Power Quality Application Guide

Education and Culture

Leonardo da Vinci

Costs

The Cost of Poor Power Quality

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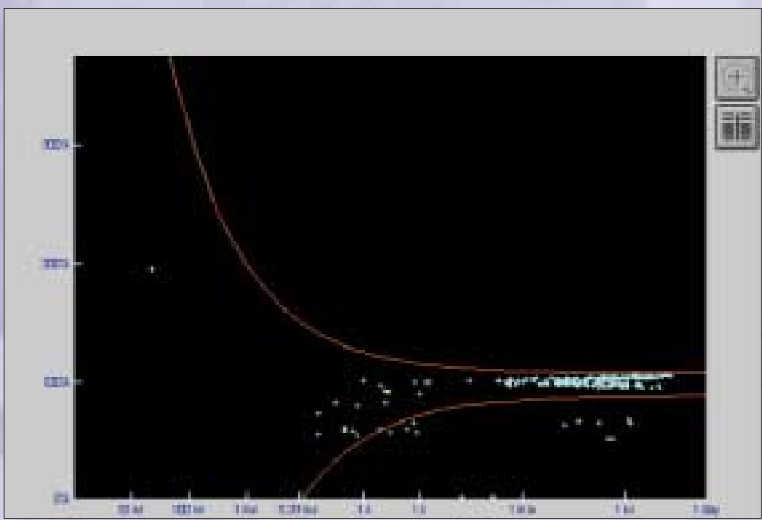

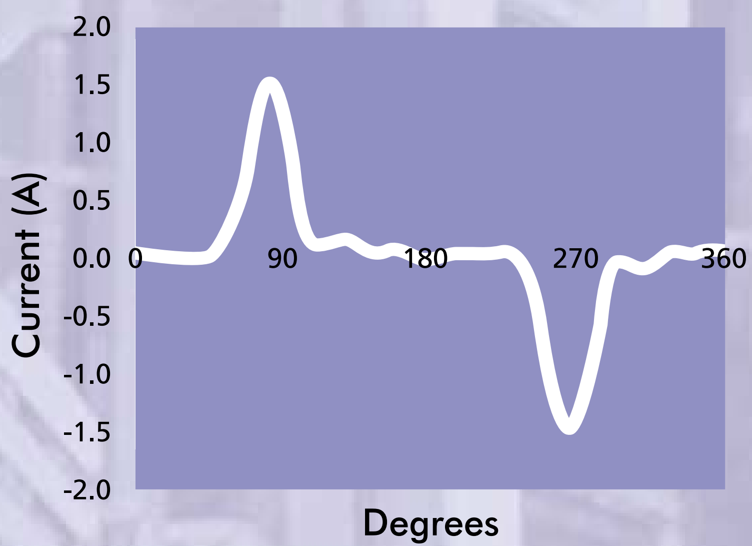

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Costs

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The Cost of Poor Power Quality

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Copper Development Association
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The Cost of Poor Power Quality

Electrical power is an important raw material for all commercial operations and, like any other raw material, the quality of supply is very important. The nature and causes of power quality defects have been outlined in Section 1 and are discussed in detail in later sections; this section concentrates on the effects of defects on production and the costs that can be expected to occur. As discussed in Section 1 there are five basic types of defect, each with different causes and effects and, of course, different cost implications.

It is estimated that power quality problems cost industry and commerce in the EU about €10 billion per annum while expenditure on preventative measures is less than 5 % of this. The question is the obvious one: 'How much money should be invested in prevention to balance the risk of failure?' and the answer depends on the nature of the business. The first step is to understand the nature of the problems and assess how each of them relates to the business and what losses might result. The following sections discuss power quality problems from the point of view of their business interruption potential; information on their causes, effects and how to deal with them is contained in later sections of this Guide.

Harmonic distortion

Harmonic distortion, caused by non-linear loads on the electricity supply system, result in currents in the system that are of higher magnitude than expected and contain harmonic frequency components. These currents cannot be adequately measured by some of the lower cost portable test meters commonly used by installation and maintenance technicians, leading to current levels being seriously under-estimated – sometimes by as much as 40 %. This error in magnitude alone can result in circuits being installed with conductors that are too small. Even if the current is within the capacity of the overcurrent protection device, conductors run at higher temperatures and waste energy – typically 2-3 % of the load. Frequently the overcurrent protection device rating is too close to the real load current (because it was under-estimated) and the circuit is prone to so-called nuisance tripping.

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The harmonic frequency components cause greatly increased eddy current losses in transformers because such losses are proportional to the square of the frequency. Because the losses are higher, the operating temperature of the transformer is higher and the lifetime is considerably shortened. Even moderately loaded transformers supplying IT loads will have much lower lifetimes than expected unless proper precautions are taken.

