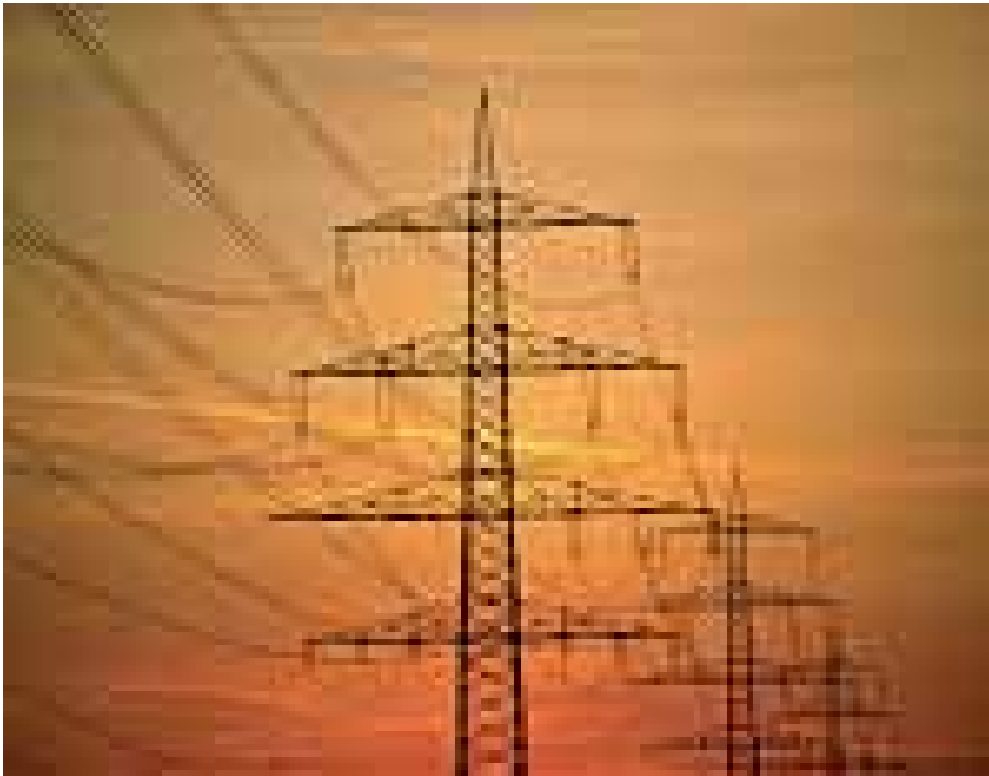


# Power Quality

Whoever stops trying to be better  
has stopped being good.



## Introduction

The subject of Power Quality has many aspects. The electricity generating and transmitting companies have a legal obligation to provide electrical power to consumers which is within specified limits for the distortion of the voltage sine-wave, variation of frequency, voltage fluctuations, sags and drop-outs. They also have to protect their own mains supply network, which includes distribution cables and transformers, from overloading caused by badly applied loads. From an economic point-of-view they want to ensure that the cables in the ground are not required to carry excessive currents, otherwise replacement would be very costly and disruptive. Therefore, in their own interest they monitor the equipment and plant used by industrial electricity consumers to make certain that excessive currents are not induced on the supply network.



Furthermore controlling organisations have a vested interest in ensuring that manufacturers of domestic appliances, air-conditioning equipment and computers, which are produced in vast numbers, take due care to ensure that their products, when connected to the public supply, do not cumulatively cause power quality problems. Electrical equipment producers have to conform to EMC Directives and Standards before they place their electrical goods and systems in the market place, to make sure that their products do not disrupt other electrical equipment and will continue to operate within specified limits of EMC

interference of different types. Even though these are State imposed regulations, it is in the interest of reputable producers to ensure that their electrical goods are immune to EMC phenomena and perhaps at levels that exceed standards because otherwise it will be expensive to replace goods under warranty and they will gain a reputation for supplying unreliable goods.

There are also nuisance considerations to power quality such as flickering lights, loss of production or services, software crashes or complete loss of power but more importantly there is human safety to consider. Safety laws are becoming more rigorous and insurance companies consider due diligence much more critically before making a pay out. Incorrect distribution of loads and excessive harmonics can induce high protective earth currents that are potentially dangerous.

