Power Quality Measurements – Considerations at Electronic Data Processing Centres

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Abstract: - In general, power quality measurements are conducted at the interface between the public power grid and the main feed-in of a client's power supply system in order to verify the compliance with legal limit values. The operator of the public power grid is obliged to supply a minimum power quality in terms of stability of amplitude and frequency, flicker, harmonics, voltage drops, et cetera. The client has to substantiate not to cause an intolerable amount of disturbance to the public power grid due to an excessive demand for non-sinusoidal power.

This paper displays the motivation for performing power quality measurements within the power grid of industrial enterprises. The benefit achieved by a structured and effective layout of the power grid – especially the grounding system – is validated by showing exemplary measurement results. The consequences of power quality are discussed considering Electronic Data Processing Centres (EDPC) situated within an industrial environment as example. Furthermore, the pros and cons of the application of Uninterruptible Power Supply (UPS) systems are assessed.

Key-Words: - Power Quality, Harmonics, EDPC, UPS

1 Introduction

Electronic Data Processing Centres (EDPC) put a new challenge in terms of prospected availability on service and maintenance personnel. Due to the deficiency of inductive load, e.g. transformers and asynchronous motors, the power factor of EDPCs is rather of capacitive than of inductive nature. This is because computers and air-conditioning systems with switching power supplies comprise the majority of the equipment at use. Especially when EDPCs are located on the campus of industrial plants, the challenge to assure the power quality required by sensitive electronic equipment might be even higher.

2 Problem Formulation

The problem when assessing power quality is the clear, transparent and distinct assessment of the relevant parameters. Therefore, especially the reactive power of the load has to be known as well as the expected influence of the load on power quality parameters.

The assessment should be based on normative regulations without limiting the point of view solely to normatively regulated sections.

It should be borne in mind that normative regulations do not guarantee for an absence of problems under all possible circumstances. They just fortify the assumption that interference from the analyzed system will be unlikely.

Slavish adherence to one standard only is not considered to be reasonable either. It is recommended to try and support the argumentation which values to apply for the case at hand with values derived from other valid standards. For example, power quality standards can be matched with legal limit values of the EMC standards of the DIN EN 61000-4-X series.

What can be observed in practice is the effort to "cure" power quality parameters without an immediate call for action. Due to the fact that some equipment is considered to be sensitive, many companies install UPS systems without prior power quality measurement. In most cases, people installing sensitive equipment do not know the exact power quality requirements that the equipment puts up. So an additional UPS is installed as prophylactical treatment of a supposed bad power quality.

2.1 Total Harmonic Distortion

Considering total harmonic distortion (*THD*), neither DIN EN 50160 nor DIN EN 61000-2-4 reveal, whether the *THD* of voltage (*THD-V*, respectively *THD-U*) or the *THD* of current (*THD-I*) shall be prioritized.

For example, the total harmonic distortion value of the current is calculated as follows:

$$\mathit{THD\text{-}I} = \sqrt{\sum_{\nu=2}^{50} \left(\frac{I_\nu}{I_0} \right)^2} \qquad (1)$$

Where switching power supplies are concerned, voltage has a more or less sinusoidal shape while the current is rather rectangular. Transferred into the frequency domain, the Fourier transform of the current may have a wider spectrum with more contribution of higher harmonics to the total level than the Fourier transform of the voltage.

That is why the *THD-V* value and the individual harmonics of the voltage may comply with the legal limit value of $THD = 8\,\%$ (DIN EN 61000-2-4, Class 2) while at the same time and for the same measuring point the *THD-I* value and the current harmonics do not.

The question at hand is, whether the measuring point is regarded as complying with legal limit values because of the analyzed voltage or not complying due to the measured current values.

Recent surveys at EDPCs show that the *THD-I* value may add up to 30 % and more.[6]

2.2 Power Factor

The power factor is the ratio between real power and apparent power.

$$\lambda = \operatorname{sgn} Q_{\mathrm{RMS}} \cdot \left(\frac{P_{\mathrm{RMS}}}{V_{\mathrm{RMS}} \cdot I_{\mathrm{RMS}}} \right) \qquad (2)$$

P_{RMS} denotes the RMS-value of real power, Q_{RMS} the reactive power, V_{RMS} the voltage and I_{RMS} the measured current. The preceding factor $\operatorname{sgn} Q_{\mathrm{RMS}}$ denotes not the direction of power flow but rather the type of load supplied with power. Regarding the load reference arrow system, $\lambda > 0$ indicates inductive load, $\lambda < 0$ indicates capacitive load.

For sinusoidal waveforms of apparent power, λ is identical to $\cos\varphi$, which is the phase angle between current and voltage. For non-sinusoidal waveforms, λ and $\cos\varphi$ differ considerably. So when in doubt, λ is the parameter to consider.

A recent survey at 14 EDPCs in Australia showed an average power factor (leading) of $\lambda = -0.87$. The sign indicates a capacitive behaviour of the load. It could also be shown that the power factor of switching power supplies increases (towards $\lambda = 1$) with an increasing load.[6]

To meet the limits placed by the new set of EMC standards DIN EN 61000-3-2, manufacturers have to apply active or passive Power Factor Correction (PFC). Additionally, EMI-filters are widely used. Due to the desired low-pass behaviour, they consist of a capacitor that is in parallel to the load. Furthermore, the present generation of servers employ redundant power supplies. So, half of the switching power supplies are in a no-load state for most of the time.[6]

3 Power Quality Measurements

To obtain some information on power quality measurements and the most significant results, five test setups are discussed at this contribution.

