General Information
Power Factor Correction Questions and Answers

- Back to Basics: What does Power Factor Mean and Why Must We Correct it?

Power factor is the ratio between the kW and the kVA drawn by an electrical load where the kW is the actual load power and the kVA is the apparent load power.

Simply, it is a measure of how efficiently the load current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system.

Consider this:

When you buy fuel for a vehicle, the manufacturer makes in it in litres, the pump dispenses it in litres and you pay for it in litres. Dollars/litre – simple!

When you buy potatoes, the supplier bags them in kilos the shop sells them in kilos and you pay for them in kilos. Dollars/kg – simple!

When you buy electricity, the "manufacturer" (electricity generator) makes kVA (kilo volt amperes) and you pay for it in kWh (kilowatt hours) or maybe on your bill (Units) – not so simple!

Maybe we all should have kVA meters to make life simple.

So what is the kilowatt hour (or unit) we get on our bills? Simply, 1000 watts of electricity being used for 1 hour.

Example: 10 x 100 watt lamps x 1 hour=1000 watts/hr divided by 1000=1kWh – simple!

Now here comes the problem: In an alternating current (AC) electrical supply, a mysterious thing called "Power Factor" comes into play. Power Factor is simply the measure of the efficiency of the power being used, so, a power factor of 1 would mean 100% of the supply is being used efficiently. A power factor of 0.5 means the use of the power is very inefficient or wasteful.

So what causes Power Factor to change? In the real world of industry and commerce, a power factor of 1 is not obtainable because equipment such as electric motors, welding sets, fluorescent and high bay lighting create what is called an "inductive load" which in turn causes the amps in the supply to lag the volts. The resulting lag is called Power Factor.

For a 3 phase power supply: kVA, which the electricity generator makes=Line Volts x Amps x 1.73÷ 1000. This is converted to kilowatts kW by the formula: Line Volts x Amps x 1.73 ÷ 1000 x Power Factor=kW (V x A x 1.73÷ 1000 x pf) or kVA x pf=kW (N.B. 1.73 is the square root of 3) so as the power factor worsens from say 0.98 to 0.5, the generator has to supply more kVA for each kW you are using.

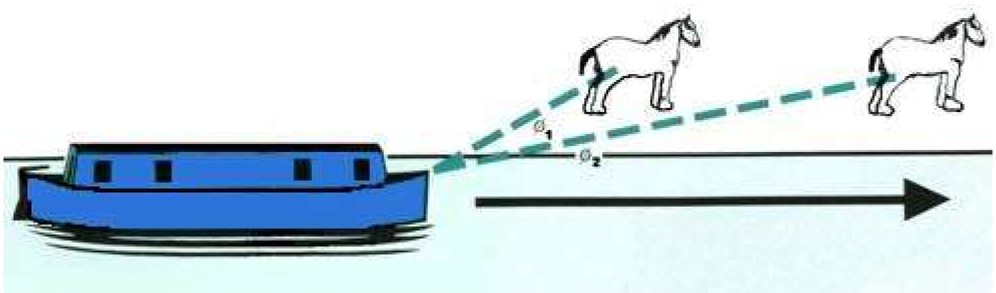
For example, a large electric motor will typically have a Power Factor of about 0.85 at full load. If we have a hypothetical electric motor rated at 100kW, then ignoring the inherent inefficiency of the motor, when running at full load the electricity supplier would have to supply 100÷0.85=118kVA to provide the 100kW to run the motor.

Or put the other way they would be supplying 18% more electricity than they are charging you for. If the same motor was operating "off load" at say 50kW or being used on a cyclic duty then the power factor may go as low as 0.5.

In this case the supplier would have to supply "double" the kVA to match the 50kW duty point. (50÷0.5=100kVA)

How this power is wasted can be shown graphically since in 3 phase power supplies "power" can be represented and measured as a triangle. ACTIVE Power is the base line and is the "real" usable power measured and paid for in kW. REACTIVE power is the vertical or that part of the supply which causes the inductive load. The reactive power in is measured in kVAr (kilo volt-amperes reactive). APPARENT Power is the hypotenuse. This is the component the electricity generator must supply and it is the resultant of the other two components, measured in kVA. Mathematically the power can be calculated by pythagoras or trigonometry whereby Power Factor is expressed as COS phi Ø (The angle between Apparent Power and Active power)

But we want a simple explanation so consider a barge being pulled by a horse:



Since the horse cannot walk on water its pulling effort is reduced by the "angle" of the tow rope.

If the horse could walk on water then the angle Phi Ø would be zero and COSINE Ø=1. Meaning all the horse power is being used to pull the load.

