MODERN POWER QUALITY MEASUREMENT TECHNIQUES

Code No. 20 750 592

METREL®

Table of Contents

1. Preface

1.1. Purpose of the handbook »Modern Power Quality Measurement Techniques

The purpose of this hanbook is to better acquaint the reader with the extensive challenges of measuring power quality.

The first part describes the standards and terminology used in this field.
Current standards and drafts are given and explained.

Special attention is given to the terms and definitions that users of measuring equipment meet daily.
A special chapter is devoted to EN 50160 which is probably the most important standard in this field. This standard can be considered as a systematic and proven framework for the monitoring and documentation of voltage quality parameters.

We hope that this chapter is written in a consice and understandable manner. We expect that this document will serve the reader as a groundwork for dealing with terms, parameters or standards of this field.

The second part of the handbook acquaints the reader with the functions of Metrel's instruments. The most important tools and functions for solving complex problems on power distribution networks are presented.
Each function is presented as a real problem that was measured and solved with Metrel's instruments. The complete process is shown, from the perception of the problem, the preparation and measurement itself and the analysis and final solution of the problem.

The problems solved clearly prove that Metrel's instrument are suitable for solving all kind of problems on power networks.

The third and final part briefly presents Metrel's existing instruments for measuring power quality (Power Harmonics Analyser, Power Quality Analyser and Voltscanner). More detailed information can be given by visiting our web sites or by your local distributor.

The authors will be grateful for any comment or additional suggestion that would help us to supplement the handbook and Metrel's products.

METREL family of Power Analysers represents top-level instruments in this field, which are fully in accordance with the latest international standards – see also the letter from the Power Measurement Center »ICEM« of the Faculty of Electrical Engineering and Computer Science at the University of Maribor, which summarizes the evaluation of applicability of Power Quality Analyzer Plus (page 80).

1.2. Presentation of METREL d.d. company and its production program

METREL, Measurement and Regulating Equipment Manufacturer has 42 years experience in the development and production of measuring and regulating equipment. It is amongst the leading manufacturers and suppliers of test and measurement instruments for testing of safety on low-voltage electrical installations, earthing systems, testing of safety on machines and electrical appliances, instruments for measurement and testing of cable networks and instruments for the measurement, recording and analysis of power quality.

240 workers are employed, half of them on the measurement program. 17 engineers are employed in the R & D department.

One of METREL's superior aspects is the speed at which it completes its development projects so that it takes at most 12 months from the initial idea to the production of the first series.
With regard to construction of the test equipment, METREL has been linked with The University of Ljubljana and the Ministry of Science and Technology. The results of our R & D activities are also demonstrated by the numerous patents, which have been registered, both at home and in other European countries.
New products produced by METREL are launched in the market every year, in 2002 there will be 6 new measurement instruments coming from the production line. Each product is checked by the calibration laboratory after completing the production process and the relevant calibration certificates are enclosed. Very soon Metrel Calibration Laboratory will be fully internationally approved.

METREL pays the greatest attention to the relationship with their partners and to the quality of its products. Certification to ISO 9001 has also been achieved and has been continuously maintained.
The distribution network has been developed in most countries worldwide.

This manual was written to enable better understanding of the problems associated with the measurement of power quality.
METREL has manufactured a demonstration set consisting of this handbook, an additional Quick Guide on Power Quality and Advanced Measurement Techniques, and a Power Quality Simulator. These can be used for training on power quality measurement techniques, as well as for the presentation of typical measuring instruments currently used in the field of power quality measurements.

2. Introduction

Past ...

When electricity supply networks were first established the widespread availability of low cost electrical power sparked off a sustained demand from both Industrial and Domestic users.
Over time, the power requirements rose to a level nearing the full capacity of local networks. This presented significant problems for both electricity generation and supply companies.
In response to this increased demand some countries encouraged the development of more efficient ways of utilising electrical energy by various switching methods. Also the miniaturisation of electronics led directly to increasingly complex systems in industry, telecommunications, health care, domestic appliances etc. These circuits, although introducing increased speed of operation and complexity of task, typically use the same or lower amounts of power than their more basic predecessors. However, the majority of these circuits (variable speed controllers, PC's, medical equipment, arc welders and furnaces etc.), use 'switch mode' techniques which act as a non-linear load or 'disturbance generator' which degrades the quality of the electricity supply.
Equipment with switch mode input circuitry is usually more sensitive to mains variations and disturbances than linear loads. The traditional method of controlling these variations was with capacitor banks, however capacitor bank switching can damage sensitive electronic circuitry. At the same time non-linear loads can damage capacitor banks by increasing the current drawn or by causing resonance. Non-linear loads can also adversely affect transformers.
Such combinations of traditional and non-traditional loads, coupled with fluctuating loads, causes problems often classified as *"random"* or *"sporadic*" (problems with sensitive devices), annoying (light flickering) or as "strange" or "without apparent reason" (problems with cabling, capacitor banks, tripping, signalling, etc.).

And present

The European Council directive on ***Product Liability (85/374/EEC)*** explicitly qualifies electricity as a product. The purchaser becomes the customer and electrical power becomes merchandise. There is a customer expectation that the price of goods is set according to its quality. The determination of European countries to establish an area for compatible economy without boundaries and the deregulation of electricity markets in America established a new concept of *"**Power Quality**".*

3. What is Power Quality?

There are many definitions of power quality depending on a person's point of view. A simple definition accepted by most customers interprets power quality as good if the appliances connected to an electrical system work satisfactorily. Usually, poor or low quality of the supplied power shows itself as a need to repeatedly re-boot your computer, sensitive devices locking up, lights flickering or the faulty operation of electronic control or drive devices. On the other hand, electrical utility companies will characterise power quality as the parameters of voltage that will affect sensitive equipment.

It is true that the cause of many problems can be found in disturbances of the supply voltage. A survey conducted by Georgia Power during the 1990's discovered that the utility's perception was that 1% of the power quality problems were caused by the utility and that 25% are caused by the customer. The users' perception is that the utility causes 17% of the problems and that the customer is only 12% to blame.

Another definition of power quality, based on the principle of **EMC**, is as follows. ***The term "power quality" refers to a wide variety of electromagnetic phenomena that characterise voltage and current at a given time and at a given location on the power system*** (IEEE 1159:1995 "IEEE recommended practice for monitoring electric power quality").

IEC 61000-4-30 "Testing and measurement techniques-power quality measurement methods" (in preparation) defines power quality as ***"the characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters"***.

And finally, one of the most illustrative perceptions of a power system from a power quality view:

"An energy network can be compared to a water reservoir with lots of people putting water in (the utility), and even more people drinking that water (consumers). If someone pollutes the water, many will be unsatisfied. You can buy water from a company on the opposite side of the pool, but the quality of water you get will depend on the person that must prevent pollution in your part of the reservoir (local network operator)." (Alexander McEachern, is active in drafting and approving international power standards, represents the United States on the International Electrotechnical Commission (IEC) TF77A Working Group 9, which is setting the standard for power quality instruments. He is a Senior Member of the IEEE, Chairman of IEEE 1159.1, and a voting member of the IEEE Standards Co-ordination Committee on Power Quality).

Regardless of the definition used, power quality is a mayor strategic issue in the open electricity market economy. There are several reasons to encourage a systematic and constant approach to the monitoring of power quality parameters.

Technical objectives

- **ease of identification and elimination of problems on the utilities or customers installation,**
- **preventive maintenance, by the early location of potential sources of disturbances or failures,**
- **optimisation of the network upon PQ parameters.**

Financial objectives

- **administering special contract,**
- **lower costs due to loss of supply penalties,**
- **improving in investment management,**
- **quality of delivered energy influences the price of energy.**

Marketing objectives

- **offering a more competitive service – differentiation between supply companies,**
- **building new relations between customer and supplier,**
- **special care for customers with high quality power demands (e.g. semiconductor industries),**
- **feedback for improving competitiveness and customer satisfaction,**
- **annual reports on power quality events.**

3.1 EMC standardisation

An issue of the **European Council Directive** ***"on the approximation of the laws of the Member States relating to electromagnetic compatibility"*** (89/336/EEC) defines terms such as "electromagnetic disturbances", "immunity" and "electromagnetic compatibility". This directive set the criterion which equipment must meet in order to be sold in the EC. This unification is known as "EMC approach". Technical support of the Directive is made by CENELEC by issuing EN standards. CENELEC introduced the practice of relying only on internationally published standards. There are more international (IEC, IEEE, ISO, CIGRE, UNIPEDE...), national (ANSI, BSI, VDE...), regional (CENELEC, APEC...) or professional (ECMA) organisations that sets EMC standard. Most of the international standards are set by the IEC. Lots of effort in EMC standardisation has been made recently by the IEEE for North and South America. IEC organisation work on EMC standardisation will be presented here.

IEC standards equivalence for the term ***"power quality"*** as used in IEEE standardisation is ***"low frequency conducted EMC phenomena"****.* Some basic IEC definitions from the International electrotechnical vocabulary (IEV) concerning EMC is presented here.

Electromagnetic compatibility -EMC (IEV 161-01-07):

The ability of any equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Electromagnetic environment (IEV 161-01-01):

The totality of electromagnetic phenomena existing at a given location.
NOTE – *In general, the electromagnetic environment is time dependent and its description may need a statistical approach.*

Electromagnetic disturbance (IEV161-01-05):

Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter.
Note. - An electromagnetic disturbance may be electromagnetic noise, an unwanted signal or a change in the propagation medium itself.
Immunity (to a disturbance) (IEV 161-01-20):
The ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.
Mains immunity (IEV 161-03-03):
Immunity from mains-borne disturbance.
Susceptibility (electromagnetic) (IEV 161-01-21):
The inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.
Note. - Susceptibility is a lack of immunity.

As already mentioned in an introductory chapter, proper functioning of an appliance connected to a electrical network depends on:

- ***amount of disturbance in vicinity***
- ***susceptibility of an appliance to such disturbance***
- ***impact of appliance to environment.***

According to this, the EMC standard, amongst others, must indicate compatibility levels and emission limitations for a particular environment.

There are three types of EMC standards in IEC.

Basic EMC publications

Presented in the form of a standard or technical report, the basic publications define the general qualification and rules concerning EMC. They are used as guidance for product standard technical committees.

Generic standards

General standards are not as detailed as product standards and they are applicable to products not covered by a product EMC standard. Each standard is published in either a domestic or industrial range dependant on the environment in which a particular product will be installed. This principle is adopted from CENELEC.

Product standard

Generic EMC standards – standard for products
Standards for products or product families with emission limitations and immunity test specification.

Almost all EMC basic and generic standards are drafted and issued by the IEC technical committee IEC TC77 and CISPR. CISPR activity is aimed at issuing standards for the prevention of emissions causing interference with telecommunications. IEC TC77 along with its subcommittees has published the IEC EMC 61000 series standards. Numerous other technical committees are engaged in the completion of EMC product standards. IEC TC77A is a subcommittee responsible for low frequency phenomena. Among other standards, IEC 61000-2-2 “Environment – Compatibility levers for low-frequency conducted disturbance and signalling in public low-voltage power supply systems” *is a standard to which a customers supplied power to can be compared. However, in EU and other European counties,* **CENELEC EN50160 standard is used for characterisation of the supplied power***.*

Table 1: IEC EMC - power quality standards

IEC Publication	***Subject***
Basic EMC Publications: Compatibility levels	
61000-2-5	Classification of the EM environments
61000-2-1	Description of the EM environment in public LV power systems
61000-2-2	Compatibility levels in public LV power systems
61000-2-4	Compatibility levels in industrial plants
61000-2-6	Assessment of emission levels in industrial plants
61000-2-8	Voltage dips, short interruptions
60725	Reference impedance for LV power lines
Basic EMC Publications: Emission	
61000-3-2	Limits for harmonic current emissions (n ≤ 40), I ≤ 16A, LV
61000-3-3	Limitation of voltage fluctuations & flicker, I ≤ 16A
61000-3-4	Limits for harmonic current emissions (n ≤ 40), I ≤ 16A, LV
61000-3-5	Limitation of voltage fluctuations & flicker, I > 16A
61000-3-6	Limits for harmonic emissions in MV & HV power systems
61000-3-7	Limitation of voltage fluctuations & flicker in MV & HV power systems
61000-3-8	Emission levels, frequency bands and disturbance levels for signaling on LV installations
Basic EMC Publications: Measurement – emission	
61000-4-7	General guide on harmonics and interharmonics measurements and instrumentation
61000-4-15	Flickermeter – functional and design specification
61000-4-30	Power quality measurement

4. Power Quality Parameters

The performance of a customer's equipment can be degraded by conducted or radiated disturbance. Depending on a frequency, disturbance is classified as low frequency *(<9 kHz) or a* high frequency *(≥ 9 kHz).* Electrostatic discharge (ESD) and high-altitude nuclear electromagnetic pulse (HEMP) *are also covered by EMC standards.*
Power quality measurement is usually considered as a measurement of low frequency conducted disturbance with the addition of transient phenomena.
The following parameters of supply voltage are influenced by disturbances:

- frequency
- voltage level
- waveshape
- symmetry of three phase system.

Power quality events

The ideal supply voltage of a single phase is a pure sinusoidal voltage with nominal frequency and voltage amplitude. **Any variation from this is considered as a power quality event or a disturbance***.*
Classification of power quality parameters is shown in table 2.

