Press Release

For your business and technology editors

Power Factor improved by Variable Speed AC Drives

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The use of AC induction motors is essential for industry and utilities. AC induction motors consume more than 50 percent of the energy used in industry. As compared to other type of loads, the induction motor has a relatively poor power factor, causing higher line currents, which causes additional heat in line cables and transformers. The power factor is especially low in cases when the motor is oversized for the application and, therefore, running lightly loaded.

The use of Variable speed AC Drives (VSD) to control motor speed has the advantage of clearly improving the power factor and thus reducing losses in the supply cables and transformers. It also avoids the cost of investment in power-factor-correction equipment.

This article explains the reason for the phenomena, which may result in the input current to the Variable speed AC Drive can be lower than the output current. The article also gives some guidelines when compared with fixed speed applications or other speed control methods like DC drives.

What is the Difference Between Power Factor and Cosφ?

Power Factor (PF) is an important measure for electrical systems and it is defined as ratio of Real or Active Power, in total kilowatts, to total Apparent Power, in kilovolt amps.

$$\mathrm{PF} = \frac{P}{S} = \frac{\text{Real Power}}{\text{Apparent Power}}$$

The Power Factor topic is of interest to a large number of people. An Internet search with one of the search engines gave more than three million hits. There sometimes seems to be confusion between the terms Power Factor and cosφ (phi). Just remember that the cosφ is equal to Power Factor only in cases where both system voltage (U) and system current (I) are sinusoidal (cosφ is equal to Power Factor only when the voltage and current considered are at the same frequency). In real-world electrical installations, both voltages and currents contain harmonics and the Power Factor is not equal to cosφ.

To understand Power Factor, it can help to consider phasor diagrams. An electrical circuit under consideration is shown in Fig. 1. The supply voltage U connected to the circuit is at a single frequency; that voltage causes current I to flow through the components. According to Ohms law, the voltage drop in each component is calculated by multiplying the current I (in Amps) by the resistance (in Ohms). The phasor diagrams for this circuit are shown in Fig. 2.

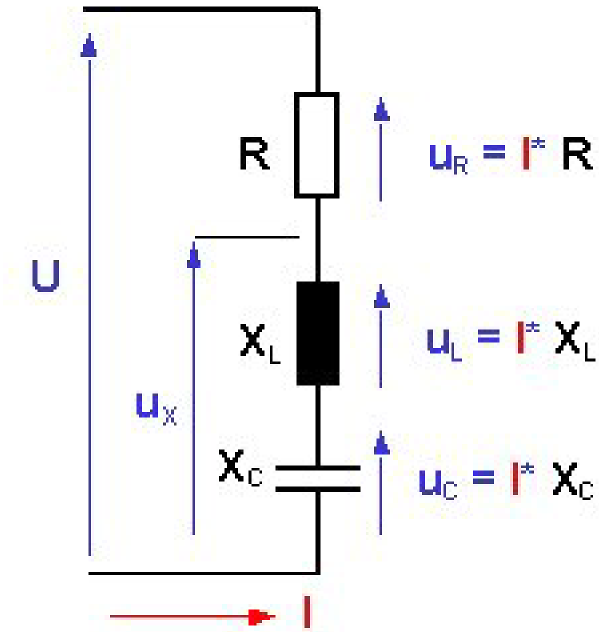

Figure 1. The three basic linear electrical components in serial connection with the voltage U, causing the current I to flow through the circuit. The components are:

- Resistor R with resistance measured in Ohms and a voltage drop u_R
- Inductor with inductive impedance X_L measured in Ohms and a voltage drop u_L
- Capacitor with capacitive impedance X_C measured in Ohms and a voltage drop u_C

The voltages and currents in Fig. 1 can be illustrated in phasor form in Fig. 2. The current I is common for each component in the system, but the voltages are of different magnitude and their phasors are in different directions -- 90 degrees apart from each other's. The three diagrams in Fig. 2. show the steps for defining the voltage phasors and the angle between the total voltage U and the current I. As result, we get the definition for the cos φ:

$$\cos\varphi = \frac{\text{Real Power}}{\text{Apparent Power}} = \frac{U_R I}{UI} = \frac{U_R}{U}$$