3.1 Measurement Concept

The power quality measurements were conducted using the power analyzer system TOPAS 1000 by Fluke Instruments. Eight channels provide access to the signal course of voltage, current and power for a three-phase, four (PE combined with N) or five (PE and N separated) conductor system.

3.2 Measurement Results

Numerous power quality measurements were analyzed in order to find the proper set of parameters that illustrate the statements of this article and the circumstances at each measuring point.

The diagrams at the end of this paper (Fig. 1 up to Fig. 10) show λ, respectively *THD-I* and apparent power vs. time (in hh.dd-format).

Fig. 1 and Fig. 2 show power quality measurements conducted at an industrial environment A, at a sub-distribution board.

With a sag of the load, an increase of the of the power factor from $\lambda = -0.2$ mean to $\lambda = -0.4$ mean can be observed in Fig. 1. So, for measuring point 1, the power factor behaves diametrically opposed to the apparent power.

Fig. 2 illustrates that the total harmonic distortion of current *THD-I* reaches a comparatively high value of $THD\text{-}I = 115\,\%$ mean and $THD\text{-}I = 140\,\%$ maximum of the 50-Hz fundamental wave. We can conclude that the load has a mainly capacitive character. When the load is switched off, we see an increase of the power factor back towards $\lambda = 1$ and a decreasing *THD-I* value towards $THD\text{-}I = 40\,\%$ with two peaks as exception. So, the load likely causes a high *THD-I* value and a low capacitive power factor. It is evident that e.g. control systems, computers or other devices that are connected to the measured sub-distribution board may likely be affected. Furthermore, UPS systems may suffer from overload.

Fig. 3 and Fig. 4 show power quality measurements conducted at an industrial environment B, at a main distribution board. We can see from Fig. 3 that the power factor ranges between $\lambda = +0.8$ and $\lambda = -0.92$. Compared to measuring point 1, the power factor is closer to $\lambda = 1$. It is also obvious that the power factor behaves similar to the apparent power. The *THD-I* value in Fig. 4 behaves oppositely to the apparent power. During the switch-off of the main load, we see a strong increase of the *THD-I* value and a decrease of the power factor. So, we can assume that an inductive part of the total load was switched off while some load with a capacitive behaviour remained.

Fig. 5 and Fig. 6 show power quality measurements performed in an industrial environment C, at a sub-distribution board (power). We see a power factor of $\lambda = +0.48$ that indicates a highly inductive load. Because the apparent power remains relatively stable at $S \approx 8.8\,\text{kVA}$, the power factor does not vary considerably either. The *THD-I* value shown in Fig. 6 shows a course that is in contrary to the apparent power.

Fig. 7 and Fig. 8 show power quality measurements carried out in an industrial environment D, at a sub-distribution board (data) with UPS attached. Fig. 7 shows that the power factor correction (PFC) works satisfactorily and keeps the power factor at $\lambda = +0.8$. As mentioned before, due to current harmonics, the *THD-I* value shows an average of about $THD\text{-}I = 24\,\%$.

Fig. 9 and Fig. 10 show power quality measurements carried out at a sub-distribution board of an EDPC , with power factor correction 400 kVar, 7 % choking installed at the main distribution board. Fig. 9 shows the interesting behaviour that the power factor increases, i.e. the load becomes more inductive when the load decreases. This means that some of the capacitive load is switched off. Due to the fact that switching power supplies become more capacitive for if the load is reduced, the results shown in Fig. 9 are very interesting. In Fig. 10, a rise in the *THD-I* level is visible that coincides with the drop of the load.

3.3 Consequences of Varying Power Factors

As mentioned in chapter 2.2, EMI-filters with capacitors in parallel to the load are widely applied. It is common practice to indicate the nominal power of static UPS-systems at $\lambda = +0.8$, i.e. inductive load. The EMI-capacitor is designed to have 30 % of the load's nominal power.

To understand the effects of EMI-filters on the engineering of static UPS-systems, it should be borne in mind that for inductive load $(\lambda > 0)$, the capacitor of the EMI-filter supplies about half of the reactive power. The inverter only has to supply about 86 % of the total current.

Vice versa, for capacitive load $(\lambda < 0)$, the inverter has to supply the reactive power for the EMI-filter and the load.

If we keep the current of the inverter at the aforementioned 86 % and modify the power factor, the output power that is available for the load changes drastically.

Table 1: power factor of load and apparent power output of static UPS designed for $\lambda = +0.8$

λ_{load}	+0.8	+0.9	1.0	-0.9	-0.8
$\frac{S_{\text{load}}}{S_{\text{load, nominal}}}$	100%	94.1%	80%	68%	64%

As can be seen from Table 1, for a power factor of $\lambda = -0.8$, the load can merely add up to 64 % of its nominal value before the UPS system suffers from overload.

Considering this, static UPS systems should rather be designed for $\lambda = +0.9$. Alternatively, UPS systems should be implemented as dynamic UPS instead of static UPS systems. Dynamic UPS systems consist of separately-excited synchronous generators with a variable excitation. The variable excitation controls the reactive power output of the generator. At full load, the dynamic UPS can supply up to 60 % reactive power (reference: 100 % apparent power at $\lambda = +0.8$). At no-load state, the dynamic UPS can still supply about 40 % reactive power for capacitive load, respectively 100 % reactive power for inductive load. [6]

4 Conclusion and Outlook

The conducted measurements show that it is not sufficient to carry out one single power quality measurement at the main power feed-in. The power quality within a company can very well differ significantly while the situation at the main feed-in pretends stability. So, a sufficient amount of power outages or system failures could be avoided if power quality measurements were regarded as a preventive measure to minimize productions downtimes and help to save money.