Table 2: Power quality parameters

Variation of	***Parameter***	***Explanation***
Frequency	*Variation of power frequency*	*Ch. 3.1*
Voltage	*Variation of magnitude of supplied voltage* *Rapid voltage changes* *Supply voltage dips and swells* *Voltage interruptions* *Flicker (voltage fluctuation)* *Supply voltage unbalance*	*Ch. 3.2* *Ch. 3.3* *Ch. 3.4 & 3.5* *Ch. 3.6* *Ch. 3.7* *Ch. 3.8*
Waveform	*Transient overvoltages* *Voltage harmonics* *Voltage interharmonics* *Mains signaling voltage on the supply voltage* *Notching* *Noise*	*Ch. 3.9* *Ch. 3.10* *Ch. 3.11* *Ch. 3.12* *Ch. 3.13* *Ch. 3.13*

A short explanation of the influence to a customer's equipment is presented for each event from table 2.

4.1. Power frequency

Power frequency measurement is usually performed by zero crossing detection. Due to transients or harmonics multiple zero crossing cancellation techniques must be implemented.

Origin

Power frequency variation happens when the balance between generators and their loads changes. In normal circumstances, no significantly variation is likely to appear. Power frequency variations can be expected when the system is working in isolation from the public supply network. In this case the frequency may vary because of a higher impact of load switching onto a system or caused by poor load regulation.

Impact on customers' equipment

No significant impact.

Figure 1 *represents the measurement of power frequency over a week. During the measurement a severe storm caused a failure on a 35kV line. Variation of the frequency is noticeable during isolated generation.*

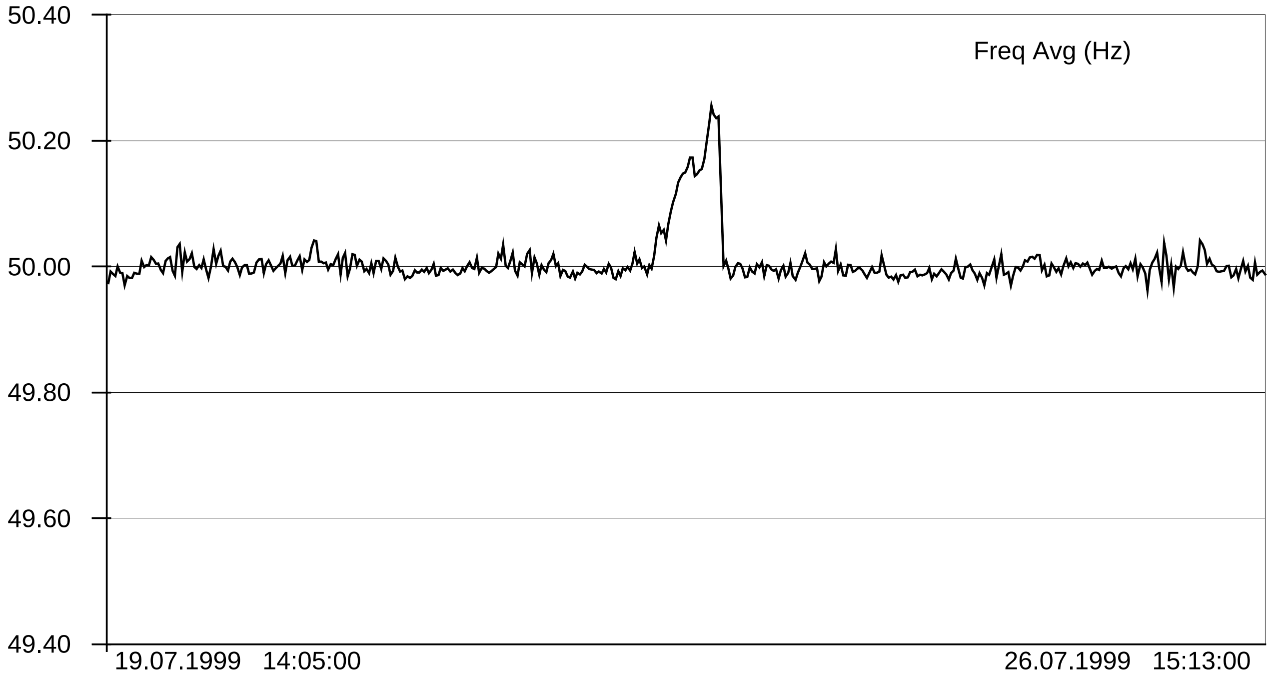


Figure 1: frequency variation

4.2. Supply voltage variation

The magnitude of the supply voltage is represented with a rms value of voltage during an aggregation period*. Statistical calculations on aggregated data are performed for a* measured period*. Aggregation interval is used for lowering the total number of measurements and can vary from a few seconds to 10 minutes. Variation in supply voltage is usually aggregated over a 10-minute interval.*

Origin

A change in rms value can happen because of load fluctuation, but installed automatic regulation can compensate for those changes within a few tens of seconds. Variations in magnitude of the supply voltage can be a problem when dealing with very long lines.

Impact on customers' equipment

Any variation in the magnitude of the supplied voltage outside of the +10% / -15% boundaries from nominal voltage can cause premature ageing, preheating or malfunctioning of connected equipment.

4.3. Rapid voltage changes

Rapid voltage change is a fast change in a voltage $U_{rms(1/2)}$ between two steady conditions. It is caused by switching on or off large loads. A typical cause of rapid voltage change is the start of a large motor. If a rapid voltage change exceeds the dip/swell threshold it is considered as a dip or swell. For the measurement of rapid voltage changes thresholds for each of the following characteristics must be set: the minimum rate of change (a), the minimum duration of steady state conditions (b), the minimum difference between two steady states (c) and the steadiness of state conditions (d). Figure 2 *demonstrates rapid voltage change with its thresholds.*

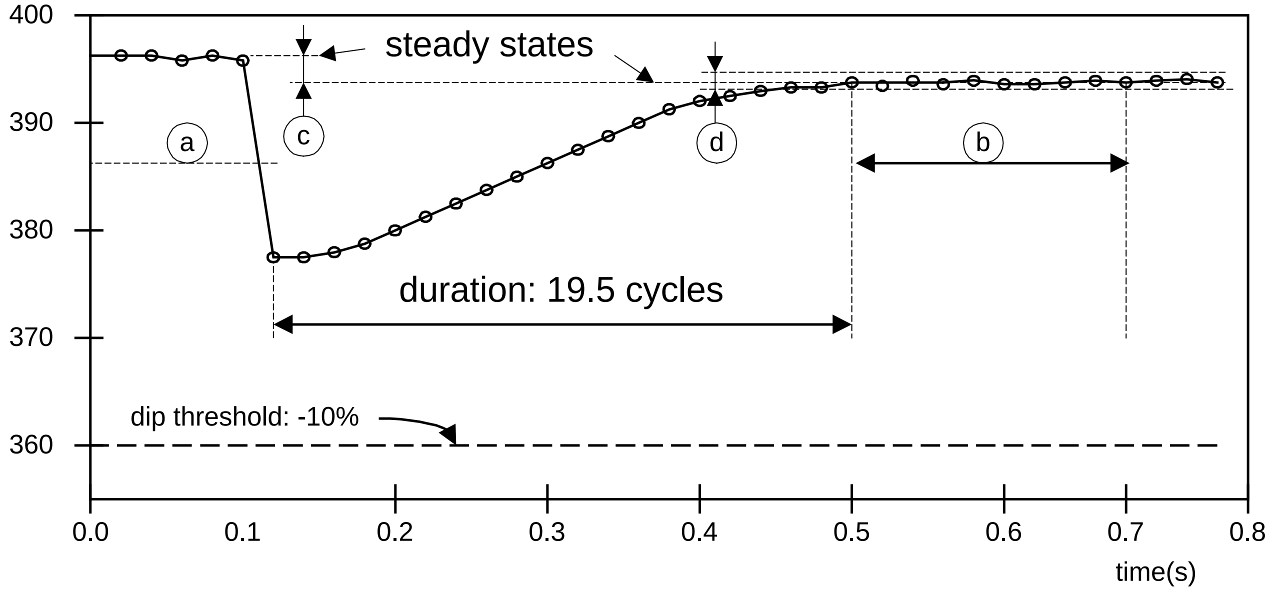


Figure 2: rapid voltage change definition

4.4. Supply voltage dips

Supply voltage dip represents temporary reduction of a voltage below a threshold. Duration of phenomena is limited up to 1 minute. Decreased voltage for period longer than a minute is considered as a magnitude variation.

Sag *is a term also used in some technical communities, but the latest efforts for EMC standard consistency defines* dip as the preferred term.

For the assessment dips the rms voltage is calculated over a single cycle or a half cycle and is refreshed each 10 ms i.e. every half of a cycle. This value is denoted as $U_{rms(1/2)}$. *The principle of a* $U_{rms(1/2)}$ *calculation is shown on figure 3. Every 10 ms a new rms value (marked with *) is presented for comparison with the dip threshold.*

Voltage dip is characterised by:

- dip threshold
- starting time of a dip
- dip duration
- retained voltage (u_{ret})

Figure 4 *presents an explanation of dip attributes. Dip threshold can be set by the user and represents part of nominal* U_n *or declared* U_c *(or* U_{dec} *in some standards) voltage and can vary from 0.9* U_c *for troubleshooting to 0.65* U_c *for contractual purposes. In this example the dip threshold is set to 0.85, i.e. 340 volts.*

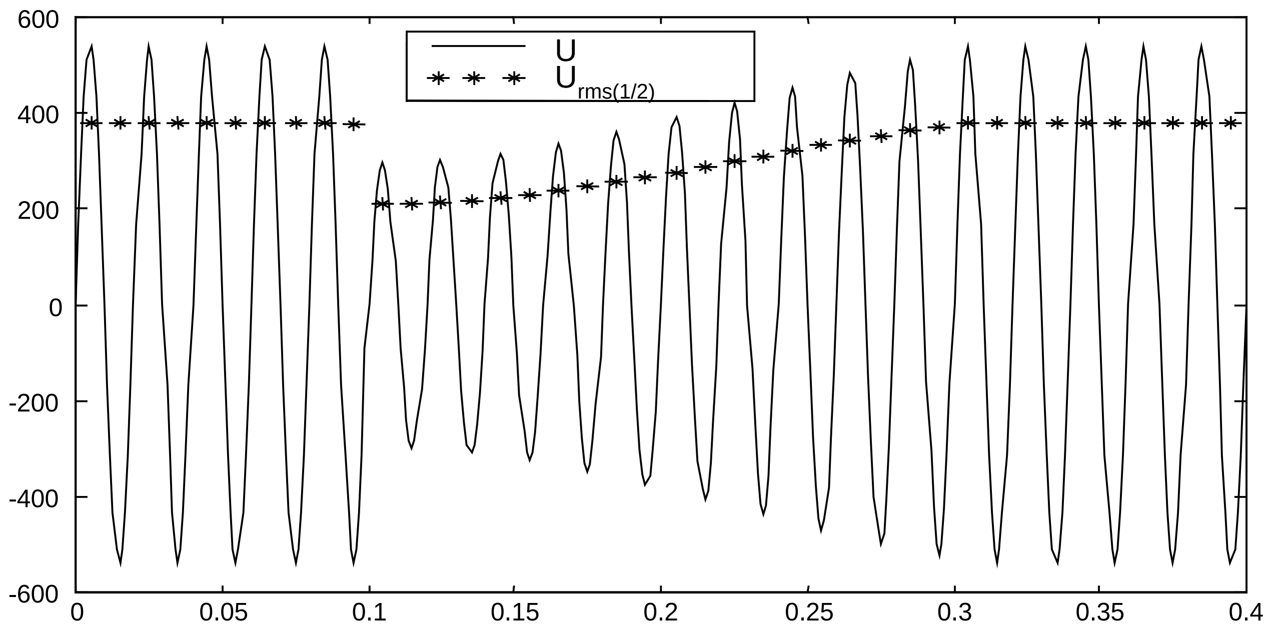


Figure 3: $U_{rms(1/2)}$ *envelope*

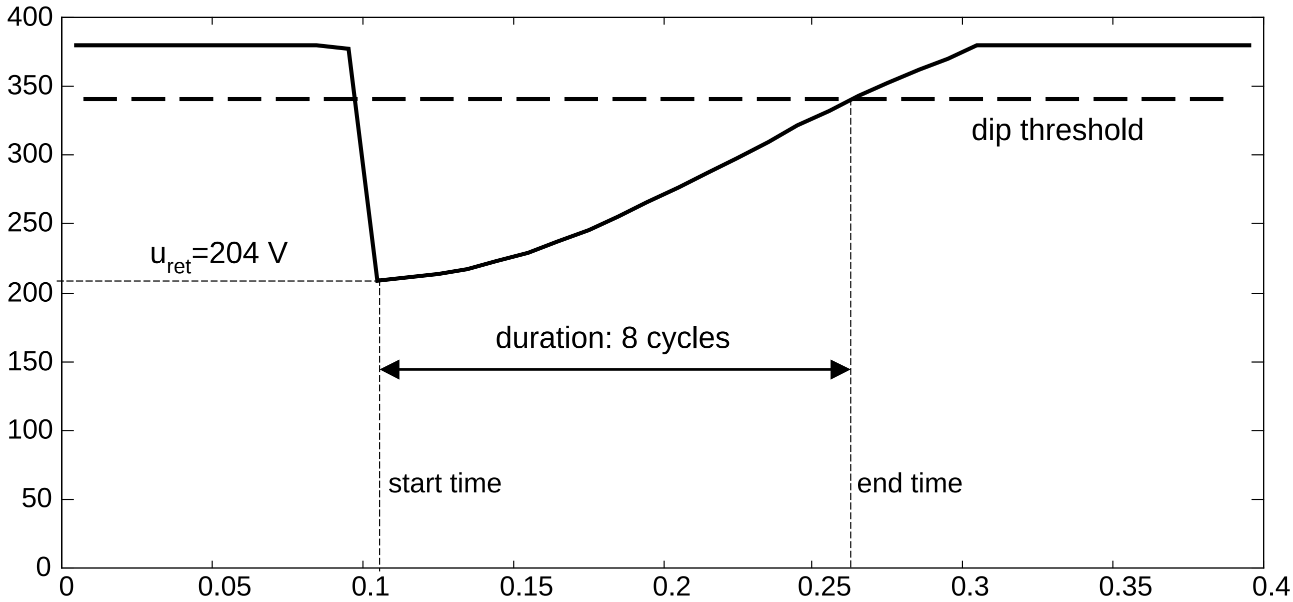


Figure 4: voltage dip attributes

The dip starts when $U_{rms(1/2)}$ drops below the dip threshold. The dip ends when $U_{rms(1/2)}$ rises above the dip threshold. The difference between end and start time is dip duration and is reported in seconds or in cycles. Retained (residual) voltage u_{ret} is the lowest $U_{rms(1/2)}$ value recorded during a dip.
The minimum set of attributes which describes a dip is a pair [u_{ret}, duration], although some instruments store more data such as the average voltage during the dip period or the shape of $U_{rms(1/2)}$ voltage. The example in figure 4 can be described as dip[209V,160ms] or dip[209 V,8c].

