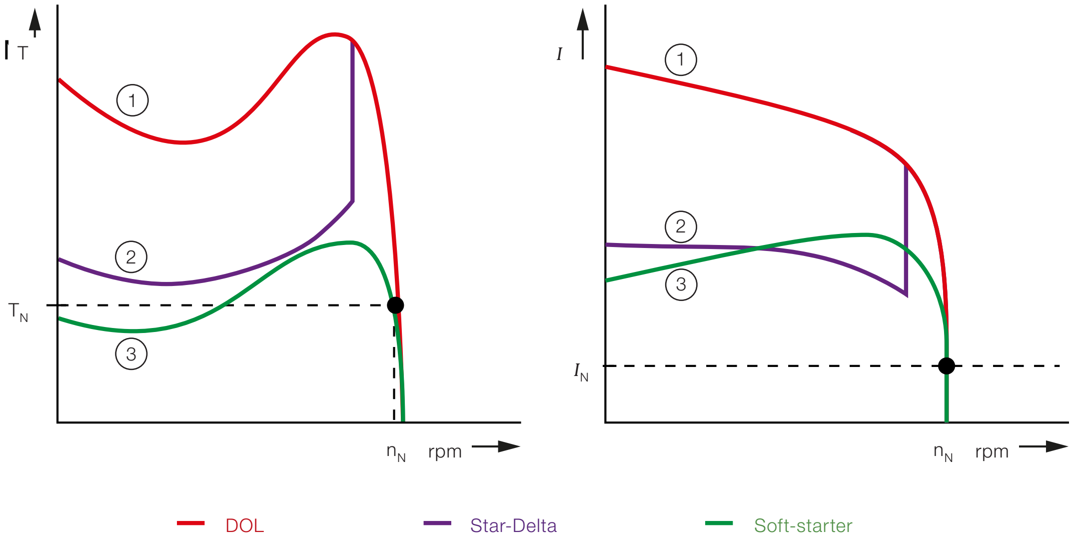


Figure 13 – Starting Methods Comparison

Soft-starters allow an optimized use of the accelerating torque. This start produces less torque and current to reach rated speed, and therefore consumes less electrical energy over the starting ramp, when compared to DOL and Star-Delta starters.

Variable speed drive (VSD)

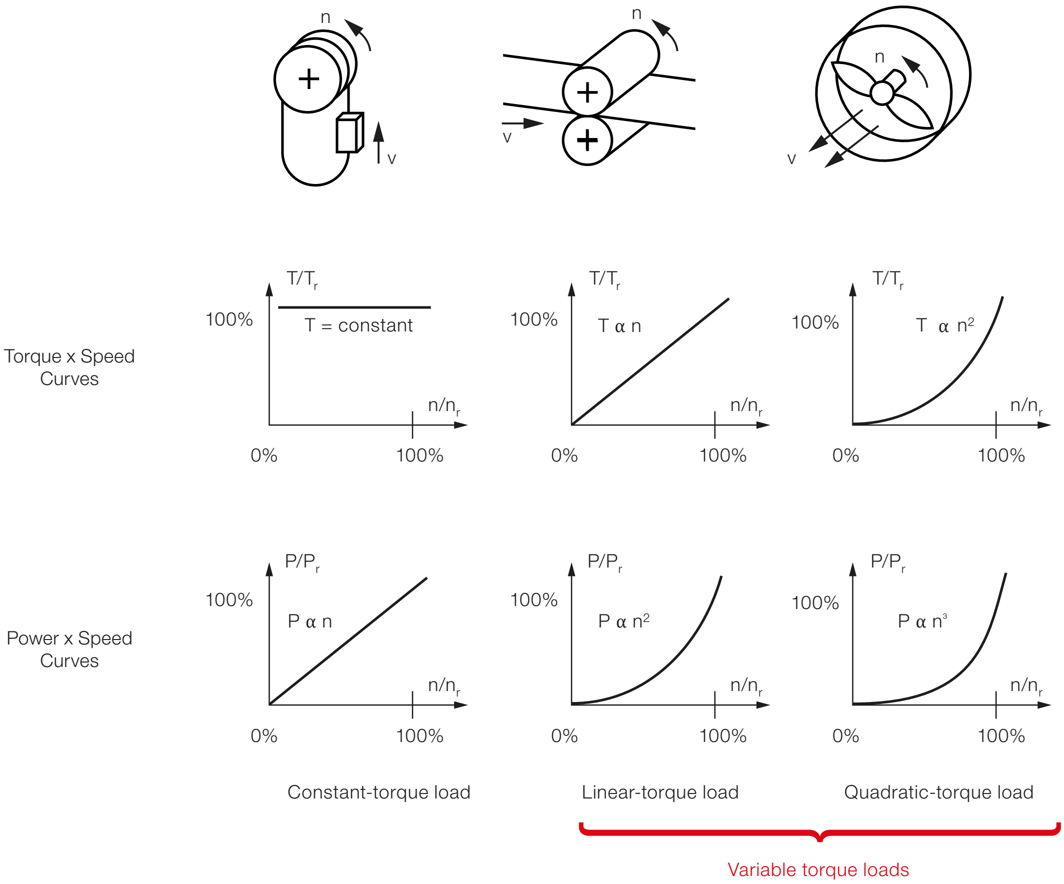
A VSD is a motor control device that protects and controls the speed of an AC induction motor. A VSD can control the speed of the motor during the start and stop cycle, as well as throughout the run cycle, by controlling the voltage and frequency of the motor power supply.

