Application Note

Troubleshooting in 3-phase power networks with the Fluke 430 Series Power Quality Analyzers

Three-phase power network analysis has always been regarded as complex and expensive. Now however, with advanced instruments like the Fluke's 430 Series Power Quality Analyzers, it has become inexpensive and easy to carry out even against standards like EN50160 and IEC 61000-4-30.

This application note describes some typical problems found on power distribution networks, what causes them, how they can be measured using state of the art Power Quality Analyzers and what the remedy is to minimize or solve the problems.

Typical network faults and causes

Transients

A frequent and everyday cause of transients is switching operations in a network. These are operationally unavoidable. Furthermore, triggering of a thermal fuse in a low-voltage network causes a considerable voltage peak, since these fuses blow in current-limiting fashion. The abrupt ramping of the current cut-off is responsible for transients up to several thousand volts. These include power converter commutation peaks which are not very high but are regular (from 6x per period or more), thus causing considerable interruptive effects.
How do these transients affect electronic equipment? In comparison with early technologies with relatively high operating and control voltages, modern microelectronic devices run on voltages of 5 V or less (PC processors for example sometimes need only 1.6 V). This makes them more susceptible to interference from the power supply network. Beside the effect on electronic devices, these transients can also cause interference with a data or control network. Consider, for example, a feeder to a power converter that causes the commutation peaks described above to interfere with a network cable lying next to it. The transmitted signal packets will be distorted at least 6 times per second. This lowers the transmission rate significantly and the repetition of the pulses can even lead to total loss of data traffic. If pulse inverters are used, transients even occur at the clock frequency, i.e. several thousand times per second.

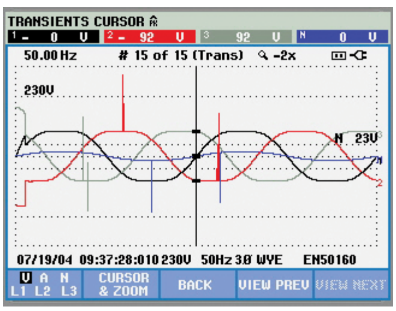

Figure 1– Transients on a network.

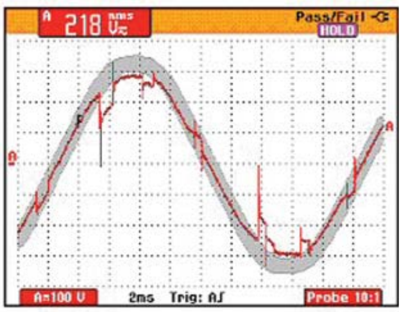

Figure 2– Commutation dips (measured using the ScopeMeter 199C).

Harmonics

With the increasing use of rectifiers, harmonics were introduced in power distribution systems. In the beginning their effect was negligible, but today with a lot of industrial and consumer equipment running on rectified mains voltages, harmonics can no longer be discarded. The voltage and current characteristics of these instruments generate power distortions including troublesome third-harmonic components. Examples of instruments running on rectified mains:

- Switching power supplies of all types in, for example, PCs, televisions, video recorders, and in almost all consumer equipment using DC.
- Switching power supplies in low-voltage halogen lighting where they are increasingly replacing transformers.
- Electronic ballasts for fluorescent lights.

- Power converters for variable RPM drives

All these loads cause harmonics since the combination of rectifiers and smoothing capacitors takes current from the supply in pulses.

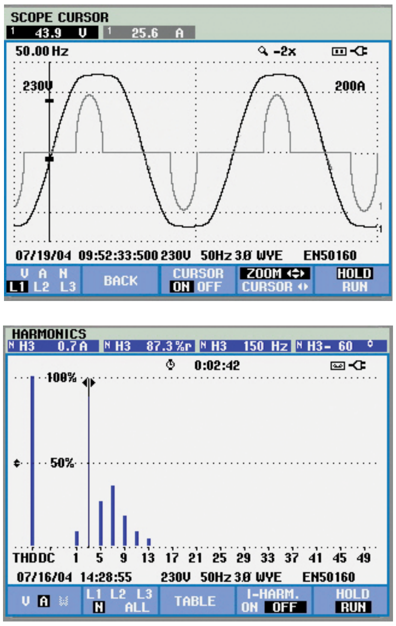

Figure 3 – Typical current through a rectifier load with spectrum

These pulse shaped currents lead to a 'flattening' of the voltage waveform (Figure 3), which is visible in the voltage spectrum as a 5th and 7th harmonic component. The 3^{rd} harmonic in the voltage is hardly present since the current 3rd harmonic is short-circuited in the Delta/Wye-transformer. Contrary to what one might expect, this is undesirable as it causes incidental losses of up to €2000 per year for a 630 kVA transformer. In addition, the neutral conductor is very heavily loaded since the 3rd harmonic of the current flows back through it (Figure 4). The neutral conductor often burns out without this being noticed. This will produce a voltage swing which can damage the connected equipment. There is also danger of fire due to the conductor overheating.