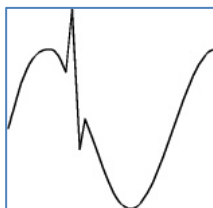
The liberalisation of the electricity market, coupled with the ever increasing need for the reduction of carbon emissions has created a great deal of interest in renewable energy sources and there is rapid development of new systems for converting ambient energy into electrical power.

However, introduction of such systems is not without its difficulties because the existing national electrical generating companies and transmission network operators are naturally opposed to connecting other equipment to their network on the grounds of reliability and more importantly they want to protect their own markets. Because of the insistence of governments and electricity regulators they have to concede to connection of small generators but restrict this to a local level, i.e. only the low voltage system and not the high-voltage network and referred to as "Distributed Generation". Even with such concessions there is strict control over the reliability and compatibility of other electrical generating equipment.

Obviously the developers and manufacturers of renewable energy equipment recognise that their products must not cause disturbances or instability of the network and so they ensure utmost reliability of their designs. Whilst it is envisaged that in the early days of local, small-scale electrical generation each additional connection will be scrutinised, in the future it will be a more relaxed procedure of "fit and inform" when confidence has grown and equipment conforms to a standard technical protocol.

**The Power Quality Standard EN 50160:2000**

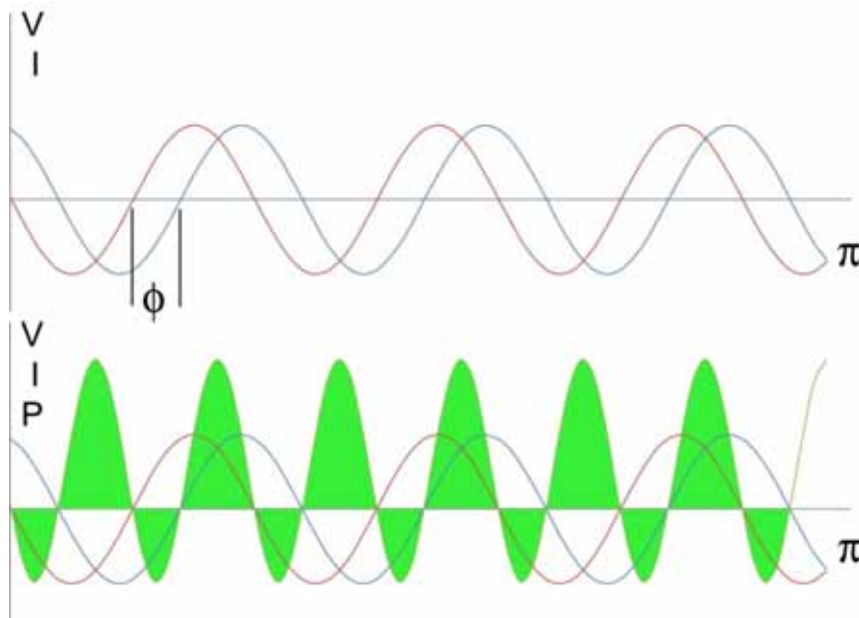
Supply voltage phenomenon	Acceptable limits	Measurement Interval	Monitoring Period	Acceptance Percentage
Grid frequency	49.5Hz to 50.5Hz 47Hz to 52Hz	10 s	1 week	95% 100%
Slow voltage changes	230V $\pm$ 10%	10 min	1 week	95%
Flicker Severity	P <sub>ft</sub>	$\leq 1$	N/A	95%
Voltage Sags or Dips ( $\leq 1$ min)	10 to 1000 times per year (under 85% of nominal)	10 ms	1 year	100%
Short Interruptions ( $\leq 3$ min)	10 to 100 times per year (under 1% of nominal)	10 ms	1 year	100%
Accidental, long interruptions ( $> 3$ min)	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 $< 6$ kV	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%



*Locations near to power lines are particularly vulnerable to transients, typically 10kV ten times a year, whereas an office in a town could expect up to 3kV ten times a year.*

