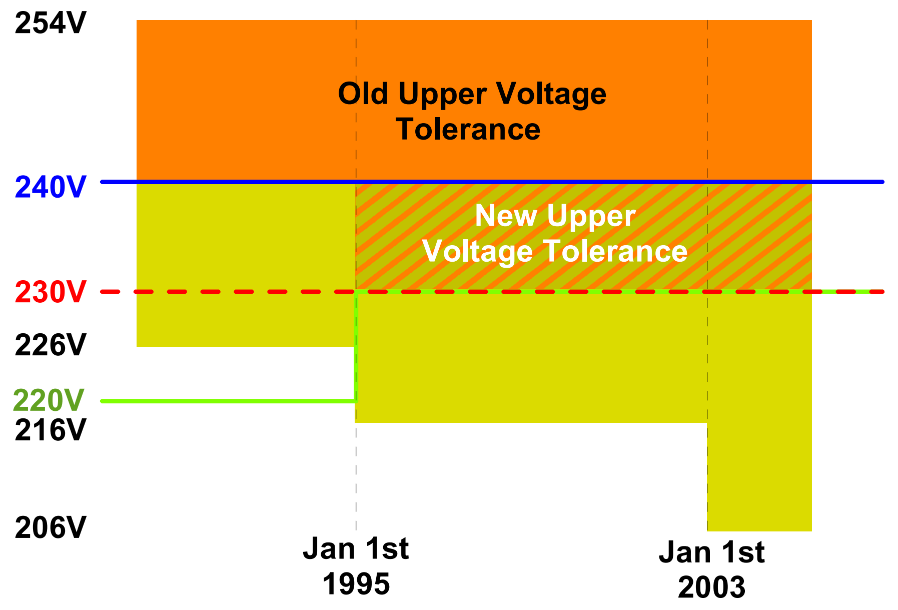
Power Quality — Fact Sheet 1

A few interesting facts about the UK power supply (that not a lot of people know about)



Moving the supply voltage goalposts

- For many years the electricity supply in the UK was **240V** and **3 x 415V +/- 6%.**
- In mainland Europe it was **220V** and **3 x 380V.**
- In **1995** the supplies were harmonised at **230V** and **3 x 400V.**
- To make things easy for the electricity suppliers the tolerance band was increased to -6% + 10% and on 1st January 2003 it was increased to +/- 10%.
- The UK power suppliers still produce power at **240V** and **415V because there is no incentive to do otherwise.** On the contrary because most equipment is designed to run on 230V this means that they are supplying and selling more energy. In fact to reduce the supply to 230V would mean that they would lose about **8%** of their income from domestic consumers. Why 8% do you ask? Don't forget that a higher voltage causes the load to consume more current.
- For instance a **1 kW** immersion heater designed to run at 230V will actually consume **1.088 kW** when connected to a 240V supply.
- Taking the simple light bulb as another example. This is designed to run for **1000 hours** when the supply is 230V. The life is reduced drastically to **550 hours** when it is connected to 240V.

Questions to ask yourself !

1. If I tune equipment to run on 240V in the UK and then supply it to Mainland Europe will it still give the same performance?
2. Will the equipment I buy, rated for 230V but used on the UK supply, last as long as I expect it to?

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Transients (surges)

What is a transient? It is an electrical disturbance with a fast rise and decay time and a high peak voltage or current (usually kV's or kA's). A number of surveys have proven that transients are the most common cause of power quality problems and surge suppression is the most widely used power quality solution. This is difficult to comprehend because transient phenomena are not easy to predict and are rarely monitored or witnessed. To put the problem into perspective there are 300,000 ground strikes every year in Britain, between 30 and 60 people are struck by lightning and on average three may be killed. (Source: Tornado and Storm Research Organisation www.torro.org.uk)
However, many experts say that only 20% of transients are caused externally; by lightning or switching on the supply network, the other 80% are generated internally from plant or even office equipment. In fact the switching of any load can generate transients.

What are the effects and causes transients? Lightning transients have high energy levels and are capable of destroying equipment or starting fires. Areas most at risk are those sited near to power lines where transient voltage levels can be in excess of 10kV approximately ten times a year, compared with an office block in town which can expect levels of 3kV.
Self-generated transients can be equally as damaging because they gradually cause components to break down and fail prematurely. Semiconductors such as rectifiers used in switch-mode power supplies are particularly vulnerable. The interruption of a process can be particularly disruptive and expensive. Internal transients can be caused by welding equipment, the starting and stopping of heavy plant, or even the humble photo-copier.