A further effect of harmonics is their influence on compensating circuits (Figure 5). Here especially the higher-order harmonics are amplified.
The strong effect of harmonics on the current flowing through a capacitor leads to overheating and destruction.

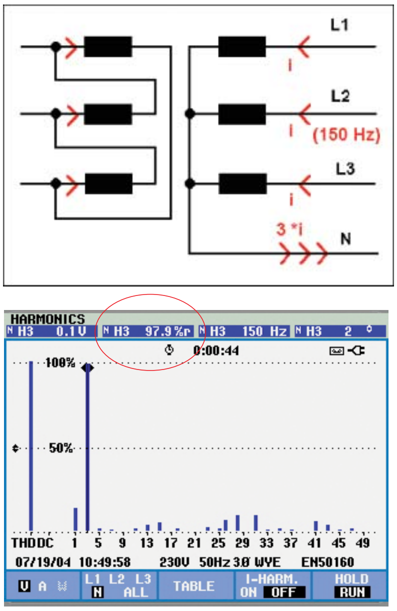

Figure 4 – Loading of neutral conductor by 3rd harmonic. Current circulating in primary winding

Apart from the damage to the unit, this may also lead to fire. Given the loading of the supply caused by today's high level of harmonics, chokes are often insufficient, but current technology permits the use of intelligent active filters. These are self-adjusting, resonance-free and cascade able, and they also compensate each phase individually.

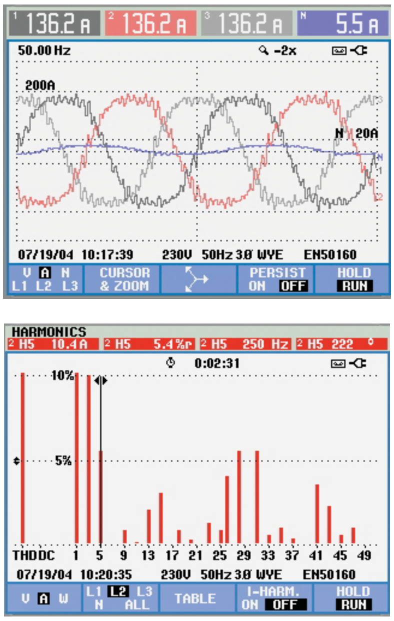

Figure 5 – Typical current through a rectifier load with spectrum

Inter-harmonics

In addition to full harmonics, intermediate harmonics (so-called inter-harmonics) can occur and need to be measured. These have divider numbers that are not whole numbers, for example 2.25 times the fundamental frequency. They are caused by modulated signals in electronic devices and by the non-linear mixing effects of electronic devices on a typical power network of today.

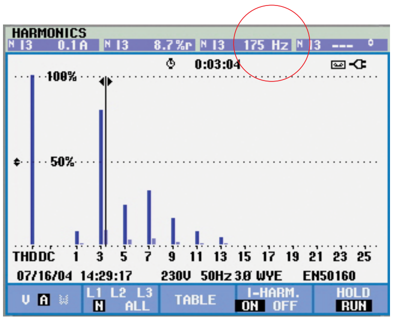

Figure 6 – Hz inter-harmonics

Voltage fluctuations, dips and flickering

Ever-increasing loading and the switching of systems such as elevator drive units cause short-term voltage feedback effects that show up as voltage dips (Figure 7) or, if the load is removed, as voltage swells. Voltage dips or interruptions trigger switching power supply units to send a reset command to the processor via their Power Good or Watchdog outputs.
In general, such variations over one or more periods affect a lot of equipment such as production systems and control and drive equipment.

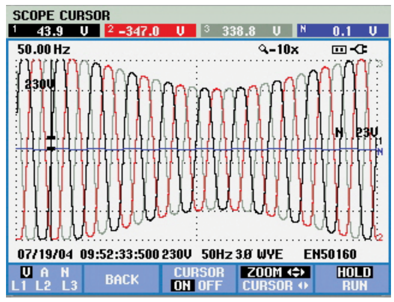

Figure 7 – Voltage dip of 40% caused by a load being switched into circuit.