In applications that do not require the motor to run at rated speed all the time, the use of VSDs can lead to major energy savings. The transmitted power is proportional to the rotor speed times torque, as presented in the equation below. Thus, when the motor speed slows down, the power decreases.

$$P = \frac{T.n}{9555}$$

Figure 14 – WEG Variable Speed Drive CFW900

Note that the VSD energy savings are even greater when driving variable torque loads (loads that present speed-proportional torque), at speeds lower than the rated speed. The following charts illustrate how the power consumption varies with speed for each type of load.



Centrifugal equipment (e.g. fans, pumps and some compressors) follow a general set of speed affinity laws. These laws state that the power required is proportional to the cube of the speed or flow. It means that if the motor speed drops, it brings about a cubed power drop.

For example, if a motor is operated at 80% of its rated speed (reduction of 20%), the required power at this new speed is:

$$\frac{Power_{80\%\ speed}}{Power_{rated\ speed}} = \left(\frac{0.8^{*}\ rated\ speed}{rated\ speed}\right)^{3}$$

$$\frac{Power_{80\%\ speed}}{Power_{rated\ speed}} = (0.8)^{3} = 0.512$$

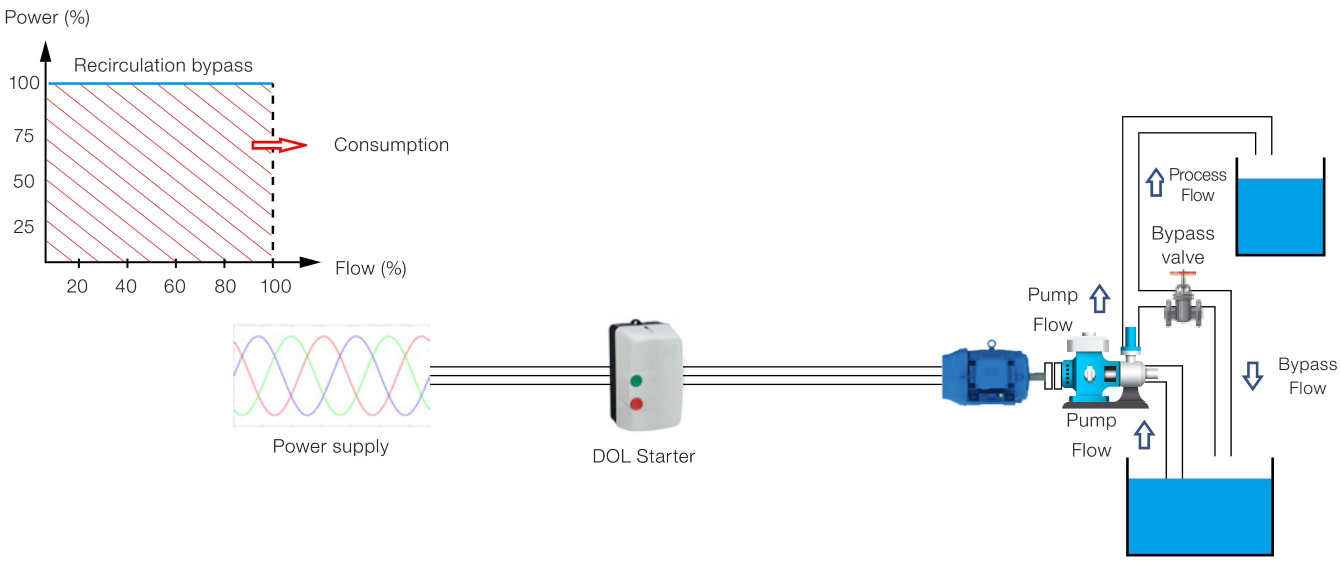
0.512 → 48.8% Reduction

Therefore, the power required to operate a fan (or pump, or compressor) at 80% speed is almost ***half of the rated power***.

To better understand where these applications can take place, an example is presented.