However the relative position of the horse influences the power. As the horse gets closer to the barge, angle Ø1 increases and power is wasted, but, as the horse is positioned further away, then angle Ø2 gets closer to zero and less power is wasted

So, by improving Power Factor (reducing the angle), the reactive power component is reduced

What does it do to my electricity bill?

As stated above in a 3 phase power supply, kW consumed is 3 phase VOLTS x AMPS x 1.73 x Power Factor. The Electricity Company supply you VOLTS x

AMPS and they have to supply extra to make up for the loss caused by poor Power Factor.

When the power factor falls below a set figure, the electricity supply companies charge a premium on the kW being consumed, or, charge for the whole supply as kVA by adding reactive power charges (kVar) to the bill.

- What are the Causes of Poor Power Factor?

Today's commercial, industrial, retail and even domestic premises are increasingly populated by electronic devices such as PCs, monitors, servers and photocopiers which are usually powered by switched mode power supplies (SMPS). If not properly designed, these can present non-linear loads which impose harmonic currents and possibly voltages onto the mains power network.

Harmonics can damage cabling and equipment within this network, as well as other equipment connected to it. Problems include overheating and fire risk, high voltages and circulating currents, equipment malfunctions and component failures, and other possible consequences.

A non-linear load is liable to generate these harmonics if it has a poor power factor. Other loads can present poor power factors without creating harmonics. This post looks at these issues, the circumstances that can lead to damaging harmonic generation, and practical approaches to reducing it.

- The two causes of poor power factor

At the simplest level, we could say that an electrical or electronic device's power factor is the ratio of the power that it draws from the mains supply and the power that it actually consumes. An 'ideal' device has a power factor of 1.0 and consumes all the power that it draws. It would present a load that is linear and entirely resistive: that is, one that remains constant irrespective of input voltage, and has no significant inductance or capacitance. Fig. 1. Shows the input waveforms that such a device would exhibit. Firstly, the current waveform is in phase with the voltage, and secondly both waveforms are sinusoidal.

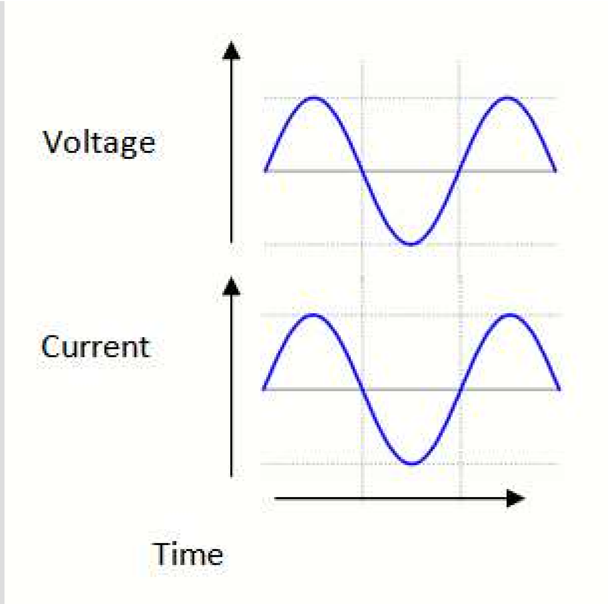


Fig 1: Input voltage and current waveforms for a device with PF = 1.0

In practice, some devices do have unity power factors, but many others do not. A device has a poor power factor for one of two reasons; either it draws current out of phase with the supply voltage, or it draws current in a non-sinusoidal waveform. The out of phase case, known as 'displacement' power factor, is typically associated with electric motors inside industrial equipment, while the non-sinusoidal case, known as 'distortion' power factor, is typically seen with electronic devices such as PCs, copiers and battery chargers driven by switched-mode power supplies (SMPSs). We shall look briefly at the displacement power factor before moving on to the distortion case, which is of more immediate concern to electronic power system designers. However it is important to be aware of both cases. For example, some engineering courses discuss the power factor issue only in terms of motors, which causes confusion when their students later encounter poor power factor as exhibited by an SMPS.

- Electric motors and displacement power factor problems

Electric motors create powerful magnetic fields which produce a voltage, or back emf, in opposition to the applied voltage. This causes the supply current to lag the applied voltage. The resulting out of phase current component cannot deliver usable power, yet it adds to the facility's required supply capacity and electricity costs. Fitting capacitors across motors reduces the phase lag and improves their power factor.

- SMPSs and distortion power factor problems

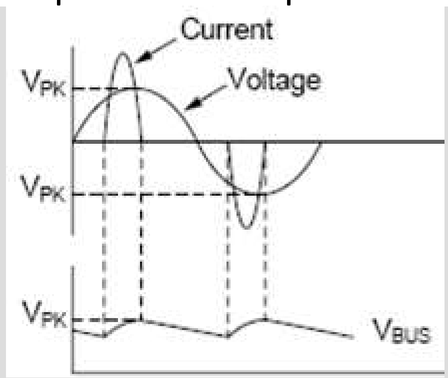


Fig 2: Non-sinusoidal current waveform drawn by SMPS with poor power factor

Whereas displacement power factor loads do not cause harmonics and their associated problems, distortion power factor loads such as SMPSs will do so unless their power factor is improved.