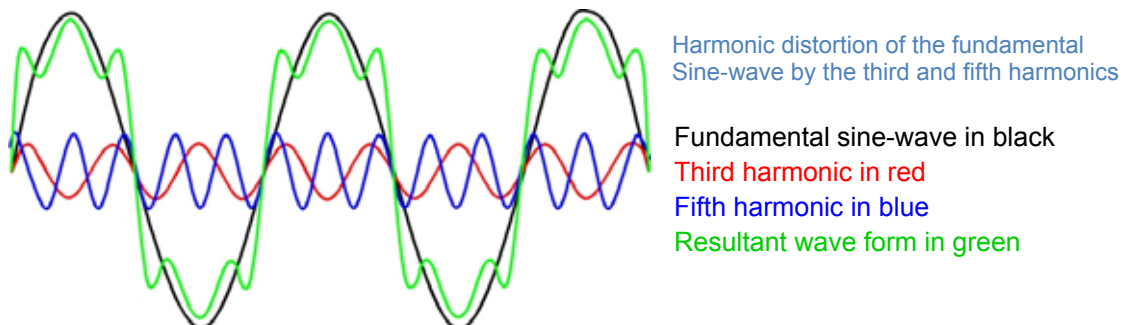
## Displacement Power Factor (Cos $\Phi$ ) and Harmonics

When an inductive load is connected to the AC supply network because of its electrical properties the current sine-wave lags behind the voltage sine-wave (50Hz or 60Hz in most countries). As can be seen from the diagram below the resultant power can be negative ( $P = V \times I$ ) which means that sometimes the power is flowing back into the mains network.



This power has to come from somewhere and this is provided extra current supplied on top of the real current drawn by the load and sometimes referred to as the “blind current”, or KVAR. What this means in reality is that delivered current is much higher than it should be and so power cables, protection devices and the network cables in the ground all have to be rated for a current that is significantly higher than that required by the load. Not all of the power can be used because some of it is lost due to cable and connector resistance and transformer losses. Therefore bad power factor displacement can be wasteful and requires extra cable current capacity.

Harmonics are also sine-waves but at frequencies that are multiples of the mains frequency, or fundamental frequency. Any non-linear switching on the AC mains supply can be analysed and it will be found to comprise lots of harmonic frequencies, some predominant and some not depending upon the nature of the circuit and the components that are connected together. The problem with harmonics is that they do not contribute any useful power; they are undesirable because they distort the fundamental sine-wave shape which the grid operators are obliged to maintain and furthermore they draw excessive currents caused by the displacement power factor plus the combined harmonic power factors.



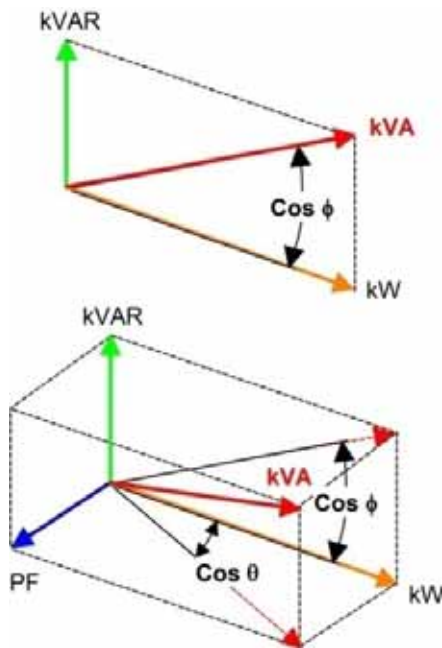


Figure 1: Power Factor Vector Diagram

Top – Displacement Power Factor

Bottom – Displacement Power Factor + Harmonic Power Factor

kW = Work producing power

kVAR = Non work producing power caused by inductive reactance

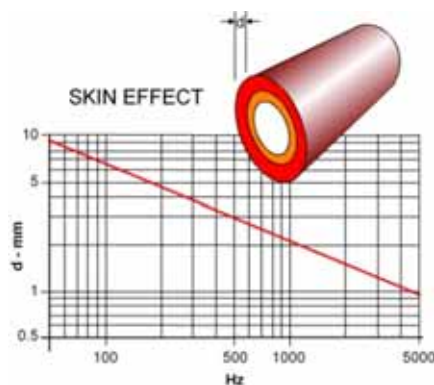
CosΦ = Displacement Power Factor

PF = Non work producing power caused by harmonic distortion

Cosθ = Harmonic Power Factor

kVA = Apparent power, e.g. power that has to be supplied from the mains network

However, there are also much more serious effects that are caused by harmonics. Being at higher frequencies cables suffer from a phenomenon known as the “skin-effect”, whereby the current tends to flow near to the outer surface of the cable and not near to the centre thus reducing the current carrying capacity. Transformers will not operate correctly they will generate more losses and run hot and – special types transformers are used for harmonics, known as K factor rated.



