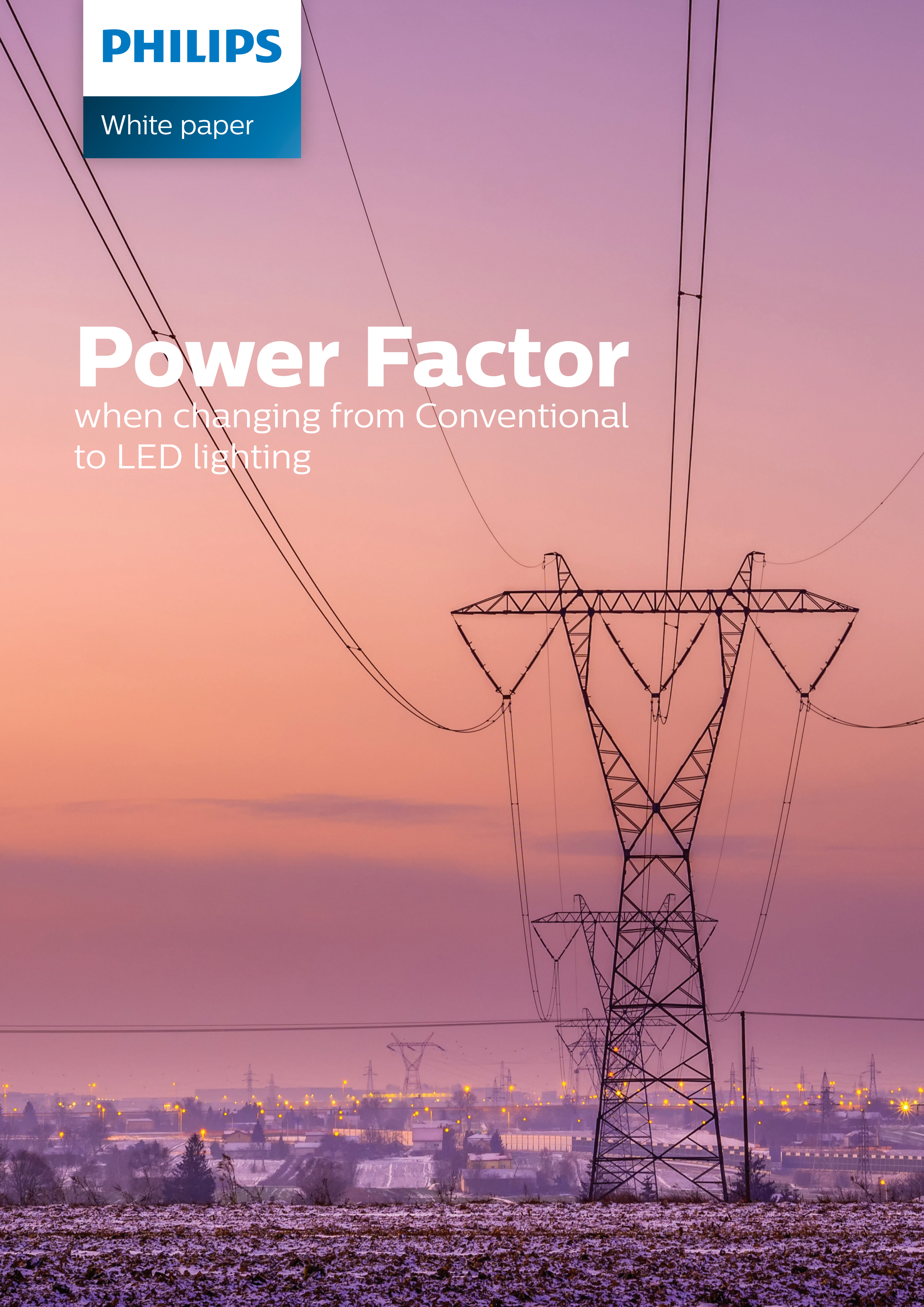
White paper

Power Factor

when changing from Conventional to LED lighting



Background

Relevance of power factor in conventional installations

For decades, lighting installations, especially outdoor installations, were dominated by conventional High Intensity Discharge (HID) lamps. These lamps need an electro-magnetic ballast (copper-iron coil), to guarantee a proper operation. The nature of these HID ballast-lamps systems makes them difficult to dim, so dimming was never a relevant topic for conventional lighting installations.