As for the design of static UPS systems at capacitive load, the UPS systems should be designed for a capacitive power factor from the start. Alternatively, the application of dynamic UPS systems is advised. Due to their design, they have a higher reactive power output over a widely variable power factor.

The authors would like to emphasize that in general, it is not mandatory to supply sensitive electronic equipment with UPS systems. If the power supply system of a company is engineered properly and UPS systems are not mandatory due to redundancy requirements, it is not advised to install a UPS and pretend to have improved the power quality.

The installation of UPS systems is no substitution for an accurate engineering of the power supply system in terms of grid structure (application of TN-S system), distributed equipotential bonding etc.

The improvement of power quality should be justified by the requirements of the installed equipment and decided on a case-by-case basis.

In most cases, a multitude of locations operating in various electromagnetic environments is affected by the decision whether or not to execute power quality improvements. That is where power quality measurements can form a rational basis to decide if improvements should be implemented or not.

So, power quality measurements accomplish preventive maintenance of power supply systems.

It is clearly visible that power quality measurements, seen from the point of view of assuring availability, can help optimize the company's expenditures and help save a considerable amount of money.

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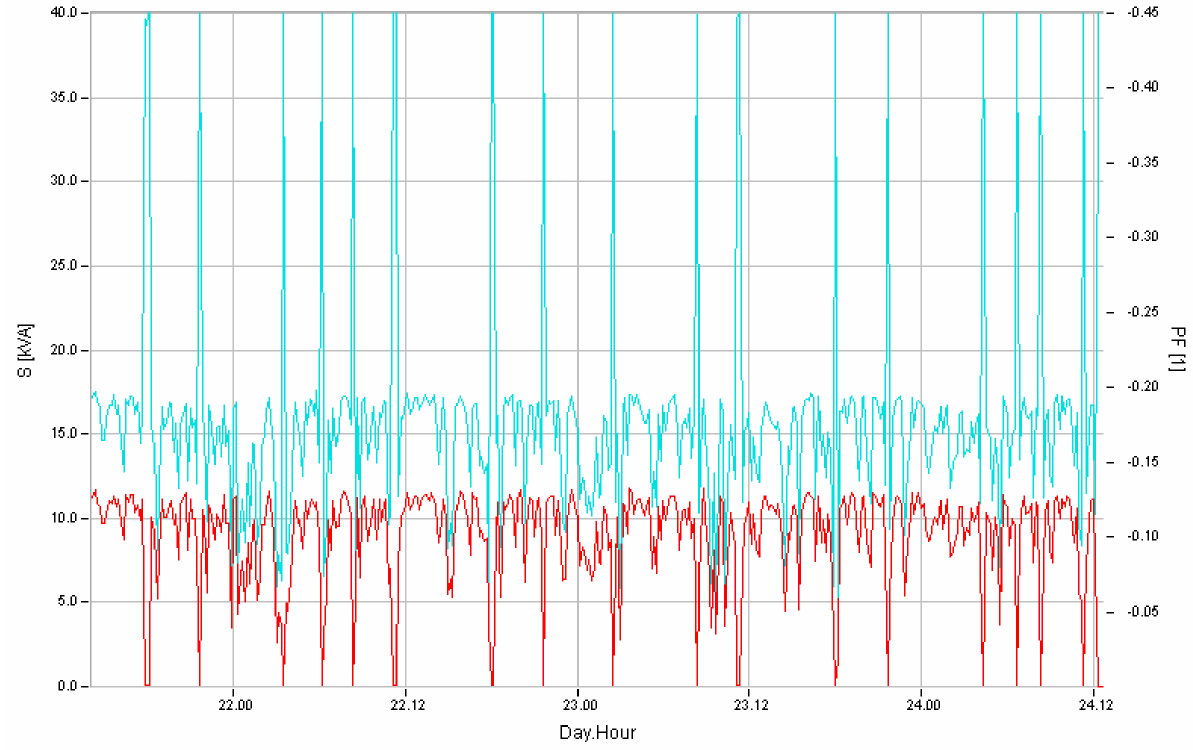

Fig. 1: power factor (top) and apparent power (bottom) vs. time at industrial environment A, sub-distribution board (power), phase conductor L2