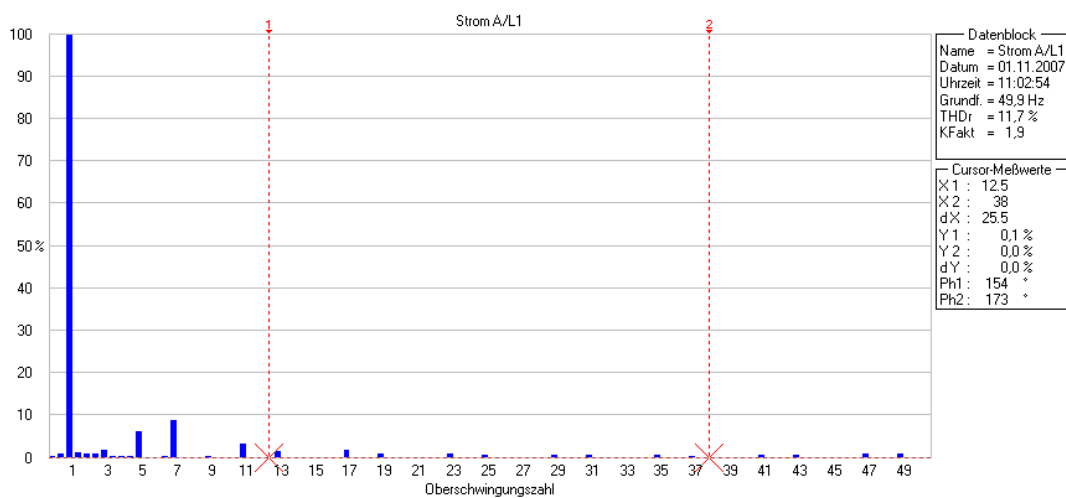
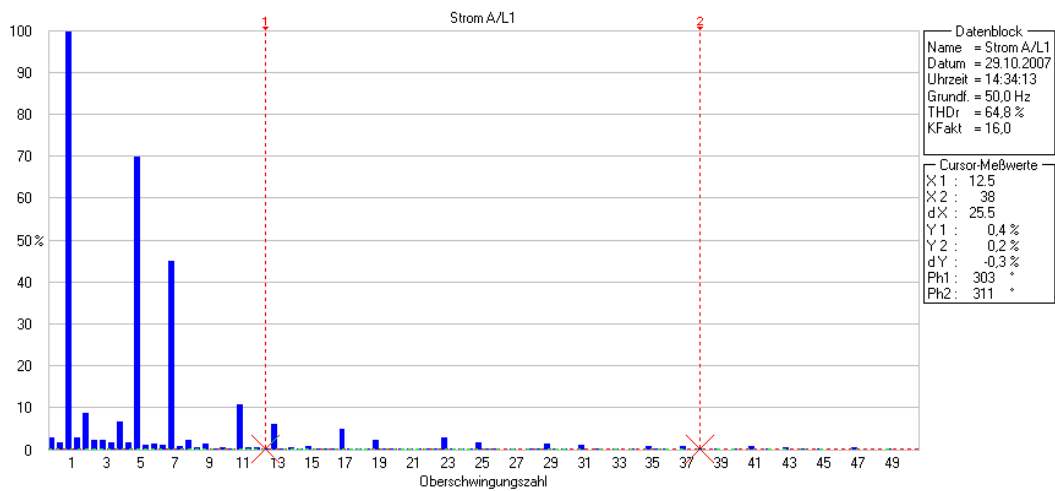
Therefore it is very important for the grid operators to control power factor otherwise the power grid infrastructure would soon have insufficient capacity and would have to be replaced completely, which is an unacceptable proposition. Also certain combinations of harmonics can cause zero-crossing synchronisation problems for electronic control equipment or heating problems in neutral conductors.

