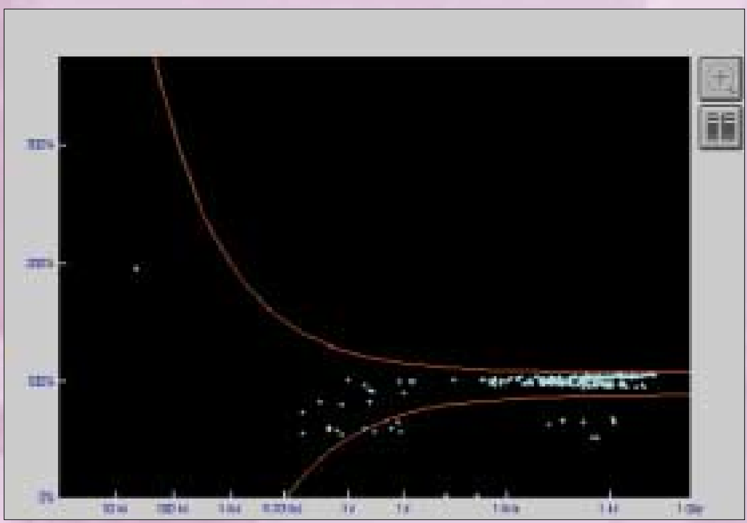
Power Quality Application Guide

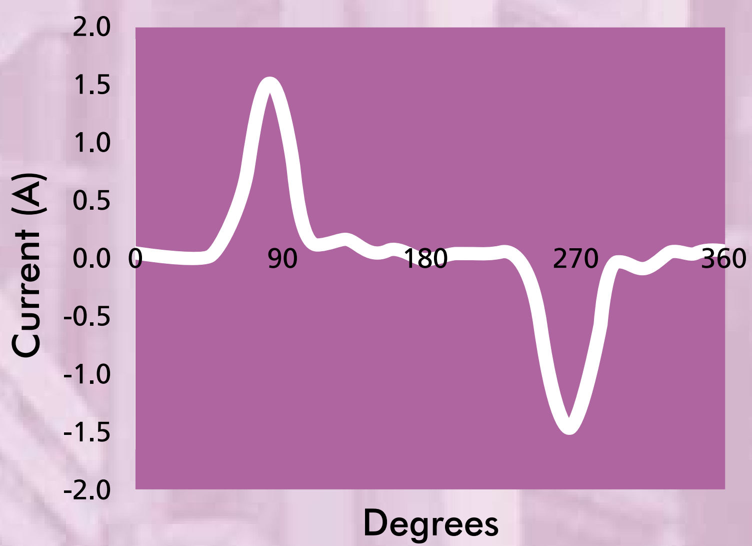
Education and Culture

Leonardo da Vinci

Introduction

1.1





Copper Development Association

Introduction

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Introduction to Power Quality

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European Copper Institute (ECI)

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Introduction to Power Quality

Electrical power is perhaps the most essential raw material used by commerce and industry today. It is an unusual commodity because it is required as a continuous flow - it cannot be conveniently stored in quantity - and it cannot be subject to quality assurance checks before it is used. It is, in fact, the epitome of the 'Just in Time' philosophy in which components are delivered to a production line at the point and time of use by a trusted and approved supplier with no requirement for 'goods in' inspection. For 'Just in Time' (JIT) to be successful it is necessary to have good control of the component specification, a high confidence that the supplier can produce and deliver to specification and on time, and a knowledge of the overall product behaviour with 'on limit' components.

The situation with electricity is similar; the reliability of the supply must be known and the resilience of the process to variations must be understood. In reality, of course, electricity is very different from any other product – it is generated far from the point of use, is fed to the grid together with the output of many other generators and arrives at the point of use via several transformers and many kilometres of overhead and possibly underground cabling. Where the industry has been privatised, these network assets will be owned, managed and maintained by a number of different organisations. Assuring the quality of delivered power at the point of use is no easy task – and there is no way that sub-standard electricity can be withdrawn from the supply chain or rejected by the customer.