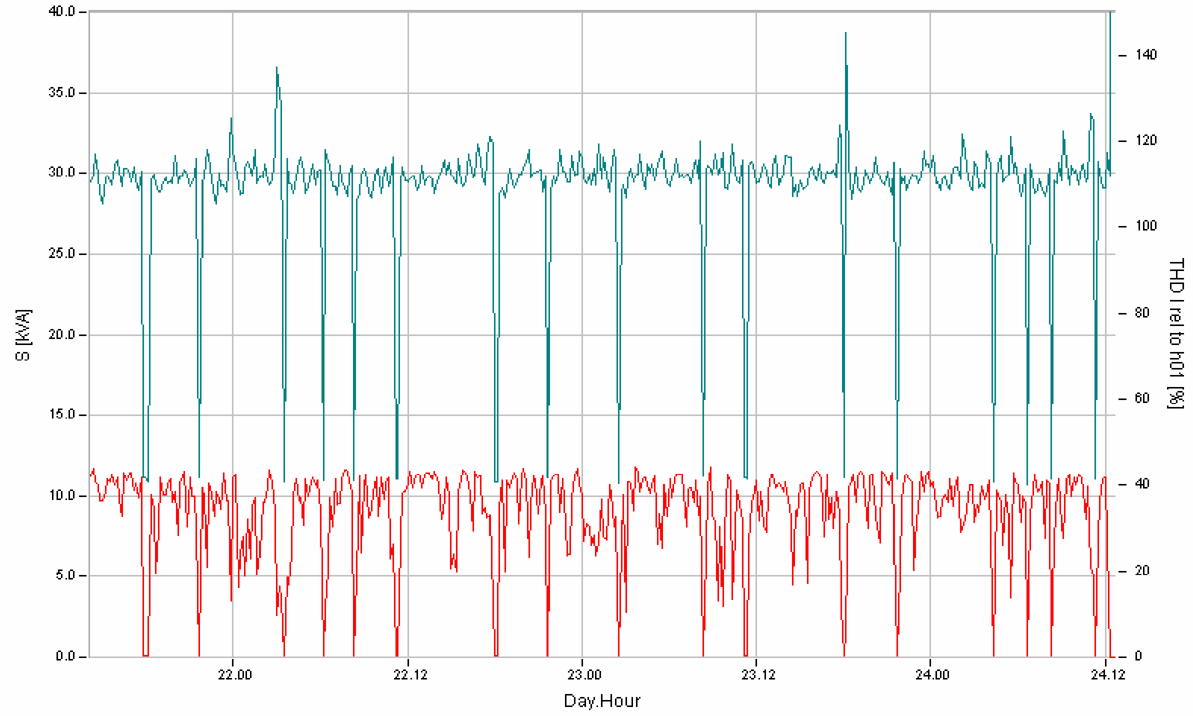

Fig. 2: total harmonic distortion of current THD-I (top) and apparent power (bottom) vs. time at industrial environment A, sub-distribution board (power), phase conductor L2

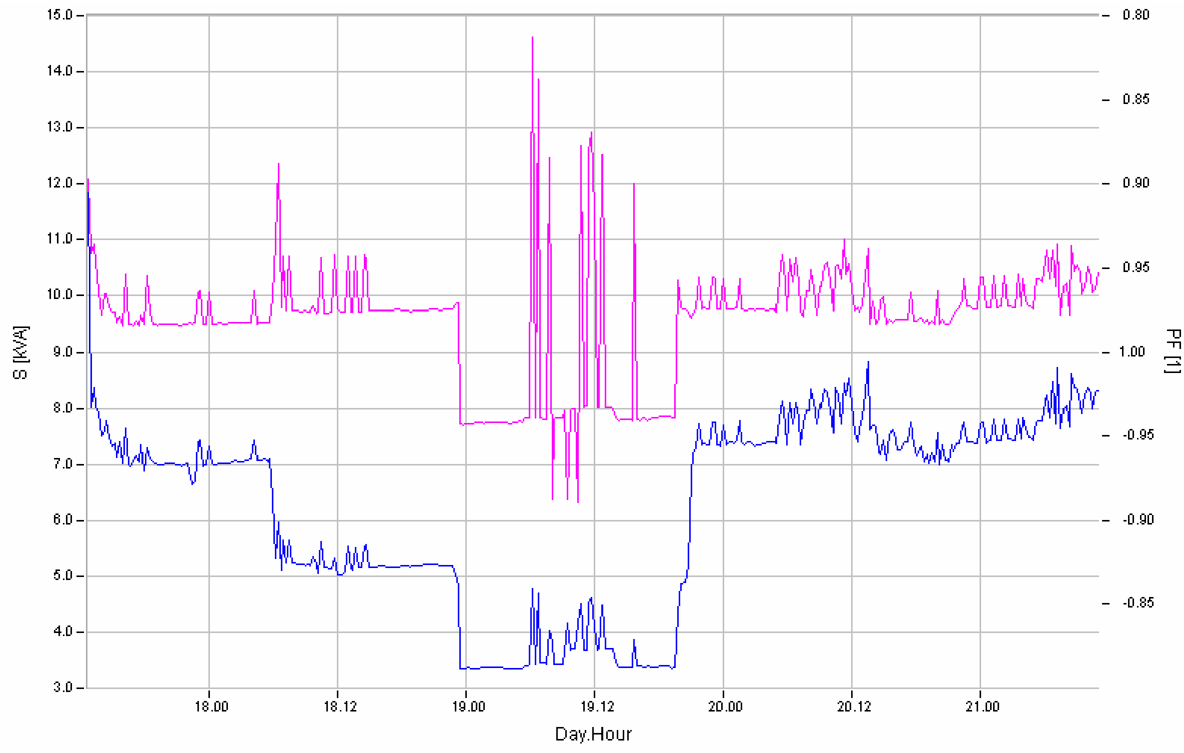

Fig. 3: power factor (top) and apparent power (bottom) vs. time at industrial environment B, main distribution switchboard, phase conductor L1