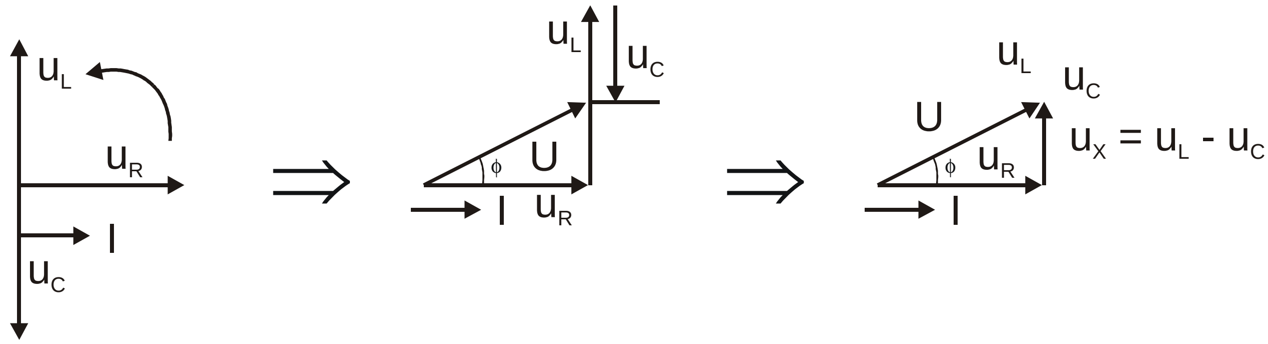

Figure 2. The current phasor I rotates in phase with the voltage vector u_R, but it is lagging the voltage phasor u_L and leading the voltage phasor u_C. All phasors rotate counter-clockwise. Because the u_L and u_C are pointing in opposite directions, they are subtracted and the difference u_X is the reactive component of the total system voltage. The u_R is the active or real component and the phasor sum of these voltages is the total voltage U. The cosine of the angle φ between total voltage U and the active voltage u_R is the Power Factor of an ideal system, which is known as cosφ. If U and u_R have one single, fundamental frequency, cosφ is sometimes called displacement Power Factor.

To understand, power factor is sometimes visualized with a horse pulling a railroad car down a railroad track. Because the railroad ties are uneven, the horse must pull the car from the side of the track. The horse is pulling the railroad car at an angle to the direction of car's travel. The power required to move the car down the track is the real power. The effort of the horse is the total (apparent) power. The car will not move sideways. Therefore the sideways pull of the horse is wasted effort or reactive power. These three different power vectors are shown in Fig. 3.

