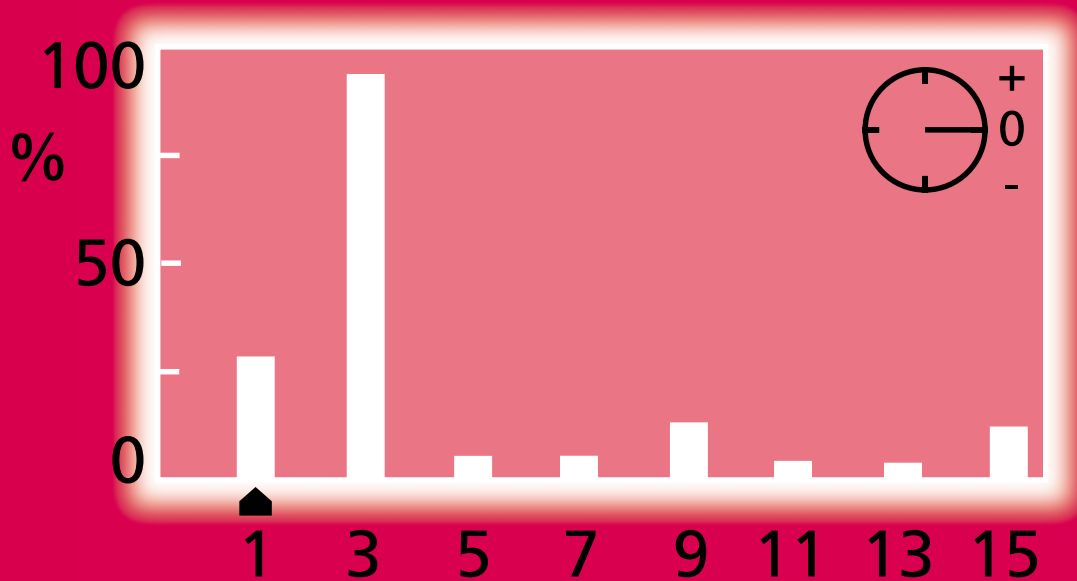
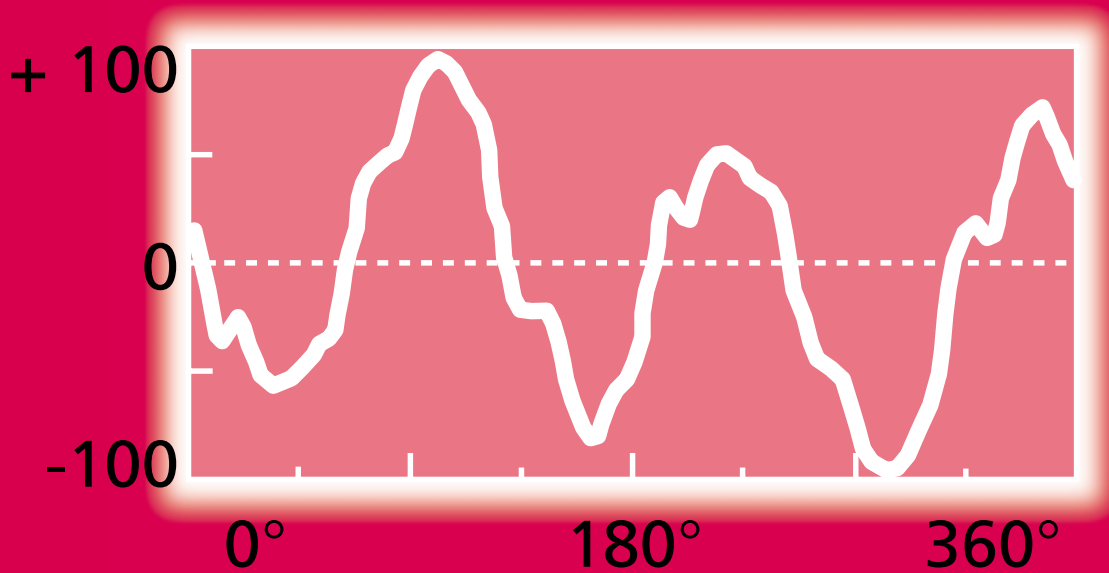




Harmonics in Practice



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Harmonics in Practice

Over recent years, harmonics have become a serious problem in many industrial and commercial installations. Solving these problems requires careful analysis of the causes and a good understanding of the sources and behaviour of harmonics in the installation. Once understood, there is a range of counter measures available to improve the system performance. The background to harmonics, the type of equipment that generates them and the effects that they have on equipment and system performance are covered in CDA Publication 123, 'Electrical Design – A Good Practice Guide'. The aim of this technical note is to illustrate how practice matches theory by reference to examples of real measurements.