The answer is to control the harmonic interference at source and so grid codes and electrical equipment standards are gradually being introduced to limit the amount of harmonic pollution, i.e. EN 61000-3-2 the standard for harmonic distortion limits for all electrical equipment from 16A to 75A per phase. In the USA harmonics are the scope of the IEEE 519 Standard. Therefore it comes down to the electrical equipment manufacturer to design equipment that has built-in power factor correction – either passive harmonic filters or active power factor correction.

## Typical REO Harmonic Reduction Components



Example frequency spectrum without (top) and with (bottom) harmonic filter fitted

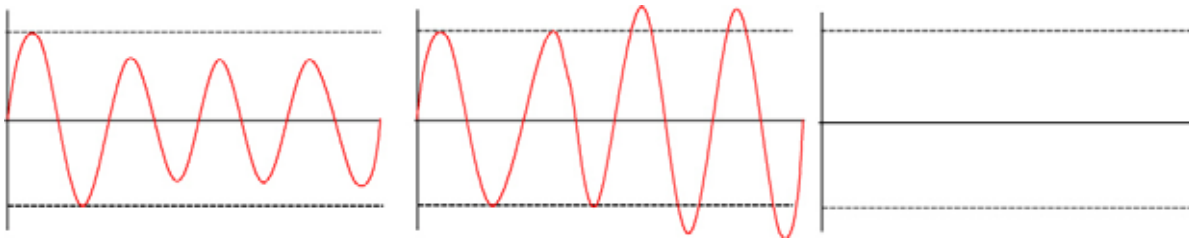


## Causes of harmonics

Any non-linear load, which includes switching, on the mains distribution network will generate harmonics and the waveform associated with a load can be analysed and broken down to give a harmonic spectrum. The following are just a few examples of electrical equipment that produces harmonics:

- Uninterruptible power supplies
- Motors, fans and pumps
- Servers (especially blade-servers which have a leading power factor)
- Personal computers, video monitors, printers and photocopiers
- Fluorescent lights, low energy bulbs and low voltage lighting using electronic transformers
- Lifts and escalators
- Variable speed drives and switched-mode power supplies
- Rectifiers, power converters and thyristor power controllers
- Chillers, compressors, freezers and microwave cookers
- Air-conditioning, heating and ventilating equipment

## Voltage changes, sags, dips and interruptions



Voltage waveforms for sags, surges and interruptions

All electrical equipment should be tested to ensure that it is immune to voltage changes that are within the operating limits of the public supply network, however there are some instances where processes depend on an uninterrupted voltage, e.g. float glass production plants, hospitals, money exchanges and silicon chip production lines and in such cases stand-by generators and UPS's have to be used which can also be the source of power quality problems because of the disturbances they create.

Often for the sake of standardisation equipment might be required to operate in all parts of the world, without any special adaption, such as in the case of airport X-ray machines for example. Many of these incorporate a transformer-based voltage stabiliser. Ocean-going boats use shore-side power when they are moored. The widely ranging voltages and variations are firstly fed through an isolation transformer which is required for safety reasons and to protect the hull of the boat from corrosion and then on to a voltage converter/stabiliser before being distributed on to battery-charging, lighting and service circuits. Sometimes, high-performance production machines, airport lighting, and test systems rely on a steady voltage for correct operation and in such cases voltage stabilisers can be fitted.

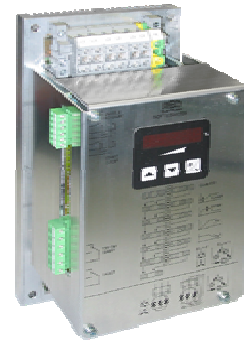
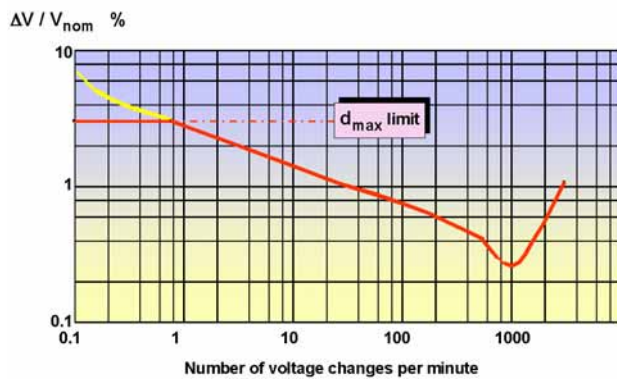
Often dips are caused when local heavy electrical loads are switched on, for example refrigeration compressors, air-conditioning fans and pumps are notorious for high current inrush during a start-up phase with a corresponding drop in mains voltage. To overcome such problems soft-start units can be fitted to the offending loads and these gradually increase the supply voltage in a controlled manner until the running voltage is reached and then the soft-start unit is switched out of circuit. Without a soft-start protection devices have to have higher ratings because the current in-rush can be up to ten times the normal running current.