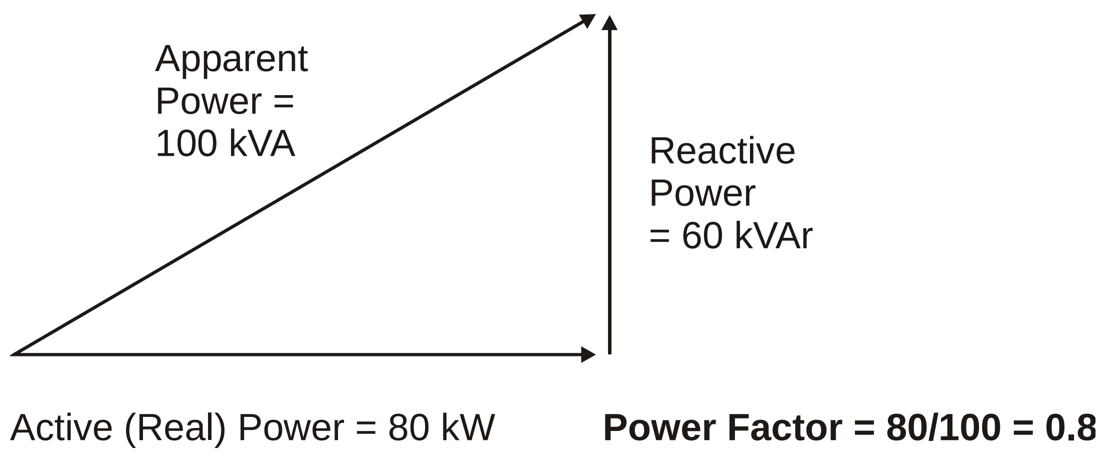

Figure 3. The Power factor definition by using power vectors

In summary:

- Power Factor (PF) is the Real Power divided by Apparent Power
- Power Factor of the system with sinusoidal current and voltage is cosφ

- In both cases, the value of PF is from 0 to 1, sometimes given as 0 to 100%
- The real-world PF is influenced by harmonic disturbances and other non linearity's
- The real-world PF is therefore lower than with sinusoidal current and voltage

When Should the Power Factor be improved?

Power plant generators usually are designed for PF = 0.8 to 0.9. Therefore, if the actual demand-side Power Factor is lower than the designed (0.8), either the generator current increases above the rated current or the active power output has to be limited. For that reason, the power companies put limits on reactive power consumed by the customers. The limits usually are set for large industrial or public customers only.

Customers have to pay a power factor penalty if power factor falls below a certain limit. The limits can vary widely from 0.8 to 0.97. Electric motors connected to the power line is the main reason for reduced power factor. The rated power factor of a standard motor depends on its rated power and, typically, is around 0.85 but can be much lower if the motor is lightly loaded. This topic will be studied in the next section.

Why Do Electric Motors Cause Low Power Factor?

The use of AC induction motors is essential for industry and utilities. AC induction motors consume more than 50 per cent of the energy used in industry. As compared to other type of loads, motor loads have relatively poor power factor. Poor power factor causes higher line currents, which causes additional heat in line cables and transformers. The power factor is especially low in cases when the motors are oversized and are running with a light load.