Note about retained voltage:

In some standards the term “voltage depth” *is used. A voltage depth of 90% equals a retained voltage of 10%.*

Notes about dip thresholds:

- instead of using U_n or U_c, a sliding reference voltage can be used for the calculation of a dip threshold. This option is useful for avoiding problems with transformer ratios when measurement is taken on both the LV and MV side of a system. Also, the retained voltage can be reported as a % or p.u. of rms value before dip.
- The end threshold is typically 1% higher than the start threshold. This is due to a problem, which can arise if a measured value is near to the start of a dip threshold.

Figure 5 presents single-phase (a), two phases (b) and all three phases (c) voltage dip. Mainly, because of contractual reasons, dips on different phases are assumed to be one event if those dips overlap in time (i.e. dip is started on one phase and finished on another).

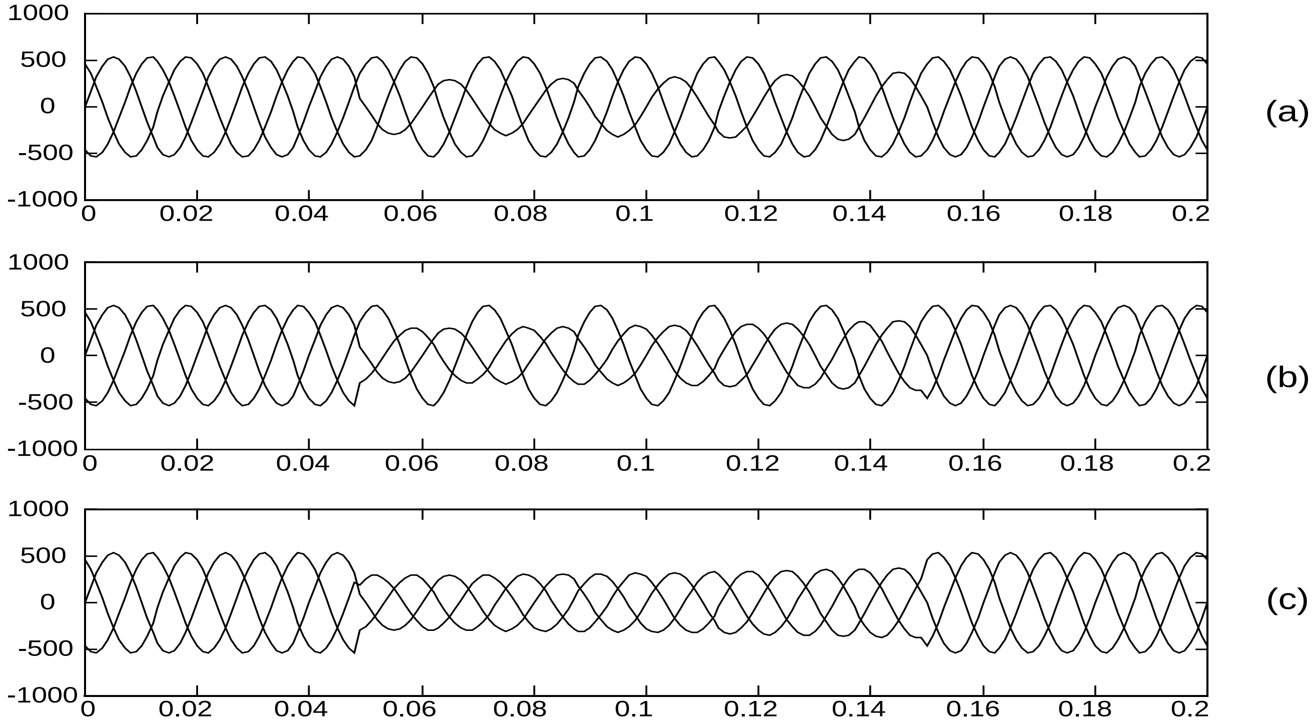


Figure 5: three-phase system dips

Origin

Voltage dips are caused by failures in the network or by excessively large inrush currents.

Impact on customers' equipment

Studies conducted over recent years have confirmed that voltage dips cause the majority of malfunctions of equipment. Relays and contractors can drop out if a dip is 60% for longer that 1 cycle. Potential damage is dependent on the ability of the equipment to sustain lower voltage for short periods. Information technology is particular sensitive to a dip. There are several criteria for the evaluation of dip severity such as the ITIC curve. Electronic drives, converters and equipment with an electronic input stage are also sensitive to dips. An asynchronous motor can draw a current higher than it's starting current at dip recover.

4.5. Supply voltage swells

Swells are instantaneous voltage increases (opposite to dips). A graphical representation of a swell is shown on figure 6. The same attributes are used for the classification of swells as are used for dips.

Origin

The origin of swells are single line ground failures (SLG), upstream failures, switching off a large load or switching on a large capacitor.

Impact on customers' equipment

Since swells usually last for a short period, there is no significant impact on equipment. However, light bulbs can burn out and safety problems may arise.

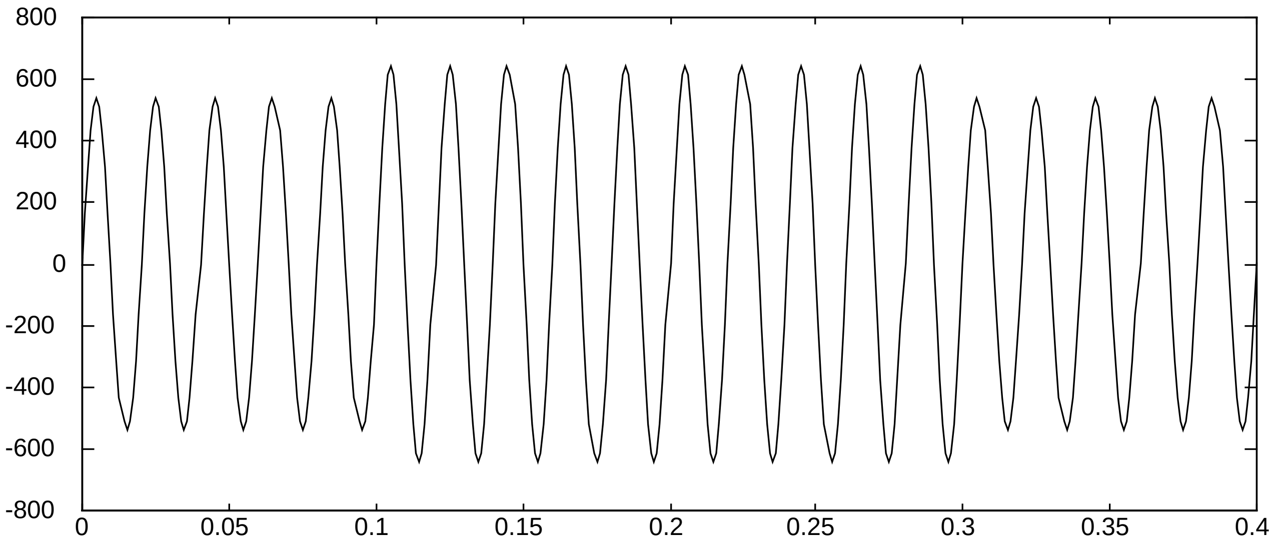


Figure 6:voltage swell

4.6. Voltage interruptions

An interruption is classified as a network's isolation from any source of supply. Because of energy stored in a network, a specific voltage above zero, exists for a short period after the interruption commences. For this reason an interruption is detected as a $U_{rms(1/2)}$ drop below an interruption threshold. The interruption threshold can vary but is usually set to 1%, 5% or 10% of the declared voltage. The duration of an interruption is measured in the same manner as a measurement of dip duration after setting an interruption threshold.
Because of the measurement technique a short circuit fault can appear as a short interruption in one section of the network and a dip in another.
Interruptions are classified in two groups:

- ***short interruptions***
- ***long interruptions.***

Origin

Short interruptions are introduced by a fault condition in a network, which causes switchgear to operate. Complex schemes of operations are used for reclosing purposes. The duration of a short interruption is limited to 1 minute or 3 minutes depending upon the reclosing operation, the standard used or the contract between supplier and customer.
Long interruptions are interruptions in excess of the short interruption duration limit. They arise when a fault condition cannot be terminated with a control sequence and the final tripping of a circuit breaker occurs.
A comparison between the IEC and EN50160 standard for interruption limits i.e. short and long interruption is shown on figure 7.

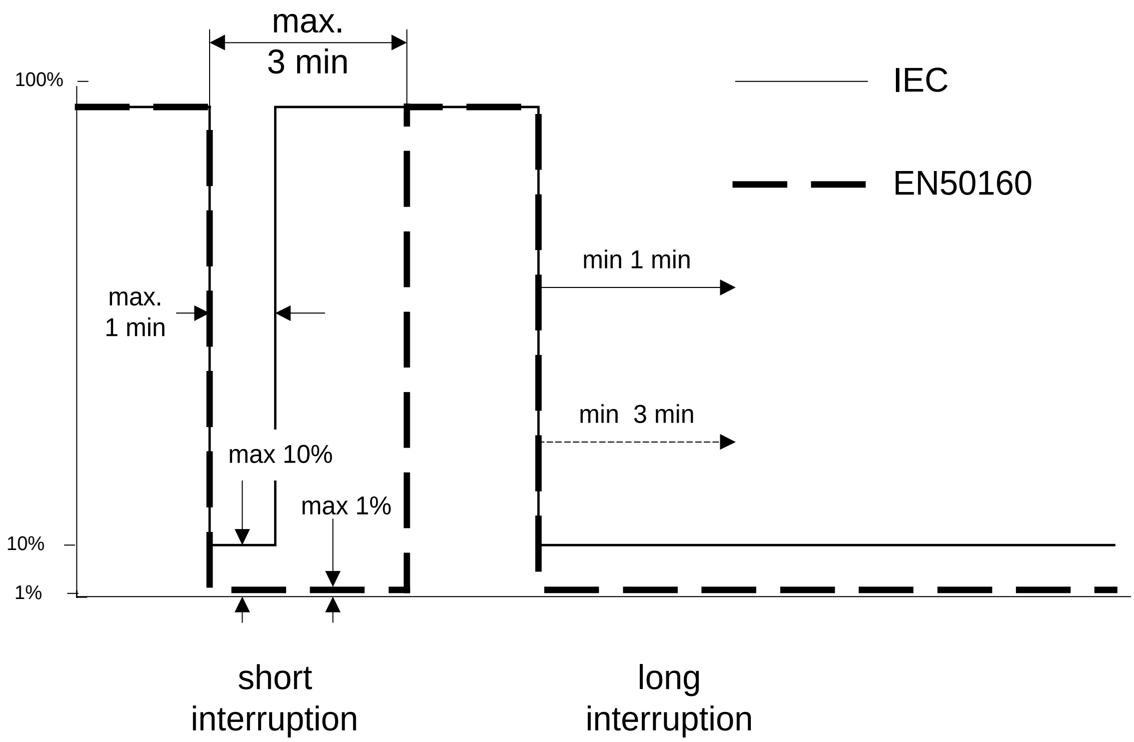


Figure 7: interruption threshold and duration definitions

Impact on customers’ equipment

In an industrial environment interruptions can cause disruption in production by increasing the number of rejects or material wastage. In some areas, interruptions can increase the risk of equipment damage or even injury. Information technology is affected in two ways. First, current data can be lost and the system can be corrupted. Second, after interruption is over, the re-boot process, especially on a large and complex system, can last for several hours. Because of these reasons, critical computer systems and telecommunication equipment are supplied with UPS power.

4.7. Flicker

Flicker is a visual sensation caused by unsteadiness of a light. The level of the sensation depends on the frequency and magnitude of a light change and on the observer.
Changing of a lighting flux can be correlated to a voltage envelope on a figure 8.