## Flicker

Electrical AC power distribution systems always have some impedance associated with it, so the current drawn from it by an item of equipment can cause its voltage to change, fluctuate or flicker. Flicker is the term used for, because they cause the intensity of the visible light from filament lamps, powered by the same supply, to flicker. This can cause annoyance, stress, headaches, migraines and seizures.

Sometimes switching on a motor can cause flicker because the sudden current inrush can cause the supply voltage level to drop and increase rapidly for a few mains supply cycles. This is undesirable on a luxury yacht for instance, when pumps or other loads are switched on.

The red curve in the diagram is taken from EN61000-3-3 and shows the voltage fluctuation levels in lighting systems that cause irritation. The very worst condition occurs at about 1000 voltage fluctuations per minute (around 8 Hz).



The REO VAREOSOFT Soft-Start unit reduces current inrush and flicker

## Transients

Broadly speaking, surges emanate from electrical storms or switching of heavy reactive loads and insulation faults on the AC power distribution networks, whereas fast transient bursts are associated with sparking contacts. Surges are more location dependent, occurring more frequently in Pacific Rim and North and South America where there is a greater predominance of electrical storms. Sites supplied by overhead power lines tend to be more susceptible than those in a suburban or city centre area with underground power distribution. Therefore local conditions should be considered and the protection system designed accordingly.

Semiconductors are particularly vulnerable to surges and transients and since these are used extensively in power supplies, variable speed drives and PLCs it is almost inevitable that they will be present in a control panel. Perhaps more significant is the nuisance factor attributed to transients such as the inexplicable crashing or corruption of software, and the intermittent failure of controllers. These sorts of problems cannot be analysed because there is usually no evidence for proving that the event has occurred.

Therefore, it is imperative that some form of surge protection is fitted to an industrial controller or panel and there is no reason not to because generally the devices used for this purpose are inexpensive. Another basic requirement is to have an installation earthing system that is designed to have low-impedance over a wide frequency band, with a good low-impedance connection to the lightning protection system's earth electrode system. Installation earthing for EMC is described by IEC 61000-5-2.

Low-cost components such as metal-oxide varistors (MOVs) and gas discharge tubes are used widely for local surge-suppression and often these are built into input circuitry of electronic equipment. Varistors although relatively quick-acting are bulky, not very rugged and have a limited life whereas gas-discharge devices are slower but can handle higher power levels and have negligible leakage current. For direct mains applications, a good solution is to use a combination of both of these components with the gas-discharge device handling the majority of the surge energy and the varistor taking care of the initial spike that sneaks past it. A few microhenries is required between these two device types, otherwise the varistor can prevent the gas-discharge tube from operating correctly. Signal cables are typically protected by varistors and/or silicon avalanche rectifier suppressors (such as "Transzorbs"), which are essentially a sort of Zener diode with very high current and energy capabilities. Manufacturers of bolt-on transient voltage suppression devices recommend a hierarchical structure with varying degrees of protection at controller, group (e.g. process or office equipment) and distribution board levels.

## Power Quality Applications

The diagram below shows a typical motor-powered escalator which is used in public buildings. The REO harmonic adsorption filter components are selected by the REO design team after testing the motor and frequency inverter combination and deriving measurements for the harmonic spectrum up to the 40<sup>th</sup> harmonic.