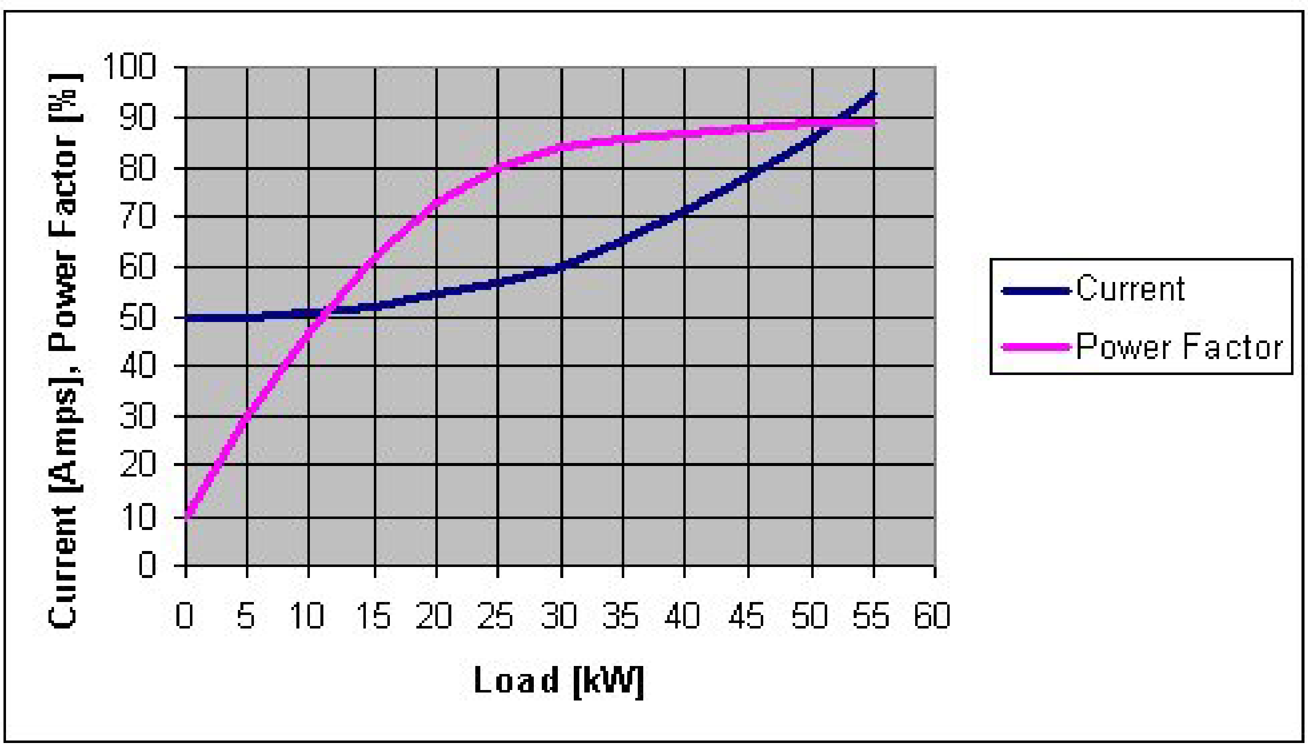

Figure 4. Line current and power factor of a 55 kW AC induction motor as function of the motor load.

To produce the required rotating torque and speed, the induction motor takes both active current and reactive current from the power supply. The rotating torque of the motor is created as an interaction between the active current component and the magnetic field. The field is produced by the reactive current component. Light load takes less active current but the magnetic field, as well as the reactive current, stays constant. This means that the power factor decreases with decreasing load, as shown in the Fig. 4. At the full load, the current is mainly active but, at the light load, the current is mainly reactive.

How to Improve the Power Factor?

There are many different methods to improve the power factor or compensate for the reactive power:

- At the power plant, the excessive reactive power can be compensated by increasing the excitation of synchronous generators; or, by using separate rotating synchronous compensators.

- At transmission or transformer stations, the reactive power can be compensated by power- factor-correction capacitors. The capacitors can be installed to improve the power factor for a single load or an entire power system.

- At the plant level, the power factor correction can be accomplished by using power-factor-correction capacitors, or by using variable speed AC drives. When AC drives are used, power-factor-correction capacitors should not be used, because it is usually unnecessary, and because drive harmonics could damage power factor capacitors. See the next section.

The principle of Variable Speed AC Drives

On a so-called PWM (Pulse Width Modulated) drive with a diode bridge converter input, the Power Factor to the AC line is near unity (see Fig. 5). The output may have an inductive (lagging) power factor, due to the motor's inductive reactance. However, the motor's reactive current is circulated between the motor and the inverter bus capacitors – and not to the input line.