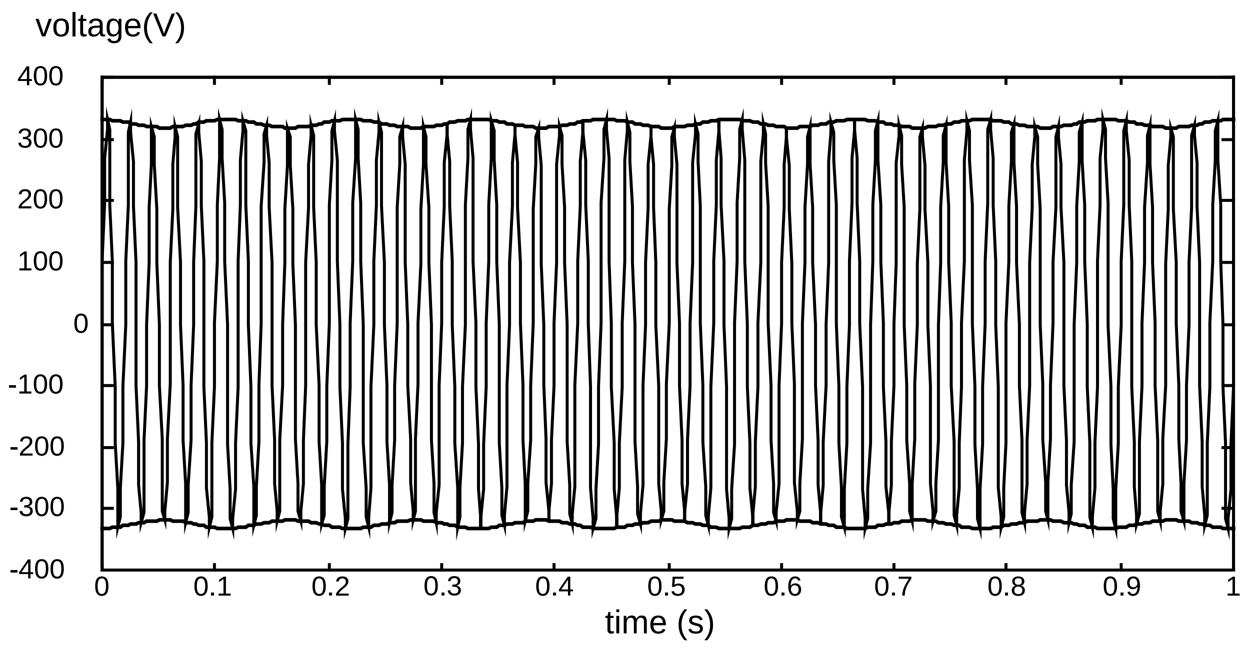


Figure 8: voltage fluctuation

Flicker is measured in accordance with standard IEC 61000-4-15 “Flickermeter-function and design specifications”*. It is based on a 230V/60W lamp-eye-brain chain response. That function is the basis for flickermeter implementation and is presented on figure 9.*

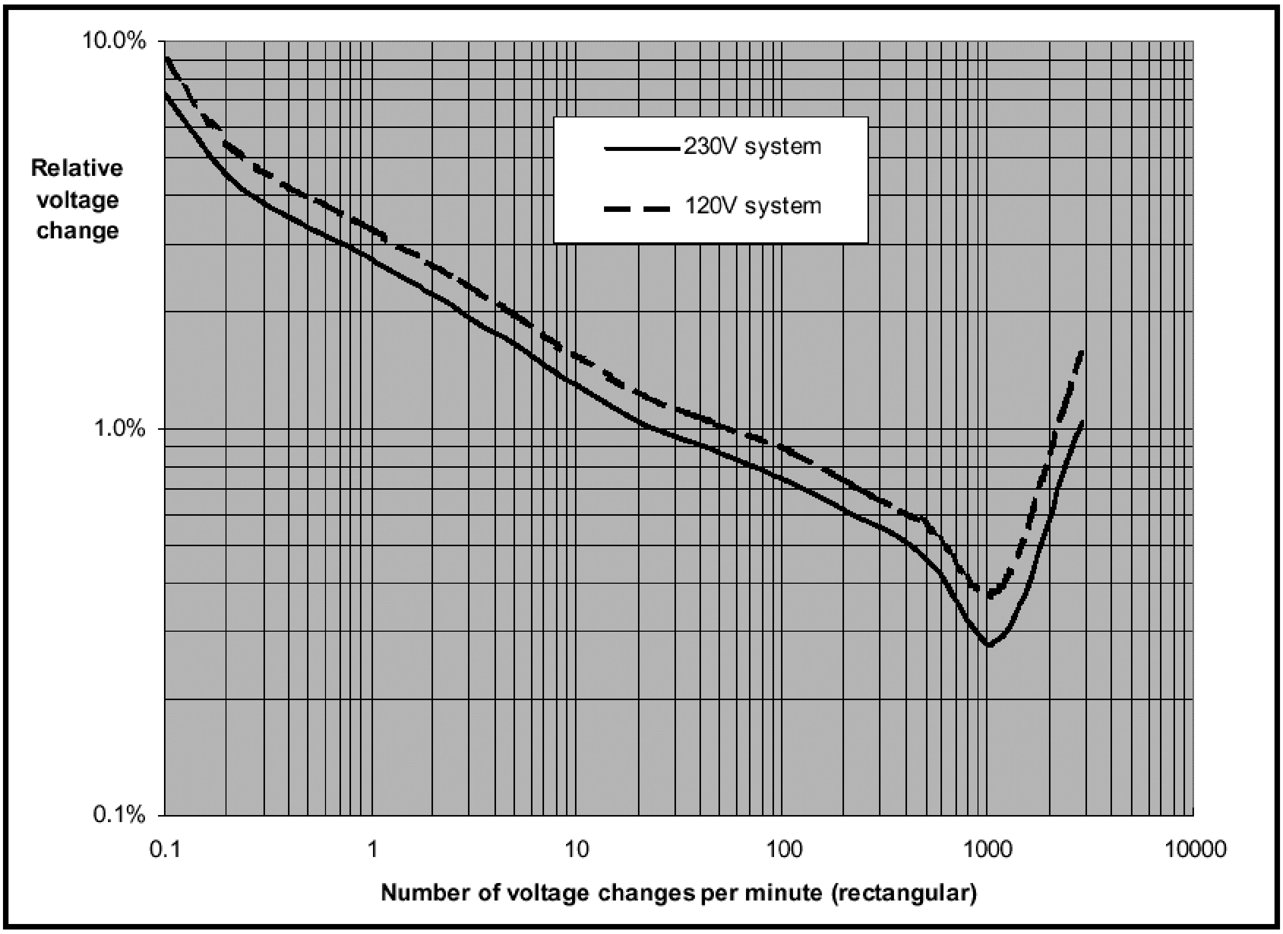


Figure 9: Curve of equal severity (Pst=1) for rectangular voltage changes on LV power supply systems.

Flickermeter *is an instrument designed to measure any quantity representative of flicker (IEV 161-08-14). It measures voltage fluctuation, performs filtering (calculations) and provides a* ***short-term*** ***(P_{st})*** *and* ***long-term*** ***(P_{lt})*** *flicker indicator.*
Short-term flicker indicator *has a value equal to 1 for the fluctuation of luminance that is found annoying by 50% of the population. Short-term flicker is measured over a period of 10 minutes.*
Long-term flicker indication *is calculated from the last 12 short-term indicators i.e. the last 2 hours period, by equation (1).*

$$P_{lt} = \sqrt[3]{\frac{1}{12}\sum_{i=0}^{11} P_{st}(i)^3} \qquad (1)$$

Origin

Origins of voltage fluctuation are arc furnaces, welding machines and similar heavy loads that consume greatly varying currents. Flicker can arise in the presence of interharmonics with a frequency close to the base frequency or harmonic.

Impact to customers' equipment

Magnitude of voltage fluctuation is usually below 3% of supply voltage and does not have any noticeable influence to equipment. Flickering caused by voltage fluctuation of just 0.2% with frequency of 9 Hz is considered as annoying.

4.8. Supply voltage unbalance

Supply voltage unbalance *arises when rms values or phase angles between consecutive phases are not equal. Term* imbalance *is also used as an alternative.*
Supply voltage unbalance is defined as the ratio of the negative sequence component to the positive sequence component (2). Several other formulas can also be used for supply voltage unbalance (3,4,5).

$$u_u = \frac{|V_i|}{|V_d|} \cdot 100\ \% = \frac{negative\ sequence}{postive\ sequence} \cdot 100\ \% \qquad (2)$$

$$u_u = \sqrt{\frac{6\left(U_{12}^2 + U_{23}^2 + U_{31}^2\right)}{\left(U_{12} + U_{23} + U_{31}\right)}} \cdot 100\ \% \qquad (3)$$

U_{12}, U_{23}, U_{31} - *line voltages*

$$u_u = \sqrt{\frac{1 - \sqrt{3 - 6\beta}}{1 + \sqrt{3 - 6\beta}}} \cdot 100\ \% \qquad (4)$$

$$\beta = \frac{U_{12}^4 + U_{23}^4 + U_{31}^4}{\left(U_{12}^2 + U_{23}^2 + U_{31}^2\right)^2}$$

$$u_u = \max_i \frac{U_i - U_{avg}}{U_{avg}} \cdot 100\ \% \qquad (5)$$

U_i − *phase voltage*; $U_{avg} = \frac{U_1 + U_2 + U_3}{3}$

Origin

Unbalance happens when current consumption is not balanced or during a faulty condition before tripping

Impact on customers’ equipment

Voltage unbalance affects three phase asynchronous motors causing overheating and a tripping of protective devices.

4.9. Transient overvoltages

*Transient is a term for **short, highly damped** momentary voltage or current disturbance.*

There are two types of transient overvoltages:

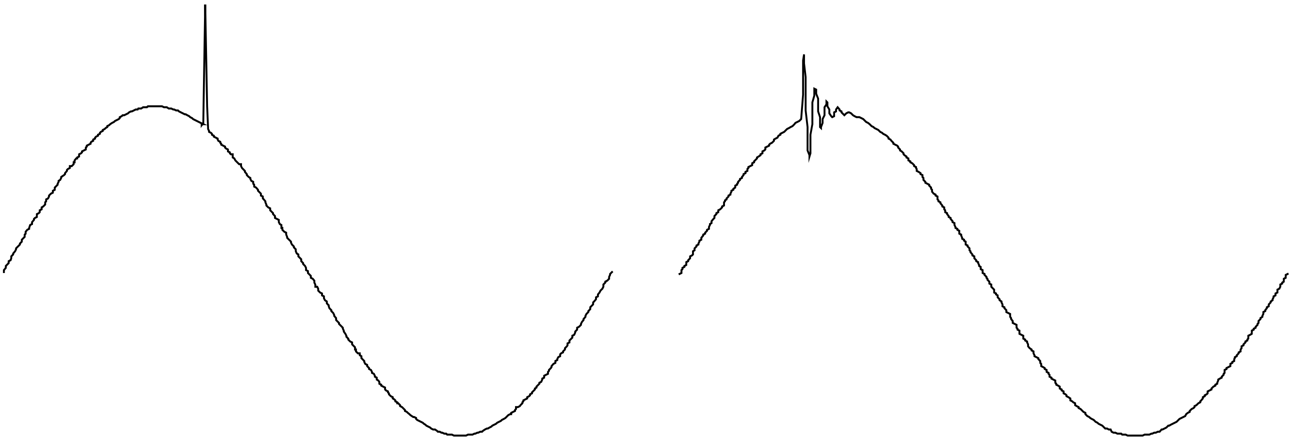
- impulsive overvoltage
- oscillatory overvoltage

Origin

Impulsive transient overvoltages *are* unidirectional *disturbances caused by lighting and have a high magnitude but low energy. Frequency range is above 5kHz with duration 30-200 microseconds.*
Oscillatory transient overvoltages *are caused by switching, ferroresonance or can arise as a system response to an impulsive overvoltage. Switching overvoltages have high energy and are classified as low (<5kHz), medium (5kHz<f<500kHz) and high frequency (>500kHz) transients.*

Impact on customers’ equipment

Transient overvoltages cause the immediate failure or degradation of a transformer, capacitor or semiconductor or causes cable isolation that can lead to faulty operation. Electronic drives may fall out. Also, magnification of MW transients caused by capacitor bank switching may occur under some circumstances producing 2-4 p.u. overvoltages on LV side.



impulse transient oscillatory transient

Figure 10: transients

4.10.Harmonics

Basics

Any periodic deviation of a pure sinusoidal voltage waveform can be presented with the sum of sinusoids of the power frequency and its integer multiples*. Power frequency is called the* **fundamental frequency***. A sinusoidal wave with a* frequency k times higher than the fundamental (k is an integer) *is called* **harmonic wave** *and is denoted with* amplitude and a phase shift (phase angle) *to a fundamental frequency signal. The ratio between harmonic frequency and a fundamental frequency (k) is called* **harmonic order***.*
The term harmonic is usually used for a rms value of a harmonic wave
Instruments used for measuring power quality events perform an A/D conversion *changing the input voltage into a* sequence of data*. A calculation called* discrete Fourier transformation (DFT) *or its faster version* fast Fourier transformation (FFT) *is used to translate the sequence of input data into* sinusoidal components*. The equation (6) describes the relationship between an input signal and its frequency presentation. The upper sum limits in equation (6) is limited by the sampling rate. The highest harmonic frequency is* half of the sampling frequency*.*

$$u(t) = c_{U0} + \sum_{k=0}^{\infty} c_{Uk} \sin\left(k \cdot 2\pi\, f_1 t + \phi_{Uk}\right) \qquad (6)$$

c_{U0} - *DC component*

c_{Uk} – *amplitude of k ordered voltage harmonic*

ϕ_{Uk} – *phase shift of k ordered voltage harmonic*

f_1 – *fundamental freqency*

The presence of harmonics is evaluated through total harmonic distortion (THD)*. Voltage harmonics are asserted with THDU. THDU is a ratio of the rms value of the harmonic voltage to the rms value of the fundamental and is calculated by equation (7). THD is usually stated as a percentage.*

$$THDU = \sqrt{\frac{\sum_{k=2}^{40} U_k^2}{U_1^2}} = \sqrt{\frac{\sum_{k=2}^{40} c_{Uk}^2}{c_{U1}^2}} \qquad (7)$$

$$U_k = c_{Uk} / \sqrt{2} \qquad - \text{rms value of voltage harmonic } k$$

$$u_k = \frac{U_k}{U_1} \cdot 100\% \quad - \text{procentual value of voltage harmonic } k$$