The economic effects of harmonics are shorter equipment lifetime, reduced energy efficiency and a susceptibility to nuisance tripping. The cost of nuisance tripping, like any other unplanned shortage, can be very significant and is discussed further in the section on voltage dips. Shorter equipment lifetime can be very expensive. Equipment such as transformers is usually expected to last for 30 or 40 years and having to replace it in 7 to 10 years can have serious financial consequences. The cost of avoidance is relatively small, requiring only good installation practice and proper equipment selection. Installing cables that are one to two sizes greater than the calculated minimum reduces losses and operating costs at very little increase in initial cost.

Blackouts

Blackouts are the most basic of power quality problems, lasting from several seconds up to, in one famous extreme case, months. In the UK, the average blackout lasts for about 100 minutes and occurs every 15 months, but individual events may be very short and much more frequent. Of course, the public supply is not the only source of failures.

Within the installation in a building or plant there will be many areas where the failure of a single component, cable or connection will cause complete shutdown.

Protection against complete power failure requires two types of action. The installation must be designed to eliminate single points of failure, or at least those identified in a risk assessment as posing the greatest risk, and steps must be taken to identify the need for a backup power supply. Resilient design is dealt with in Section 4. The techniques required are neither difficult nor particularly expensive but can, alone, provide considerable benefit. As always, these techniques are far cheaper to apply at the initial design stage than during commissioning. Alternative sources of power can be very expensive both to purchase and to maintain – there is little point in having a standby generator, for example, if it is not ready for an instant start-up – and the need for and type of supply required must be carefully considered. In judging the economic viability of investing in on-site generation plant it should be remembered that, once installed, it will protect against failures over many years.

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Large, power-hungry industries such as steel or paper-making will require a second supply taken from a different section of the grid so that a single failure is very unlikely to affect both supplies. Alternatively, on-site full demand generation may be viable, if suitable fuel supplies are available. In either case the initial cost of this is likely to be very high, but so is the potential cost of power failure. Paper, for example, is manufactured in a continuous process requiring precisely controlled speeds of hundreds of rollers in a machine that may be over 500 metres in length. Any failure of the power supply, even a dip, will cause loss of synchronisation, and halt the process. All the part processed paper and pulp must be cleared from the machine and the surrounding area before restarting; this can take many hours. Apart from the loss of output, the waste of raw materials and manpower, the inability to supply the customer is very important. Newsprint, for example, is used in such vast quantities that it is impossible for either supplier or customer to keep a buffer stock. It is required 'just in time', and it is manufactured, used and discarded in just a few days. Failure of the papermaker to deliver means that the publisher cannot print and, since yesterday's news has no value (but considerable costs), there are severe financial consequences. This may lead to a change of supplier or a change in the terms of the supply contract, such as penalty clauses.

For smaller industries with lower power requirements it may be viable to have on-site generation to handle essential equipment during blackouts and to reduce demand peaks. This is much cheaper, but the cost must still be judged against the risks of failure – an assessment that can only be made by the organisation itself. It must be remembered that a standby generator takes time to start, so some other backup supply,

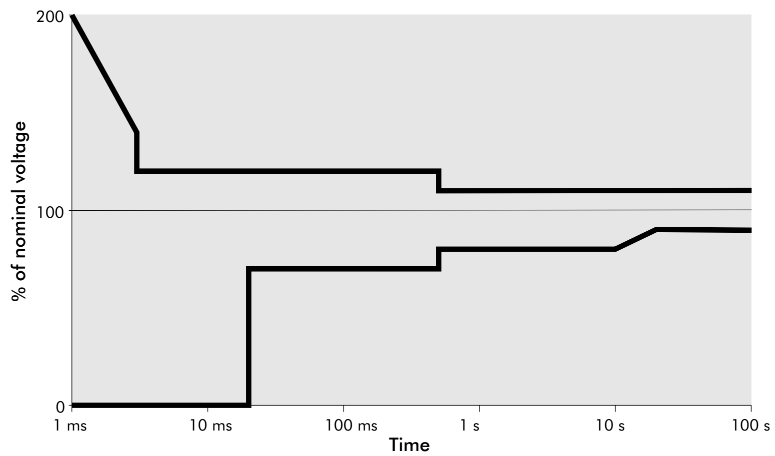

Figure 1 - ITIC curve

such as a UPS, must be provided for sensitive loads. A UPS has limited capacity and it is important that it is used to support only the essential loads, such as the computer network servers and critical workstations, and nothing else. As always, good maintenance procedures are essential.

Dips or sags

Dips are short-term reductions in the RMS magnitude of the supply voltage lasting from a fraction of a second up to several seconds. Dips are described in terms of duration and retained voltage, i.e. the percentage of the nominal supply voltage (RMS) remaining during the event. Note that a very short but complete loss of supply is called an interruption but is frequently referred to as a dip.