Should I be concerned about transients? Like most preventative measures, this depends on the circumstances. In a plant that is susceptible to transients the chief engineer should be responsible for fitting surge suppression devices at three levels which depend on the degree of exposure: firstly on the incoming supply, then on plant and finally on telecommunications and sensitive IT equipment.
Furthermore, there is a standard, EN 50160:2000 for voltage characteristics of electricity supplied by public distribution systems, which specifies a limit of 6kV but we have already seen that this is not realistic. Finally, there is another standard EN61000–4–5 which provides the testing and measurement techniques used for checking surge immunity. Interestingly this standard only calls for a 4kV surge test on equipment interconnected through outdoor cables and 1 – 2 kV for a normal factory environment, which hardly seems adequate. However, reputable manufacturers should, at the very least, be working to this standard, especially if the equipment they produce is particularly vulnerable to transients.
North America, South America and Pacific Rim countries have a higher frequency of lightning but generally thunderstorms are increasing in intensity due to global warming and so this is potentially a growing problem.
Therefore, in conclusion, if equipment is failing for mysterious reasons (especially rectifiers and semi-conductors) then there is a good chance that this will have been caused by transients and surge suppression devices should be fitted as a first course of action.

How can transient problems be prevented? Fortunately, there are a number of proprietary and inexpensive surge suppression modules on the market that are easy to fit. These utilise varistors, gas-discharge devices and silicon avalanche diodes, often used in combination.

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A Power Quality Standard

How do we assess the quality of our electricity supply?

There is a standard: **BS EN 50160:2000 Voltage characteristics of electricity supplied by public distribution systems** that provides the limits and tolerances of various phenomena that can occur on the mains. Below is a summary of the criteria for the low-voltage side of the supply network:-

Supply voltage phenomenon	Acceptable limits	Measurement Interval	Monitoring Period	Acceptance Percentage
Grid frequency	49.5Hz to 50.5Hz 47Hz to 52Hz	10 s	1 Week	95% 100%
Slow voltage changes	230V ± 10%	10 min	1 Week	95%
Voltage Sags or Dips (≤1min)	10 to 1000 times per year (under 85% of nominal)	10 ms	1 Year	100%
Short Interruptions (≤ 3min)	10 to 100 times per year (under 1% of nominal)	10 ms	1 Year	100%
Accidental, long interruptions (> 3min)	10 to 50 times per year (under 1% of nominal)	10 ms	1 Year	100%
Temporary over-voltages (line-to-ground)	Mostly < 1.5 kV	10 ms	N/A	100%
Transient over-voltages (line-to-ground)	Mostly < 6kV	N/A	N/A	100%
Voltage unbalance	Mostly 2% but occasionally 3%	10 min	1 Week	95%
Harmonic Voltages	8% Total Harmonic Distortion (THD)	10 min	1 Week	95%

What practical conclusions can be made from this data?

1) The limits are wide, perhaps more than one would expect.
2) It is important to check that safety interlocks and relays can reset after a sag or dip because such incidents can occur quite frequently.
3) Control and process equipment that is voltage sensitive should be applied with caution because the allowable voltage tolerance is very wide and can drift outside ±10% for 5% of the time.
4) The transient tolerances are high and so the use of surge-protection devices should be carefully considered, especially where manufacturing of high-cost components or processes involving lengthy and expensive restart times are concerned.