The electrical characteristic of electro-magnetic ballasts for HID lamps is inherently inductive which results in increased current load on the mains grid, thus requiring thicker copper wires to reduce thermal overloading of mains cabling and voltage drop. Its power factor is typically around 0.5 which is poor. However, the increased current load can be compensated very easily by connecting a compensation capacitor in parallel to the ballast-lamp system. This was done for decades to have a good power factor (e.g. 0.9 or higher), resulting in a reduced current load and voltage drop of the grid.

Electronic drivers in LED lighting support high power factor

Nowadays, many lighting installations are upgraded from conventional lighting systems to LED based lighting systems. This upgrade has benefits regarding energy consumption, lifetime and dimming performances. LED lighting systems are driven (ballasted) by electronic LED drivers which have an inherently capacitive electrical characteristic. These drivers have an integrated active power factor corrector, resulting in a high-power factor of around 0.99 (same applies for electronic ballasts for HID lamps).

As the use of the power factor has been in place for conventional installations for such a long time, grid operators might still charge extra fees to municipalities for the (capacitive) reactive power (kVAr) drawn by LED lighting systems. Also, the belief can be that capacitive reactive power (versus inductive reactive power) causes problems for energy providers.

In the meantime, network power meter measurement devices have improved: now both active and reactive power both in inductive and in capacitive mode can be measured and charged separately. As a result of that, even extra charges to users can be introduced on reactive power, also in dimming mode which is supposed to bring a major part of the targeted energy savings. These extra fees are in some cases ten times more than those fees charged for the actual consumed energy (kWh). Therefore, the total energy bill (consumed reactive + active power) for an upgraded LED lighting system could become significantly higher than that of a conventional lighting system in use before the upgrade. The same topic is valid also for some Indoor applications (e.g. schools) where the lighting is the major load of power consumption without having other high-power devices.

It is important to understand the relevance of the power factor in an LED installation both in full load situation and in dimming mode, to prevent that energy (cost) savings are impacted.

What is Power Factor?

The power factor (PF) gives an indication of the phase shift between the mains voltage and the current drawn by the load connected to that mains voltage. Phase shift between the mains voltage and the mains current appears when an inductive or capacitive load is connected to the (sinusoidal shaped) mains voltage.

Pure Ohmic load:

When connecting a pure ohmic load (e.g. an incandescent lamp) to the mains voltage, the voltage and current will have the same phase. This current is real current (Watt current) and is translated in a form of energy, in this case heat dissipated in the incandescent lamp. See picture below:

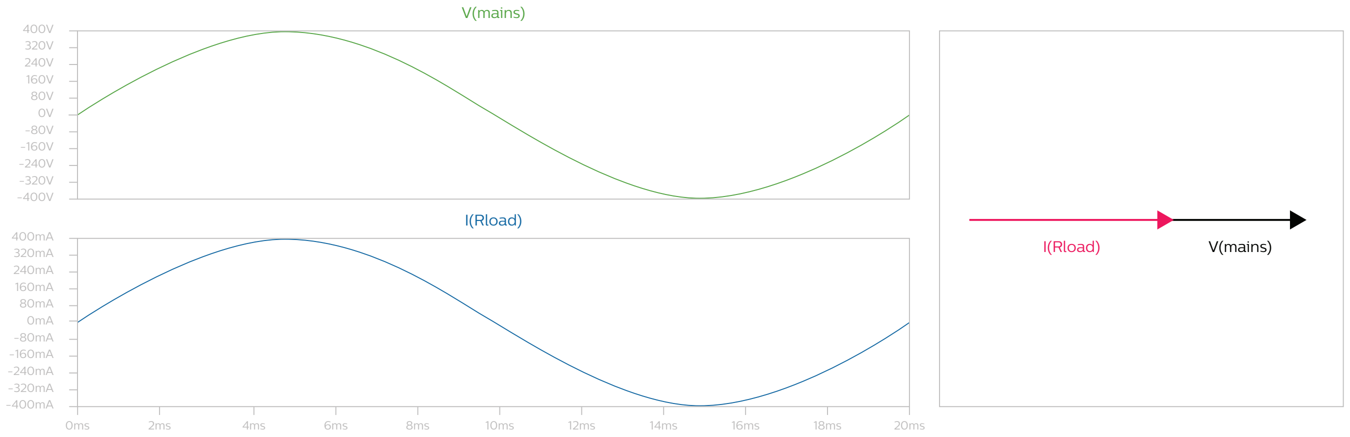


Figure 1: Voltage and current waveform of resistive load (green = voltage, blue = current)

Inductive load:

When connecting a pure inductive load (e.g. an ideal Coil) to the mains, the current lags 90° behind the mains voltage. There is a phase shift of 90°, that is 5 ms in the picture below. This current is called inductive reactive current and is not transformed into a form of energy in the load.