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From the consumers' point of view the problem is even more difficult. There are some limited statistics available on the quality of delivered power, but the acceptable quality level as perceived by the supplier (and the industry regulator) may be very different from that required, or perhaps desired, by the consumer. The most obvious power defects are complete interruption (which may last from a few seconds to several hours) and voltage dips or sags where the voltage drops to a lower value for a short duration. Naturally, long power interruptions are a problem for all users, but many operations are very sensitive to even very short interruptions. Examples of sensitive operation are:

- Continuous process operations, where short interruptions can disrupt the synchronisation of the machinery and result in large volumes of semi-processed product. A typical example is the paper making industry where the clean-up operation is long and expensive.

- Multi-stage batch operations, where an interruption during one process can destroy the value of previous operations. An example of this type is the semiconductor industry, where the production of a wafer requires a few dozen processes over several days and the failure of a single process is catastrophic.

- Data processing, where the value of the transaction is high but the cost of processing is low, such as share and foreign exchange dealing. The inability to trade can result in large losses that far exceed the cost of the operation. In a recent example a claim for €15m compensation was made as a result of a 20 minute power interruption.

These are examples of the most sensitive industries, but it is surprising how many apparently mundane operations have quite critical power supply requirements. Examples include large retail units with computerised point of sale and stock control equipment and manufacturing plant with distributed control.

So, what do we mean by 'power quality'? A perfect power supply would be one that is always available, always within voltage and frequency tolerances, and has a pure noise-free sinusoidal wave shape. Just how much deviation from perfection can be tolerated depends on the user's application, the type of equipment installed and his view of his requirements.

Power quality defects – the deviations from perfection – fall into five categories: –

Harmonic distortion	(see Section 3)
Blackouts	(see Section 4)
Under or over voltage	(see Section 5)
Dips (or sags) and surges	(see Section 5)
Transients	(see Sections 5 & 6)

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Each of these power quality problems has a different cause. Some problems are a result of the shared infrastructure. For example, a fault on the network may cause a dip that will affect some customers and the higher the level of the fault, the greater the number affected, or a problem on one customer's site may cause a transient that affects all other customers on the same subsystem. Other problems, such as harmonics, arise within the customer's own installation and may or may not propagate onto the network and so affect other customers. Harmonic problems can be dealt with by a combination of good design practice and well proven reduction equipment.

Electricity suppliers argue that critical users must bear the costs of ensuring supply quality themselves rather than expect the supply industry to provide a very high reliability supply to every customer everywhere on the network. Such a guaranteed quality supply would require a very substantial investment in additional network assets for the benefit of relatively few customers (in numerical, not consumption, terms) and would be uneconomic. It is also doubtful whether it would be technically feasible within the current social and legal framework in which any customer is normally entitled to be connected to the supply and utility providers have the right to excavate roadways with the risk of cable damage. Weather conditions, such as high winds and freezing rain, frequently cause damage to overhead lines, which, under the same conditions, are difficult and time consuming to repair. It is therefore the consumer's responsibility to take steps to ensure that the quality of power *delivered to his process* is good enough, with the clear implication that this quality level may well be higher than that *delivered to the plant* by the supplier.

There are a variety of engineering solutions available to eliminate or reduce the effects of supply quality problems and it is a very active area of innovation and development. As such, customers need to be aware of the range of solutions available and the relative merits and costs. Further sections of this guide discuss individual problems and the range of solutions available in detail.

Users are faced with the need to make design investment decisions about the type and quantity of additional plant required to achieve the quality of supply required. Unfortunately, some vital information is missing – the extent and severity of power quality problems likely to be experienced in any particular location is largely unknown. Because there are so few published statistics it is very difficult for consumers to quantify the cost of failure and justify the cost of preventative measures. This subject is covered in more detail in Section 2. In the UK, for example, the only data available gives the number and average duration of interruptions longer than one minute, broken down by supplier. On average, for 1998/9, each consumer was likely to have one interruption of about 100 minutes every 15 months representing an availability of 99.98 %. Unfortunately, it is the 0.02 % that causes the problems. The reported performance of most suppliers was close to their historic best, with the best and worst performers at 50 % and 200 % of the average so the current situation is probably close to the best that can be achieved economically. It has to be remembered that these figures relate only to interruptions of longer than one minute and there is an unknown, but large, number of interruptions in the 0.1 to 5 second range. The disruption caused by one of these interruptions can be just as costly as a one-hour interruption.

