A guide to power factor

What does this guide cover?

This guide provides an introduction to power factor and covers the following:

- What is power factor?
- What is poor power factor?
- What causes poor power factor?
- What is the impact of poor power factor?
- What are the benefits of power factor correction?
- How to correct poor power factor.

Who is it aimed at?

This guide is for half-hourly metered customers (generally industrial and commercial customers), and is aimed at energy managers, facility managers, electrical contractors, and in cases where there are no such roles; business owners. Whether you are going through the connection journey, or are already connected, this guide is for you.

If you are not yet connected to our network, our connections experts are here to help you. Please visit www.northernpowergrid.com/getconnected.

If you are already connected to our network, we are also here to help you. Please visit www.northernpowergrid.com/contact-us.

The most important thing to remember is that if your site has poor power factor and incurs either high reactive power charges or high capacity charges, there may be potential to reduce these charges and your carbon footprint by installing power factor correction (PFC), or undertaking other actions that could improve power factor and energy efficiency.

If you have any comments or questions, please contact us by email at yourpowergrid@northernpowergrid.com.

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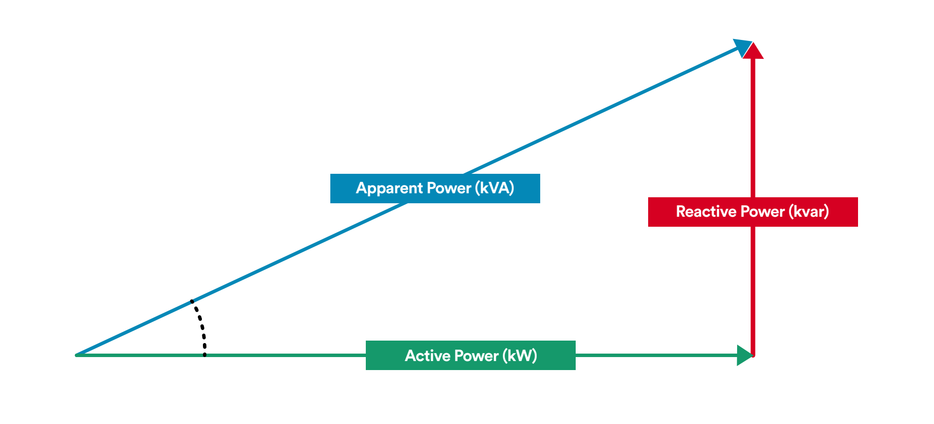
What is power factor?

Power factor is the ratio of active power (kW) to apparent power (kVA) and can be thought of as the amount of total power supplied (kVA) that is converted into something useful (kW), and therefore how efficiently the power supply is being utilised.

To explain power factor in more detail, the information in this guide provides an overview of the different types of power (apparent, active, reactive), some examples of different power factor, and illustrates the concept graphically by using the 'power triangle' as shown below.



Power triangle showing active power, reactive power and apparent power. The power triangle is fundamental to understanding power factor, which is the ratio of active power to apparent power. At a high level, apparent power is what you pay for, active power is what you use. You can reduce apparent power by reducing active power and/or reactive power.

$$\text{power factor} = \frac{\text{active power}}{\text{apparent power}} \quad \text{or} \quad \frac{kW}{kVA}$$

Power Factor shown as an equation.

Active power (often called 'real' power) is the power consumed by an electrical device. Active power is sometimes referred to as 'useful' power when explaining the concept of power factor, as this power is converted by the device into something useful. Active power is measured in 'Watts', and will appear on an energy bill as **kWh** (kilo-Watt hours).

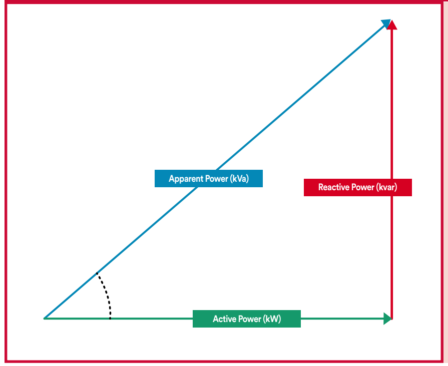
Reactive power (often called 'imaginary' power) is the power required for certain electrical devices to function, but is not consumed. It is typically devices such as transformers and motors that require large quantities of reactive power to function properly. Reactive power is measured in 'var', and will appear on an energy bill expressed in terms of units of energy as **kvarh** (kilo-var hours).

Apparent power is the combination of active power and reactive power. We cannot simply 'add-up' the active power and reactive power, but instead need to draw the active and reactive power using the power triangle. Apparent power can be thought of as the total power, and it is important to recognise that this total power is what the network transmits. Apparent power is measured in 'VA', and will only appear on an energy bill in relation to capacity charges in terms of **kVA** (kilo-Volt-Amps).

Power factor is the ratio of active power to apparent power, i.e. kW/kVA or kWh/kVAh. Power factor can be thought of as the proportion of total power that is used to do useful work, and takes the form of a number between 0 and 1 (1 being most efficient and 0 being least efficient). Power factor is unlikely to appear on your bill, and as a result, determining power factor requires the use of the power triangle (shown on the left).