If the voltage fluctuations occur continuously with, for example, a regular or stochastic pattern, they are referred to as flicker. This term is derived from the visible flickering of lamps in a lit room. It is important to be able to give an objective measure of flicker, therefore is being defined in the IEC61000-4-15 standard for short-term flicker (P_{st}).

P_{st} is a value measured over 10 minutes that characterizes the likelihood that the voltage fluctuations would result in perceptible light flicker. A value of 1 represents the level that 50% of people would perceive flicker in a 60 W bulb. This test is carried out for different modulation frequencies, the result being an evaluation curve. With a flicker measurement, this pattern of recognition is replicated by an algorithm defined in this standard. This allows the measured voltage fluctuations to be converted into objective data.

Figure 8 – Recording the flicker value per phase

Evaluating flicker according to a standard is one thing, locating it is another. The aim is, of course, to find the source causing the interference – mostly a varying load such as automatic welding equipment or a photocopier. Locating flicker can be explained using an example:

Occupants on one floor of a building are complaining about the flickering of the light. An earlier measurement gave a P_{st} value of 0.95, which lies within the permissible limits. Despite the P_{st} measurement being within the limits, many staff members still complain about the flickering where at the same time frequent equipment failures were reported as well. Since $P_{st} < 1$, no action is at first taken.

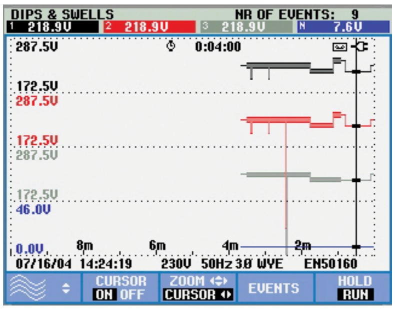

Figure 9 – The trend of the curves indicates the direction of the source of the flicker.

The problem is now remedied as follows. The voltage path of the Fluke 434 is connected into the feeder branch circuit. Each tap-off is now briefly recorded with the current clamp. If the trend curves for current and voltage are in the same direction, the fluctuation is coming from the supply side (voltage drop-out causes less current and vice-versa). A search must be carried on at one distribution level higher or a neighboring tap-off must be examined. If, however, the trend curves are in opposite directions, the fluctuation comes from the equipment side (increasing current causes a fall in voltage and vice-versa). The search must then be carried on at one distribution level lower. The tree structure of the power supply network allows the search to localize the source quickly and accurately.

Unbalance

One speaks of unbalance when the voltages of the three phases are not the same or phase shifts are not equal to 120 degrees. The causes are generally unsymmetrical phase loads. The active (real) load is mostly the source of differing voltages and the reactive load the cause of phase shifts away from the ideal 120 degrees. The result is a shift in the phase sequence, which e.g. causes motors to run hot. Further consequences are currents in the PEN (combined Neutral with earth) which will flow through all conductive structures of a building including i.e. shielding of data network cables causing expensive damage.

Figure 10 shows how simply unbalance can be recognized with the Fluke 430 Series power quality analyzer. One need only observe the arrows of the indicator.

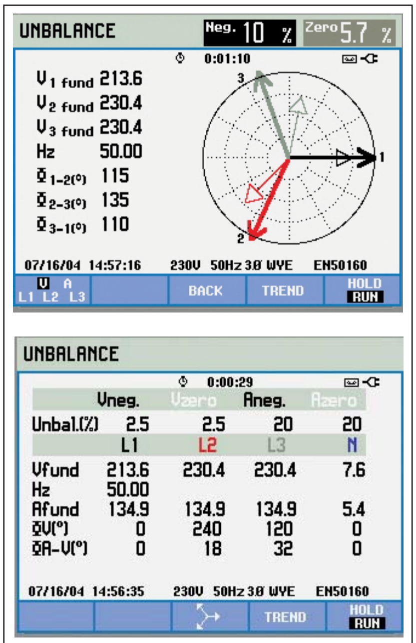

Figure 10 – Exposing unbalance in the network.

The bottom table gives the exact data. The phase sequence consists of three components:

- The positive sequence system, normally rotating clockwise. This supplies the necessary drive power to the motor.
- The negative sequence system, which rotates counter-clockwise and acts as a brake. Motors are limited in performance and become hot.
- The zero sequence system, which receives no phase, it loads the neutral conductor. The third harmonic is, for example, a pure null system.

The aim is therefore to avoid the occurrence of negative and zero sequence systems. The percentage values for the negative sequence and zero sequence can be immediately seen on the right in Figure 10 for voltage and current.

