

Understanding Power Quality

Produced by Dr Bruce Girdwood

For Energy Mad Ltd

Version 1: 23 October 2007

The electronics revolution and the growing number of “utility” programmes promoting compact fluorescent lamps are making power quality an issue for the residential sector.

There is a growing desire to reduce electrical loading by increasing the efficiency of the use of electrical energy. The use of energy efficient lighting is a rich source of cost effective energy savings. There is a high level of interest in replacing conventional incandescent lamps with Compact Fluorescent Lamps (CFL).

What is power quality?

Most new electronic equipment, while more efficient than their mechanical predecessors, consume electricity differently to traditional mechanical appliances. While older devices, like incandescent bulbs, use power as supplied by the utility, electronic devices draw currents in bursts, altering the electricity that flows through them, so that what comes out the other side and returns to the grid is distorted. This “dirty” power under-utilises utility equipment and increases line losses. Utilities must invest in costly filters and capacitors to “clean” this “dirty” power. Poor power quality causes transformers, cables and other transmission equipment to burn out more quickly, thus increasing utility equipment costs.

For a specific electric device power quality describes the extent to which the device:

1. Distorts the voltage waveform; and
2. Changes the phase relationship between the voltage and the current.

1. Waveform distortion

How is a voltage waveform distorted by CFLs?

CFLs, with electronic ballasts, distort the current waveform by creating harmonics, introduced when the CFL draws current in short bursts (instead of drawing it smoothly as is the case for an incandescent lamp).

- Each harmonic waveform has a frequency which is an integer multiple of the original, or fundamental, waveform. High frequency harmonics can affect frequency sensitive equipment if these harmonics are of similar frequency to the line-carrier signal that operates such equipment. For example, the relays which manage the supply of electricity to hot water cylinders during times of system peak.
- The distorted current waveform distorts the voltage waveform. *A constant voltage is important for the safe and efficient operation of equipment on an electricity system.*

Harmonics are a distortion of the utility supplied waveform and are caused by “non-linear” (distorting) loads, which include motor controls, computers, office equipment, CFLs, light dimmers, televisions and, in general, most electronic loads. High harmonics increase lines losses and decrease equipment lifetime.

Harmonic distortion is the difference between the shape of the current wave drawn by the device, and the shape of the voltage wave supplied to that device.

Total harmonic distortion (THD) measures the degree to which the input is distorted, and is the relative value of all the harmonics combined, as a percentage of the fundamental current. Utilities typically supply voltage with less than 2% THD. However, the current THD for electronic devices may be over 100%.

What consequences arise from harmonics?

Problems caused by harmonic currents include:

- Introduce neutral currents above 100% of the phase current, resulting in overheating and failure of the neutral phase. Case studies in commercial buildings have shown neutral currents of between 150% and 210% of the phase currents in the presence of high 3rd harmonic currents.
- Transformers can overheat resulting in reduced life and reduced rating (losses increase with the square of the harmonic number).
- Nuisance tripping of residual current circuit breakers.
- Over stressing of power factor correction capacitors.

Problems caused by harmonic voltages include:

- Increased losses in motors resulting in reduced power output and increased heating (reducing life expectancy)

Problems caused by harmonic frequencies

- Devices that use power-line carrier signals, such as synchronised clocks, control modules for building management systems and ripple control relays for management of hot water load may experience problems if harmonics exist at frequencies close to the carrier signal. *These harmonics cannot be filtered out as the filtering will also filter out the power-line carrier signals.*

2. Phase relationship between the voltage and the current

When phase displacements occur there are periods in the cycle when the current is positive and the voltage is negative (or vice versa) as illustrated by the shaded area in the figure below. During these periods the device creates reactive power and does not produce any useful work (active power).