The following examples show power triangles and the associated power factor for a 100 kW demand each with a different reactive power demand. Notice how the size of the apparent power increases with lower (poor) power factor, and that power factor is lower (poor) with higher values of reactive power.

EXAMPLE 1:
Power factor of 0.8 — POOR



Active power = 100 kW

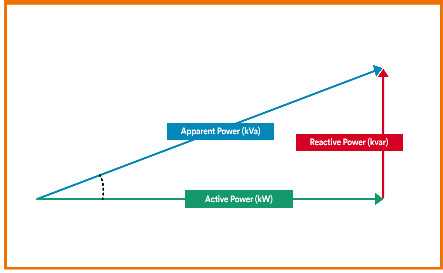
Reactive power = 75 kvar

Apparent power = $\sqrt{(100^2+75^2)}$ = 125 kVA

Power factor = 100/125 = 0.8

POOR

EXAMPLE 2:
Power factor of 0.95 — GOOD



Active power = 100 kW

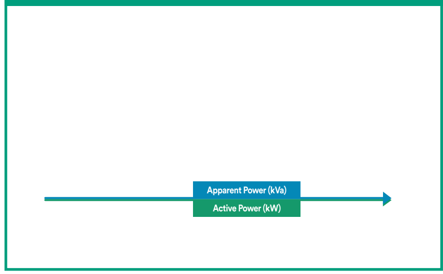
Reactive power = 33 kvar

Apparent power = $\sqrt{(100^2+33^2)}$ = 105 kVA

Power factor = 100/105 = 0.95

GOOD

EXAMPLE 3:
Power factor of 1.0 (unity) — PERFECT



Active power = 100 kW

Reactive power = 0 kvar

Apparent power = $\sqrt{(100^2+0^2)}$ = 100 kVA

Power factor = 100/100 = 1

PERFECT (UNITY)

What is poor power factor?

Poor power factor is not a strictly defined term, however it is broadly accepted that:

- **Poor** power factor has a value less than 0.95 (examples 1).
- **Good** power factor has a value between 0.95 and 1 (example 2).
- **Perfect** (unity) power factor has a value of 1 (example 3).

It is important to note that nearly all devices require a certain amount of reactive power, which will result in a reduction in power factor.

What causes poor power factor?

Poor power factor is often caused by equipment that requires large amounts of reactive power. Typically, this will include transformers and motors and is therefore particularly problematic for industrial and manufacturing sites. The power factor can deteriorate further if the equipment used is not fit for purpose or is not used efficiently – for example, part loaded motors will operate at a worse power factor than fully loaded motors.

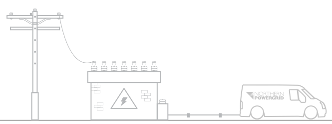
What is the impact of poor power factor?

Poor power factor at a customer's site has an impact on the distribution and transmission network to which the customer connects, along with an impact on the customer's site. Ultimately the cost associated with the network impact is paid for by customers, typically via network (DUoS) charges. We will explore the network impacts first, and then review the customer impact of poor power factor.

Network Impact:

Poor power factor is the result of a high reactive power demand, and there is a subsequent increase in network loading to facilitate this reactive power. There are three key impacts of poor power factor on the distribution and transmission networks:

1. **Losses increase** as a result of increased loading on the network. For example, a power factor of 0.9 (when compared to unity power factor) results in an increase in loading by 11% (i.e. 1/0.9 = 1.11), which in turn increases the variable losses by 23%. This means that for every unit of real power (kWh) consumed by a customer, the electrical losses (kWh) are increased by 23% as a result of a 0.9 power factor when compared to unity power factor. The cost of energy losses and the associated environmental impact (carbon footprint) are ultimately paid for by everyone.
2. **Capacity constraints** can arise on the network given that the capacity of network is based on the apparent power rating (kVA). Poor power factor requires the flow of large amounts of reactive power (kvar), which uses up capacity that could otherwise be used to transmit more active power (kW) for existing or future customers. Any network reinforcement required to connect more load is paid for by customers.
3. **Voltage problems** can arise on the network as a result of the reactive power flow. Again, any network reinforcement required to resolve the voltage problems are paid for by customers.



Customer Impact:

The network impacts to the left are ultimately paid for by customers, and these are applied via Distribution Use of System (DUoS) charges. The charges are discussed below, along with other customer impacts that are associated with poor power factor.

1. **Energy bills.** DUoS Charges are calculated by Distribution Network Operators (e.g. Northern Powergrid) and are passed on to suppliers, who then recover the cost from customers. The DUoS charges relevant to power factor are detailed below.
2. **Capacity utilisation** is higher for a given active power load. Many customers pay a capacity charge, therefore operating at a poor power factor results in higher capacity charges.
3. **High loading of equipment** on assets that are used on site to distribute power can result in high stress, electrical losses and large voltage drops. For example, cables on site that are connecting poor power factor loads.
4. **Environmental impact** is higher as a result of increased losses across the energy system. This includes the losses on the transmission and distribution networks, and also the customer's site. Whilst the cost of losses is reflected in energy bills, it is important to recognise the carbon footprint of the losses.
5. **Connection costs.** The cost of connecting to our network is based on the apparent power (kVA) and the cost of reinforcement triggered by the connection. Both of these factors could be minimised with improved power factor.

