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Special Publication

Power Quality
PQ-Box 100/200

Expert opinions: Emergency power supply for hospitals and computer centres.

Power Quality PQ-Box 100/200

Emergency power supply for hospitals and computer centres.

If the power on one or more external feeders of the main distributor of the main power supply for a hospital falls to less than 90% of the network's nominal voltage over a period of more than 0.5 seconds, according to the DIN VDE 0100 Part 710 standard, there must be a self-actuating and automatic switch for a safety power supply.

This switch for safety purposes must occur on the main distribution level behind the infeed transformers and voltage sources in the direction of the energy flow. It must ensure that the electrical facility is connected to a secure power supply that has the capacity of 24 hours and connects within 15 seconds. A requirement modification of the 24 hours operational limit to three hours is only permitted if the medical treatments and examinations of patients can be terminated safely and the hospital can be safely evacuated.

Electrical systems for security and safety purpose in hospitals serve to prevent dangers, fire and the escape of persons from the hospital. This includes the following systems:

- Safety Lighting
- Bed Lifts
- Fire Department Lifts
- Fire Detection Systems
- Alarm Systems
- Water pressure increase systems for extinguisher water supply
- Electrical systems for medical gas supply, including compressed air
- Vacuum supply and anaesthetic suction and its monitoring systems
- Surgery lights and medical devices within group 2
- Smoke extraction systems

In hospitals the secure voltage sources for such security and safety purposes are the power supply generators (internal combustion reciprocating piston engines – usually diesel engines). These represent a construction which consists of a diesel motor and a salient pole synchronous generator. The diesel engine and synchronous generator create effective power, but the synchronous generator creates also reactive power. The voltage consistency is dependent on the voltage regulator, the frequency consistency on the speed controller and the relative harmonic oscillation associated load of the damper winding.

An emergency power supply generator should be able to provide at least 80% of its apparent power within 15 seconds with a displacement factor of the basic oscillation $\cos\alpha = 0.8$ in a maximum of two levels. The residual 20% of its apparent power should be available within an additional 5 seconds.

The requirements regarding voltage and frequency consistency for most electrical equipment, used in hospitals, meet the conditions present during the feed from the main power supply (e.g. the public grid).

When supplying a hospital from the public grid, the connection network is available in interconnected operation with the parallel operation of all power plants, hence all synchronous generators of all power plants.

Load changes in the connection and disconnection of large loads in non symmetric networks usually hardly influence the frequency and voltage in interconnected operation. Load changes in interconnected operation will be distributed over many power plants and their synchronous generators and do not re-present a significant demand on individual units. In interconnected operation, there is usually a very high short circuit AC line available, as a guarantee for high voltage consistency.

When the power is supplied from the public grid, the short circuit AC line supply is mainly limited by the impedance of the infeed transformer.

A load change in the amount of the apparent power of the infeed transformer causes a fall in voltage in the transformer terminals. This can be up to the rated input voltage of its relative short circuit voltage. It is also dependent on:

- the effective value of the differential load current
- the inductive transformer reactivity
- the impedance angle of the transformer
- the load angle of the load.

In a suitable electrical connection (at a transformer station of the hospital) to the public grid, the stability requirements for frequency and voltage can usually be fulfilled without a problem.