Figure 11 (a) presents a typical power supply voltage waveform in a residential or light industrial environment. Switching devices (see explanation for figure 12) cause a flattening of the top of the sinusoidal wave. Diagram (b) is the frequency spectrum *and shows the distortion of a sinusoidal wave caused by voltage harmonics. Each harmonic can be expressed with its amplitude (c_k), rms values (U_k) or percentage (u_k,). Percentage presentation as used in figure 11(b) is the most commonly used when dealing with power quality.*
In this example the input signal is sampled at 128 samples per period, resulting in the 64th harmonic as the highest that can be measured.
For power quality measurements the analysis of harmonics is reduced to the 50th harmonic i.e. to 2500 Hz for a 50 Hz network*. Phase angle between voltage harmonics and the fundamental is not considered as a power quality issue. However, phase differences between the voltage and current harmonics of same the harmonic order can be used for tracing a harmonic disturbance generator.*

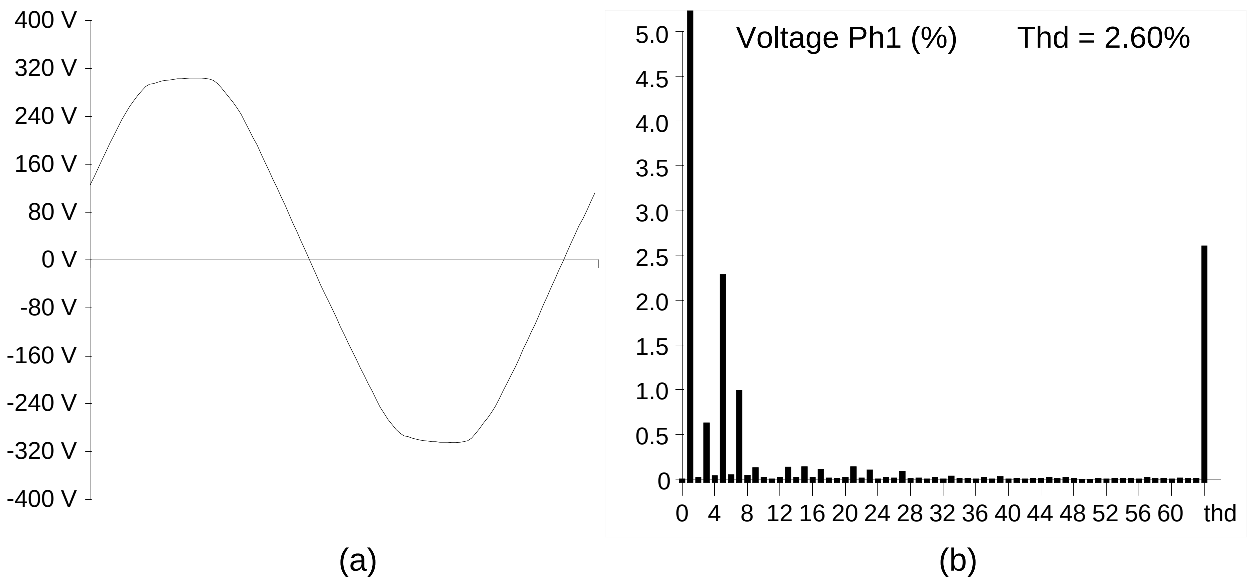


Figure 11: typical voltage waveform and its harmonic representation

Everything presented for voltage harmonics is also valid for current harmonics and THDI.

$$i(t) = c_{I0} + \sum_{k=0}^{\infty} c_{Ik} \sin\left(k \cdot 2\pi f_1 t + \phi_{Ik}\right) \qquad (8)$$

c_{I0} - *DC component*

c_{Ik} – *amplitude of k ordered current harmonic*

ϕ_{Ik} – *phase shift of k ordered current harmonic*

$$THDI = \sqrt{\frac{\sum_{k=2}^{40} I_k^2}{I_1^2}} = \sqrt{\frac{\sum_{k=2}^{40} c_{Ik}^2}{c_{I1}^2}} \qquad (9)$$

$I_k = c_{Ik} / \sqrt{2}$ – *rms value of current harmonic k*

$i_k = \frac{I_k}{I_1} \cdot 100\%$ – *procentual value of current harmonic k*

Harmonics origin

Figure 12 explains the principle of harmonic origination. From the user's perspective a power supply network can be presented as generator G *and* reference impedance Xs*. The generator voltage is considered as a pure sinusoidal voltage with a nominal rms value. The voltage on a customer's supply terminals differs from the generator voltage because of voltage drop on the reference impedance. In the case of a linear load (a resistor in this example, but the example is valid for any RLC combination) the current and consequential voltage drop will also be sinusoidal. Gathering voltage on terminals will be pure sinusoid with decreased amplitude and with a phase shift to the generator's voltage.*

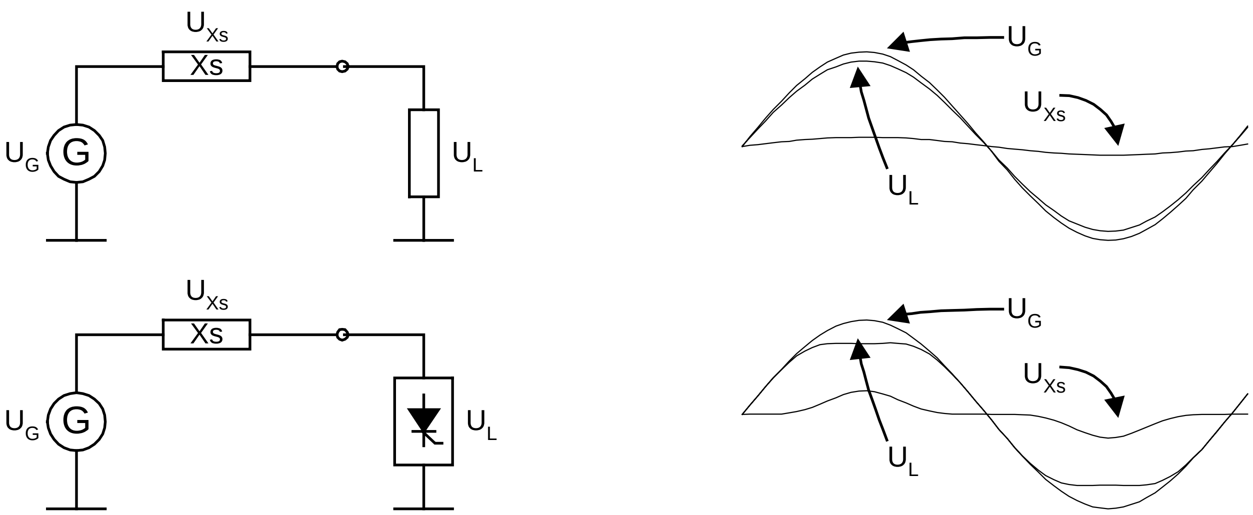


Figure 12: harmonics origin

Non-linear loads (rectifiers, variable speed drives, fluorescent lamps, PC, TV...) draw current with a high THDI (highly non-sinusoidal waveform). For analysis purposes, non-linear loads can be modelled with linear loads and the (current) source of harmonics. Current harmonics cause a non-sinusoidal voltage drop on the reference impedance and a distorted voltage at the power supply terminals. Non-linear loads disturb the supply voltage in such a way that only **odd harmonics** *can be detected with a measurement instrument*.
If the load is non-symmetrically controlled, positive and negative half periods of current differ in shape and rms value causing **even harmonics and a DC component** *to arise. This situation causes saturation and overheating of transformer cores. A significant DC component can be caused by geomagnetic storms in some areas.*
Another source of harmonics is the supply network itself. Magnetisation of the energy transformer core and its saturation cause non-sinusoidal currents that are manifested as a THDU on the supply terminals.
Figure 13 shows how harmonic disturbance can spread. The voltage waveform at a specific measuring point is distorted by the influence of current generated by all of the disturbance generators (frequency converters, welders, PC, power transformers...) in a system

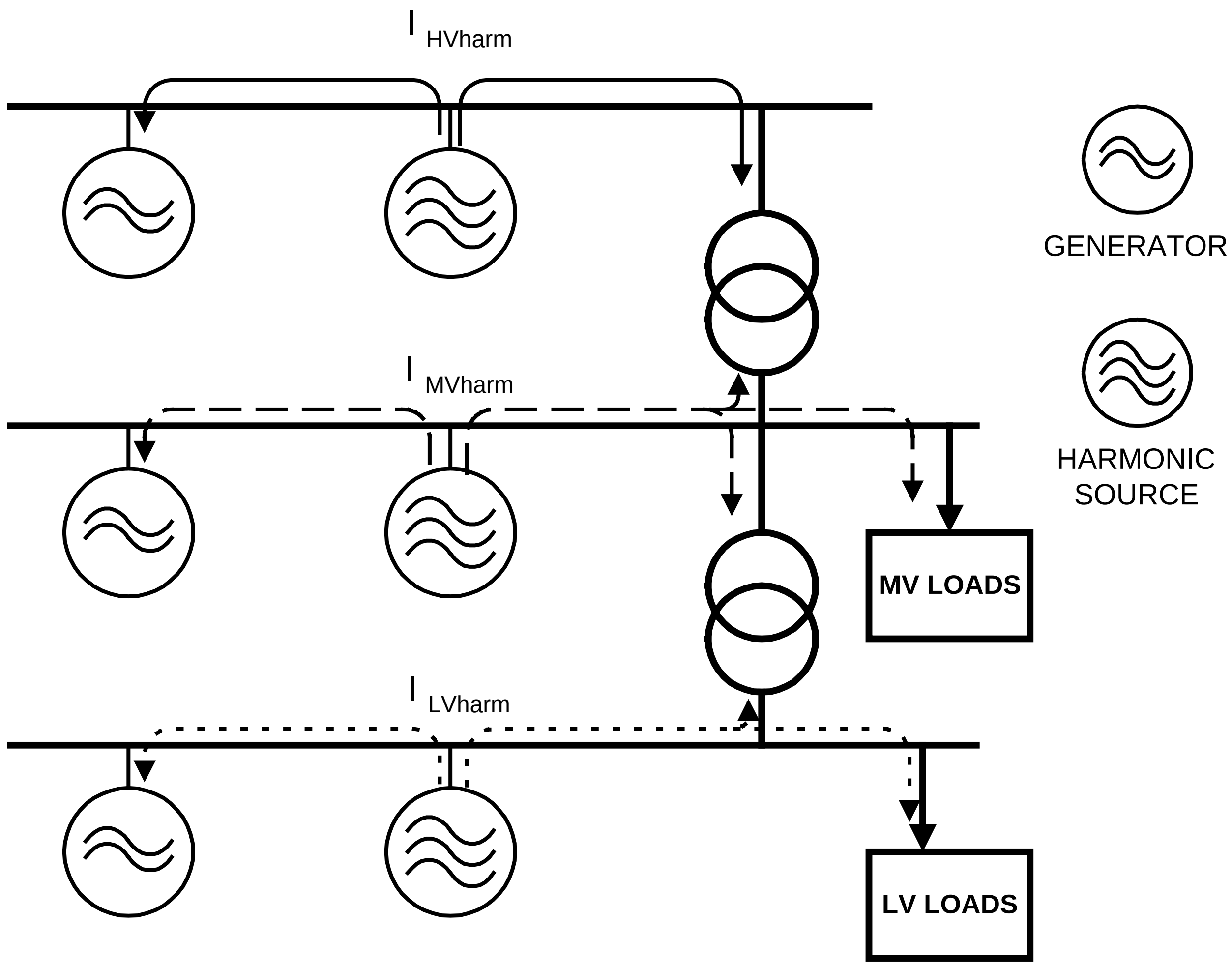


Figure 13: harmonic disturbance spreading

Origins of harmonics disturbances

- ***single phase rectifiers – high 3rd harmonic, THDI 80%***
- ***three phase loads – 5th, 7th, 11th, 13th, 17th harmonic***
- ***non-symmetrically controlled supply – even harmonics and DC***
- ***higher pulse number – lower THDI***
- ***serial inductance decreases THDI***
- ***LV power supply network – THDU 1.5 ÷ 4.5%, mainly 5th harmonic***

Impact on customers' equipment

- ***overall energy efficiency is decreased***
- ***premature ageing of system components***
- ***triple harmonics can produce high currents in a neutral line causing overheating and losses***
- ***increased heating, noise and vibrations in transformers and motors***
- ***current into capacitor bank increases with harmonic order causing failures***
- ***presence of harmonic increase possibility of resonance***
- ***problems with signalling frequencies***
- ***tripping of protection devices***
- ***electronic drives and switchers failure rate increases if THDU rises above 8%***

Table 3: harmonic level limits for LV networks (IEC)

Odd harmonics				**Even harmonics**	
Non-multiple of 3		**Multiple of 3**			
Harmonic Order h	**Harmonic Voltage %**	**Harmonic Order h**	**Harmonic Voltage %**	**Harmonic Order h**	**Harmonic Voltage %**
5	*6*	*3*	*5*	*2*	*2*
7	*5*	*9*	*1,5*	*4*	*1*
11	*3,5*	*15*	*0,4*	*6*	*0,5*
13	*3*	*21*	*0,3*	*8*	*0,5*
$17 \leq h \leq 49$	*2,27x(17/h)–0,27*	$21 < h \leq 45$	*0,2*	$10 \leq h \leq 50$	*0,25 x (10/h) + 0,25*

NOTE - The levels given for odd harmonics that are multiples of three apply to zero sequence harmonics. Also, on a three-phase network without a neutral conductor or without load connected between line and ground, the values of the 3rd and 9th harmonics may be much lower than the compatibility levels, depending on the unbalance of the system.