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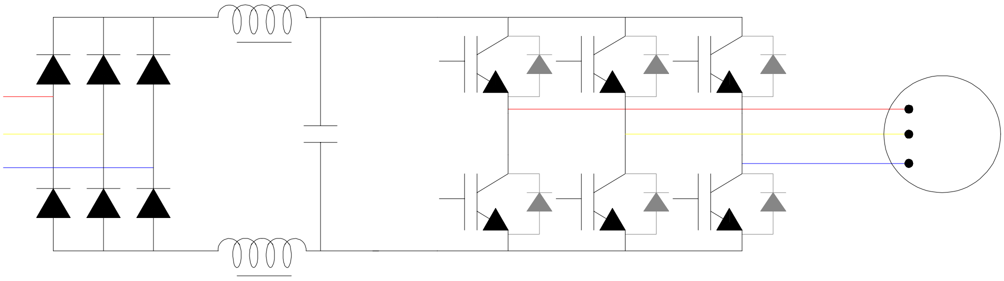
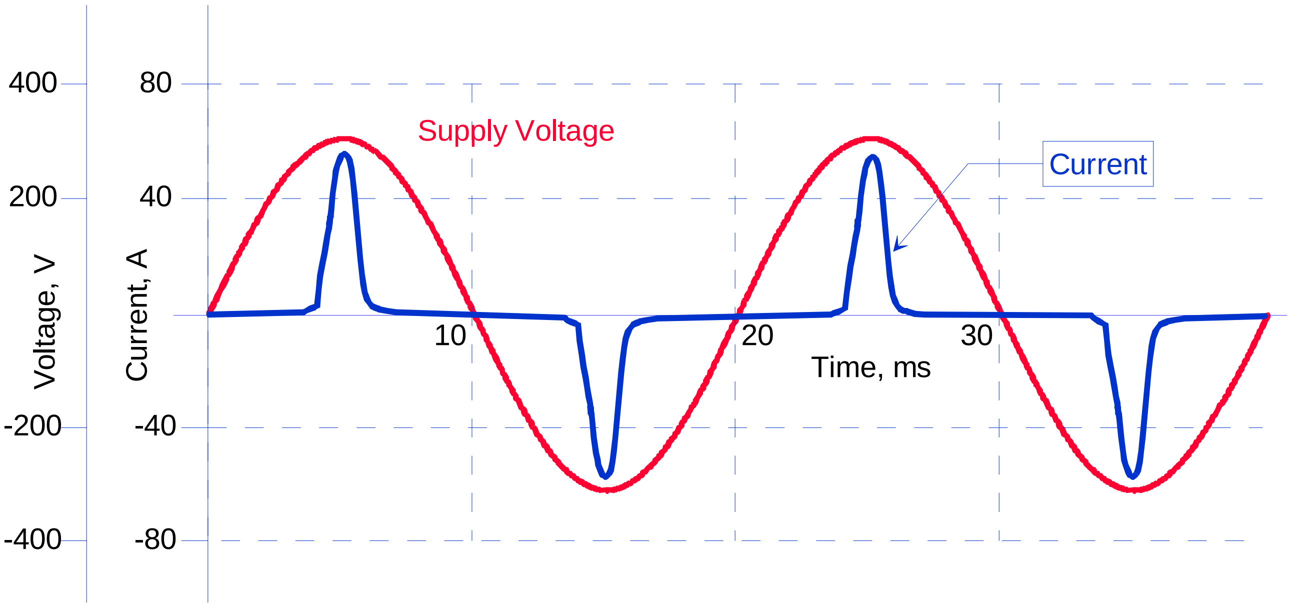
Harmonics

Harmonics are defined as the sinusoidal components of a non-linear periodic waveform with a frequency that is a whole multiple of the fundamental frequency. Putting this simply; any switching operation of the mains supply sine wave will produce lots of other sine waves at higher frequencies. These are not apparent but they are harmful.

Taking a variable speed drive or switch-mode power supply as an example:



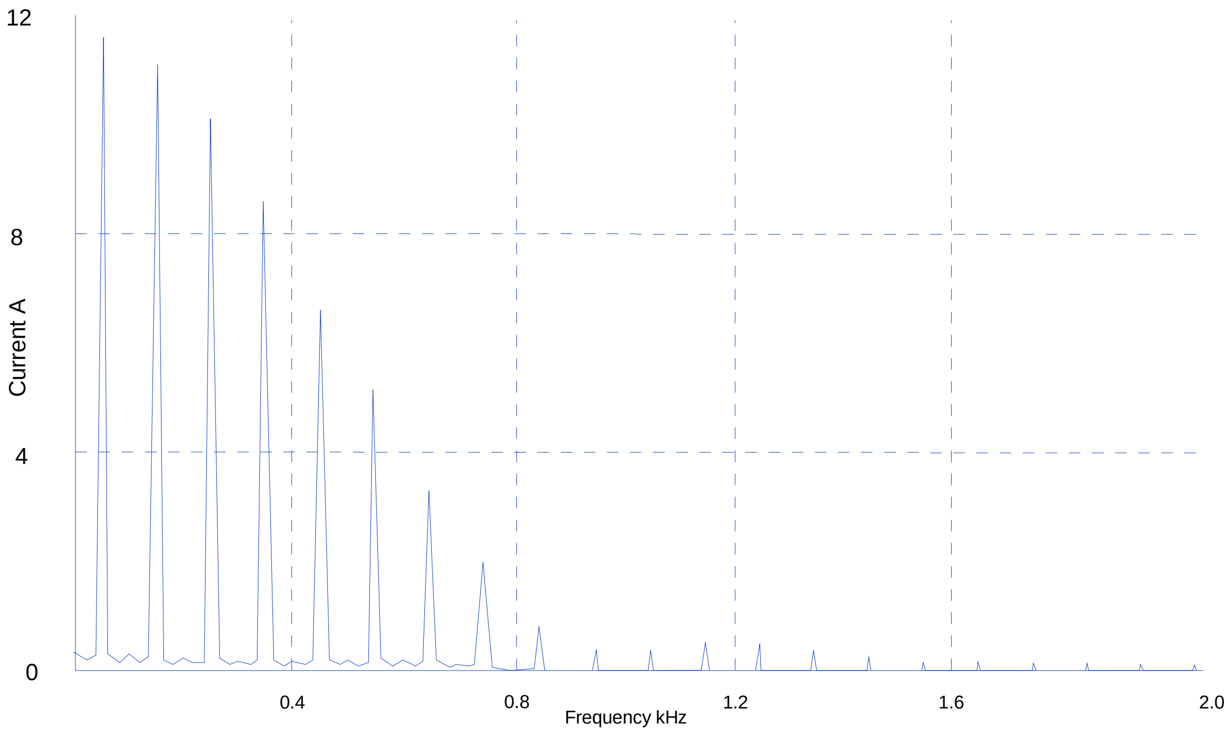
The storage capacitor in the centre of the circuit is used to maintain the DC voltage, produced by the input rectifier, at a constant level. However, the DC only requires "topping-up" for part of the mains cycle, so current is drawn in a non-linear manner, at the peaks of the AC supply waveform. Below are the input-voltage and current wave-forms for a single phase, 1.5 kW drive:-