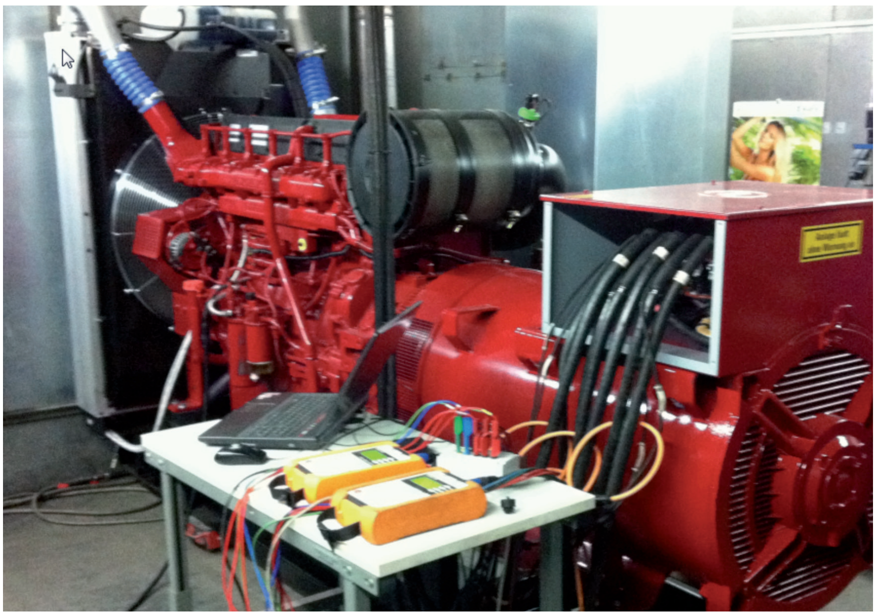

Figure 1 *Test Set-up of network analyser PQ-Box100 on a 500 kVA emergency power supply diesel generator at factory approval*

If the main power supply of the hospital fails, the emergency power diesel generator must activate automatically and guarantee the power supply to the facilities, both for safety purposes and a stable island emergency supply operation.

In island emergency power operation, the emergency generator is the only power source and its main engine is confronted with load changes, which are relatively large based on their rated output and can thus cause strong frequency and voltage deviations.

The generator terminals loss of voltage while in island mode happens as a result of load changes. This makes the generator apparent output dependent on:

- the effective value of the differential load current
- the stator resistance
- the inductive transient reactance
- the angle of the transient generator impedance as well as
- the load angle of the load.

The voltage losses can be up to three times larger than in a distribution transformer with an equal power performance rating.

Therefore the emergency power supply generator must be configured with regard to the following parameters:

- the maximum continuous load output
- the maximum reliable load
- the required main class
- the static electrical operational limit
- the dynamic electrical operational limit
- the subtransient, transient and continual rated short circuit AC line
- performance during overload
- performance during short circuit
- performance during parallel operation with the grid as well as the generator island mode and
- performance when loaded by harmonic afflicted loads

Adequate values of the displacement factor of the base oscillation-related apparent power guarantees that, when generator is in an island mode, any load change represents only a temporary angular speed change and hence only a temporary change in the generator voltage, therefore the dynamic electrical operating limits will be maintained.

The successful selective discharging/deactivation of short circuits, required by the DIN VDE 0100-710 standard, can be ensured if proper consideration of the listed short circuit AC lines through correctly dimensioned grid protection is given. Often, an oversizing of the diesel motor and the synchronous generator is needed for this to happen.

Even if the emergency power supply diesel engine is oversized with respect to its rated output, the harmonic factor of the generator voltage is so significant due to various electronic loads provided such as:

- speed regulated engines
- BPS and UPS systems
- energy saving bulbs
- office electronics, etc.

that the permitted compatibility level of the relative voltage harmonics can be exceeded, and therefore device failures or total failures may be experienced.

Whether the projected emergency power diesel generator meets the requirements projected at the planning phase, must be verified by proper measurement and tests. The measurements should be made both during factory tests as well when the generator is in position at the customer site.

The following are some of the properties of a comprehensive measurement system:

1) Inspection of an emergency power diesel generator at the manufacturer's site.

2) Emergency power diesel generator at the hospital with a star connection.

3) Emergency, power diesel generator blackout test at the customer site.

4) Changeover of power from a UPS system from the grid to an EPS of the computer centre.

Efficient network quality analysers are necessary for measurement and grid testing. The qualified analysis of the results requires a high degree of understanding of the device specification and results.