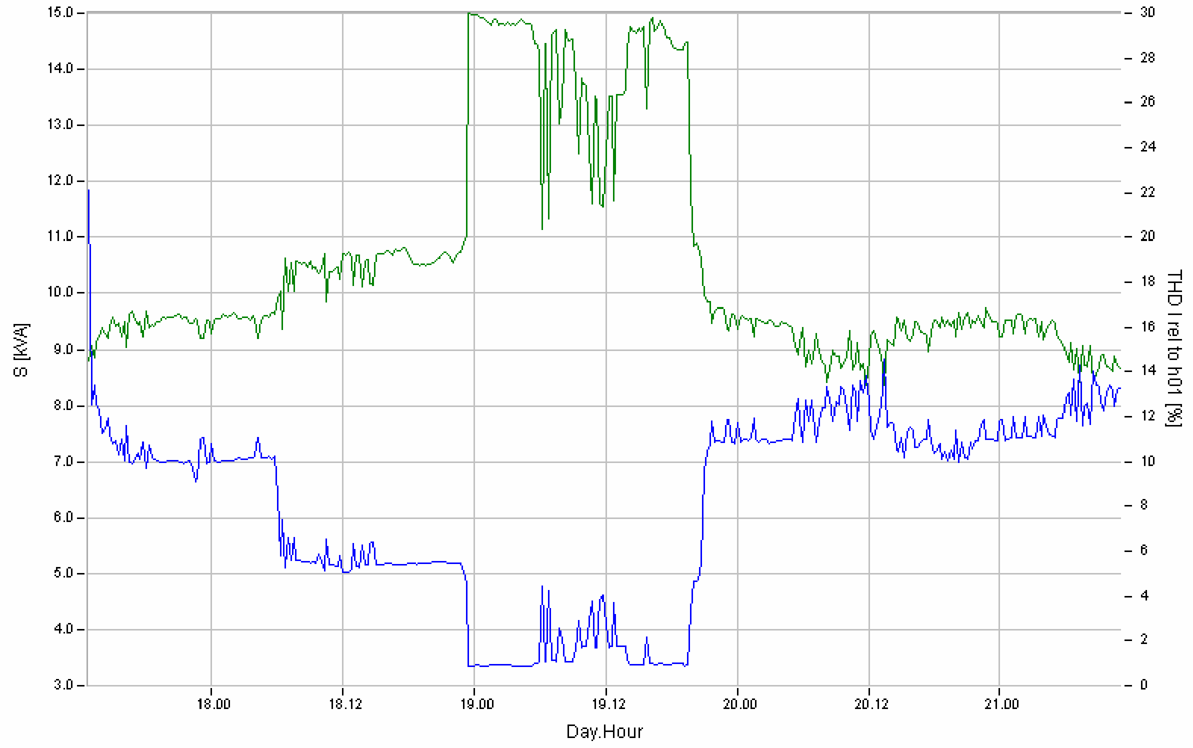

Fig. 4: total harmonic distortion of current THD-I (top) and apparent power (bottom) vs. time at industrial environment B, main distribution switchboard, phase conductor L1

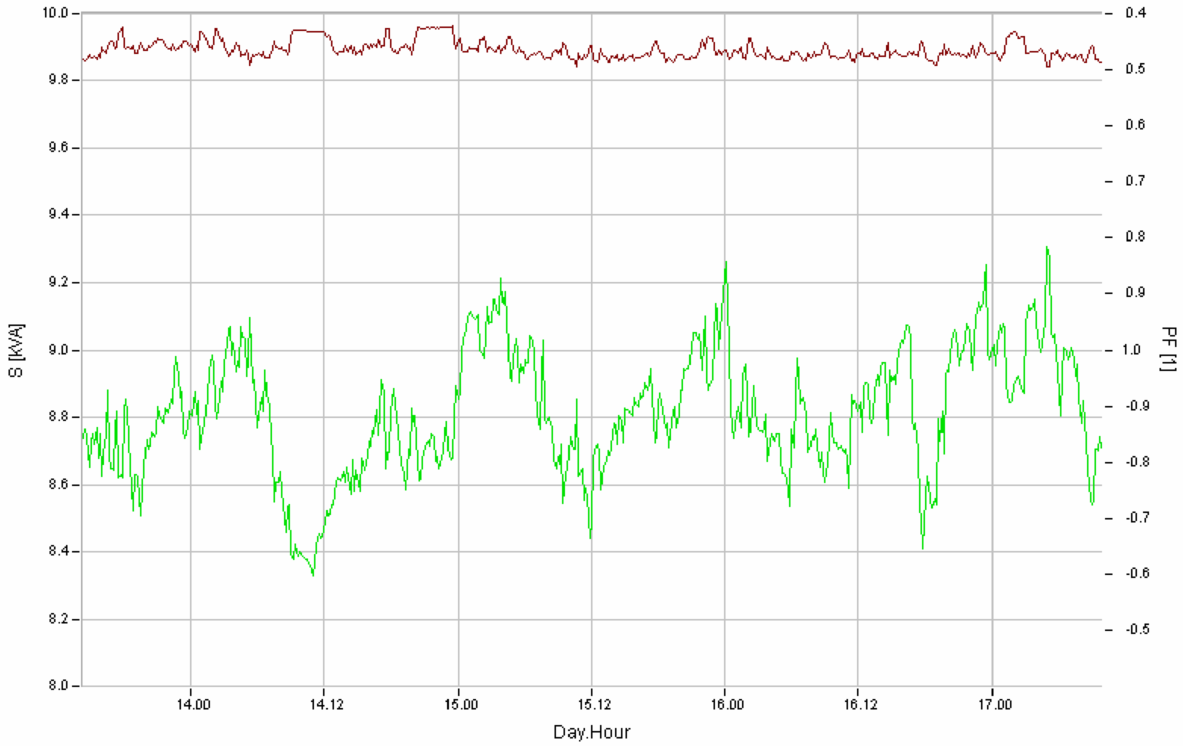

Fig. 5: power factor (top) and apparent power (bottom) vs. time at industrial environment C, sub-distribution board (power), phase conductor L3