Table 4: values of the individual harmonic voltage at the supply terminals for order up to 25 given in percent of Uc (EN50160)

Odd harmonics				***Even harmonics***	
Non-multiple of 3		***Multiple of 3***			
Harmonic Order h	***Harmonic Voltage %***	***Harmonic Order h***	***Harmonic Voltage %***	***Harmonic Order h***	***Harmonic Voltage %***
5	*6*	*3*	*5*	*2*	*2*
7	*5*	*9*	*1,5*	*4*	*1*
11	*3,5*	*15*	*0,5*	*6..24*	*0,5*
13	*3*	*21*	*0,5*		
17	*2*				
19	*1.5*				
23	*1.5*				
25	*1.5*				
NOTE – No values are given for harmonics of order higher than 25, as they are usually small but largely unpredictable due to resonance effects.					

4.11.<u>Interharmonics</u>

If a signal decomposition with Fourier transformation results in the presence of a frequency that is not an integer multiple of the fundamental*, this frequency is called an* interharmonic frequency *and a component of such a frequency is called an* interharmonic*.*

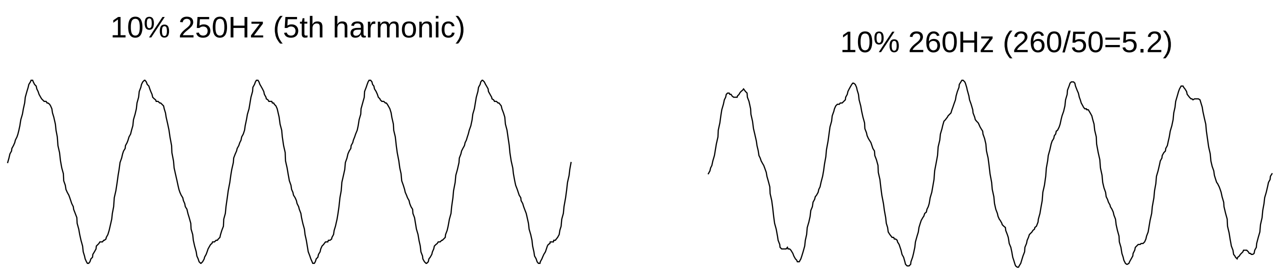


Figure 14: interharmonics example

The IEC 61000-4-7 Standard "General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto" specifies the principle of interharmonics measurement. A 200 ms window (10 periods of 50 Hz or 12 periods of 60 Hz signal) is used in DFT calculation resulting with 5 Hz increment in frequency spectrum. Part of the spectrum is presented on figure 15. Each 10th bar in the frequency spectra represents harmonic frequency and the terminology used for denomination of harmonic is $\boldsymbol{C_{10k}}$, $\boldsymbol{U_{10k}}$ *and* $\boldsymbol{u_{10k}}$ *where k is harmonic order. For assessment of harmonics, spectral lines are grouped in harmonics and interharmonics groups.*

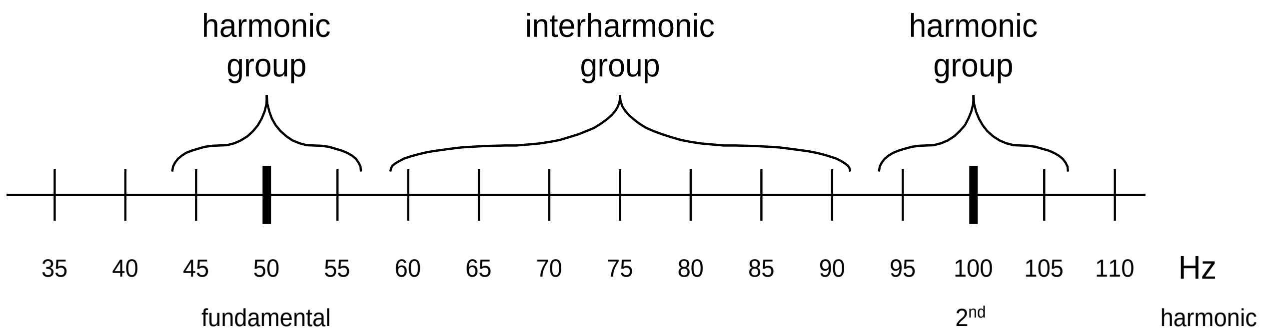


Figure 15: detail of interharmonics DFT spectra

Origin

Sources of interharmonics are **highly fluctuating loads** such as arc furnaces, welders and welding machines, cycloconverters, intermittent regulators, frequency converters and low frequency power line carriers (ripple control).

Impact on customers' equipment

In addition to the problems encountered in the harmonic description, interharmonics cause

- ***flicker in the presence of interharmonics near to harmonic frequency***
- ***excitation of low frequency mechanical oscillations (a torsion stress because of generator-load oscillation)***
- ***variations in processes and other measurements***
- ***malfunction in ripple control.***

4.12. Mains signaling

Main signalling is classified in four groups:

- ripple control systems (110 Hz to 3000 Hz)
- medium-frequency power-line carrier systems (3kHz – 20kHz)
- radio-frequency power-line carrier systems (20kHz – 148.5kHz)
- mains-mark system

A comparison between IEC and EN50160 limits is shown on figure 16.
Note: IEC standard limits for a signalling voltage with frequencies above 3kHz are under consideration.

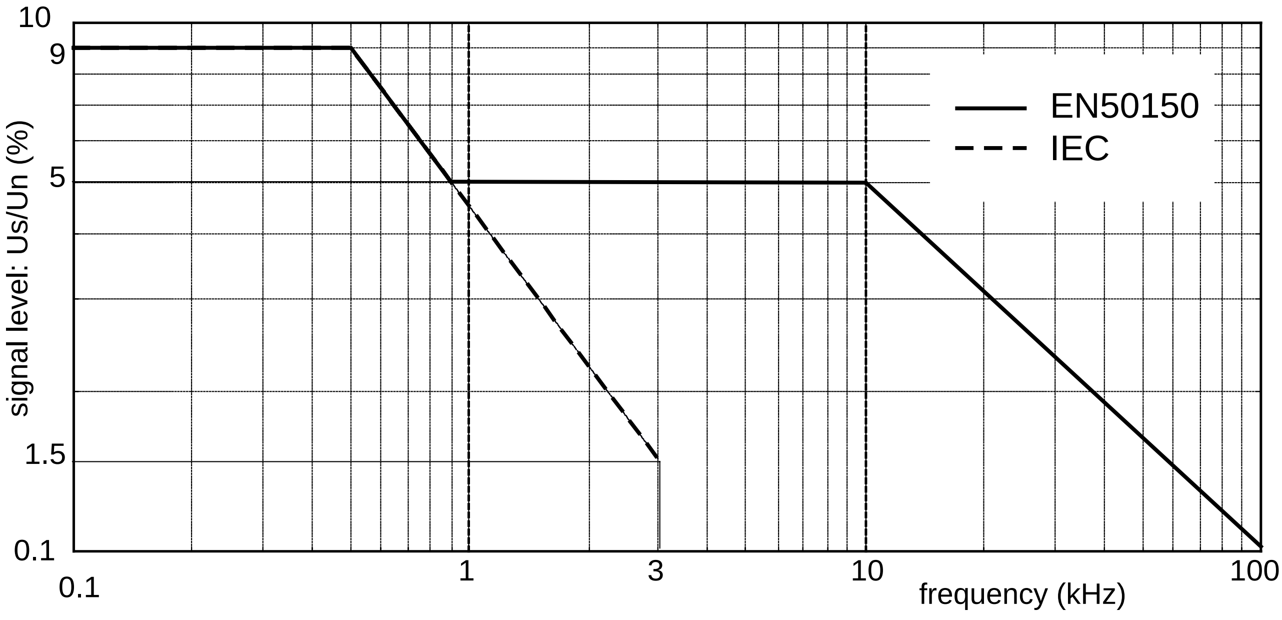


Figure 16: signaling voltage level limits

4.13. Notching and noise

Origin

Notching is a phenomenon caused by the internal circuitry of controlled rectifiers which generate a short period, high current spike which also influences the voltage.
Noise is wide spectrum signal superimposed on the power supply voltage. It is generated mainly by telecommunication equipment, PCs and PLCs. Serial inductance, filters, isolation transformers and line conditioners can be used for the suppression of noise and notching.

Impact on customers' equipment

Notching can impact zero crossing circuitry. A high dU/dt ratio can cause faulty SCR triggering. Troubleshooting often demands time domain techniques.

Note: Both disturbances are evaluated through THD in power quality measurement.

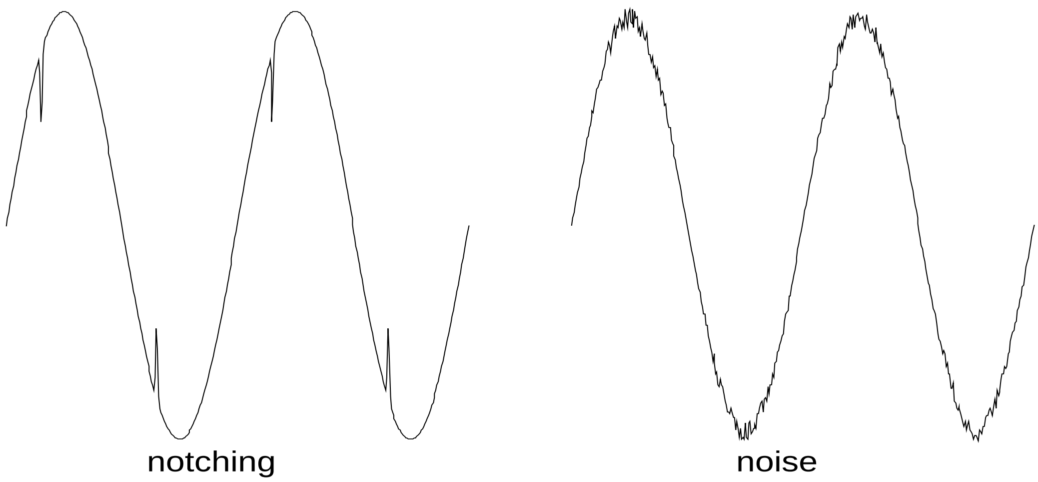


Figure 17: notching and noise

4.14. Integrating interval

To obtain adequate information about the behaviour of a network, the power quality events explained in chapters 3.1 to 3.13 must be measured over a longer period of time. One week is considered as the minimum cyclic time that the whole variety of different states of the network can be seen.
During that time a large quantity of data must be processed. For example, a dip/sag assessment is based on a 10ms rms value of a voltage. There are approximately 60.480.000 such values for just one phase voltage per a week. Harmonics, flicker and three-phase measurements just increase the amount of data. To ensure efficiency the data must be concentrated.
Concentration of data is achieved by **integrating** (aggregating, integrating) *the data over a specific time period known as the* **integrating** (aggregating, averaging) **interval.** *There are three values involved in each integrating interval:* average, minimum and maximum *value of measurement in that value. At the end of an integrating interval each record (average, minimum, maximum) is saved in the instruments memory and after the measurement is complete, the data is downloaded from the instrument to the PC. The duration of the integrating interval can set by the user from a few seconds to 15 minutes, but standards dealing with power quality use 10 minutes integrating.*

4.15.Cumulative frequency

When using data averaging within the integrating interval the amount of data stored in an instrument's memory is greatly reduced. However, there are still 1008 ten minute intervals in a week and 3024 values (average, minimum, maximum) are stored for each user selectable channel enabled in recording. Additional data concentration can be performed on a PC after the data is downloaded from the instrument. The "statistics of the statistics" is performed for two reasons:

- due to the stochastic nature of voltage variations, some events in power quality measurement **results are better characterised by statistical means** then averages and extremes
- result of a whole measurement can be presented with a **single value**

Cumulative frequency *is a method used for statistical evaluation of the measured values. Figure 18 shows the characteristic* **histogram** *of a recorded voltage THD. The cumulative frequency (bold line) is used as a criterion in the EN50160 standard. The values on a x-axis called* bins *represents the number of integrating periods. For example, bin 2 has a value of 190 that means that 190 average values of 10 minute voltage THD are within the range 2.25 to 2.75.*
Another value stated on the histogram is called **CP95** and is the percentage of readings which are greater than 95% of the samples in a measurement period*.* ***The CP95 value of a particular measurement is used for validation on standard defined limits****.*

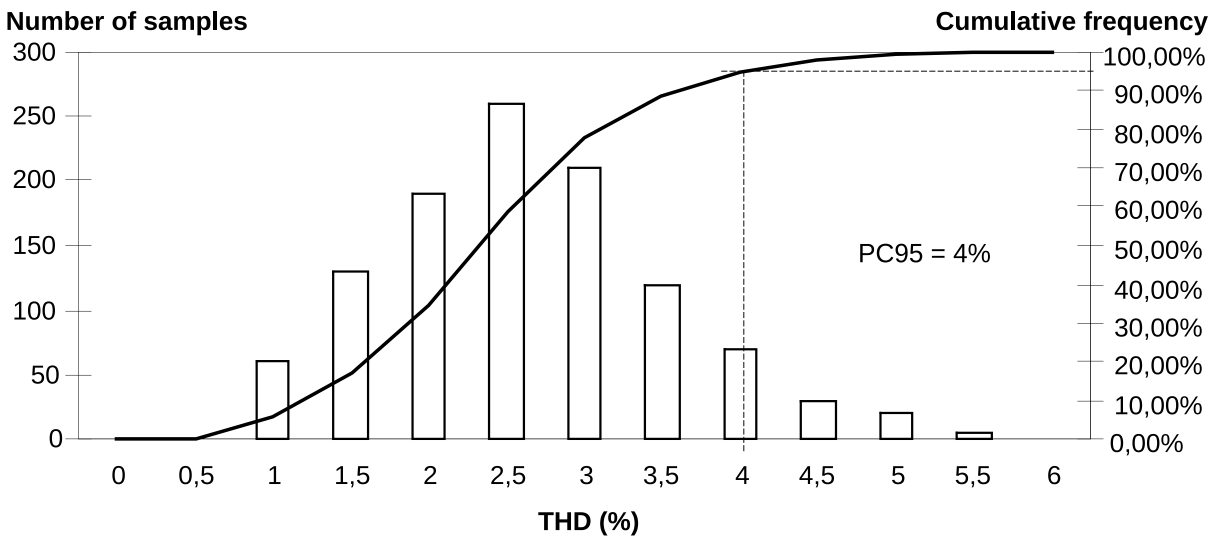


Figure 18: cumulative frequency

4.16.Evaluation against standard's limits

In order to confirm that the disturbances in a power supply remain within allowable boundaries, the results of the power quality measurements must be evaluated against the limits defined in the standards.