DUoS charge	Affected customers	Power factor impact
Capacity charge (£/kVA)	LV, HV, EHV	Increased capacity is required to accommodate poor power factor.
Exceed capacity charge (£/kVA)	LV, HV, EHV	Increased probability of incurring exceed capacity charges with poor power factor.
Excess reactive power charge (£/kvar)	LV, HV	For every half-hour, any reactive power in excess of that associated with a 0.95 power factor is charged.
Line loss factor (adjusts £/kWh)	LV, HV	This charge is calculated and then socialised across a region, hence this charge is unlikely to be materially impacted by an individual customer's power factor.
Loss adjustment factor (adjusts £/kWh)	EHV	This charge adjusts the unit rate applied and is calculated via a site specific losses assessment. This charge is therefore impacted directly by the power factor.

Note: LV, HV and EHV refers to the voltage at your point of connection, where LV is low voltage (voltages up to and including 1,000 V), HV is high voltage (voltages above 1,000 V and less than 33,000 V), EHV is extra high voltage (voltages above 33,000 V and less than 132,000 V; and includes 25,000 V traction supplies).

What are the benefits of power factor correction?

Reduction in energy bills as a result of the reduced DUoS charges. Savings can result in payback within two years for some customers.

Reduced capacity required for existing equipment. This can either be translated into reduced capacity charges, or could accommodate additional load without the need for additional infrastructure on site or increased capacity agreement with DNOs and suppliers.

Reduced loading of equipment on the customer's site, which may reduce the stress on equipment, reduce losses and reduce voltage drops across the customer's site. Environmental impact is reduced as a result of the reduced losses across the energy system.

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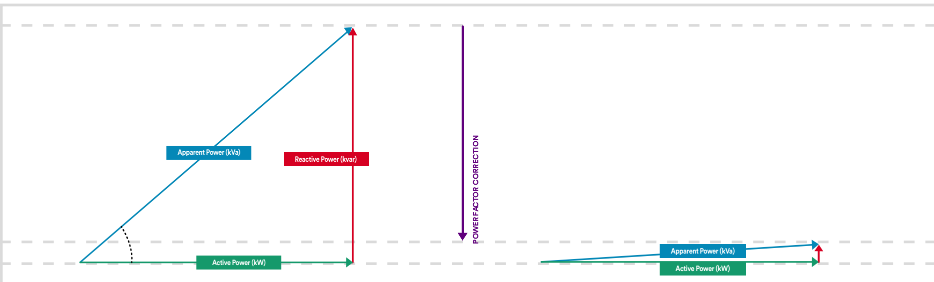
How to correct poor power factor

There are numerous ways to correct poor power factor, and one of these is Power Factor Correction (PFC). PFC is a type of technology that can be installed at the customer's site to correct poor power factor. The principles of PFC are based around the use of equipment called capacitors. Capacitors produce reactive power, which is then utilised by equipment such as motors that require reactive power. In short, the reactive power is provided locally on site by PFC and not from distant power stations. The example below illustrates graphically how this is achieved.



The first power triangle is for a power factor of 0.8. For a 100 kW load, this would equate to a reactive power of 75 kvar and apparent power of 125 kVA. The Power Factor Correction applied to achieve near perfect power factor would be 75 kvar, which is shown by a purple arrow in the second power triangle (slightly less than 75kvar). The reactive power required by the load on site is provided locally by PFC, and the net reactive power demand from the network would be zero, and the apparent power (kVA) is equal to the active power (kW). In practice its difficult to achieve perfect power factor, which is why a small amount of reactive power demand is present on the second triangle.

PFC typically costs between £2,000 and £10,000 and requires installation by a specialist company, as there are other issues to consider when determining the site specific PFC solution. The financial payback for PFC is typically two to three years, based on discussions with PFC providers.

Power factor correction is just one of the measures you can take to reduce your carbon footprint and your energy bills - in fact, there are other measures available that could improve your power factor, such as installing newer machinery, or operating your site more efficiently. The term energy management is used as an umbrella term, which includes PFC, as it is important that your energy management as a whole is optimised. We would recommend visiting The Carbon Trust's website for more information about PFC and other energy management measures available at www.carbontrust.com.

Next steps

1. Review your electricity bill and any metering data you have, using the information from this guide to help understand your power factor and the potential benefits of better energy management (such as PFC).
2. If you think that there may be benefit, contact an energy management provider. You may need to contact several organisations, as sometimes each organisation specialises in a specific technology.
3. The energy management provider will then arrange a site assessment to determine the site specific solution.
4. The energy management provider will install the chosen solution, typically several weeks following the site assessment.
5. The benefits of better energy management (such as PFC) will be realised upon implementation of the chosen solution.

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Contact us

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www.northernpowergrid/losses