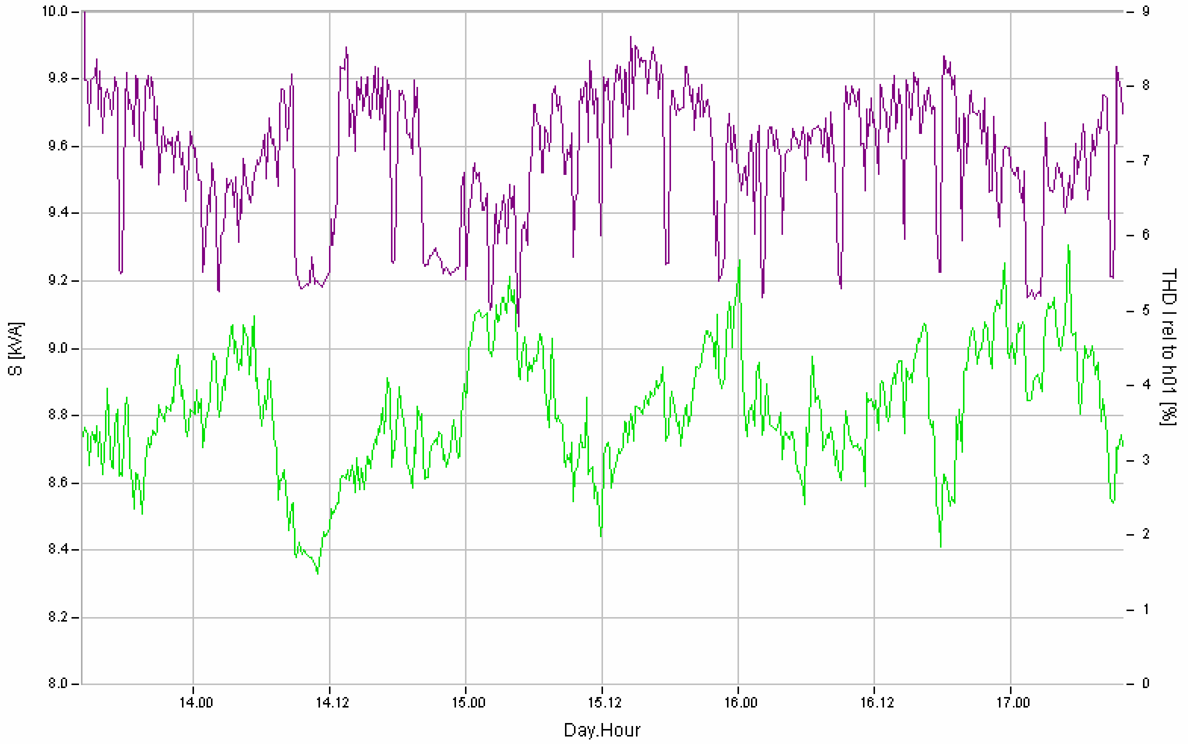

Fig. 6: total harmonic distortion of current THD-I (top) and apparent power (bottom) vs. time at industrial environment C, sub-distribution board (power), phase conductor L3

