



# Power factor correction

An introduction to technology  
and techniques



Making business sense  
of climate change

Reducing energy use makes perfect business sense; it saves money, enhances corporate reputation and helps everyone in the fight against climate change.

The Carbon Trust provides simple, effective advice to help businesses take action to reduce carbon emissions, and the simplest way to do this is to use energy more efficiently.

This technology guide introduces power factor correction, discussing practical action that organisations can take.

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# Understanding power factor

## What is power factor?

Power factor is a way of describing how efficiently electrical power is consumed. It refers to power in an alternating current (AC) electrical circuit, either for a single piece of equipment or all of the electrical equipment at a site.

The power that is drawn from the network can be described as consisting of two parts – **useful power** and **reactive power**.

**Useful power** is the power that equipment needs to achieve the task at hand and it is measured in kW.

**Reactive power** is drawn in addition to useful power by a reactive load and is measured in kVA<sub>R</sub>. The consumption of reactive power does not contribute to achieving the task.

The useful power and the reactive power together determine the power drawn from the network, that is, the **total power** (also known as **apparent power**), measured in kVA. Total power is not the linear sum of useful power and reactive power. However, lessening the effects of reactive power will reduce the power needed from the network to complete the same tasks.

Power factor is the ratio of delivered useful power to the total power taken from the supply. An ideal ratio is 1.0, that is, a perfect match between power drawn from the network and useful power for the task. This is also known as unity power factor.

In reality, many loads do not easily achieve unity power factor due to their inherently reactive nature. However, it is possible to compensate for the reactive power. By doing so, less power will be needed from the network to achieve the same tasks, resulting in energy and cost savings.

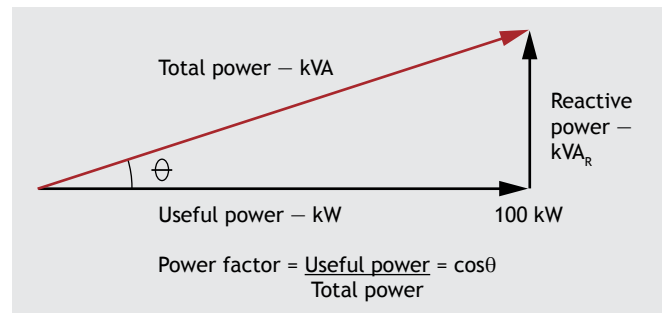
If the ratio is under 0.85, the power factor is generally considered to be poor. Correction would typically achieve 0.95-0.98.

## How is poor power factor caused?

Figure 1 shows the relationship between useful and total power. The length of the heavy black line represents the useful power consumed by a 100kW machine, while the red line shows the power taken from the electrical system.

The angle in the diagram ( $\theta$ ) shows the extent of the difference. In this diagram, significantly more power is needed to deliver 100kW of useful power<sup>1</sup>.

Figure 1 Relationship between total power and useful power



Reducing the effects of reactive power will cause the angle  $\theta$  to get closer to  $0^\circ$ , meaning the power factor will get closer to unity. Power factor correction techniques can achieve this.

Poor power factor has negative implications for businesses because it:

- ▶ Draws more power from the network – costing more to achieve the same tasks
- ▶ Can incur a 'poor power factor penalty' from the supplier, sometimes called a 'reactive power charge'
- ▶ Reduces the effective capacity of the electrical supply, – the more reactive power that is carried, the less useful power can be carried
- ▶ Causes losses at transformers and other devices, leading to inefficiency and unwanted heat gains
- ▶ Can cause excessive voltage drops in the supply network
- ▶ Can reduce the life expectancy of electrical equipment in extreme cases.

## Which devices could have poor power factor?

Reactive power will be consumed by all 'uncorrected' reactive devices – it is just a part of how they work. Commonly-used inductive devices include motors, welding sets, induction heaters and fluorescent lights. Inductive loads are not always easily identifiable, and the most certain way of identifying them is through a power factor survey.

<sup>1</sup> Total power here calculated as  $100 \div \cos\theta$ .