Typical input current waveform for a 1.5 kW PWM drive

You will see that the current peaks at approximately 60 A. But this is a 1.5 kW drive on a 230V supply and 1500/230 = 6.52 A..... What is happening?

If the current waveform is broken down into its component harmonics (using a technique called Fourier analysis), then the harmonic spectrum looks something like this:



Spectrum showing harmonic content of current waveform for 1.5kW PWM drive

There are lots of harmonic currents at higher frequencies and if you add all of these together their sum is approximately 60 A.

This demonstrates one of the main effects of harmonics – exceptionally high currents – and switch-mode power supplies are used everywhere! In computers, televisions, energy-saving bulbs, drives, air-conditioning equipment and phase-angle controllers. Therefore, the limits on harmonics are gradually being tightened; otherwise the supply network cables and transformers would simply not be able to carry sufficient current to satisfy the demand.

Not only this but the harmonic currents cause distortion of the supply voltage waveform, heating of transformers and capacitors, and reduced carrying capacity of cables due to the “skin effect” (the phenomenon of higher frequency currents flowing only in the outer layer of a cable).

From the equipment manufacturers point-of-view it is important to be aware of harmonics because they can cause protective devices and cabling to be seriously under-rated for their required duty. In olden days the loads were usually simple inductive types and capacitors were added to provide power factor correction. Now the loads are much more complex and made up of many different resistive, capacitive reactive and inductive reactive elements. More sophisticated solutions are required to correct for these influences but the term used is curiously still the same – PFC (Power Factor Correction).

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Why is power quality becoming such an important issue?

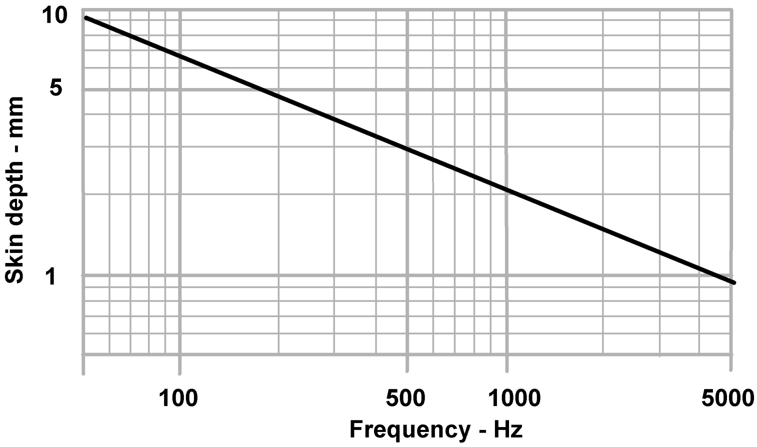
There is a challenge for electronic designers to run at the highest possible clock speed. As an example of this Illinois University recently claimed the record of switching a transistor at 509 GHz and furthermore, they have an ultimate goal of making a 1 terahertz transistor in the future. This does have practical applications in the creation of faster computers, video games, secure wireless communication systems and rapid analogue to digital conversion fro radar an other electronic combat systems.

At a more down-to-earth level the use of higher speed in switch-mode power supplies, for instance, has many advantages. The components become much smaller, especially inductors and transformers which are often the bulkiest and heaviest items. Consequently, most appliances today such as TV’s, fridges, air-conditioning equipment, low-energy lighting and computers invariably use a switch-mode power system. In the industrial sector nearly all variable speed drives operate on the switch-mode principle. Another big advantage of the switch-mode power supply is that it is a simple matter to make it self-regulating. In other words; if the supply voltage drops, the mark-space ratio is adjusted and so the supply current rises. The output voltage remains constant thus ensuring a healthy supply to the load.