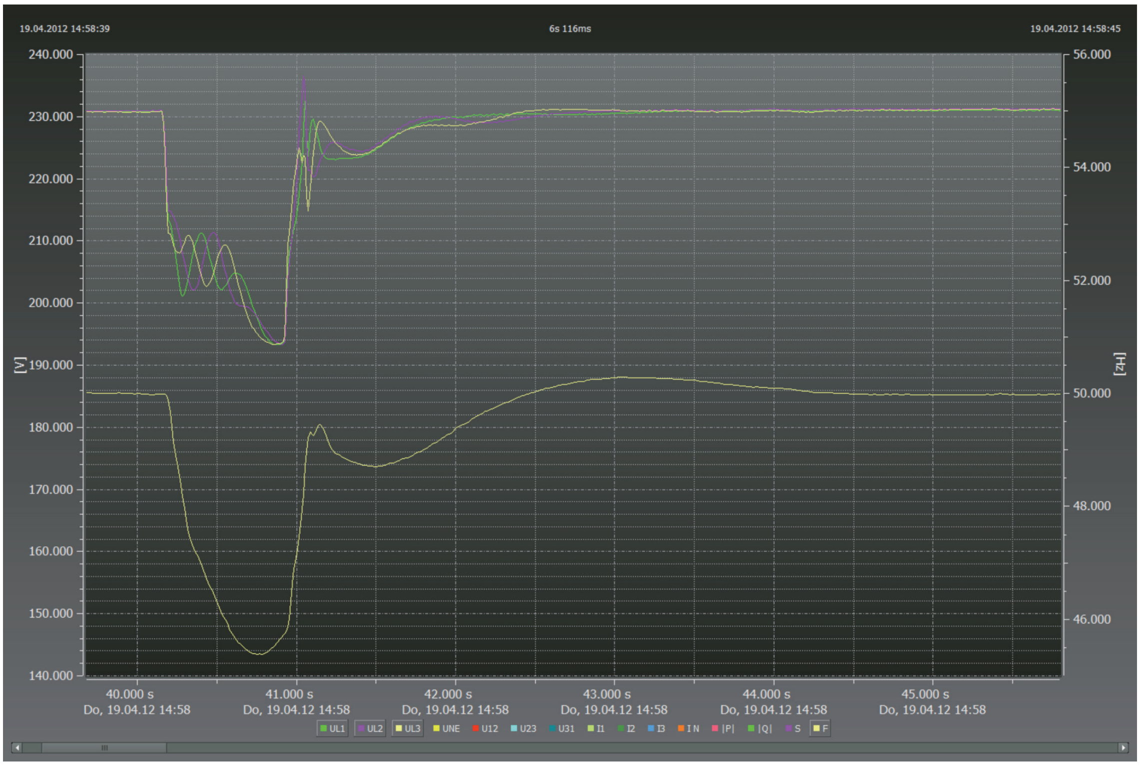

Figure 2 *Connection of 60% (ohm-inductive cosα = 0,8) of the rated apparent output of a 500 kVA emergency power supply diesel generator at factory approval stage.*

Testing of an emergency power supply diesel generator at the manufacturer's plant *(Figures 1 and 2)*

In order to avoid any surprises later at the customer site, when using the generator at the factory, in addition to the emergency power control, the adherence to the permitted:

- static and in particular dynamic electrical limits as well as
- the harmonic factor of the generator voltage

must be inspected and confirmed by measurement and expertise.

Figure 2 shows the voltage in the individual phases and the frequency. After intrusion of 60% (ohm-inductive with cosα = 0,8) of the rated apparent output of the 500kVA emergency power diesel generator the voltage would first drop to 201V and after a short vibration further to 193V. Then it would rise to a maximum value of 237V. After a duration of 1.7 seconds, the voltage oscillation process died down and the voltage is stable.

The frequency falls from 50 Hz to 45.4 Hz and rises to 49.4 Hz. After a duration of 4.2 seconds, the voltage oscillation process died down and the frequency is stable.

The 10 ms sampling of the high performance network analysers PQ-Box 100 or PQ-Box 200 are perfect for such measurements. In addition to the voltages and currents, the frequency, effective, blind and apparent output are recorded with this high 10 ms resolution. The recording can last up to 120 seconds. The pre-history and post-history of the recording are freely adjustable.

The emergency power diesel generator meets the dynamic electrical limit values for frequency pursuant to DIN 6280-13 (operative range 1 for medical facilities). Note that the required dynamic electrical limit values for voltage could not be maintained inspite the chronologically correct readjustment.