As part of a multi-client study, BSRIA carried out a number of site surveys, measuring the harmonic content in typical buildings. Measurements were taken in locations where harmonics were likely to be apparent to ascertain typical levels and to identify the scale of the problem. These measurements were made by BSRIA under 'Power Quality Project ref. IL14078, 1998 and are used here with permission.

The first case study relates to a data centre housed on one floor of a multi-floor building. The installation has been carried out to a good standard, with double sized neutrals and, on this floor, a delta-star isolating transformer. Figure 1 shows the circuit arrangement.

Delta Star transformer

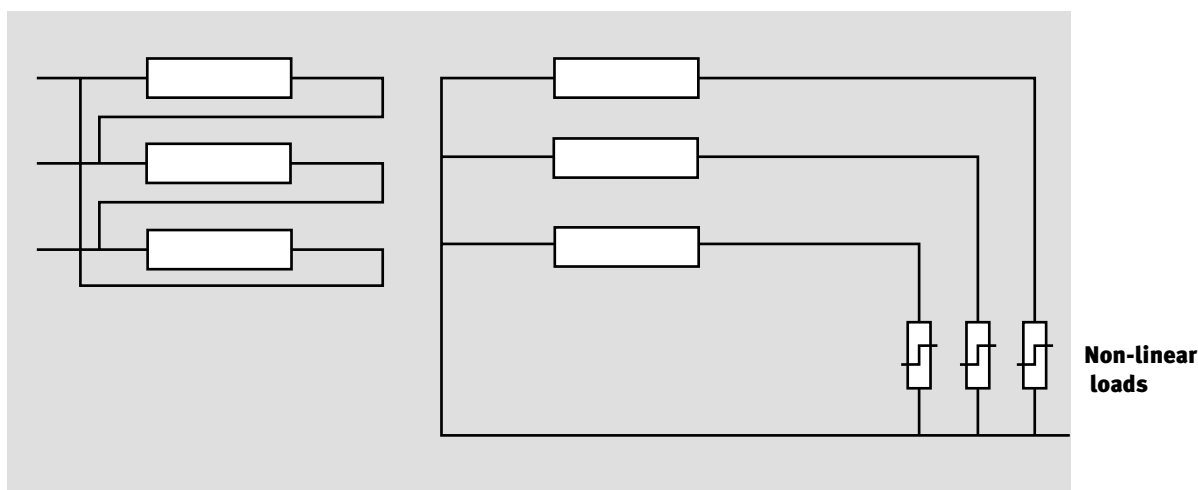


Figure 1 – Circuit arrangement

It is important to realise that harmonic distortion arises as a current, converted by the load from fundamental current. Harmonic voltage distortion results when the harmonic current flows through impedance so that, for example, at the point of common coupling, a harmonic voltage is developed across the supply impedance. Harmonic problems are rarely caused by a poor supply or by neighbouring facilities; the causes are almost always to be found within the installation itself. (An exception to this is when harmonic filtering has been provided close to the point of common coupling; the filter appears as a low impedance sink for harmonics and they can be imported from the supply.)

Phase load currents

As would be expected, there is a large number of computer and communications equipment in the data centre and consequently much of the load is non-linear. The harmonic profile and waveform of the final circuit load current for one of the phases is shown in Figure 2. Notice that the harmonic current content is rather lower than might be expected from a typical computer load because a significant part of the load is made up of ancillary equipment, such as ventilation, heating and cooling equipment. The high 11th harmonic suggests that there is also some three-phase variable speed drive or UPS load. This phase, the yellow, is running at 50 Amps. The loads on the other two phases are very similar in character but differ in magnitude.

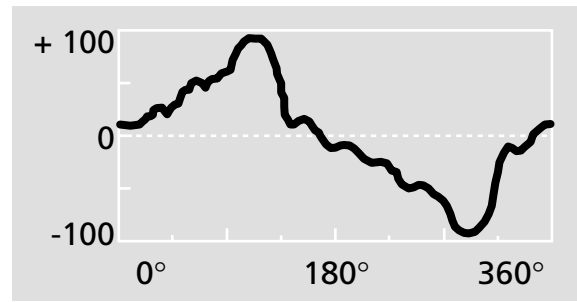
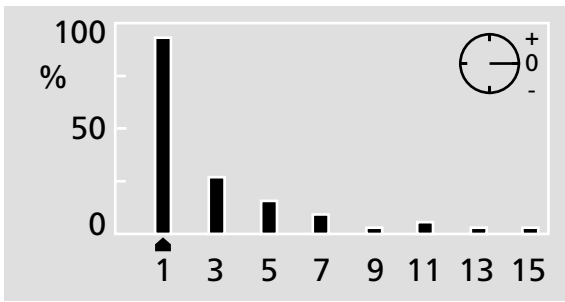