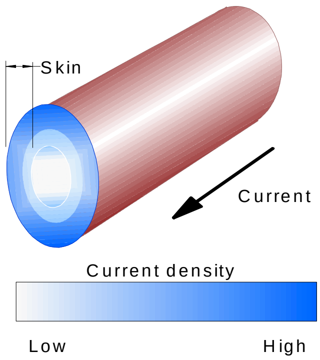
All of these factors impact on power quality. The smaller, faster electronic devices do not have the same immunity to abuse from the electrical environment that their predecessors did. What is worse they also contribute to the growing proliferation of EMC disturbances and in so doing jeopardise their own ability to function correctly.

The general rise in current has multiple implications. Many safety trips are designed to release at a current limit and so the mains network could shut-down even though in theory it has sufficient power capacity. Switching of any description generates harmonics (high frequency current wave-forms that are multiples of the mains or fundamental waveform). So these are hidden currents that are wasteful and can accumulate to very high levels.

What is more, higher currents create higher losses (I^2R) and also higher frequency currents cause the skin effect in conductors, which can also create losses or derating.



$$Depth\,(mm) = \frac{66.04}{\sqrt{f}}$$



The “skin effect”; the higher frequency the more current tends to flow in the outer layers of a conductor. This becomes significant at the 7th harmonic (350Hz) and above.

Furthermore, eddy current losses in transformers and motors can increase. The net effect is that there is a higher probability of power failure, equipment loss, fire caused by overheating, component failure or malfunction of electrical equipment.

Therefore it is inevitable that must stricter controls over power quality will be enforced to coincide with the continuous drive forward for more sophisticated electrical equipment.

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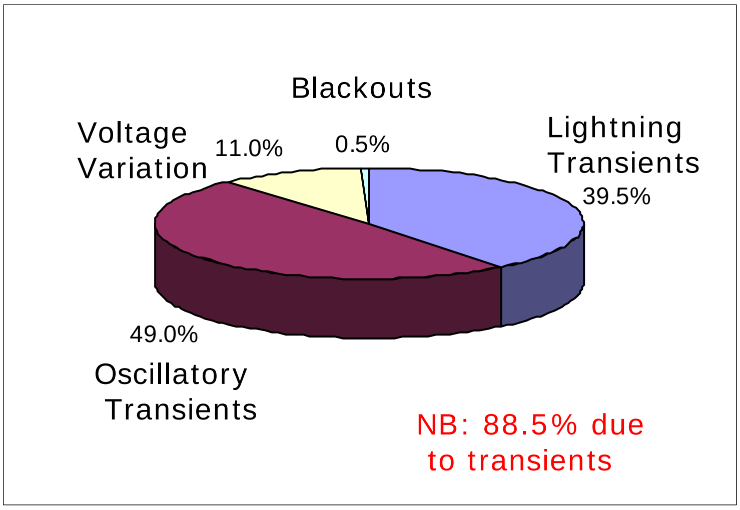
What are the main causes of power quality problems?

The diagram on the left is an attempt to show, in diagrammatic form, the various EMC phenomena that can influence power quality, where the network is highly reliable (conforms to EN 50160:2000 Voltage characteristics of electricity supplied by public distribution systems).

The closeness to the centre of the target indicates the significance of the phenomena. Therefore it can be seen that transients are the most prolific. Arrows that are on the left –hand side indicate the problems that are more likely to be caused by external influences – the supply network. Whilst those on the right-hand side indicate that the problems are more likely to be self-inflicted. It is interesting to note that the arrow representing transients is nearly central, indicating that this phenomena is just as likely to be generated from an internal source as an external one e.g. heavy plant.

It is a little known fact that transients account for the largest percentage of power quality problems. Probably because the event is very short (nanoseconds to milliseconds in duration) and in most instances it is not apparent. Occurrence is also random and spontaneous which makes transients very difficult to monitor.

It is difficult to obtain meaningful statistics on failures due to power phenomena, however there was one survey carried out for IBM by Allen & Segall, relating to the incidence rates of harmful power disturbances causing computer equipment failures. The results can be seen below…..



Therefore, in terms of protection or fault finding it would be logical to consider transients as the most likely source of power quality problems, not forgetting that these are just as likely to be generated from an internal source as an external one.

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What are the most commonly used solutions for solving power quality problems?