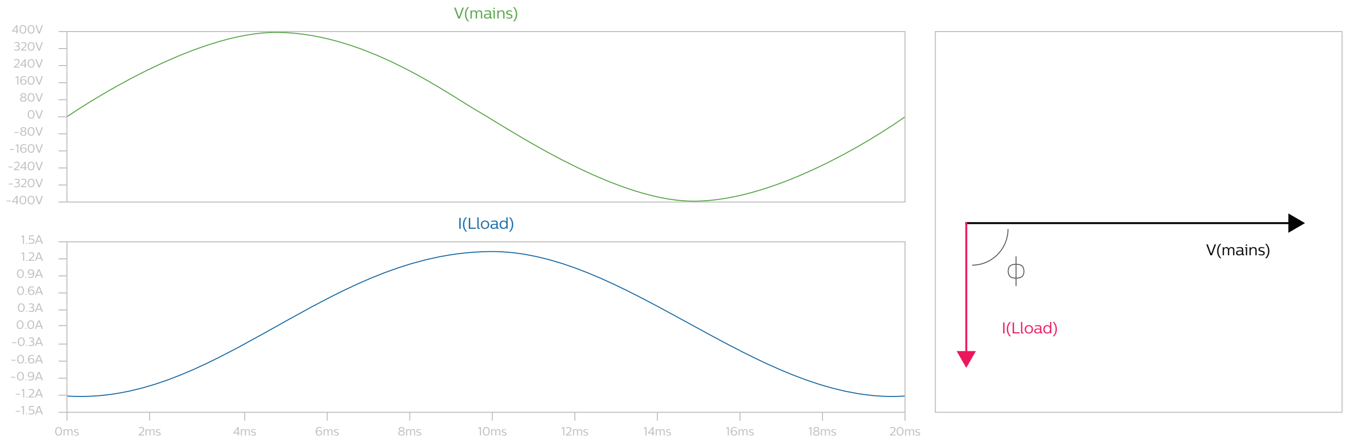


Figure 2: Voltage and current waveform of inductive load (green = voltage, blue = current)

Capacitive load:

When connecting a purely capacitive load (e.g. an ideal Capacitor) to the mains, the current leads 90° before the mains voltage. There is a phase shift of -90°, that is 5 ms in the picture below. This current is called capacitive reactive current and is not transformed either into a form of energy in the load.