Figure 2 - Load current (Yellow phase)

The current waveform is also interesting. The crest factor, the ratio between peak and RMS current, is 1.88 rather than 1.414 as would be the case for a pure sine wave. Since resistive losses are proportional to the square of instantaneous current, losses – and therefore operating temperatures – in cables and busbars are much higher when carrying distorted current. Harmonic content should always be taken into account when sizing conductors. The high crest factor also means that normal test instruments will not measure the current accurately. Most instruments measure the mean value of the rectified waveform and then apply a correction factor to give the RMS result. However, the correction factors are valid only for a pure sine wave and are seriously in error – typically reading up to 40% low - for waveforms such as seen here. A true RMS meter calculates the real value and yields a correct result as long as the crest factor does not exceed three. The technology to build true RMS meters has been available for many years and they are now easily available at economic prices, although they are still more expensive than standard meters. Unfortunately, true RMS meters account for only about 25% of sales, so it is a fairly safe bet that the majority of current readings taken in industrial and commercial installations are considerable underestimates of the real values. Often this results in new loads being added to circuits that are already fully loaded and in circuit breakers being blamed for nuisance tripping when in fact they are responding to genuine over-current.

Neutral current

The neutral current is shown in Figure 3. Looking at the waveform first, it is clear that it is predominantly third harmonic. This is confirmed by the profile that shows the presence of 3rd, 9th and 15th harmonics, together with unbalanced residual components at the fundamental and 5th, 7th, 11th and 13th harmonics.

This happens because those harmonics that are a multiple of three are all in phase in the neutral and their magnitudes add. These harmonics are commonly referred to as 'Triple Ns'. Other harmonics and the fundamental are not in phase and cancel out. In this case, the unbalanced fundamental neutral current was 14.8 Amps, but the total current is actually 51.5 Amps - the same order as the load current. The size of the neutral current is virtually impossible to foresee since it depends on the amount of non-linear load, the amount of linear load and their disposition among the phases – in other words, it is not designable!

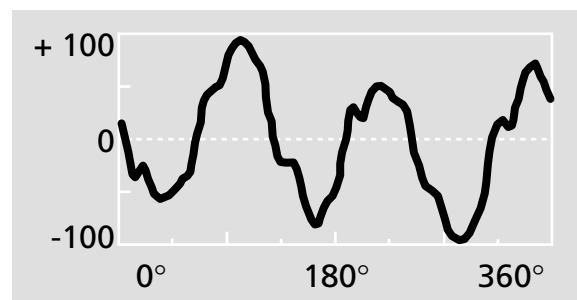
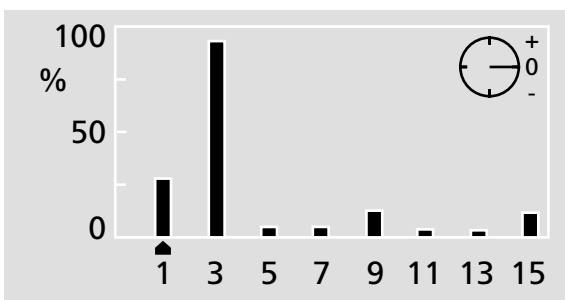


Figure 3 - Neutral (Star point) current

One rule of thumb, recommended by many authorities, is to use double-sized neutrals in installations of this type. This is sound advice since neutral currents exceeding the phase current are very common, but those exceeding twice the phase current, although known to exist, are relatively rare. Another approach that is gaining support is to provide protection so that an over-current in the neutral trips all the phases, but not necessarily the neutral. This is the safest approach because an overload can never cause dangerous situations to arise. The disadvantage is that the protection may trip to protect the neutral at much lower phase currents than anticipated – in effect reducing the effective capacity of the circuit. This approach is inherently safe, but may reduce the intended functionality of the circuit. Perhaps the best approach is a compromise – over-size the neutral because it is necessary, and provide over-current protection for safety. This requires a linked circuit breaker with double capacity on the neutral pole.

Supply current

The current drawn by the primary of the isolation transformer is shown in Figure 4.