430 Series operation and handling

Operation and handling of the 430 Series is extremely simple. The current clamp only needs to be clamped to the conductor and the voltage path established. The function desired is then started in the menu.

The *AutoTrend* function is unique. It gives a quick overview of change over time without having to set certain swell values or intervals or to start the process manually. All measurement values are continually recorded and it is possible to switch between data and trend plots and even to use zoom and cursor functions to perform detailed analyses while continuing recording in background. *AutoTrend* offers the important advantage that no valuable data or time is wasted in setting up the instrument and starting separate measurements. Moreover, the type of network and the connection points are clearly shown in the menu.

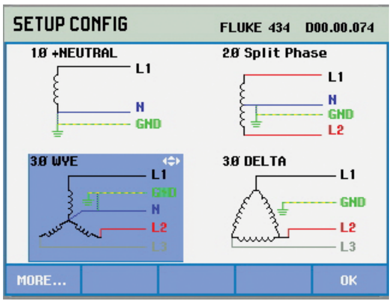

Figure 11 *– Clearly structured connection plans, the conductor colors can be assigned depending on the country identification.*

Measurement to standards

Measurement to standards used to be complicated and above all, expensive. This problem is elegantly solved by the Fluke 434. There are three standards to be taken into account:

- EN 61010:
  This standard describes the design of measurement equipment with regard to user safety. Since network analyzers are used in high-energy environments, it is extremely important to conform to this standard.

- EN 61000-4-30:
  This describes how the measurement device records and logs the data internally. For example, for measuring harmonics, ten periods are recorded.

- EN 50160:
  This standard defines the quality of the voltage to be delivered by the energy provider.

With the System-Monitor function of the Fluke 430 series measurements according the standards have become real easy. Just press a single button and the measurement is started. Just drill down into the event list to get detailed insight into those falling outside the limits.

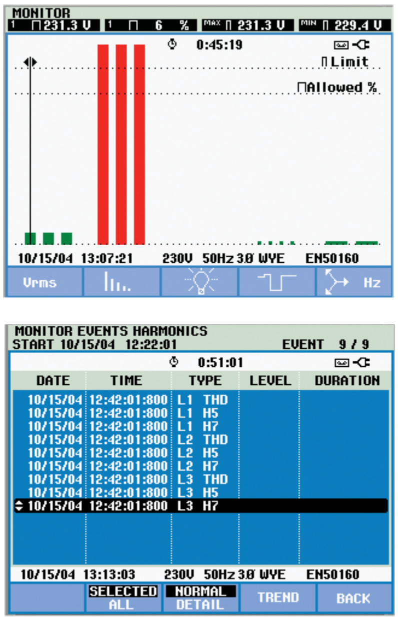

Figure 12 *– Simple EN 50160 measurement, red = failed, green = passed and a detailed event list.*

Summary – Fluke 430 series

Today, network quality measurement equipment is an indispensable tool. Whether as a replacement or a new procurement, operation and price are always priorities when such an investment is being considered and both these issues are effectively addressed by the Fluke 430 Series.

The Fluke 433 and 434 have been designed as professional measurement devices for applications in industry, healthcare, financial services and banks, computer centers and all areas where power quality is critical. Their versatility, automatic measurement and recording functions and ease of operation make them the ideal tool for fault-finding in 3-phase systems.

They measure all power system parameters in accordance with the latest EN 61000-4-30 EN standard such as true RMS voltage and current, frequency, power, power consumption, unbalance and flicker.

They also automatically capture and follow harmonics and capture automatic events such as transients as fast as 5 microseconds and as high as 6 kV, interruptions, rapid voltage fluctuations and voltage dips and swells.

Optimized for mobile use, these robust instruments provide more than 7 hours' operation independently of mains power on a single battery charge. The large data memory stores up to 50 screens and up to 10 measurements each comprising 32 parameters – including device setups and trend data – recorded for more than a year, all of which can be transferred to a PC via FlukeView® software for analysis or use in reports. Both models also possess versatile oscilloscope functions.

The Fluke 430 Series three-phase solutions join the Fluke 43B single-phase power quality analyzer, an instrument that combines the capabilities of a power quality analyzer, a 20 MHz oscilloscope, a multimeter and a data recorder.
The Fluke 43B, 433 and 434 network analyzers cover the whole range of applications from simple fault-finding up to complex analysis of all measurement possibilities needed by modern users at an extremely attractive price.

Fluke. *Keeping your world up and running.*

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