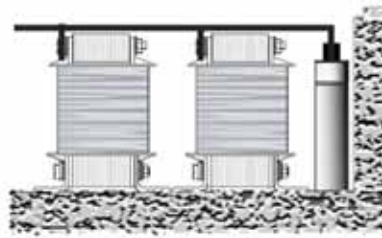
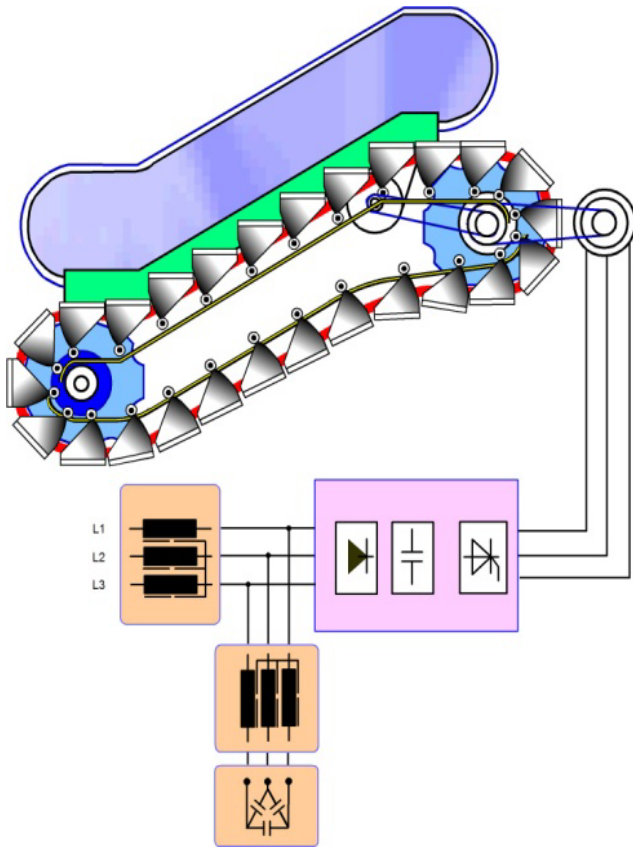
The filter was then designed to reduce harmonics according to the Lifts Directive 95/16/EC which states that a manufacturer may apply harmonised standards in order to satisfy the essential requirements of the EMC Directive:

EN 12016:2004 – Immunity

EN 12015:2004 – Emissions

(which include tables for RFI and Harmonic distortion limits).

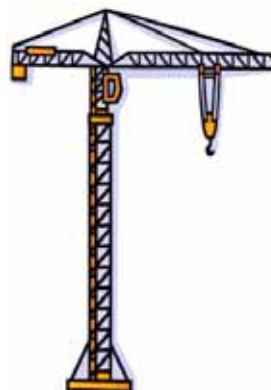
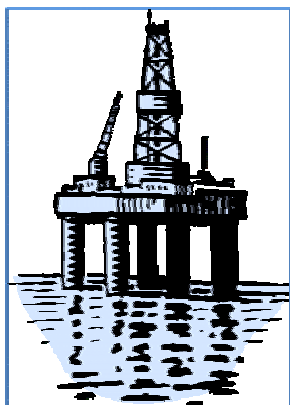
It was important that the filter fitted in the available under floor space adjacent to the motors and this was achieved by building inductors with low profiles.



### Installation details

The REO Harmonic Absorption Filter comprises two 3-phase chokes and three capacitors. In this instance dimensions of the inductor's core laminations were selected to give a low profile so that the whole filter could fit inside the floor cavity adjacent to the motor and drive gear.

Two further good examples include oil platforms, which have a large drilling motor and inverter which creates an environment that is rich in harmonics and cranes which also have large motors and frequency inverters.



## Regenerative Systems

There is a growing need for the efficient regeneration of surplus power, created from potential and kinetic energy in loads, powered by electrical controllers, instead of converting it into wasteful heat energy. Also with the prospect of global warming and the necessity for all nations to develop integrated generation using natural energy provided by water, wind, solar, biomass and geo-thermal sources, there is a requirement for equipment to convert this energy into electricity and to feed it back onto the public mains network.

REO are able to provide power conditioning packages that can be used with recycled or renewable electrical so that it is of a suitable quality for acceptance by the grid operators.



## REO Products for solving Power Quality Problems

- Mains Chokes
- Harmonic Filters
- Voltage stabilisers
- Soft Starts
- Transient Suppressors
- Motor Chokes
- Sinusoidal Filters
- **Sinusfilter Plus** ++
- Star/Delta Transformers
- Isolation transformers
- Neutral Connection Transformers
- Chokes and Filters for Integrated Generation (Photo-voltaics, wind turbines etc.)
- Test Equipment for Immunity Testing

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