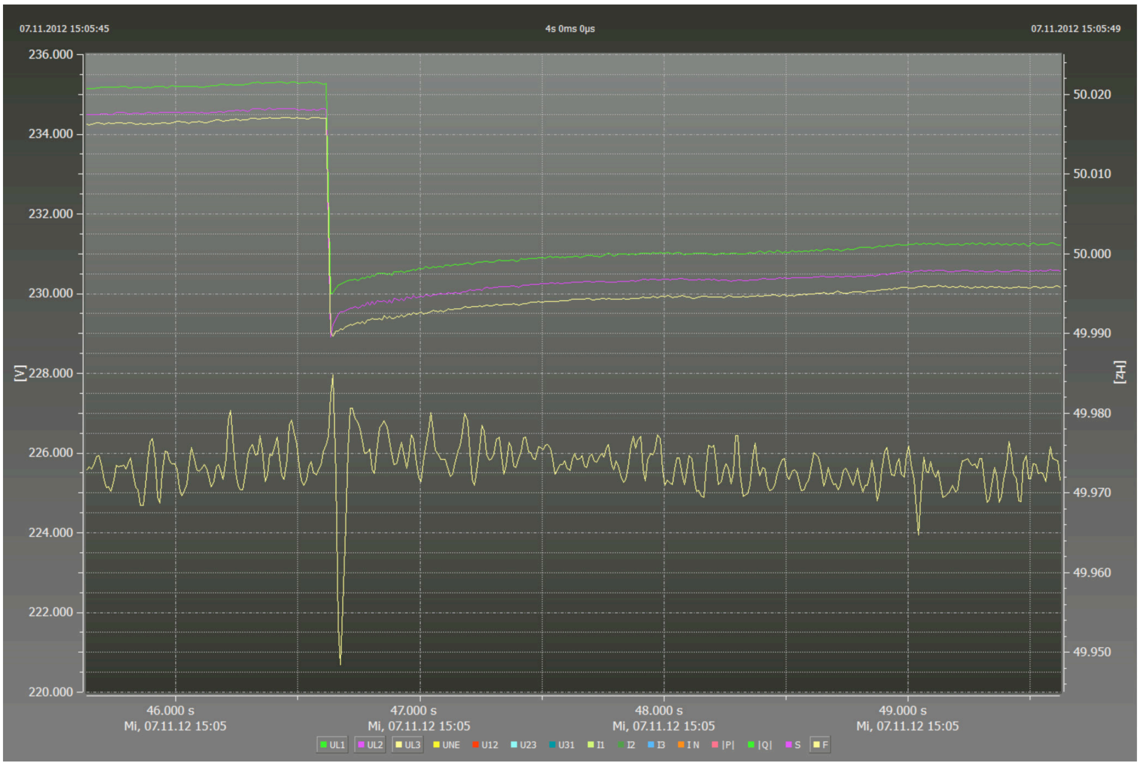

Figure 3 *Star connection of a 75 kW sprinkler system in grid operation (2x 800 kVA / 6% transformers)*

Emergency power diesel generator with a star connection to a sprinkler system *(figures 3 and 4)*

In the planning phase of the project, the estimation of voltage change was made on the busbar of the low voltage main distribution for back-up power supply when a 75kW sprinkler system is connected. This connection was taken into consideration both for grid operation (parallel operation of 2 transformers of 800kVA each / 6%) as well as for 500kVA generator in island mode.

The VDN* technical regulations were used for this and symmetrical load was assumed. There was a calculated relative voltage reduction for grid operation of 1.95% with a short circuit alternating current output of $19.21 \cdot 10^6 \cdot e^{j \cdot 74.78} \cdot$VA.

** Verband der Netzbetreiber*

There was a calculated relative voltage reduction for sole generator operation of 15.39% with a short circuit alternating current output of $2.39 \cdot 10^6 \cdot e^{j \cdot 81.13} \cdot$VA.

After project completion, the connection of the 75kW sprinkler system was tested using the A. Eberle measurement technology. First, the connection to the grid power supply was established using 2 parallel transformers of 80kVA / 6% each. As documented in figure 3, the relative voltage reductions for the individual phases were 2.29% (L1), 2.48% (L2) and 2.37% (L3).

After that, the grid was switched off and the connection recorded with a feed from the 500KVA emergency power diesel generator. The connection of the sprinkler system occurred for the idling generator, having no previous load. For this generator in island mode, the relative loss of voltage of the individual phases was registered at 16.2% (L1), 16.86% (L2) and 16.96% (L3) and it is shown in Figure 4.