An SMPS's AC front end typically comprises a bridge rectifier followed by a large filter capacitor. This circuit only draws current from the mains when the line voltage exceeds that across the capacitor. This causes current to flow discontinuously, resulting in the non-sinusoidal current waveform shown in Fig. 2.

It is possible to use Fourier transforms, a mathematical process, to analyse this waveform and break it down into a set of sinusoidal components. These comprise the fundamental frequency – 50 Hz in Europe, 60 Hz in America – and a set of predominantly odd multiples of the fundamental, known as harmonics. The third harmonic is 150 (or 180) Hz, the fifth, 250 (300) Hz and so on. Fig. 3 shows a typical harmonic spectrum for an electronic SMPS load. The fundamental component is usefully consumed by the SMPS, while the harmonics are reactive and create the problems described above. The ratio of the fundamental amplitude to the sum of all the harmonic amplitudes gives the device's power factor.

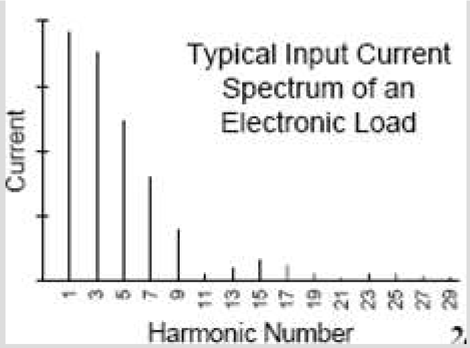


Fig 3: Typical harmonic spectrum for an electronic SMPS load

- International standard

An international standard exists to describe and set acceptable limits for a product's mains harmonics generation. Within the EU, its reference is IEC 61000-3-2, covering equipment power levels from 75 W to 600 W. The standard assigns equipment into four Classes – A, B, C and D. Class D covers personal computers, personal computer monitors and television receivers.

- How does Power Factor Correction work?

Considering most of the load with the users results in Inductive (lagging) Power Factor, by installing suitably sized switched capacitors into the power distribution circuit, the Power Factor is improved and the value becomes nearer to 1 thus minimising wasted energy, improving the efficiency of a plant,

- Who gets the savings?

First of all we must understand that savings happen due to reduction in Current drawn hence maximum savings occur due reduction in line Losses in the transmission of power.

This means maximum savings are accrued by the Authorities involved in Transmission and distribution of energy to the user.

Depending on the supply Authority they will either charge the user to cover their losses in the Transmission lines by charging in KVA as in NSW or impose penalties for Energy used at poor Power Factor.

Also All users in Australia pay for installation capacity in terms of Peak Demand. Peak Demand is measured in KVA. Hence a Poor power factor will result in User requiring more KVA for the same amount of energy used.

Alternatively an improvement in power Factor will result in liberating more kW from the available supply and save the user money!

- What is the Pay Back Period of Investment Made?

The purchase cost of the installation is usually repaid in 1 to 4years in electricity savings. This depends on how the Electricity suppliers charge for the energy supplied and how optimum is the use of the Energy by the user.

It is important therefore to make measurements to collect accurate information regarding the current Power Factor and install appropriately sized Power Factor correction equipment.

Also for large and Multiple users an Improved Power Factor enables the user to go back with the improvements made and negotiate a better Energy rate from the Energy suppliers.

- Why is there a need of putting Harmonic and line filters in Power Factor Correction Equipment?

Distortion in Supply due to Harmonics can result in Higher current being drawn by Capacitors. Line filters ensure that this effect is minimized thereby prolonging the life of the installation.

In addition some of the supply authorities use Power distribution lines also for metering purposes. This signal for measurement is done at higher frequencies and will be disturbed by the Power Factor Correction capacitors if suitable filters are not installed. Most supply authorities now demand that such filters are included with the Power Factor Correction Equipment.

- What should be the rating of capacitors used in Power Factor Correction equipment?

During switching of capacitors and due to Fluctuation of Voltages in the supply Power Factor correction capacitors are subjected to very high voltages. It is therefore important to select Power Factor correction equipment which can sustain these conditions. It is prudent to select capacitors which can withstand 480V 3Phase AC supply in normal cases and in sites prone to high voltage fluctuations 525V 3 Phase rating is appropriate.

(This document is under development and if you have any questions please feel free to raise it with R.P Switchboards for inclusion in the document.)