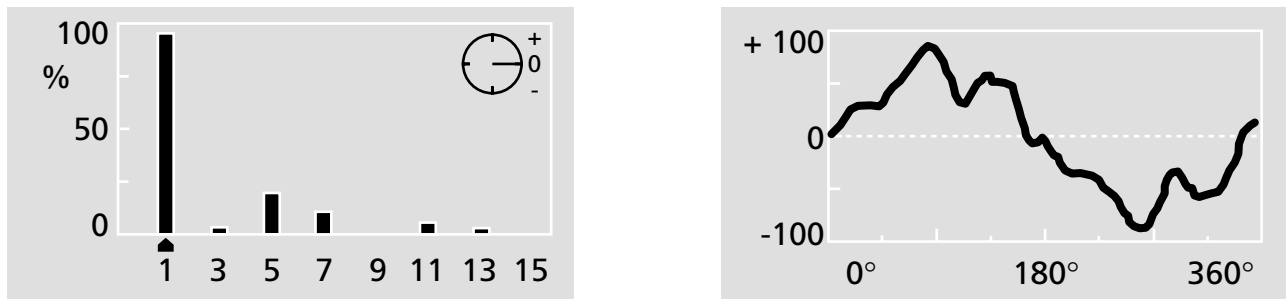


Figure 4 - Transformer primary supply current

Here there are virtually no 3rd, 9th and 15th harmonics, but significant 5th, 7th, 11th, and 13th harmonics. Comparing the primary and (phase) secondary currents side by side (Figure 5) it can be seen that they have a similar structure, except that the 3rd, 9th and 15th harmonics have been removed in the primary current.

This happens because, when the harmonic is a multiple of three, the current in the individual legs of the primary are all in phase and therefore, in a delta winding, circulate around the winding and are not drawn from the supply.

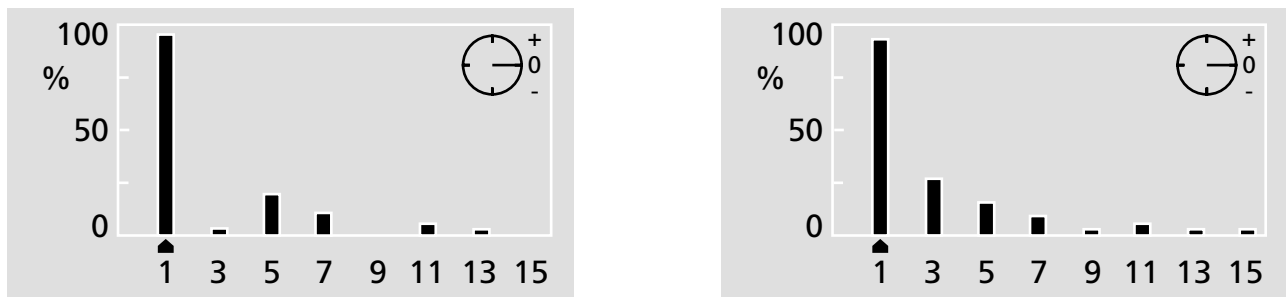


Figure 5 - Primary supply and secondary load currents



Summary

This case study exposes the reasons for some of the apparent anomalies that are seen in day to day measurements. It shows how the same harmonic problem – odd harmonics generated by switched mode power supplies in this case - is observed differently in various locations in the system.

In the first instance, the phase current is higher than expected, and, unless a true RMS reading meter is used, higher than the measured value. The result is possible nuisance tripping and over heated cables.

Secondly, the neutral current is much higher than expected, due to the additive effect of 'Triple Ns' adding to the normal out-of-balance fundamental. It is only harmonics that are a multiple of three that cause over-current in the neutral. In other words, electronic equipment such as personal computers and electronic fluorescent lighting ballasts cause over-current in the neutral. On the other hand, variable speed drives do not produce Triple Ns, and so do not cause an increase in neutral current.

Lastly, at the primary of the transformer, all the balanced Triple N harmonics have gone, but all other harmonics are fed back onto the supply network. In fact, a delta wound transformer winding is probably the best Triple N filter available, isolating the supply network from Triple N pollution. Of course, this filtering effect is not free of charge. The circulating current is part of the transformer load and contributes both eddy current and resistive losses, so reducing transformer capacity, increasing the working temperature and shortening the transformer life expectancy. All harmonics cause increased losses in transformers because eddy current losses are highly frequency dependent; this subject is discussed in more detail in Publication 144, 'Harmonics, Transformers and K-Factors'.

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