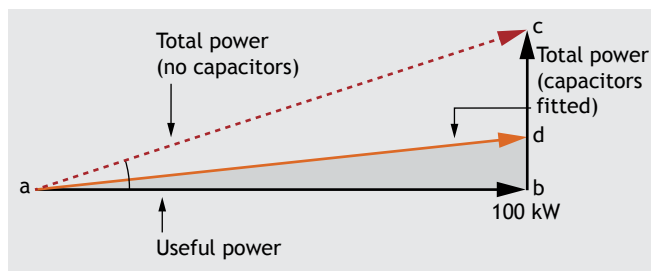
# Power factor correction

## What is power factor correction?

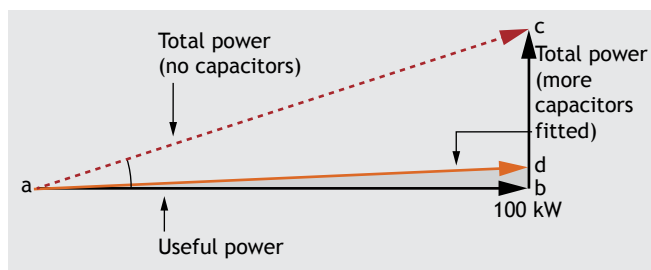
Power factor correction (PFC) techniques aim to bring the power factor closer to unity by reducing the effects of reactive power. In the great majority of cases, poor power factor is due to inductive loads which can be compensated by adding electrical devices called capacitors into the circuit.

The diagrams in Figure 2 show the effect of PFC on the poor power factor example shown in Figure 1. In Figure 2A, with the capacitors, the angle is reduced, therefore the total power drawn from the supply is less. However, there is still a 'lagging' power factor. Figure 2B shows how the addition of more capacitance brings the total power drawn nearly down to a perfect power factor. However, it is possible to overcompensate. Figure 2C shows how too much capacitance can lead to over-correction and, again, draw excess power from the network. This is called a 'leading' power factor.

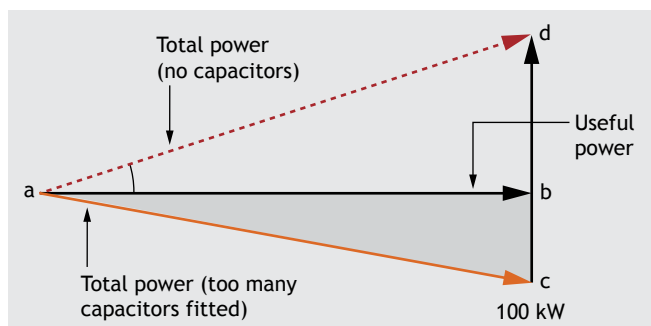
**Figure 2A** Some capacitors fitted



**Figure 2B** Near perfect power factor correction with capacitors



**Figure 2C** Over-correction of power factor



## Advantages of PFC

- ▶ By reducing losses and inefficiencies, improving your power factor means you need to draw less from the network, saving you money on your electricity bill
- ▶ Power factor correction (PFC) can prolong the life of electrical equipment
- ▶ It can help avoid voltage drops over long cables and reduce efficiency losses in your supply transformers
- ▶ PFC will increase the effective capacity of your local electricity network – potentially deferring future investment in electrical infrastructure and allowing you to connect more machinery to the same utility connection.

### Where to look for power factor information

#### Equipment specifications

Nameplates or specification manuals will include power factor specifications. Be careful about how they represent the figure – some may show the figure for power factor, while some will just show the angle.<sup>2</sup>

#### Utility bills

Depending on the contract, some suppliers may charge for reactive power use, and/or add a penalty for poor power factor. This should be identified on the invoice.

#### Power factor surveys

Power engineering specialists and electricians can conduct a survey to check for poor power factor. Some utility companies and suppliers will perform a survey at no cost and make recommendations.

### fact:

It is not uncommon for industrial installations to be operating at power factors between 0.7 and 0.8 – which is relatively poor.

<sup>2</sup> The power factor will be represented as the cosine of the angle -  $\cos\theta$ . If the product just quotes the angle  $\theta$ , use a scientific calculator to determine the cosine value.

# Implementing power factor correction techniques

## Understanding the system

The specification of a PFC system requires knowledge of several factors including:

### The voltage level and typical usage of the reactive loads on-site

This will affect the type of system and the amount of correction needed. Adding capacitors is a basic PFC technique, but other systems might be more appropriate in some circumstances. For instance, **active PFC** is an electronic PFC system that controls the amount of power drawn by a load in order to obtain a power factor as close as possible to unity. In most applications, the active PFC system controls the input current to the load using power electronics. However, active PFC systems can also be tailored to provide varying PFC characteristics for sites with unique profiles and power constraints.

### The usage profile across the site

This is particularly important if PFC equipment has been installed at some time in the past and the electrical requirements have changed since, for example, by the substitution or addition of some machinery. If so, have the power factor resurveyed.