The Information Technology Industry Council (ITIC) curve, formerly known as the Computer and Business Equipment Manufacturers Association (CBEMA) curve, shown in Figure 1, describes the tolerance of equipment to voltage disturbances of all types. The solid lines represent the maximum and minimum voltages that can be tolerated without malfunction plotted against time. For example, data processing equipment should tolerate an over-voltage of five times nominal supply for a duration of 100 µs but only 20 % over-voltage for 10 ms. On the under voltage side, a complete loss of supply should be tolerated for up to 20 ms (one mains cycle) but for 100 ms the minimum retained voltage must be 70 % of nominal. The curve was originally produced to help users of IT equipment in resolving power quality problems with electricity suppliers. By standardising the requirements of equipment it became much easier to determine by site measurement whether the supply was adequate or not. As will become clear, the ITIC curve presents a rather optimistic view of the performance of supply networks!

Many dips are caused by faults on the supply network with the severity of the dip depending on the relative positions of the generator, fault and measurement point. (See Section 5 for a full description). There are no official statistics on the severity and distribution of voltage dips but some medium scale measurements are now in progress and can be expected to yield valuable information in due course. One study, carried out by a major generator, measured voltage disturbances at 12 sites with demand between 5 and 30 MVA. In a ten-month period 858 disturbances were logged, 42 of which resulted in disruption and financial loss. Although all 12 sites were low technology manufacturing operations making low value added products the financial loss totalled € 600 000 (average € 14 300 per event or € 50 000 per site), with the highest individual loss of € 165 000. Clearly plants making high value added products and those requiring multistage manufacturing processes, such as semiconductors, would face much higher losses. The table below gives some typical values.

In a ten-month period 858 disturbances were logged with a financial loss totalling €600 000.

These are huge costs for what might seem to be trivial events lasting less than a second. The problem is that, since the response of individual items such as data processing equipment, or variable speed motor drives to dips is undefined, the behaviour of a system is impossible to predict or control. For continuous processes, such as paper-making, the effect of a dip is just as serious as a complete blackout, with the same clean-up costs, raw material losses and lost production. For computer based operations the time taken to re-boot a large number of workstations and recover pending transactions and unsaved documents can take several hours. The semiconductor industry is particularly vulnerable because wafers require two dozen or so manufacturing stages to be completed over several days. If a wafer is spoiled towards the end of the process all the value of the work done is lost. The rate of development in semiconductors is now so fast, competition so intense and product life cycles so short that the loss of product is a major concern not only to the suppliers but also to their customers who cannot build and ship their own products.

Industry	Typical financial loss per event	
Semiconductor production	€ 3 800 000	
Financial trading	€ 6 000 000	per hour
Computer centre	€ 750 000	
Telecommunications	€ 30 000	per minute
Steel works	€ 350 000	
Glass industry	€ 250 000	

On-line uninterruptible power supplies, in which the load power is continuously generated from a storage battery constantly charged from the supply, inherently provide immunity to dips. Off-line units are less secure because the absence of supply has to be detected before the load is switched to the internal generator. If the detection threshold is too high, the UPS is switched in and out frequently and unnecessarily while if the limit is too low, damaging dips will be fed to the load. Detailed specifications should be consulted before selecting a particular model.

The cost of replacing failed equipment and the cost of the downtime involved must be considered.

Transients

Transients are voltage disturbances of very short duration (up to a few milliseconds) but high magnitude (up to several thousand volts) with a very fast rise time. Most transients arise from the effects of lightning strikes or switching of heavy or reactive loads. Because of the high frequencies involved they are considerably attenuated as they propagate through the network so that those occurring close to the point of interest will be much larger than those originating further away. Protective devices in the network ensure that transients are generally kept to a safe level and most problems arise because the source of the transient is close to or within the installation. Transients are discussed in detail in Section 5.

The damage that results may be instantaneous, such as the catastrophic failure of electrical plant or appliances, or the corruption of data within computers or on network cabling, or it may be progressive with each event doing a little more damage to insulation materials until catastrophic failure occurs. The cost of replacing the failed equipment and the cost of the downtime involved must be considered.

Protection is relatively cheap. The basic requirement is that the installation earthing system should be designed to have low impedance over a wide frequency band, with a good low impedance connection to the earth electrode system. Earthing systems are discussed in detail in Section 6. The lightning protection system should be designed appropriately, taking into account local factors, such as the number of lightning days per year. Transient protection should be fitted at the entry of all incoming conductors, including telephone and other communications lines. The manufacturer should have provided suppression of transients from switching equipment and good maintenance procedures should be introduced to ensure that it continues to be effective.

Conclusion

The business risk posed by power quality problems is a real one with even ‘low tech’ industries being exposed to serious financial losses. On the other hand, prevention is relatively cheap ranging from simple good practice design techniques to the installation of widely available support equipment.

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