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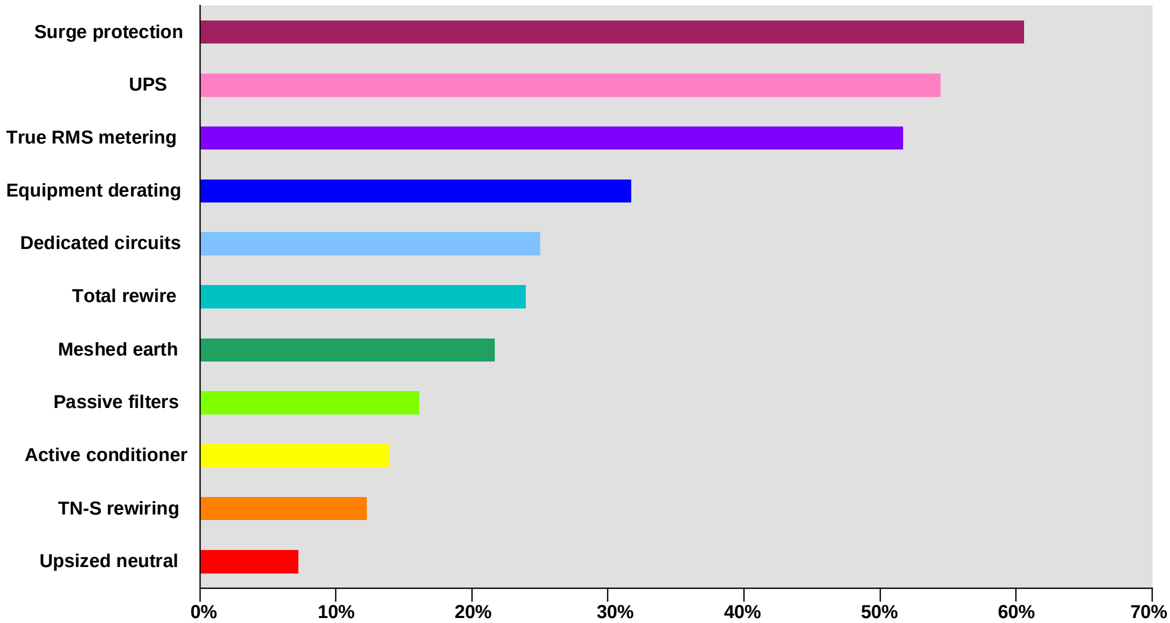
The survey involved 1,400 sites in 8 countries and it lists the most prevalent solutions used for solving power quality problems, in terms of % adoption rate.



Surge (transient) protection was the most frequently used. Passive filters came out 8th in the survey which is very surprising considering how they are so widely accepted and fitted by industry in general.

Below are brief explanations of the terms used in the table:-

Surge protection: In the LPQI survey this proposed earthing for protection against lightning and between interconnecting equipment. In a new building this may be the ideal solution however in an existing industrial installation it would not be so practical. The fitting of surge protection devices, which are readily available in the marketplace, would probably be the most sensible approach in such cases.

UPS: These are widely used and understood by most PC owners. Hardly surprising that it comes second on the list but not coming first indicates the significance of surge protection.

True RMS metering: Not the most obvious remedy but if wrong current readings are not taken incorrectly rated equipment will be installed. It is only possible to read the effective current made up of the fundamental plus harmonic currents with a true RMS meter.

Equipment derating: Transformers and motors do not like harmonic loads. The increased heating generated by harmonic pollution can lead to a number of problems. Often derating is often the easiest option but not necessarily the best long-term solution.

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Dedicated circuits: By connecting heavy loads to the distribution transformer, there is less likelihood of generating harmonic pollution or surges on start-up. Loads sensitive to harmonics should also have their own supply circuit. Multiple cables can be used for harmonic loads rather than a single cable which would be prone to heating due to neutral currents and not so efficient because of the "skin effect", caused by the 7^{th} harmonic and higher.

Complete rewiring: Often (in about 24% of cases in the survey) adopted because original wiring is not capable of supplying modern loads. Obviously this is a disruptive, expensive and drastic solution but it reduces the risk of fire and stoppages. Zoning is another method that is employed for reducing the likelihood of power quality problems. This involves classifying loads in terms of continuity, safety and EMC considerations, so that each group has its own specific wiring and earthing methods.

Meshed Earth: This provides a low impedance path to earth for a wide range of frequencies. This earthing technique also creates a large number of potential current loops but because there a large numbers of earth connections the current levels are not critical.

Passive Filters: Often line filters are fitted to reduce harmonics; however they do provide a number of other benefits which include protection against surges (transients); power factor correction; soft-starting and ride-through during supply voltage sags. Filters can be fitted on individual loads or used centrally depending on individual site requirements.

Active Conditioners: Tend to be expensive and but can be very effective when applied selectively. They offer other advantages such as tolerance waveform distortion and ride-through during dips, sags, brownouts and drop-outs. Having active PFC boost circuitry makes it easier to design power supplies which will cope with a wide range of supply voltages.

TN-S rewiring: In many countries TN-C used to be widely used. The 'C' indicates that the neutral and earth are combined in a single conductor. A system with a completely separate earth and neutral ('S') is much better for EMC.

Neutral upsizing: A number of single phase harmonic loads will create a high current in the neutral due to accumulation of triplens. This can be up to 1.7 times the effective line current. In such instances it is advisable to upgrade the neutral conductor.