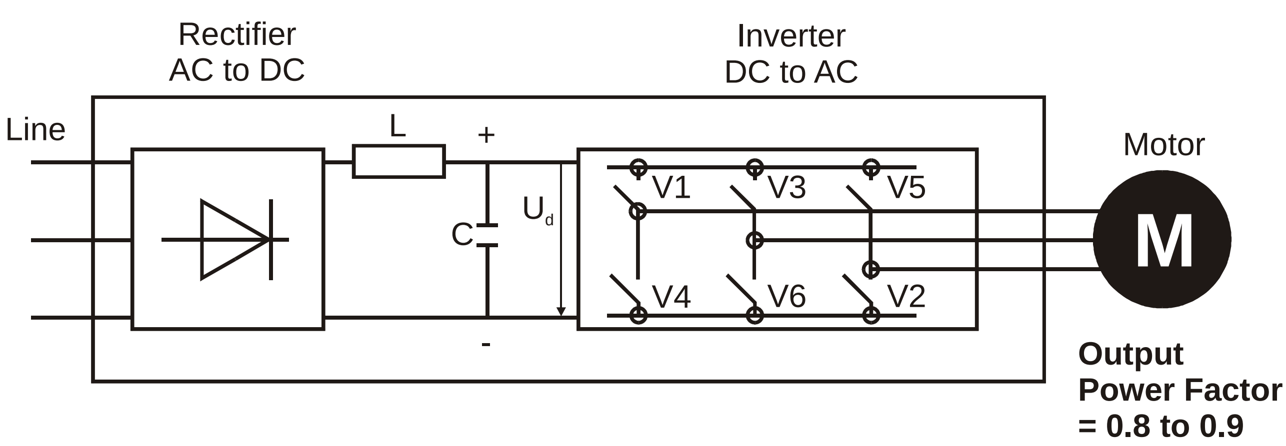

Figure 5. A Variable speed AC drive input consists of a rectifier bridge that converts the line AC voltage to DC voltage. The smoothing of the DC voltage is made via an inductor (L) and capacitor (C). The DC voltage (Ud) then is converted in the inverter to variable frequency and variable voltage AC that is connected to the AC motor. The switches V1 to V6 in the inverter are very fast semiconductors, usually IGBT's (Insulated Gate Bipolar Transistors)

in modern drives.

Because of the fast switching inside the AC drive, there is a risk of electromagnetic emissions. Emissions can be both conductive and radiating interference. International regulations set limits on both low- and high-frequency emissions. With the use of filters, screening and suitable mechanical construction inside the drive cabinet, it is possible to meet the Electromagnetic Compatibility (EMC) standards.

How Variable Speed AC Drives improve Power Factor

Let’s study the currents of the above mentioned 55 kW/400V motor and drive system:

Motor: Motor Mechanical Power = 55 kW,

Input U = 400 V, efficiency = 94.4% and power factor = 0.89

Motor Electrical Input Power= 55 kW/0.944 = 58.3 kW

Motor Electrical KVA = kW/PF = 65.5

$$I_2 = \frac{58.3 * 1000}{\sqrt{3} * 400 * 0.89} = 94.5 \text{ A}$$

AC drive: Output P = 58.3 kW, 94.5 A

Input U = 400 V, efficiency = 98% and power factor = 0.96

Drive Input Power = 58.3 kW/0.98 = 59.5 kW

Drive Input KVA = 62.0

$$I_1 = \frac{59.5 * 1000}{\sqrt{3} * 400 * 0.96} = 89.5 \text{ A}$$

One can see that the drive input current from the supply is 5 amps, or more than five percent (94.5 versus 89.5 amps), lower than the drive output current to the motor. The active power input, instead, is 1.2 kW (58.3 versus 59.5 kW) higher than the output from the drive.

The difference in drive input and output power factor is how the variable speed AC drive can improve the Power Factor and how the drive output current can be greater than the input current!

What Does This Mean in Reduced Losses and Saved Money?

The power losses in the power line, transformers and cables are proportional to the square of the current. We can estimate the following:

Assume the average load on the 55 kW motor is 35 kW.

From Fig. 4, the motor current at 35 KW is 65 amps; the AC drive input current

under these conditions is 60 amps.

The AC drive reduces the input current from 65 A to 60 A.

The reduction of losses when operating the motor from an AC drive is then:

$$P_p = 100 - \left(\frac{60}{65}\right)^2 * 100 = 15\%$$

If total losses on the supply side are 5% of the average load, the AC drive can reduce the losses to about 4%. The reduction on the total power consumption, as well as reduction on money spent, is one per cent.

(Note: The original reason to install an AC drive is not the power factor improvement but better process controls, energy savings in the process, and/or reduced wear of the machinery. PF improvement is a positive side effect.)

Power Factor Comparison Between AC and DC Drives

The main difference between standard AC and DC drives is that PWM AC drives have a diode rectifier on the front end while DC drives have SCR rectifier. The control principle of the SCR rectifier is based on phase control with line commutation, causing a phase shift between voltage and current. The lower the speed, the larger the phase shifts. This reduces the power factor of DC drives, especially in the lower speed ranges (as shown in Fig. 6).