These recordings are only related to the star connection. The recordings were made with the PQ-Box 100 on the same measurement point, namely in the low voltage main distribution for back-up power supply, just behind the fuses at the start of the connection to the sprinkler switchbox. The serious differences in frequency and voltage are clearly visible after the 29.5 second time mark.

The recordings of the switch for the 75kW sprinkler pump in both types of operation star and delta, were also measured, but are not discussed here.

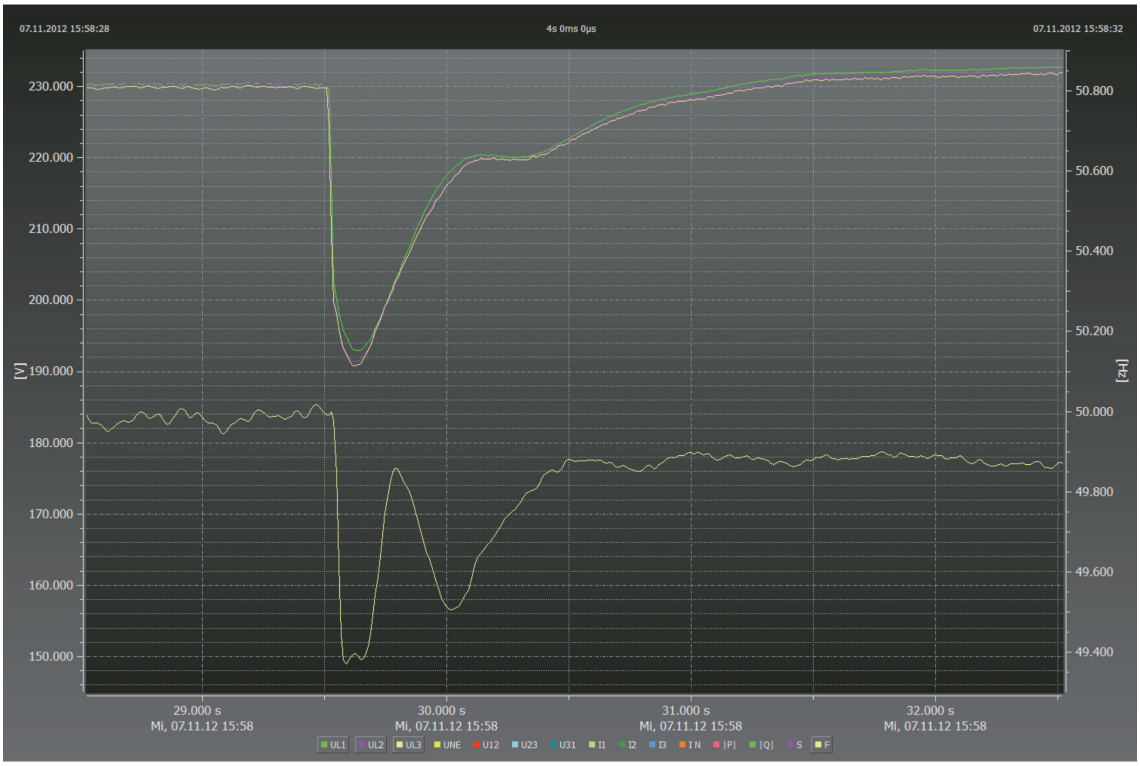

Figure 4 *Star connection of the 75 kW sprinkler system in emergency power operation (500 kVA emergency power diesel generator)*

Blackout test on emergency power diesel generator in the hospital
(Figures 5, 6 and 7)

In another hospital, this test was done to document the voltage quality as well as the efficacy of the switch from grid to the generator operation, with all associated properties in the event of a real failure of the main power supply. This test only looked at the voltage quality.

In Figure 5, you can see the measurement graph for the low voltage main distribution for back-up power supply. The recordings were done using two PQ-Boxes 100. To establish both the energy flow from the grid and that from the generator first the voltage quality on the busbar of the low voltage main distribution for back-up power supply was recorded with the infeed from the main power supply through three parallel operated distributor transformers of 100kVA / 6% each. After that, the main power supply was switched off and the 400kVA emergency power diesel generator assumed the provision of the low voltage main distribution for back-up power supply in generator, while in island mode.