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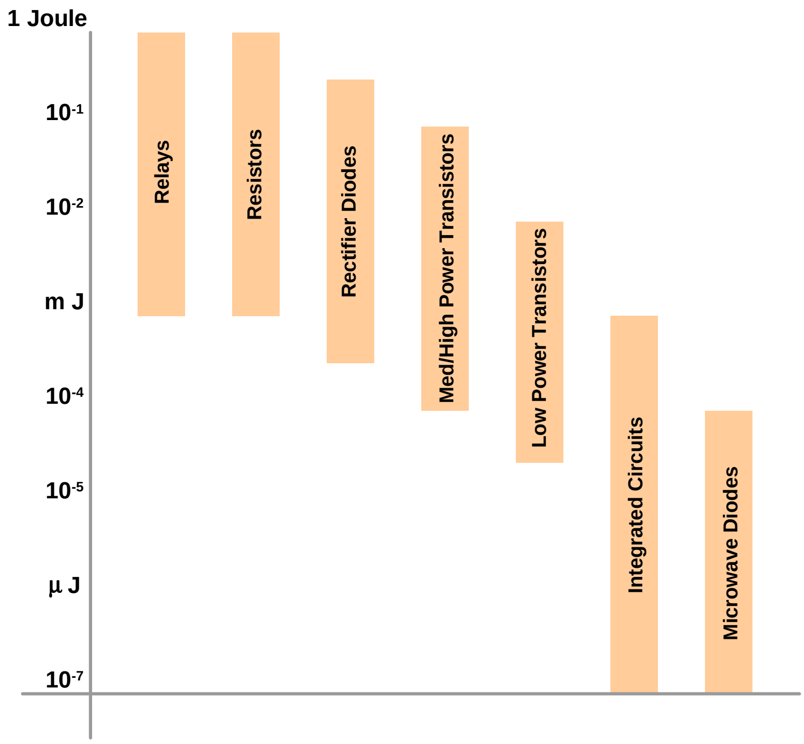
Power Quality   Fact Sheet 9

How much energy does a transient require to cause damage?



Transients of less than 3 volts peak or energy levels as low as 0.1 micro Joules can damage components or cause systems to malfunction.

The diagram on the left shows the ranges of energy levels, expressed in Joules, that are harmful to various types of electronic components.

A **Joule** is a unit of energy equal one watt of power in one second (or 1 million watts in one microsecond).

The number of repeat transients is also significant because a component may not fail on the first one.

Surge protection devices are often rated in joules, this being the amount of energy they can absorb before becoming damaged. However this value is less important than the maximum let-through voltage rating and the maximum current withstand. The other important piece of information is the location category A, B or C. Furthermore, manufacturers often quote time values in their technical data sheets (i.e.1.2/50 µs and 8/20 µs) which are the rise and fall times, of the voltage and current surge waveforms, used in the surge immunity test EN 61000-4-5

The worst voltage transients or surges are caused by lightning and can reach 6kV at locations near to overhead power lines. This is the level at which the domestic mains socket flashes-over. Corresponding current levels can reach 3kA. Considering the worst case 6,000 V x 3,000 A = 18 million Watts. However, voltage and current surges levels do depend on location and source. For instance switching on inductive reactive loads, fluorescent lights or blowing fuses can all generate transients but not normally at such high levels of energy.

The standard BS6651: 1992 Appendix C provides information on the three types of location categories and guidance on the protection of electronic equipment.

Nowadays it is becoming standard practice to fit a surge protection device on the supply side of electrical equipment. In drives applications for example a simple 2% line-reactor (choke) not only provides transient suppression but it also reduces harmonics and provides soft-starting on power-up.

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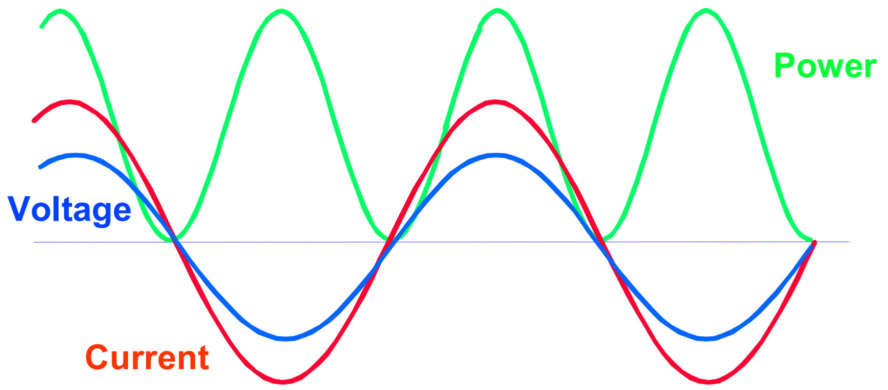
What is meant by power factor?