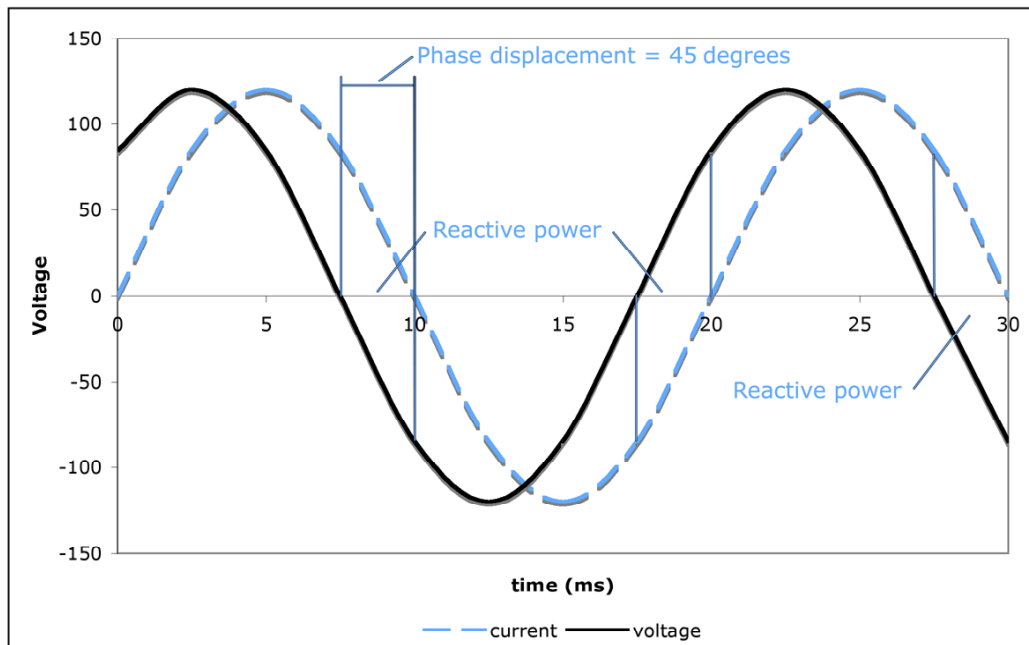


Figure 2 Phase displacement and reactive power

Reactive power arises when there are phase differences between the voltage and the current waveforms and has the units of VA. Reactive power creates no useful work but must be generated and uses up the capacity of the network.

Reactive power does not distort the voltage but it is an important power quality concern because the electricity system must have the capacity to produce and carry reactive power even though it accomplishes no useful work.

Active power is the measure of useful work done by a device and has the unit of Watt (W).

Power factor is the measure of how effectively a device converts input current and voltage into active, or useful, power. It describes the combined effect of THD and reactive power (caused by phase displacement).

A device with a power factor of 1 has 0% THD and a current draw that is synchronised with the voltage. These devices convert all the input current and voltage into useful work. Resistive loads such as incandescent lamps have power factors of 1.

Power factors can be less than or equal to 1. The lower the power factor the less efficient the device is in converting input power into useful power. These devices create more reactive power that uses up system capacity for no useful purpose. Electronic devices such as televisions, CFLs and computers have low power factors unless corrected. For example, a load with a power factor of 0.5 will require twice as much current as a load with a power factor of 1.0 for the same amount of useful power. A low power factor is a power drain that decreases system efficiency.

Leading and lagging power factor.

When the current **leads** the voltage the power factor is said to be **leading**. When the current **lags** the voltage the power factor is said to be **lagging**.

Resistive loads, such as incandescent lamps and resistive heaters, have power factor of unity.

Inductive loads, such as electric motors, have lagging power factors less than 1.

Capacitive loads, such as CFLs with electronic ballast, have leading power factors less than 1.

3. What can be done to correct power factor and minimise harmonics?

To understand the effect of power factor and harmonics the nature of the whole load needs to be considered. In a perfect world the reactive power created by devices with leading power factor would balance the reactive power created by devices with lagging power factor. Unfortunately this is rarely the case so regulators require distribution networks to maintain power factors at levels >0.95 and have no more than 5% voltage distortion at the service entrance.

In the past the harmonics injected into networks by CFLs have been ignored as each 20 Watt CFL makes a small contribution.

International standards assume that the greatest contribution to harmonic distortion comes from lighting units that consume more than 25W of power. Most residential CFLs are not affected by these standards.

Given the increasing use of devices that have poor power quality characteristics, regulators will act to ensure devices are designed to standards, which, economically, minimise power quality concerns. To this end, responsible manufacturers will act sooner, rather than later, to produce quality devices.

CFLs are not the only devices that create harmonics or have low power factor, however, with the widespread adoption of CFLs, the combined effect of these small sources can be as detrimental as one large source and is harder to mitigate because CFLs are distributed across the network rather than in one location, as for example a manufacturing plant.

Distribution networks seek to align financial consequences with good behaviour, for example, a large manufacturing plant can manage its power factor and harmonics and will therefore face a penalty if its load fails to comply with the standards set by its electricity supplier.

Due to the distributed nature of household electronics, including CFLs, it is harder for distribution networks to expect individual householders to manage power factor and harmonics in the same way as large energy users. Rather, utilities provide good power quality as part of their service. This can be achieved through a combination of measures, including: requiring large energy users to “clean” their own “dirty” power, regulating the power quality characteristics of devices and by correcting for power factor and harmonics in the network itself.

Power factor can be corrected by installing capacitors in the electricity system and harmonics can be filtered out.

No matter how well large electricity users perform there will always be the need for some power factor correction and harmonic filtering within the electricity system but this should be kept to a minimum as there are significant complications associated with this practice, particularly when harmonics are high.

Studies estimate that it is about 10 times cheaper to manufacture high power factor (0.9), low harmonic CFLs than it is for utilities to correct power factor and filter harmonics caused by CFLs with power factors in the range 0.5-0.6.