Figure 6 shows the THD value as well as the values of the relative voltage harmonics 3, 9, 15 and 21 of the grid voltage to the low voltage main distribution to the back-up power supply, while being provisioned from the main power supply.

Figure 7 shows the THD value as well as the values of the relative voltage harmonics 3, 9, 15 and 21 of the grid voltage to the low voltage main distribution to the back-up power supply, while being provisioned from the emergency power diesel generator. The strong rise in harmonic load in the generator voltage is clearly visible between time marks 12.10 and 12.13.

The analysis of the harmonic load was performed pursuant to EN 61000-2-4 class 2 and VDE 0839-2-4 EMV environmental class 2 standards.

During grid operation, the tolerance level of the listed harmonics fell significantly below the permitted levels.

During generator island mode, significant transgressions of the permissible tolerance level of the harmonics in voltage were found in harmonics 9, 15 and 21.

Figure 5 *Measurement set-up for recording the harmonic load on the low voltage main distribution to the back-up power supply during grid and emergency power island mode.*

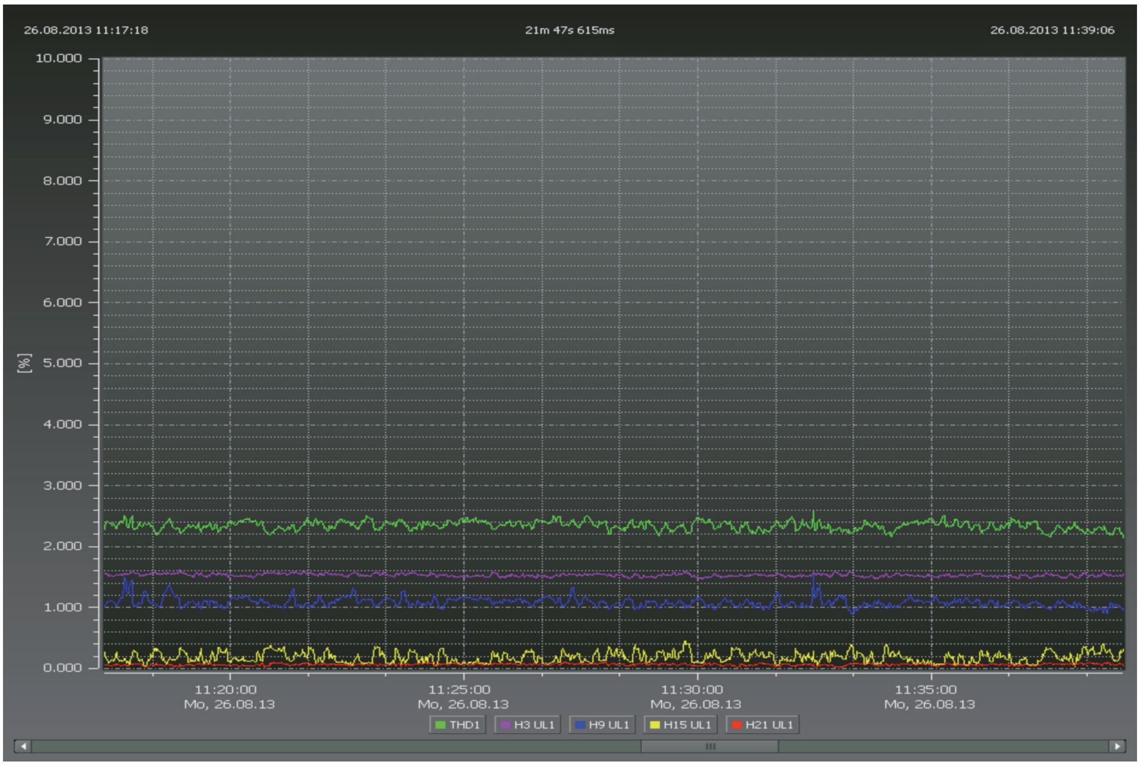

Figure 6 *THDu, Uh3; Uh9, Uh15 and Uh21 of L1 to the low voltage main distribution to the back-up power supply during grid operation (3x 1000 kVA / 6% transformers)*