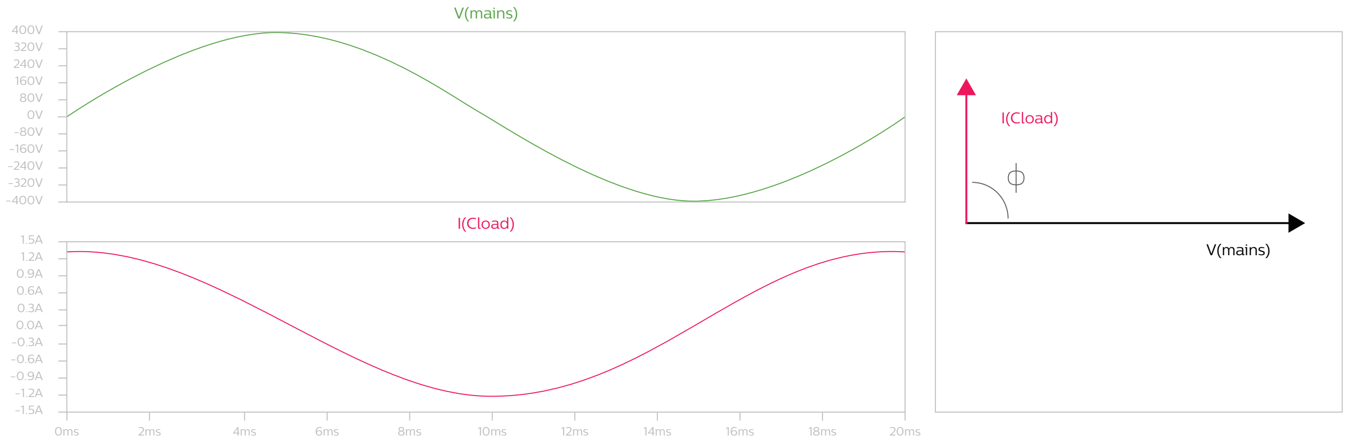


Figure 3: Voltage and current waveform of capacitive load (green = voltage, red = current)

Conventional lighting load:

A conventional lighting system will cause a phase shift between mains voltage and current: the current will lag the mains voltage. This can be seen in the picture below. The mains current will result in an apparent power S (Umains x Iload) that seems to be consumed from the mains, expressed in [VA].

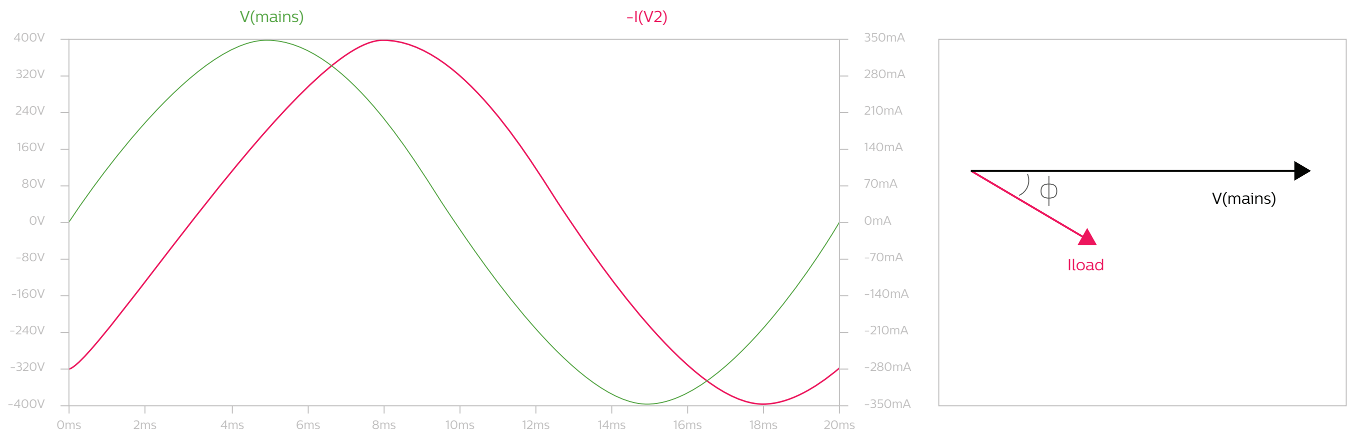


Figure 4: Voltage and current waveform of conventional lighting load (green = voltage, red = current)

This apparent power can be decomposed into two components:

- Real power, P, expressed in [W] being the power you really get and which is paid for
- Reactive power, Q, expressed in [Var], that is useless

This decomposition is given in the picture below:

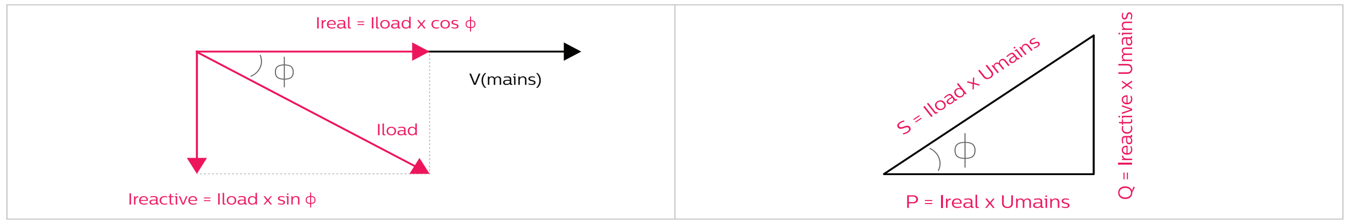


Figure 5: A: current decomposition, B: power triangle

The reactive power is electrical energy transported back and forth between the mains grid and electrical equipment connected to that grid, without being converted into another form of energy like movement, light, heat etc. Actually nothing happens, this reactive current is flowing through the network without bringing value.