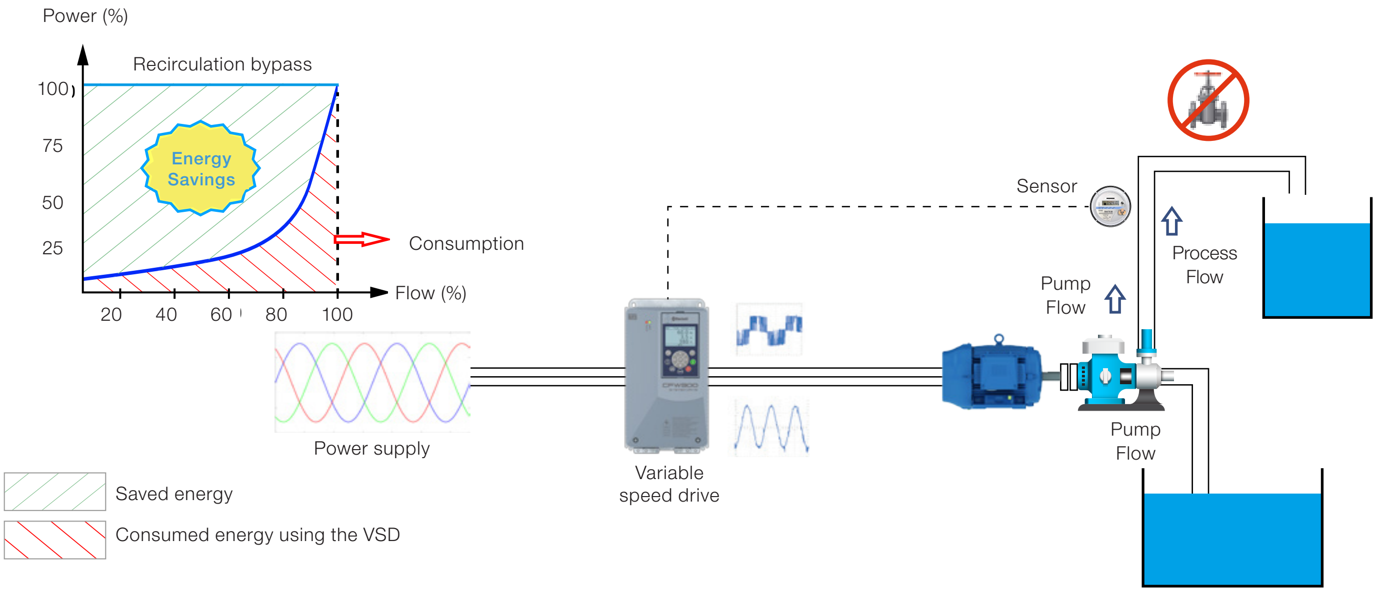
Automation example

In a pump system driven by a motor with a DOL Starter, a bypass valve is used to control the water flow in a pipe:



Note that in this application, even though the upper tank flow is controlled, the pump is working at full load and the motor is running at rated speed all time. Consequently the motor demands its rated power from the grid during the whole duty cycle. The power consumption is constant, as presented in the upper left corner.

Considering now the same system driven by a WEG VSD and without the bypass valve:



System's flow control in this scenario is done by varying the speed of the set motor/pump, which is possible due to the VSD. Therefore, when decreasing the motor speed, the system mechanical power and torque will decrease as well and, as a consequence, the absolved electrical power from grid will be reduced as well, resulting in energy savings.

For such applications, the built-in PID regulator of WEG VSDs can be used to control a closed loop process. In this example, a flow transducer is installed in the pipes and supplies an analogue feedback signal to the VSD, which is compared with a setpoint (set by the operator) and the VSD controls the motor speed in order to eliminate any error and keep the process variable equal to the setpoint.

Conclusion

Induction motors holds a major position in electricity consumption over industrial plants. Although part of this electricity consumed by induction motors is indeed demanded to deliver work, part of it can be considered as waste and its consumption can be optimized.

During the motor start, at full load and rated frequency, the motor starting characteristics demands hugely increased current levels, which turns to high starting torque. When this starting torque is considerably higher than the load demand, this surplus is waste. There are a few options to mitigate the waste over the motor starting which are:

- Star-Delta starter: consists on reducing the voltage level to the motor during part of the acceleration ramp, dropping the current and delivered torque. Since it works during part of the acceleration ramp, the other part will consume as usual.
- Soft-starter: consists on controlling the voltage level to the motor. For applications where no speed control is demanded, this option would optimize the starting to its best condition.

Now leaving the starting period aside, induction motors can also be doing work that isn't necessary, when driving / feeding them with methods that doesn't change the feeding frequency (such as DOL, Star-Delta and Soft-starter), that is, that don't have capacity to vary speed. So with a fixed speed on an application, the motor will deliver fixed torque. This excessive torque may be excessive in certain conditions, so that having the capacity to vary speed and torque would then bring electricity consumption savings.

Consider a fan or a pump. Running those with fixed speed would bring a fixed quantity of water pumped or air circulating. When excessive, a damper needs to be in place for the fans or a bypass valve for the pumps. That indeed is a waste of energy. By controlling the motor speed (read water or air flow), recirculating water/air is avoided, bringing more efficiency to the system and consequently reducing the electricity demand.

For all of these options, during start or operation, WEG has the right product to cover your demands. Contact our team closer to you to find out how you can benefit from our product portfolio.

The scope of WEG Group solutions
is not limited to products and solutions
presented in this catalogue.
To see our portfolio, contact us.

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