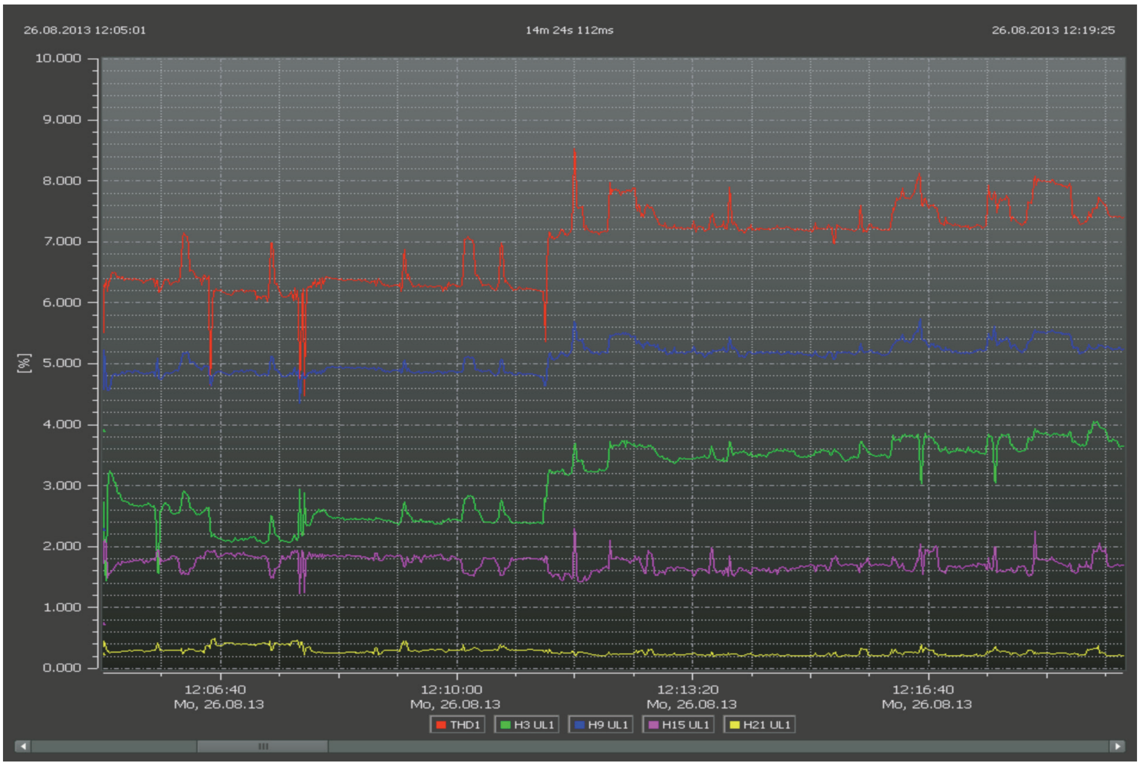

Figure 7 *THDu, Uh3; Uh9, Uh15 and Uh21 of L1 to the low voltage main distribution to the back-up power supply during emergency power island mode (400 kVA emergency power diesel generator)*

Changeover of a UPS system from the power network to an EPS in a computer centre *(Figure 8)*

Because many modern computer centres have emergency power supplies and static UPS systems and – due to the usually poor output of the EPS compared to the UPS – there are significant problems and serious interactions in their collaboration. Therefore we will briefly discuss such a case.

In this example, an emergency power supply was tested in a computer centre under real conditions, with an UPS system active during the grid failure.

In the recording, one can clearly see the opposite oscillation of the grid voltage and frequency. At maximum frequency, the voltages are at their minimum. After a few seconds, the generator was disconnected from the grid using a protective relay. The generator was able to provide the required power and was sized large enough, but the severe swings in voltage and frequency led to the protective relay being triggered, which shut down the entire system.

The A. Eberle PQ Box 100 and 200 Class A analyzers, with their high sampling resolution of 10 ms, provide unparalleled recoding accuracy allowing the device deployment in Computer/Data centers, a very sensitive environment from which may competitors shy away due to the application criticality.