### The power quality required by the on-site loads

Equipment generally needs a high quality supply with stable characteristics – that is a ‘pure’ supply. Improperly specified, PFC can introduce **harmonics**, where unwanted voltages at various frequencies can be superimposed onto the mains voltage. Adverse effects caused by harmonics include heating of equipment and electromagnetic interference, such as that to communication systems, telephones, radio, TV and computers. In extreme cases, it can lead to failure of equipment. Additional equipment, such as **line filters** can smooth the mains voltage to reduce any prominence of harmonics.

## ! Safety first

It is important to consult qualified personnel prior to the specification and installation of any PFC system.

Only appropriately trained and qualified people should specify or fit PFC equipment, or take electrical measurements.

## PFC equipment

The simplest form of PFC involves fitting capacitors. Many PFC devices exist to accommodate each type of situation. It is worth shopping around specialist companies and taking expert advice on the system that will suit you.

If a single machine has a poor power factor, capacitors can be connected in parallel with the device, that is, connected to the live and the neutral terminals of the reactive device, so that they compensate for the poor power factor whenever the machine is switched on. This is a form of ‘**fixed**’ PFC.

If the power factor at a site is permanently poor and no single item of equipment is solely responsible, fixed PFC can be employed also. In this case, the PFC capacitors will be connected across the main power supply to the premises, that is, the capacitor banks’ terminals are connected to each of the three phase cables as they enter the site. In this case, PFC can be linked with the switchgear.

However, there are other circumstances where PFC is not so straightforward. Where many machines are switching on/off at various times, the power factor may be subject to frequent change. In these cases the amount of PFC needs to be controlled automatically – that is, the banks of capacitors need to be selectively switched in and out of the power circuit appropriately. There are various solutions on the market for automatically controlled PFC.

## REMEMBER

PFC equipment has a finite life – an older installation may not be operating as originally intended. Always talk to your supplier to find out how often equipment should be checked and, if an installation is over 20 years old or if the layout has changed, consider having the equipment overhauled and site resurveyed to investigate potential improvements.

# Glossary

<b>Active power</b>	See useful power.
<b>Apparent power</b>	See total power.
<b>Capacitor</b>	An electrical device which can compensate for the effect of reactive power caused by inductive loads.
<b>Harmonics</b>	Troublesome voltages at multiples of the mains frequency (50Hz) that can be introduced into an electricity supply by the presence of certain equipment, including inappropriately specified PFC equipment.
<b>Line filter</b>	A device that 'smooths' the mains voltage to reduce the prominence of harmonics. A line filter is sometimes used in conjunction with PFC equipment to ensure there are no harmonic generation issues.
<b>Power factor</b>	The ratio of useful power to total power as drawn from an AC supply by an electrical device or installation. Power factor can also be expressed as the cosine of the angle that exists between total power and useful power vectors.
<b>Power factor correction (PFC)</b>	A technique to compensate for poor power factor and thereby optimise the transfer of useful power into electrical equipment.
<b>Reactive load</b>	A load characterised by the presence of an inductance or capacitance, such as is present in induction heaters, motors, fluorescent lights and welding sets. It consumes reactive power as well as useful power.
<b>Reactive power</b>	Power that is consumed by the reactive nature of a device yet produces no useful work; can be either inductive or capacitive and is measured in kVA <sub>R</sub> .
<b>Resistive loads</b>	A purely resistive load possesses no reactance, that is, it draws no reactive power and therefore has a power factor of 1.0 (or unity). Examples of resistive loads are incandescent lighting and resistive heating elements.
<b>Total power</b>	The total power drawn by a device or installation including that consumed by its reactive nature; units in kVA (thousands of Volt Amps). Also known as 'apparent' power.
<b>Unity</b>	A term sometimes used to describe ideal power factor ratio, that is 1.0.
<b>Useful power</b>	Power that is consumed by a device when doing useful work. Note that, depending on the efficiency of the device itself, not all of the useful power is actually converted to work. Also known as 'active' power.

## For further information...

### ▶▶▶ call the Carbon Trust on 0800 085 2005

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The Carbon Trust is a private company set up by Government in response to the threat of climate change, to accelerate the move to a low carbon economy.

The Carbon Trust works with UK business and the public sector to create practical business-focused solutions through its external work in five complementary areas: Insights, Solutions, Innovations, Enterprises and Investments. Together these help to explain, deliver, develop, create and finance low carbon enterprise.

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