In the example of the conventional lighting system, the inductive reactive current can be compensated by a compensating capacitor. This capacitor introduces a capacitive reactive current that (partly) compensate the inductive reactive current from the ballast.

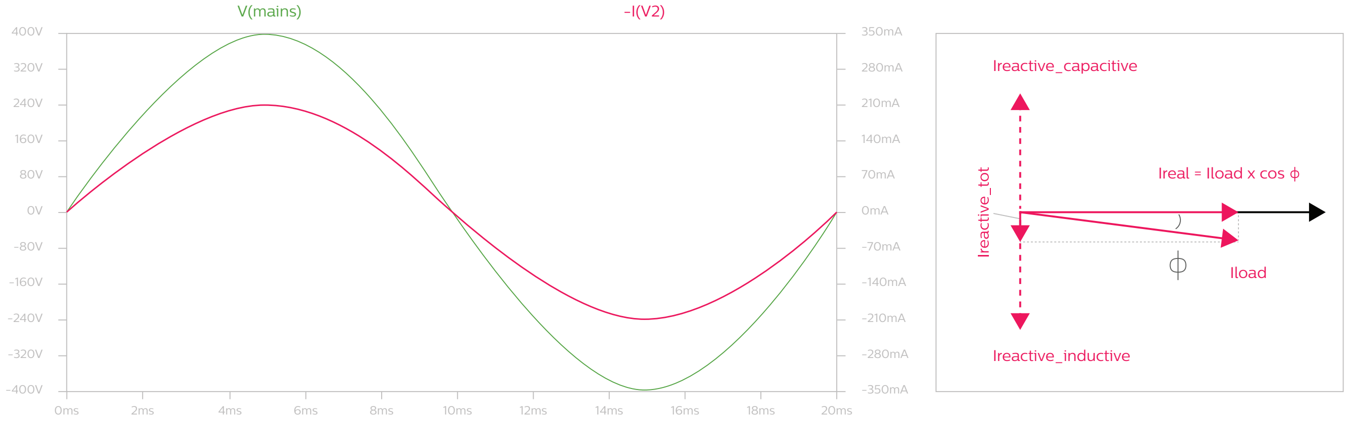


Figure 6: Voltage and current waveform of conventional lighting load compensated (green = voltage, red = current)

With this compensation the phase angle between the mains voltage and the load current is very small, resulting in a real current that is very close to the load current and a very small reactive current. With this compensation the apparent power is close to the real power.

The power factor (PF) gives the relation between the apparent power (S) and the real power (P). A high PF means that the P is almost as large as S and therefor the reactive power (Q) is very small.

A low PF means a high amount of reactive power compared to the apparent power.

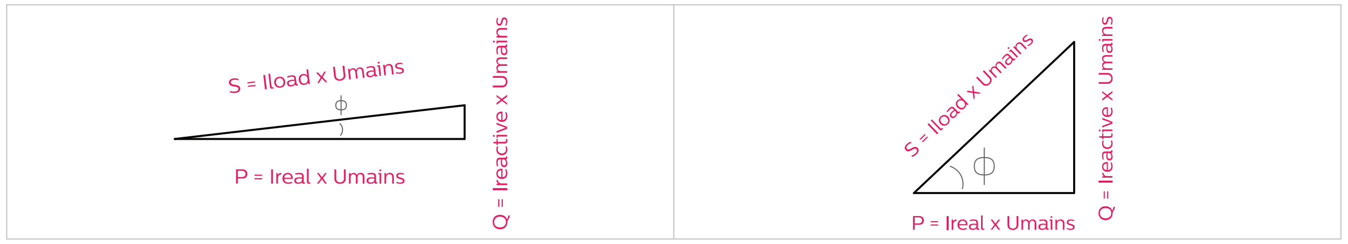


Figure 7: A power triangle with high PF, b power triangle with low PFnt)

For ideal capacitive or inductive loads, the PF = cosϕ. In that case, where no higher harmonic currents are drawn from the mains, the THD is 0%.

$$PF = \frac{\cos\phi}{\sqrt{1+THD_i^2}}$$

Cosϕ = | P | / | S | where ϕ is the angle between the real and the apparent power.