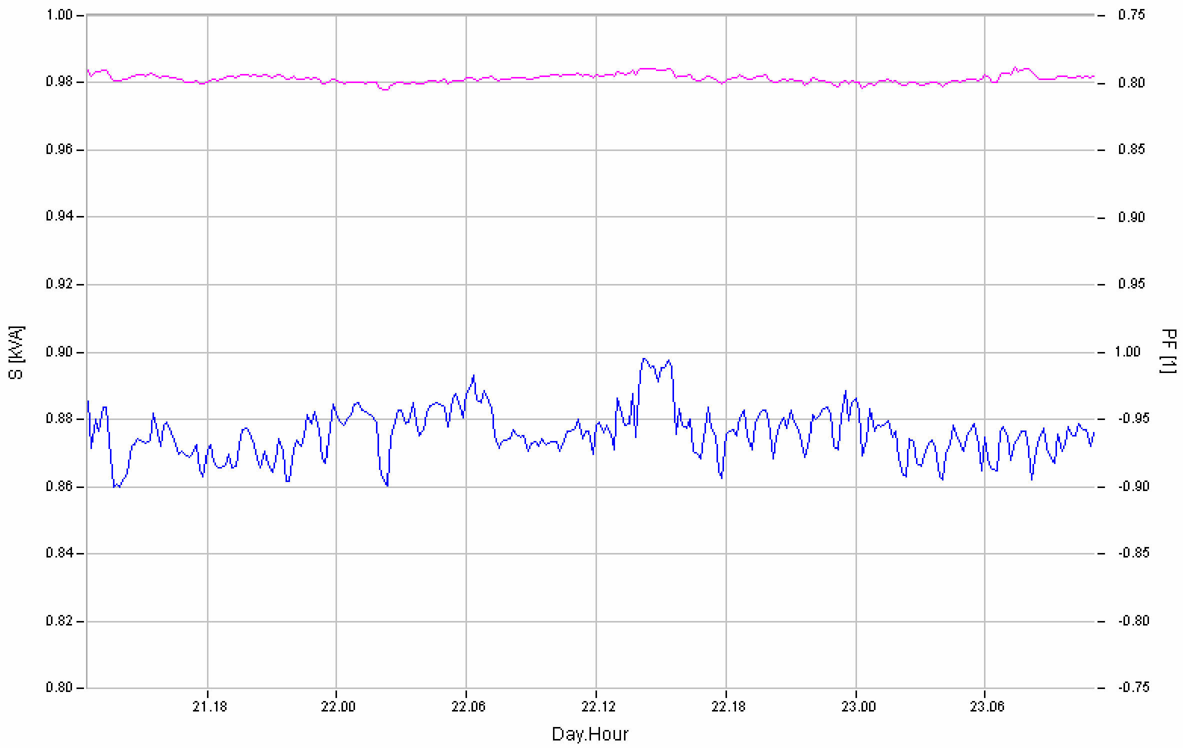

Fig. 7: power factor (top) and apparent power (bottom) vs. time at industrial environment D, power feed-in of sub-distribution board (data) with UPS, phase conductor L1

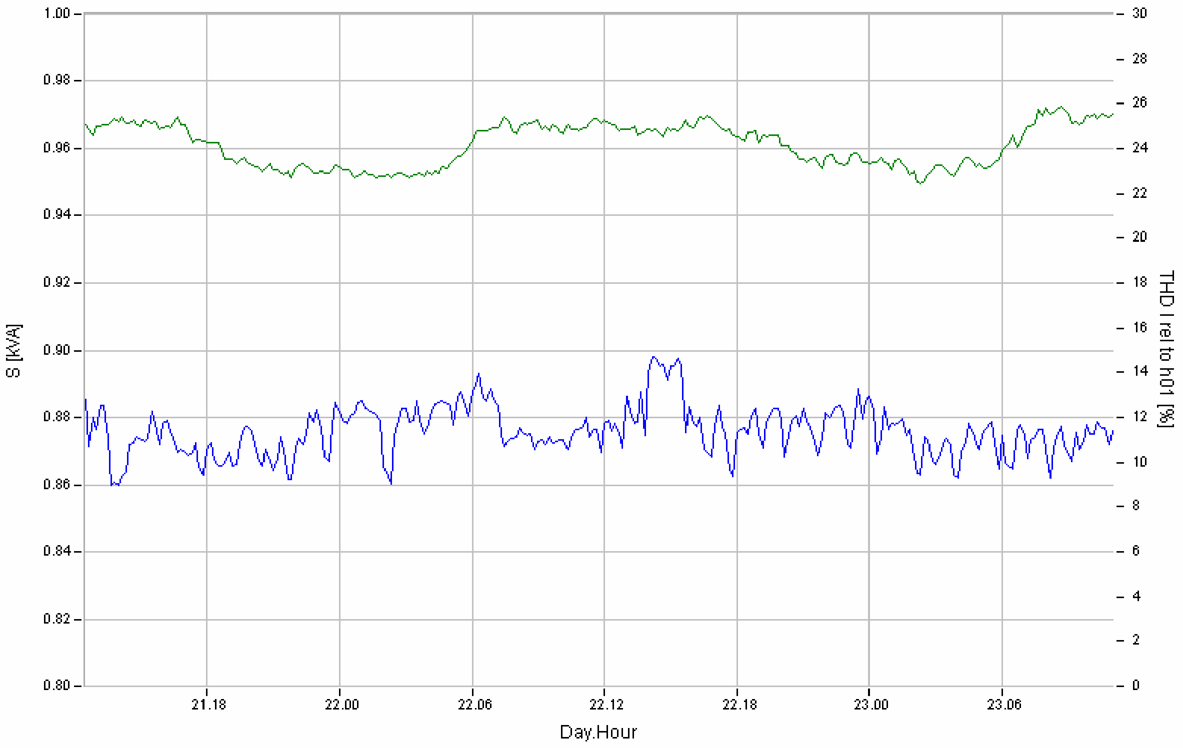

Fig. 8: total harmonic distortion of current THD-I (top) and apparent power (bottom) vs. time at industrial environment D, power feed-in of sub-distribution board (data) with UPS, phase conductor L1