When a purely resistive load is connected to the AC supply the voltage drop sine-wave and the current sine-wave are exactly in phase with each other. Furthermore, the power consumed in Watts is the product of Volts x Amps.

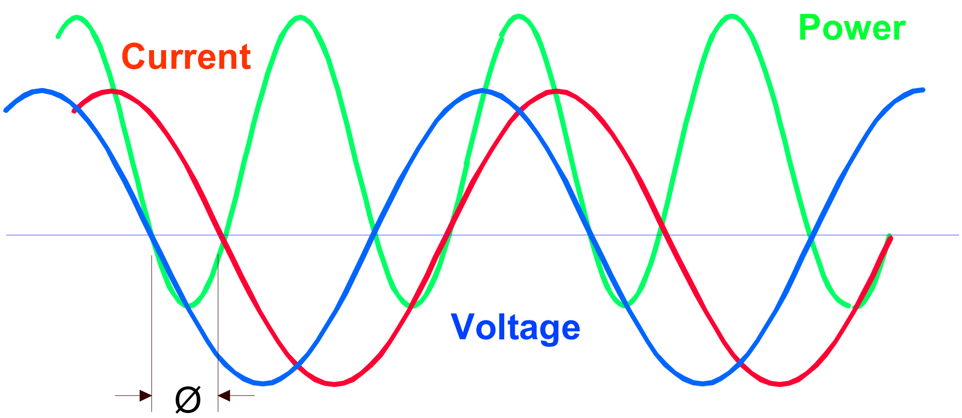
Note:
The power is always positive.



However this condition seldom arises in reality because the load invariably has an inductive or capacitive component. Now when AC voltage is applied to a pure inductor the maximum current flows when the maximum rate of change of voltage occurs i.e. at the zero crossing point. At the voltage peak the rate of change is zero and so minimum current flows. For this reason the current in a pure inductor lags the voltage by 90 degrees. Because there is no such thing as a pure inductor a resistive component always exists and so the phase shift between voltage and current can be anything between zero and 90 degrees. This angle is called Ø (phi).

The power curve changes, when the current lags the voltage, as the diagram below shows. The power is still the product of voltage and current but now the current (flow) can be negative relative to the voltage polarity.

Note:
Some of the power is now negative

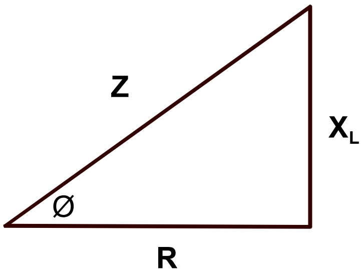


What this means is that some of the power absorbed by the load is returned to the AC supply.

Unlike DC, the resistance to flow of electrons in an AC supply is due to two components, resistance and the reactance of the inductive and capacitive components in the circuit. These values cannot be simply added together because there is a phase shift between them, as seen in the diagram above. One method of calculating the true resistance is to use vectors and the resulting value is called the impedance.

Where:-

R = Resistance
X_L = Inductive reactance
Z = Impedance



The Cosine of the angle Ø (phi) is called the Power Factor. This relationship is derived from the vector representation of resistance, inductance and impedance because from trigonometry Cos Ø = Adjacent / Hypotenuse = Resistance / Impedance.

So it is the Impedance that determines the current draw of a load and this is made up of Inductive and Resistive components in the relationship shown. Of course the inductive reactance is only there when there is an AC voltage present.

Why is this so important?

When the instantaneous RMS load voltage and load current are measured, the resulting product is “apparent power” not “true power” because the reactive component causes an additional “volts drop” resulting in a demand for higher line current to maintain the power level required by the load. This is why power components such as transformers are rated in VA and not kW because the kilowatts on the supply are not a true measure of the power used (even if some is given back). More importantly components have to be rated for the higher than expected current.

Capacitors have the same effect; however the capacitive reactance causes the current to lead the voltage instead of lag like an inductive reactance. Like inductance, a pure capacitance would cause the current to lead the voltage by 90 degrees. Therefore, capacitors can be used to correct the lagging current of an inductive load, or vice-versa; hence the term Power Factor Correction.

In modern electronic systems there are lots of inductive and capacitive components (even in cable and on circuit board solder connections). Furthermore, at different frequencies the reactive value can change; the inductive reactance increases proportional to the frequency, whilst capacitive reactance decreases inversely proportional to frequency.

Therefore, a line reactor (choke) is often used as a remedy when an electronic load, incorporating storage capacitors (e.g. switch-mode) generates lots of harmonics because the inductive reactance increases at higher frequencies, offering more impedance, thus reducing the problem. Hence the term Power Factor Correction tends to be used more in this sort of context rather than the traditional sense.