Karpri has a facility of 30,000 m³ of cooling rooms spread over 22 km³. The company supplies various-temperature refrigeration services to many concerns, including Coca Cola and Nestlé. There are three separate machine rooms for comprehensive cooling supply circulation, all monitored and maintained by an experienced staff of mechanics and electrical engineers. Since 2002 the company has experienced weekly unexplained power events which did not seem to occur as the result of a specific source or trigger. The company, together with the local utility and many consultants, spent tens of thousands of dollars, and months of man-hours, trying to identify the source of the interruptions, which caused repetitive failures in the company’s equipment and resulted in accumulated damage amounting to hundreds of thousands of dollars. Sophisticated power quality analysers from four different manufacturers were installed on site for long periods, but none were successful in determining the source of the power problems.

Karpri finally installed four Elspec G4420 power quality data centres at the secondary of each transformer and one at the MCC that accurately identified the source of the failures. The reported failure locations are named 1, 2, 3 and 4 in this article (Fig. 1). Each device recorded all the data at 512 samples per cycle for a few months in a compressed format of 1000:1.

All the devices were connected to the local network, and were synchronised by means of a unique time synchronisation algorithm to an accuracy of ±1 sample, making it possible to monitor all the information from different locations on the same graph at the same time.

All the devices were then connected to Elspec’s central servers via the internet, allowing Karpri to outsource all its power quality management – measurement devices, collecting data, data storage and power quality analysis. Within a few days after the instruments had been stalled, not only was the main source of the power events located, but its full scope was exposed.

Karpri’s power quality issues, which had been unidentifiable previously, were identified because all of the information was recorded continuously. This was achieved by:

- Not limiting the data to EN50160 violations allowed monitoring when the customer complained, not when the data was anomalous.
- Simultaneous measurement and multiple measurement points, synchronised by time, allowed analysis of anomalies propagation.
- Continuous recording of all channels, including phase to neutral and phase to ground voltages, even in delta networks, revealed lightning protection issues.
- Simultaneous monitoring according to IEC 61000-4-30 and cycle-by-cycle allowed analysis of very fast phenomena compliant to EN 50160.

Fig. 2 shows the results of EN 50160 compliance at the main service (1). Similar results were measured at each one of the transformer secondary (2 and 3). Fig. 3 shows the EN 50160 results at the MCC (4), where many faults were observed. However, similar faults occurred in locations 2 and 3 as well, which perfectly complied with EN 50160. The obvious conclusion is that compliance to EN50160 cannot provide the answer to the source of failures, although it indicates existence of voltage dips in one location.

Multiple simultaneous analysis

One of the main benefits of using data compression technology and continuous storing of all information at high resolution is the ability to monitor events at several locations synchronised in time. Fig. 5 shows the phase L2 to neutral voltage at all four locations. Only the voltage dip at location 4 was more than the commonly used 10% threshold. When using a trigger-based logger, the troubleshooting engineer would have only a few cycles before and a few cycles after the event, from location 4 only. The data from the other three locations wouldn’t be logged. Therefore, it would be difficult to understand the event propagation over the network.

Fig. 4 shows the L2 voltage on all locations. It shows two events – on the left side an event started from location 4, to the transformer secondary (3), up to the primary (1) and down to the other transformer’s secondary (2). However, the event on the right did the opposite: from locations 2 to 1 and down to 3 and 4. The lack of additional measuring points prevented better analysis of the source of failure and how to prevent it from recurring.

Fig. 1: Single line diagram with Elspec G4420.

Fig. 2: EN 50160 at the main service.
The technical justification for monitoring the line-to-ground voltages only is that the line-to-ground voltages do not go through the transformer since it is delta/wye. However, the over-and-under voltages do affect the transformer itself and can reduce its life expectancy. Moreover, in sites where there are medium voltage (MV) loads, this voltage can cause significant damage to the loads as well.

To protect the transformers, it is recommended that line to ground events be prevented. The solution can be from both sides of the meter – the utility can improve its grid and/or the customer can install better lightning arrestors. This phenomena affects the MV only, and it is not the source of the failures, so further investigation will be required in order to locate the reason for the repetitive failures.

**Line-to-ground voltages**

The site is connected using two delta/wye transformers. Since the voltage supply is delta, the measurements are commonly limited to line-to-line voltages only. This is also what is required in the different standards and regulations. The analysers record all the information all the time, including line to neutral values. When the neutral is not connected, the line-to-neutral values are the line-to-ground ones. One of the benefits of the additional measurements is shown in Fig. 7.

Due to a short circuit between phase L3 to ground, the line-to-ground voltages spiked to 26 kV, rather than the nominal 12.7 kV. During the same failure, the dip on the line to line voltage was less than 1% from nominal and 3% from the steady state level (21.8 kV with respect to 22 and 22.4 kV).

![Fig. 3: EN 50160 at MCC.](image)

![Fig. 4: L2 voltage at four locations.](image)

![Fig. 5: L2 voltage zoom.](image)

![Fig. 6: Typical dip at MCC.](image)

![Fig. 7: L2 voltage at four locations.](image)

Measurements are usually performed in accordance to IEC 61000-4-30. This standard requires an averaging of all parameters over a 200 ms period. However, this averaging may hide short-term phenomena. In some cases, short events don’t have the required energy to cause damage. However, it depends on the fragility of the most sensitive device. Fig. 9 shows the different results of the voltage and current THD when calculating every cycle (red) and according to IEC 61000-4-30 (green). Rather than maximum current THD of 19%, the true value is 53%. Similarly, the voltage THD is 12% and not 4%.

**Why is it important?**

Due to superposition, the network is represented at the 5th harmonic differently than in the fundamental (Fig. 10). The load functions as a current source. Normally, the network equivalent impedance (Zs = utility network plus transformer) is the lowest, and the harmonic current flows to the utility network which can withstand an increased network impedance, caused, for example by the connection or disconnection of capacitors and the harmonic current flows to the lowest impedance, which is a sensitive load. In addition, due to the increased impedance, the current source cannot supply the same amount of current, and during this resonance period the current is reduced.
Harmonics are normally averaged because the total energy in the harmonics is what is considered important. In this case, the peak power of this resonance is 3 kVA (Fig. 11). Obviously, the 200 ms average is less, but it was still enough to cause damage. Moreover, sensitive loads probably fail before the 200 ms period is over.

The solution

To prevent the resonance, a passive filter should be used. The filter should have low impedance at the 5th harmonic and be installed as close as possible to the transformer. Therefore, when a situation as described above happens, the lowest impedance is the passive filter which can withstand the harmonic current, and the sensitive loads will not be affected. It is not possible to install controlled filters (passive or active) because the fastest ones available have at least one cycle reaction time.

Karpri installed two fixed, passive filters tuned to the 5th harmonic (235 Hz). After installing the filters, no additional failures were reported. Furthermore, some of the loads that had been disconnected when not in use in order to protect them, were now left connected continuously.

Conclusion

Standards were created to provide an equal starting point to the power quality analysis and to help meters show the same values. However, in many cases limiting the information to standards prevented the troubleshooting engineer from monitoring the anomalies, not to mention identifying their source. By installing the Elspec power quality data centres, that measure and display measurements from multiple locations simultaneously, Karpri was able to identify the cause of the power quality problems and find a workable solution.

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