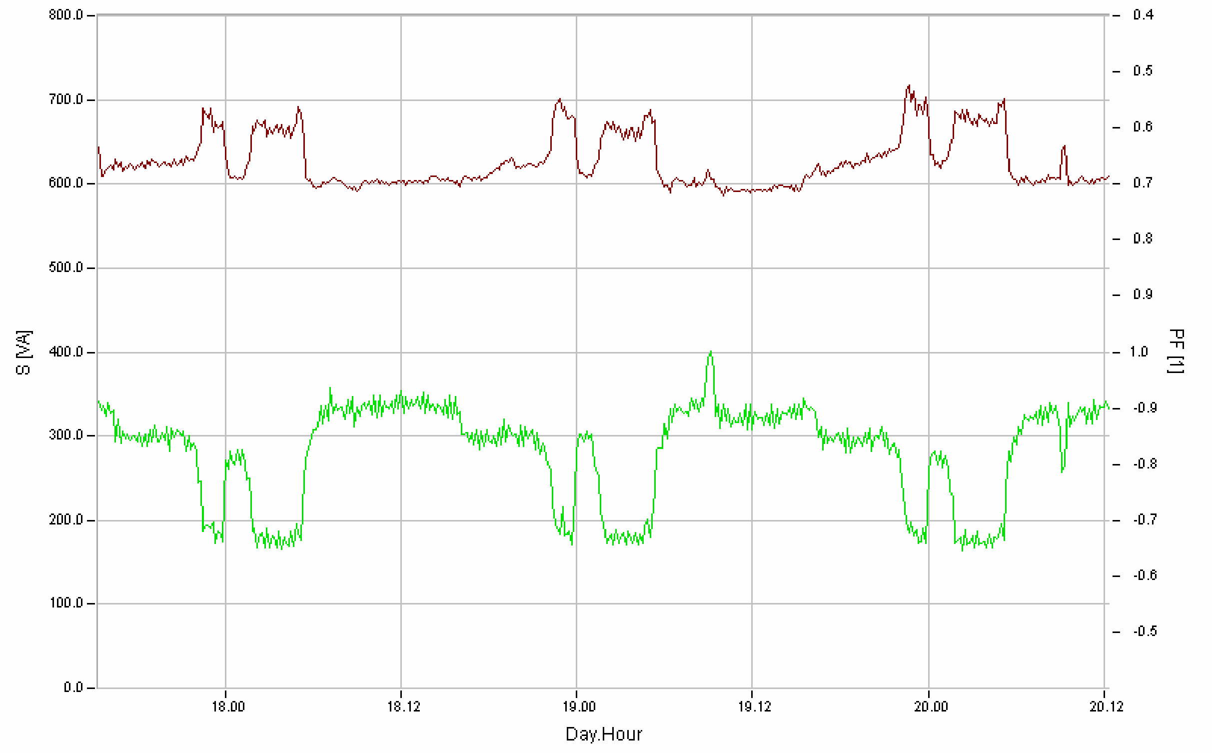

Fig. 9: power factor (top) and apparent power (bottom) vs. time at an EDPC, sub-distribution board (power) with power factor correction 400 kVar, 7 % choking, phase conductor L3

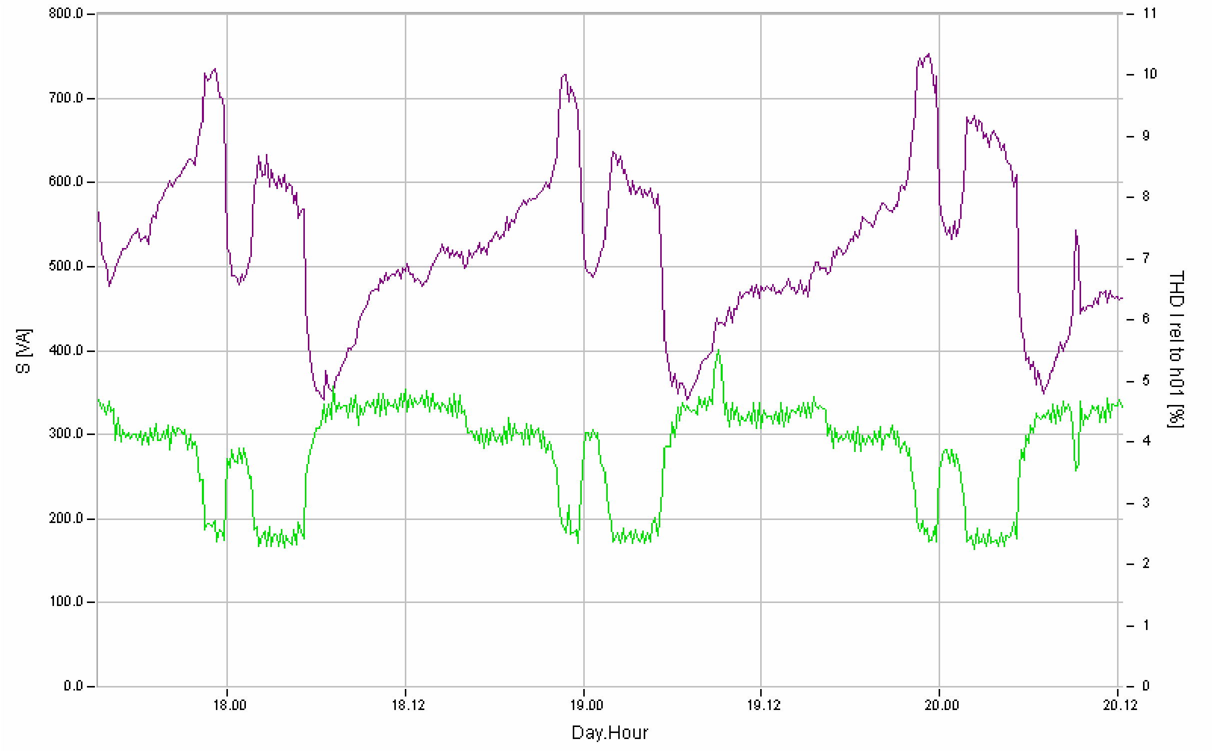

Fig. 10: total harmonic distortion of current THD-I (top) and apparent power (bottom) vs. time at an EDPC, sub-distribution board (power) with power factor correction 400 kVar, 7 % choking, phase conductor L3