Why PF is important?

Reactive power becomes relevant as soon as inductive loads (e.g. electric motors, electromagnetic ballasts) are connected, because these loads cause inductive reactive current (and reactive power). However, it also becomes relevant as soon as electronic converters (e.g. switch-mode power supplies for computers and servers, frequency converters, electronic driver and ballasts for lighting) are connected, because these loads cause capacitive reactive current (and reactive power).

Reactive power is undesired since it requires thicker cables and increases transmission losses of electrical energy from the generating plant to connected loads because the apparent power is higher in that case. This is the same for capacitive reactive power as for inductive reactive power.

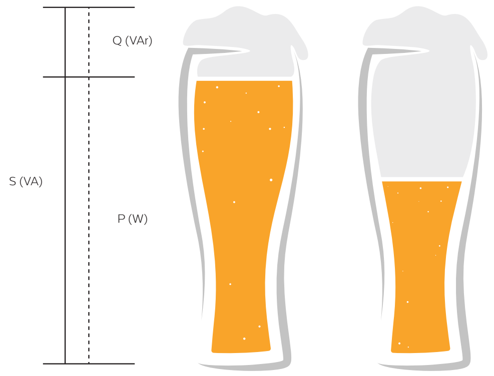
The PF must be above the required value (e.g. 0.9) so that the total current (resulting in apparent power S) is not too high and the infrastructure of the utility installation is not loaded unnecessarily.

If the PF in full-load conditions is too low (typically min. requirement is 0.9), measures need to be taken since the resulting input current would otherwise overload the grid cabling. This can be done, like in the example of the conventional lighting system, with a compensating capacitor in case of an inductive load.

In modern lighting installations where electronic drivers are used for LED lighting systems, the power factor is managed by the drivers themselves. They are equipped with an internal power factor corrector (PFC) that result in a PF of typically > 0.95 at full load.

Power Factor in an everyday example

The power factor can be explained with a glass of beer. The most important content of a glass of beer is the beer itself. The foam is less important.



The apparent power [VA] is what you seem to get. (the total glass of beer with beer + foam).

The real power [W] is what you get and what you pay for (the beer itself).

The reactive power [VAr] you get is the foam. When the amount of foam is too big, you will complain.

For capacitive power the everyday example looks a little weird, but the result is the same. You pay for everything, but the foam makes no sense.

Some types of beer do have a high PF!

Figure 8: Everyday example of Real, Apparent and Reactive power

Calculated example

LED installation:

Below a practical example is given of a lighting installation with a common LED driver, Xitanium Full Prog 150W SNLDAE 0.2-0.7A S240.

	Driver in full load	Driver fully dimmed	Driver in standby
Apparent power S	167 VA	21.9 VA	11.8 VA
Consumer power P	166 W	16.2 W	0.45 W
Input Current	0.725 A	0.095 A	0.051 A
PF	0.995	0.74	0.038
Reactive power Q	16.9 VAr	14.4 VAr	11.7 VAr

	Group of 18 drivers		
Apparent power S	3006 VA	394 VA	212 VA
Consumer power P	2988 W	292 W	8.1 W
Input Current	13 A	1.71 A	0.92 A
PF	0.995	0.74	0.038
Reactive power Q	304 VAr	259 VAr	211 VAr

Table 1: Measurement results of a practical example

What can be concluded from the numbers above?

In standby the PF drops to almost 0. Reactive power and input current drop to some extent. Despite very low PF the input current does not increase. **Therefore, the low PF in standby does not pose a problem for the application in terms of grid current load.** There is no need for thicker cables and the transmission losses are not increased.

Also in the dim situation, the PF is worse than in full load, however the apparent power (S) and the reactive power (Q) are also lower compared to the full load situation. In dim situation the total energy consumption is less compared to full load situation, but as with the standby case this doesn't give an issue for grid current load. In the picture below (Figure 9) the power triangles are drawn for the three situations (full power, dimmed, standby) from the measurement in Table 1. The triangles are drawn with the right scale, therefore they can be compared on size and the ratio in power between the different situations is shown clearly.