The issue of short interruptions and voltage dips highlights the difference in perspective between supplier and customer. They are by definition short term events so that unless there is a permanent monitor installed the very existence of the event is difficult to prove. It is even more difficult to attribute a business loss to a particular event. The electricity supply industry tends to value an interruption in terms of the cost of the electricity that was not supplied as a result, while the consumer values it in terms of the revenue lost as a consequence of the break in production. Electricity is relatively cheap and the supply interruption relatively short, while lost production can be very valuable (as in the case of semiconductors) and the downtime very long to allow for clean up (as in the paper making industry). The two parties therefore have completely different views of the importance of voltage dips and on the level of investment in reduction equipment that is justified.

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Longer interruptions – power cuts – are usually thought of as being caused by the supplier but can also be caused by the failure of on-site equipment, conductors and connections. Careful design using high resilience techniques can minimise the effects. The objective is to identify single points of failure and eliminate them by providing redundant equipment or alternative supply paths so that operation can continue despite a single failure. Systems designed in this way are easier to maintain and are better maintained as a result. It is important that maintenance procedures are developed at an early stage as part of the resilient design concept. Standby generation and UPS systems, required to cover short and longer term power cuts are essential elements of a resilient system. Resilient design is discussed in Section 4.

While the majority of voltage dips and interruptions originate in the transmission and distribution system and are the responsibility of the supplier, harmonic problems are almost always the responsibility of the consumer. It is harmonic *currents* that cause problems in installations and when these currents flow back into the supply impedance at the point of common coupling, a harmonic voltage is developed. This voltage distortion, or at least some components of it, are distributed around the system and are combined with the background harmonic voltage distortion present in any transmission system (due to the non-linearity of transformers for example). By limiting the harmonic current consumers are permitted to draw, the level of voltage distortion *on the supply* is kept within acceptable limits. Most national limits are based on the UK electrical supply industry standard, (currently G5/4) which originated as G5/1. This planning standard established arbitrary voltage distortion limits which, over the last 40 years, have been proven to be largely correct. Determining the source of harmonic distortion can be difficult and this often leads to consumers blaming the supplier for the problem. In fact, it is unusual for harmonic problems within an installation to arise from external causes – the cause is almost always due to the equipment on site and the installation practice used. Section 3 covers harmonic causes and solutions in detail.

Careful design using high resilience techniques can minimise the effects of failure of on-site equipment, conductors & components.

Transient disturbances are high frequency events with durations much less than one cycle of the supply. Causes include switching or lightning strikes on the network and switching of reactive loads on the consumer's site or on sites on the same circuit. Transients can have magnitudes of several thousand volts and so can cause serious damage to both the installation and the equipment connected to it. Electricity suppliers and telecommunications companies go to some effort to ensure that their incoming connections do not allow damaging transients to propagate into the customers' premises. Nevertheless, non-damaging transients can still cause severe disruption due to data corruption. The generation and influence of transients is greatly reduced and the efficacy of suppression techniques greatly enhanced where a good high integrity earthing system has been provided. Such an earthing system will have multiple ground connections and multiple paths to earth from any point, so ensuring high integrity and low impedance over a wide frequency band. Earthing systems are discussed in Section 6.

Power quality problems present designers with many questions, perhaps the greatest of which is, 'How good is good enough?' This question is impossible to answer. While it is relatively simple to quantify the behaviour of a particular piece of equipment to voltage dips, determining the likely incidence of voltage dips at a particular location on the supply system is rather more difficult; it will change over time as new consumers are added and assets replaced. It is extremely difficult to collect any meaningful data on the sensitivity of equipment to harmonic voltage distortion, and even on the harmonic current distortion caused by equipment. The real question is one of compatibility between the equipment and the supply.

There are some international standards available that set limits of voltage variation and harmonic voltage distortion below which equipment should function without error. Similarly, there are standard limits for voltage deviation and harmonic voltage distortion of the supply. Ideally, there should be a guard band – a safety margin – between the two limits but because supply quality is difficult to measure on a continuous basis, the supply limits are set in statistical terms and not as hard limits.

Ensuring good power quality requires good initial design, effective correction equipment, co-operation with the supplier, frequent monitoring and good maintenance. In other words, it requires a holistic approach and a good understanding of the principles and practice of power quality improvement. It is the aim of this guide to provide this understanding.

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