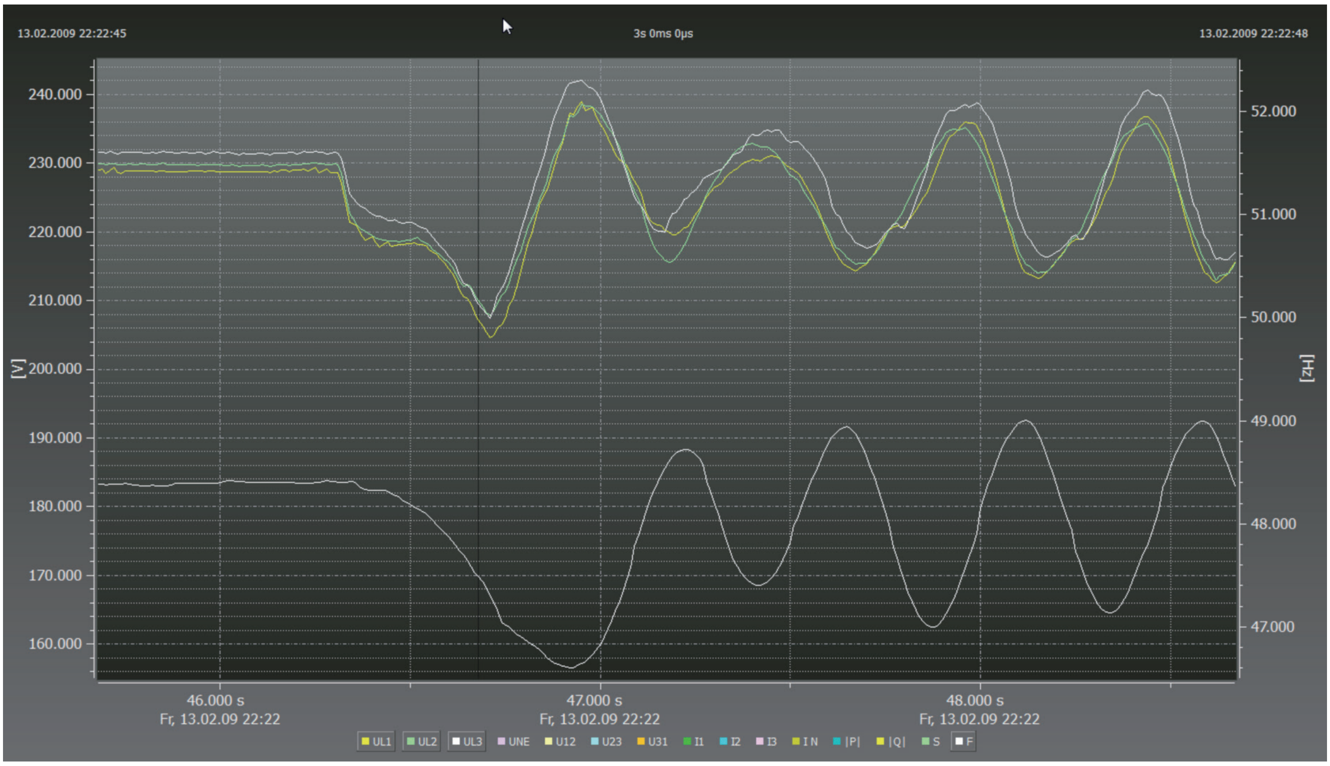

Figure 8 *Changeover of a UPS system from the power network to an EPS in a computer centre*

Conclusion

Only the proper professional projection and qualified measurements prevent surprises. The required measurement technology must fulfil certain requirements: voltages, currents, outputs and frequency are to be determined with a high resolution of 10 ms effective values, since an average value formation over 200 ms or one second would no longer allow these grid deviations to be recognized.

Deviations in the sinus waveform and voltage transients were determined based on oscillographic images. Further information on faults was gained via numerous trigger options, such as a sinus failure line trigger.

The mobile network analysers PQ-Box 100 and 200 from A. Eberle GmbH & Co. KG in Nuremberg fulfil all of these requirements. They perform parallel capture and analysis over 2,200 measurement values. The measurement devices are perfect for use as mobile devices due to their robust construction and easy operation.

For permanent monitoring of one distinctive grid point, the fixed network analyser and sequence of events recorder PQI-DA smart is a perfect choice.

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