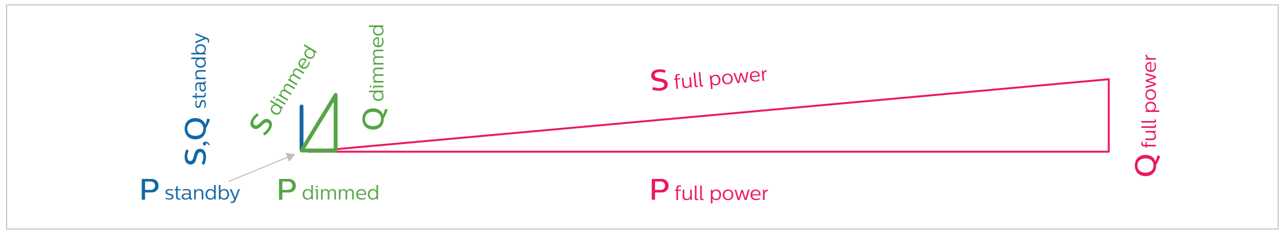


Figure 9: Power triangles for full, dimmed and standby situation of practical example of table 1

Note that dimming in general is not possible for conventional lighting systems.

Renovation of lighting installation:

Another example is an upgrade of an outdoor lighting installation from conventional to a LED lighting system. Starting point is the upgrade of a conventional system (150 W HID lamp) to a LED system equipped with a 75 W LED driver (Xi FP 75 W 0.2-0.7 A SNLDAE 230 V c133 sXt). In the table below the old situation and the situation after renovation in full load and dimmed is given.

	150W HID	75W C133 Driver full load	75W C133 Driver 10% dim
Apparent power S	187 VA	83.7 VA	12.5 VA
Consumer power P	168 W	82 W	10 W
Input Current	0.81 A	0.36 A	0.054 A
PF	0.9	0.98	0.8
Reactive power Q	81.5 VAr	16.7 VAr	7.5 VAr

	Group of 18 drivers		
Apparent power S	3366 VA	1507 VA	225 VA
Consumer power P	3029 W	1477 W	180 W
Input Current	14.6 A	6.48 A	0.972 A
PF	0.9	0.98	0.8
Reactive power Q	1467 VAr	300 VAr	135 VAr

Table 2: Measurement results of a practical example

What can be concluded from the numbers above?

When upgrading an existing installation from a conventional lighting system to a LED lighting system the Power Factor at full load will increase and the total power consumption will decrease. Due to the lower total power consumption the load of the renovated installation will be compatible with the installed wiring infrastructure of the installation. Thus, no expensive rewiring/re-cabling is required. Electronic drivers have a built-in Power Factor Corrector (PFC) that gives a high power factor in full load situation. **At full load, the current loading is smaller compared to the conventional installation and in dimming situation the current will be even smaller, albeit with reduced PF. Overloading of the existing wiring/cabling infrastructure will not happen in this situation.**

Also in dimming situation, the current loading is smaller, even if the PF becomes lower in that case. In table 2 an extreme dim situation down to 10% is given and it shows PF of 0.68 with a reactive power that is lower than the reactive power for the full load situation. Compared to the conventional system the reactive power is almost factor 10 smaller in dimming situation. In practice these extreme low dimming levels will not often occur.

In some installations, LED loads are driven with lower currents than the maximum current allowed by the LED driver. Therefore, the LED driver will not perform optimal, e.g.: lower efficiency and lower PF. For the installation that will not be a problem, because the total power is lower than in the original situation and overload of the infrastructure will not happen either.

Summary

Power Factor is an important parameter in electrical installations to limit the amount of reactive power. Since the Power Factor is a relative number, comparing the Real, Apparent and Reactive power (resp. P, S, Q) in an installation, it does only give an indication of one situation. It cannot be used to compare absolute numbers between different situations, e.g. full load and dimmed lighting systems.

During dimming, a lower power factor is not problematic with respect to consumed input current. The same does apply in renovation situation, even in non-dim applications.

There is technically no reason to charge capacitive reactive power more than inductive reactive power. The reason for the allegation that capacitive reactive currents are harmful for the electrical infrastructure is not known.

Statement that LED lighting systems compared to conventional lighting systems would not be energy-efficient is not correct.

Electronic drivers will have a much better performance on PF. This performance will be maintained over the full lifetime because of the internal Power Factor Corrector (PFC).

External devices to improve PF or compensate capacitive reactive power with Philips drivers are not needed.