Standards dealing with power quality characterise voltage variation in two different ways:

- with descriptive indices
- with statistically obtained values

Descriptive indices *are used for power quality events that have a highly random nature, can vary in time and are highly dependent on the topology of the system. Those events happen* **occasionally***. They cannot be limited uniquely and only approximate figures are given. This is approach applied for describing:*

- ***rapid voltage changes***
- ***voltage dips***
- ***voltage swells***
- ***short interruption***
- ***long interruption***
- ***transient overvoltage***

The second category is used for the assessment of a phenomenon that can be measured for a complete time period.

- ***power frequency***
- ***magnitude of supply voltage***
- ***supply voltage variations***
- ***flicker severity***
- ***supply voltage unbalance***
- ***harmonic voltage***
- ***interharmonic voltage***
- ***mains signalling voltage***

An example based on the standard criterion for supply voltage variations (EN50160:1999, 2.3) is shown below.
Criterion: "Under normal operating conditions, excluding situations arising from faults or voltage interruptions
during each period of one week 95% of the 10 min mean rms values of the supply voltage shall be within the range of $U_n \pm 10\%$.
all 10 minute mean rms values of the supply voltage shall be within the range of U_n *+10% / -15%."*

Few comments on the previous statement:

- criterion applies to a normal supply condition

- a week is used as the minimum period that represents the cyclic nature of power consumption
- 10 minute period (often referred to IP – integration period) average value of rms voltage is used for representation of the supply voltage level dynamics
- part of the 10 minute period in which an interruption or failure happens is omitted in integrating calculation.

Grey areas on figures 19 and 20 represent the allowed voltage variation area.

At the presented (hypothetical) measurement, neither the absolute (limit +10% / -15%) nor the statistical (±10% in a 95% of time) requisites are fulfilled causing a rise of PC95 over the 10% limit (slightly over 12%).

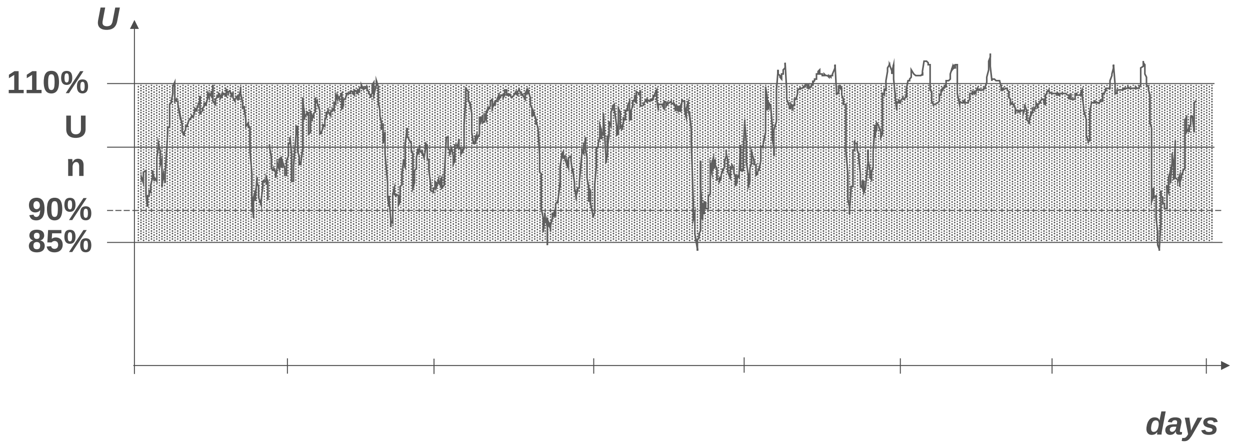


Figure 19: +10% / -15% limit

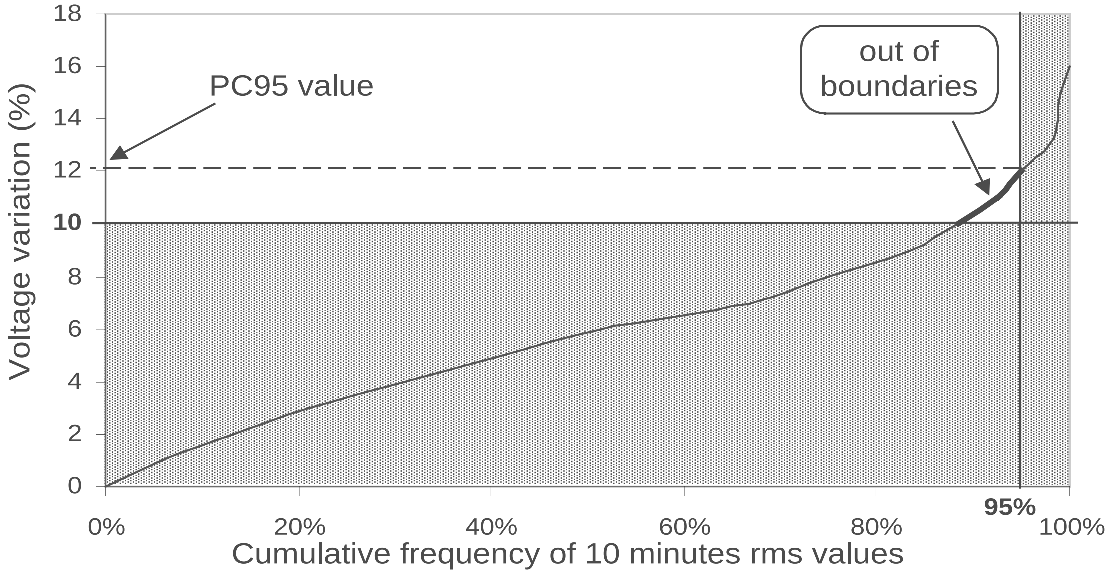


Figure 20: 95% of a 10 minutes rms average limit

4.17. Nominal and declared voltage

EN50160 introduces the following voltage definitions:

- **supply voltage:** the rms value of voltage at a given time at the supply terminals, measured over a given interval

- **nominal voltage of a system (U_n):** the voltage by which the system is designed or identified and to which certain operating characteristics are referred

- **declared supply voltage (Uc):** the declared supply voltage Uc is normally the nominal voltage Un of the system. If, by agreement between the supplier and the customer a voltage different from the nominal voltage is applied to the terminal, then this voltage is the declared supply voltage.

5. EN50160:1999 Voltage characteristic of electricity supplied by public distribution systems

International standards concerning power quality are either basic or generic electromagnetic compatibility standards and are published by IEC (IEC 61000-x-x series) and IEEE (1159, 1433, 519, 1564, 1453). Most of the EMC standards are recommendations and serve as a reference without legal status. Some of them, IEC 61000-3-2 and IEC 61000-3-3 for example, are introduced into the legislation of the EU. There are a variety of product standards that limit the influence of a particular product or family of products to the supply system and environment. Nevertheless, CENELEC EN50160 is the standard that is used for evaluation of power quality:

5.1. Purpose

CENELEC standard EN50160 "Voltage characteristic of electricity supplied by public distribution systems*" is a standard that defines the voltage characteristics of LV and MV distribution systems. It is used as a base for utility-client contracts in the European Union and for small power generation contracts.*
Published 1994 with minor changes added in 1999, the standard is mandatory in the EU and will become mandatory in all European countries by 2003.
EN50160 is not an EMC standard. It is a product standard that defines the quality of a product (supply electricity) *in terms of voltage characteristics on power supply terminals.*
This standard **can be substituted in part or completely with a contract between a customer and a supplie**r. *Due to the high cost of supplied energy in sparsely populated areas, the supplier and customer can agree upon lowering the power quality creating a lower price for the supplied power. It is the customer's responsibility to evaluate the impact of increased disturbances to connected equipment.*

5.2. Scope

The EN50160 standard can be used as a specification for the maximum levels of power quality disturbances expected anywhere in **LV or MV systems during normal operating conditions** *of an electrical network.*
The standard is not applicable for events beyond the suppliers' control (source: Guide to the application EN50160 – CENELEC BTTF-68-6*):*

Exceptional weather conditions and other natural disasters
    Storms of extreme severity, landslides, earth quakes, avalanches, floods
Third party interference
    Sabotage, vandalism
Acts by public authorities
    Constraints imposed by government for public safety concerns
Industrial action
    Withdrawal of labour, strike
Force majeure
    Major accidents
Power shortages resulting from external events
Energy restrictions or interruption of transnational transmission lines

5.3. Supply voltage characteristics

Power quality characteristics are explained with more details in “4. Power Quality Parameters".
All limits and indices presented on the following pages are defined for normal operating conditions only.

Descriptive indices *are used for power quality events that have a highly random nature, can vary in time and are highly dependent on the topology of the system. Those events happen* **occasionally***. They cannot be ascribed limits and only approximate figures are given. This approach is applied for describing:*

- ***rapid voltage changes***
- ***voltage dips***
- ***voltage swells***
- ***shot interruption***
- ***long interruption***
- ***transient overvoltage***

A second category is used for the assessment of a phenomenon that can be measured for a specific time period.

- ***power frequency***
- ***magnitude of supply voltage***
- ***supply voltage variations***
- ***flicker severity***
- ***supply voltage unbalance***
- ***harmonic voltage***
- ***interharmonic voltage***
- ***mains signalling voltage***

Note: interharmonic voltage measurement is defined but limit values are still under consideration.
More details: “4.16 Evaluation against standard’s limits”, page 33.

Integrating intervals

The standard defines three integrating intervals: 3s, 10s and 10 min. A period of 120 minutes is used for long-term flicker indication.
More details: "4.14 Integrating interval", page 31.

5.3.1. Power frequency

The nominal frequency of the power supply voltage is 50 Hz. The integrating interval is 10 seconds.
Limits for MV and LV systems connected to a transnational network are:

- 99.5% of the integrating interval values recorded during a 1 year period must be within ±1% (49.5…50.5 Hz)
- all values of the integrating intervals must be within +4/-6% (47…52 Hz)

Limits for isolated MV and LV system (islands):

- 95% of the integrating interval values, recorded during a 1 week period, must be within ±2% (49…50 Hz)
- all measured values of the integrating intervals, recorded during a 1 week period must be within ±15% (42.5…57.5 Hz)

More details: "4.1 Power frequency", page 12.

5.3.2. Supply voltage variations

The nominal voltage for LV systems is 230 V between phase and neutral for 4 wire systems and 230 V between two phases for 3 wire systems.
The nominal voltage for MV systems equals the declared voltage U_c (more info: "4.17 Nominal and declared voltage", page 35).
The integrating interval for supply voltage variation measurement is 10 minutes.
Limits for LV systems are:

- 95% of the integrating interval values recorded during a 1 week period must be within ±10% U_n
- all recorded values of integrating intervals must be within +10/-15% U_n

Limits for MV systems:

- 95% of the integrating interval values recorded during a 1 week period must be within ±10% U_n

More details: "4.2 Supply voltage variation", page 13 and "4.16 Evaluation against standard's limits", page 33.

5.3.3. Rapid voltage changes

The presence of rapid voltage changes in a system is assessed by using descriptive indices.
LV systems:

- 5% U_n limit is generally not exceeded, but occasionally a few shorter changes, up to 10% U_n per day, may occur

MV systems:

- 4% U_c limit is generally not exceeded, but occasionally a few shorter changes, up to 6% U_n per day may occur

More details: "4.3 Rapid voltage changes", page 13.

5.3.4. Supply voltage dips

The presence of supply voltage dips in a system is assessed by using descriptive indices.
LV and MV systems:

- The expected number of voltage dips can vary from a few tens to one thousand during one year. The majority of dips have a duration less than 1s and a depth less then 60%. In some areas dips with a depth of 10%-15% can happen very frequently.

More details: "4.4 Supply voltage dips*", page 14.*

5.3.5. Supply voltage swells

Supply voltage swells are defined in EN50160 standard are as "temporary power frequency overvoltages".
The presence of supply voltage swells in a system is assessed by descriptive indices.
LV systems:

- a fault in an upstream transformer can cause an overvoltage that generally does not exceed 1.5 kV on the LV side.

MV systems:

- a fault can cause overvoltages up to 1.7 U_c in systems with solid earthing and up to 2 U_c in systems with isolated or resonant earthing.

More details: "4.5 Supply voltage swells", page 17.

5.3.6. Voltage interruptions

Voltage interruptions occur when the supply voltage drops below the interruption threshold i.e. 1% of U_n when the measurement is performed in accordance with EN50160.
Short interruptions are interruptions that last less then 3 minutes.
Long interruption's duration exceeds 3 minutes.
The presence of short and long interruptions in a system is assessed by descriptive indices.
LV and MV systems:

- The expected number of **short interruptions** can vary from a few tens up to a few hundreds during one year. Approximately 70% of short interruptions have a duration of less than 1 second.
- The expected number of **long interruptions** can vary from less than 10 up to 50 during one year.