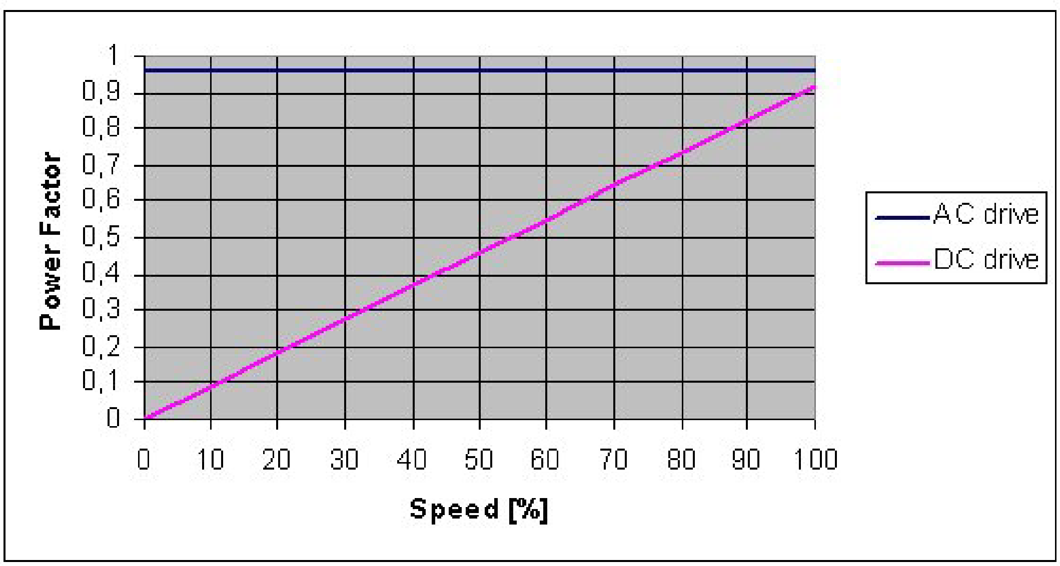

Figure 6. Power factor of AC and DC drives as function of motor speed.

Conclusions

The power factor topic is interesting and important for a number of parties within the power generation and consumption marketplace:

- Industrial, commercial and domestic customers have a desire to get the most cost effective electrical installation to serve their machinery. Low power factor can mean extra losses and penalty payments to the utility for excessive reactive power.

- Power production and transmission companies want to sell as much active power as possible to their customers. Low power factor can reduce the generating and transmission capacity.

- Manufacturers of power-factor-correction equipment are willing to sell capacitor banks and automation equipment to help improve the power factor.

- Consultants have an interest to help the power companies, consumers and other interest groups with audits and plans for better energy economy and achieving higher power factors.

- Drives and motors manufacturers can also help to improve the power factor with variable speed drives. VSDs help solve the power factor problem -- while improving process control, saving electrical energy, *and* reducing machinery wear.

# # #

Sidebar: Why is Power Factor Important?

In the mid 90's, a large semi-conductor manufacturer built a new production plant in New Mexico. A few years later, they built another, nearly identical, plant in Arizona. After operating the new Arizona plant for one year, the user noticed that the Arizona plant's electrical bill was approximately 30% higher than the New Mexico sister plant. The only discernable difference between the two plants was the method of controlling the Clean Room Re-circulating Air Handlers (RAH) Units.

In the New Mexico plant, PWM AC Drives were used on the (RAHs). In the Arizona plant, the RAH OEM provided variable-width fans and constant-speed AC Motors instead of PWM Drives. When the variable-width fan closed off (less CFM), the AC Motor unloaded, and the PF dropped drastically. The Arizona Utility had a poor PF penalty charge. The 30% increase in the electrical bill cost of the Arizona plant was due to the RAH motor's poor PF at reduced loads!

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