Note: prearranged interruptions are excluded from the number of expected long interruptions because they are announced in advance.

More details: "4.6 Voltage interruptions", page 17.

5.3.7. Flicker severity

Shot-term flicker indicator (P_{st}) *is calculated over 10 minutes integrating interval.*
Limits for LV and MV systems are:

- long-term flicker indicator (P_{lt}) must not exceed a value of 1 for 95% of a one week time period.

More details: "4.7 Flicker", page 19.

5.3.8. Supply voltage unbalance

The integrating interval for supply voltage unbalance measurement is 10 minutes.
Limits for LV systems are:

- 95% of the integrating interval values must not exceed 2% during a 1 week period. In some areas, 3% supply voltage unbalance occurs.

More details: "4.8 Supply voltage unbalance", page 21.

5.3.9. Transient overvoltages

The presence of rapid voltage changes between the live conductor and earth in a system is assessed by descriptive indices.
LV systems:

- transient overvoltages generally do not exceed a value of 6 kV.

MV systems:

(no indicative values stated)

More details: "4.9 Transient overvoltages", page 22.

5.3.10. Harmonic voltage

The Integrating interval for supply voltage unbalance measurement is 10 minutes.
Limits for LV and MV systems are:

- The voltage of each harmonic must be less or equal to the value for that harmonic in table 4, page 28, for 95% of the integrating intervals recorded in one week.
- THD of the supplied voltage (THDU) must be less or equal to 8% for 95% of integrating intervals recorded in one week.

More details: "4.10 Harmonics", page 23.

5.3.11. Interharmonic voltage

Limits for voltage interharmonics are under consideration.

More details: "4.11 Interharmonics", page 28.

5.3.12. Mains signalling

Integrating interval for mains signalling supply voltage unbalance measurement is 3 seconds.
Limits for LV and MV systems are:

- 99% of integrating intervals during 1 week must have rms value of signalling voltage less or equal to the limiting curve on figure 16, page 30.

More details: "4.12", page 30.

The following table 5 presents the limits defined in EN50160. If no voltage level is explicitly stated then the same limit is valid both for LV and MV.

Table 5: EN50160 limits for characteristics of supply voltage

Characteristic	***nominal value***	***ip***	***variation min/max***	***meas. period***	***note***
Power frequency	*50Hz*	*10s*	*-1% / +1% @ 99.5% of a year* *-6% / +4% @ 100% of a year*	*1 week*	
	50Hz	*10s*	*-2%/+2% @ 95% of a week* *-15%/+15%@ 100 % of a time*	*1 week*	*for systems isolated systems*
Magnitude of supply voltage	*LV: 230V* *MV: Uc*				*until 2003 LV Un may be according natonal HD 472 S1*
Supply voltage variation	*LV: Un* *MV: Uc*	*10min* *10min*	*-10% / +10% @ 95% of a week* *-15% / +10% @ 100% of a week* *-10% / +10% @ 95% of a week*	*1 week* *1 week*	
Rapid voltage changes	*LV: Un* *MV: Uc*		*generally ±5%* *max ±10% several time a day* *generally ±4%* *max ±6% several time a day*	*1 day*	*indicative*
Flicker severity			*Plt < 1 @ 95% of a week*	*1 week*	*Pst is not used*
Supply voltage dips	*LV* *MV*		*10-1000 / year, <1s,depth< 60% caused by large loads* *10-1000 / year, <1s,depth< 60% caused by large loads and faults*	*1 year*	*indicative* *depth% of Un (Uc)*
Short interruptions			*10 to several hundreds , 70%<1s*	*1 year*	*indicative; duration < 3 min*
Long interruptions			*10-50*	*1 year*	*indicative; prearranged are not counted in*
Temporary overvoltages	*LV* *MV*		*<1.5 kV rms up to 5s* *< 2.0 Uc; failures* *< 3 Uc; ferroresonance*		*indicative*
Transient overvoltages	*LV* *MV*		*< 6 kV*		*indicative*
Supply voltage unbalance		*10min*	*<2% @ 95% of the week, occasionally up to 3%*	*1 week*	
Harmonics		*10min*	*table 4 @ 95% of the week*	*1 week*	
Inter-harmonics		*10min*	*limits under consideration*	*1 week*	
Mains signalling		*3s*	*less then EN50160 curve on figure 16 @ 99% of a day*	*1 day*	

5.3.13. Example of complete measurement and report on power quality in accordance with EN50160

Using the: METREL POWER QUALITY ANALYSER

The power quality characteristics described in previous chapters must be measured and evaluated against the levels defined in the EN50160 standard.
"EN50160" *measurement is one of several measurement methods available from the Metrel Power Quality Analyser that simplify the measurement and evaluation of power quality events against limits defined by the EN50160 standard.*
EN50160 measurement has a two steps process:

- ***recording performed by Power quality analyser on a site***
- ***generation of a 50160 report***

5.4. Measurement procedure

The measurement procedure is very simple: one must connect the voltage of all 3 phases to the instrument, select "EN50160" measurement and measurement can start. All parameters except the beginning and end times of the recording are automatically set. Start and stop time can be set or a manual start-stop sequence must be performed over a one-week period.
To evaluate the quality of the supplied electrical power the instrument must be connected to the point of common coupling (PCC) i.e. to the point where the customer's system is connected to the public network. In a large system the power quality parameters can vary because of the network topology and the status of nearby loads. In this case the instrument is connected to the nearest point of interest (local LV buss bar, main locker, outlet in a part of the building).

5.5. EN50160 report

The second step, generation of EN50160 report, is performed on a PC. After the data is downloaded from the instrument to a PC, statistical evaluation of the recorded data is performed. The results are compared to EN50160 standard's limits and a single page pass-failed report is issued.
Fig. 21 is a report of a measurement conducted during the week 14th to 21st of September 2001. A Power quality analyser was connected to the main buss bars in Metrel's factory.
This simple diagram concentrates all of the information needed for certification of power quality.
The cumulative frequency principle (see: "4.15 Cumulative frequency", page 32) is used for the projection of results. A statistical calculation is performed on the data for each signal. The CP95 and the maximum values of a particular signal are properly scaled to fit in the common diagram with limit lines representing the allowable deviation. Black bars represent the CP95 value of each measured signal. Grey bars represent the maximum value of integrating period recorded during the measurement. ***Each power quality parameter is in accordance with EN50160 if it remains below the limiting line.***

There are 13 bars on a diagram:

- U1, U2 and U3 - supply voltage variation of each phase
- interruption – instrument power supply failure
- events – dips, swells and interruptions
- H1,H2 and H3 – harmonics (including THD) presence
- FLK1, FLK2 and FLK3 – flicker severity
- imbl. – unbalance
- freq. – power frequency variation.

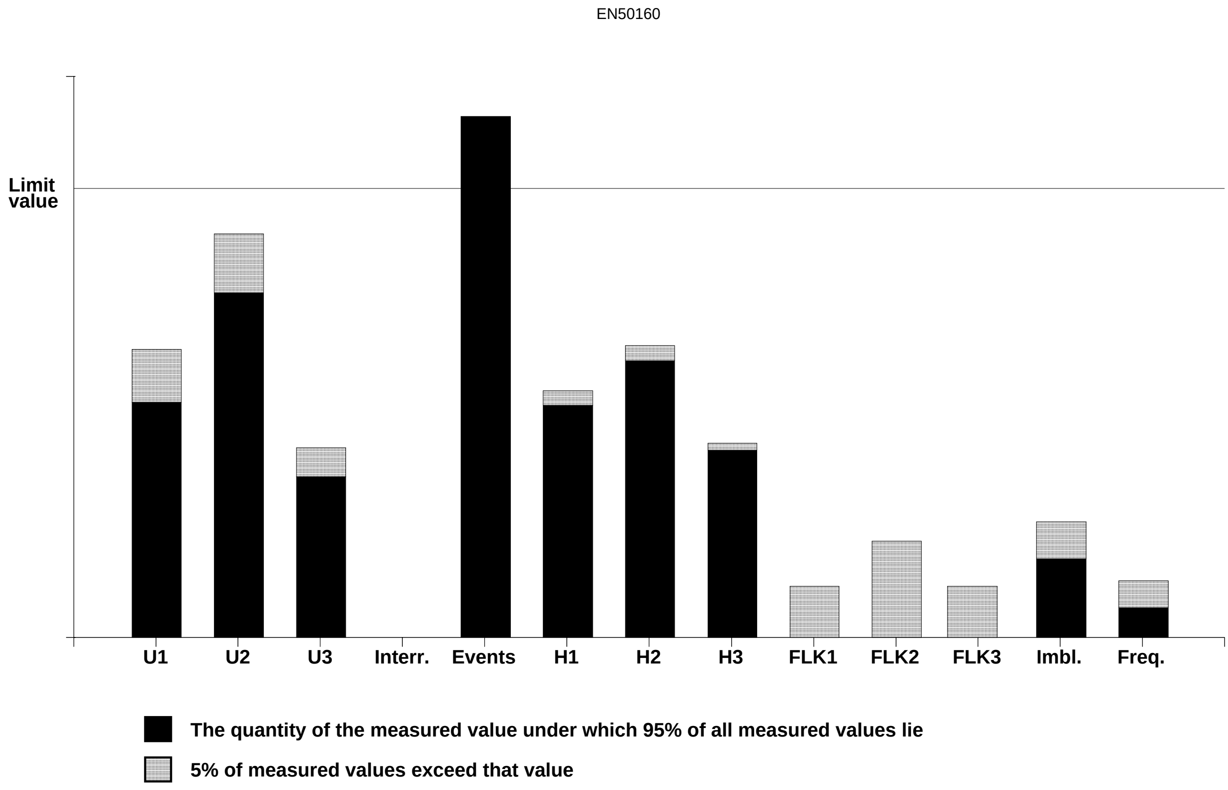


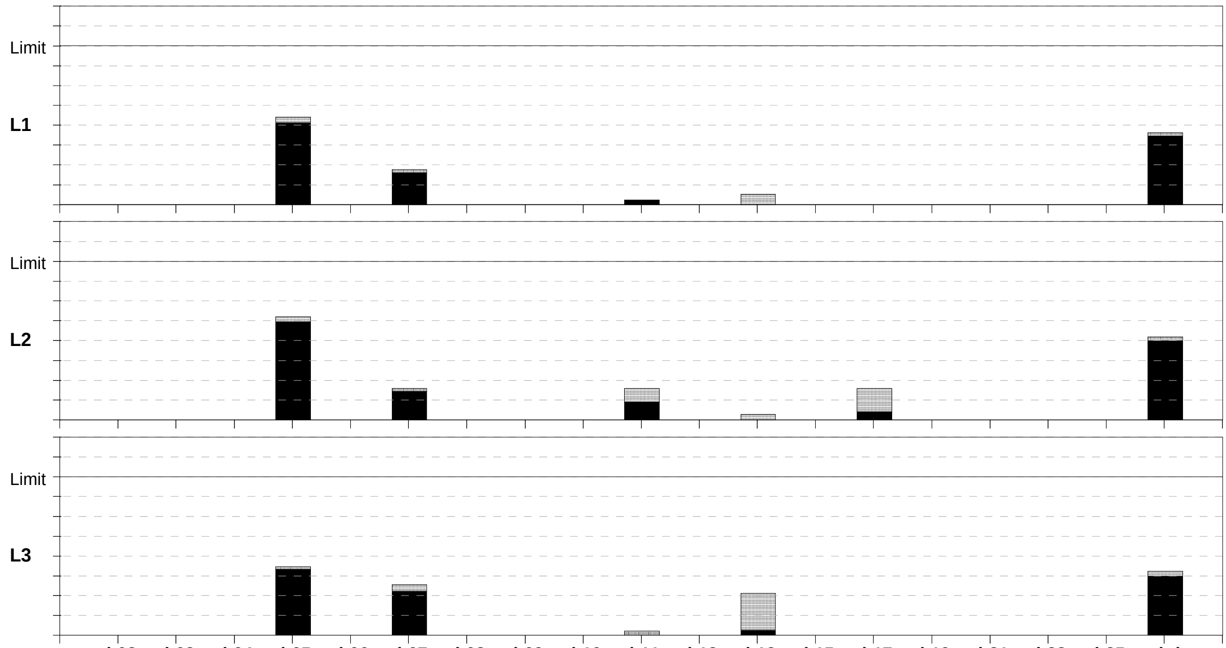
Figure 21: EN50160 report

All values except "events" are within the allowable area.
The following pages explain how to obtain more details about each parameter when using the Power Quality Analyser software.

5.6. Harmonics report

On the report featured on figure 21, the harmonics and the THD are marked with a single bar per phase (H1, H2 and H3).
Figure 22 is a report on the harmonics recorded during the measurement period. It presents the statistics for each harmonic and THD. The worst case for all CP95 values and maximum values are chosen independently which means that the black bar (CP95) can present the 5th harmonic and the blue bar (maximum) can stand for the 11th harmonic. In this case the 5th harmonic is closest to the limit line so it is used in the EN50160 report.

The presence of 5th and 7th harmonic is typical for most areas. 11th, 13th and 17th harmonics are caused with switching supply. Closer examination of the recorded data (see: 5.10 Examination of recorded data, page 50) *shows that higher harmonics are present in the evening and night hours. Since there is no activity in the factory during this time, those harmonics are not caused with factory's consumption.*
Overall, phase 2 is most affected by harmonics (CP95 of THD is 4.0%).



		h02	h03	h04	h05	h06	h07	h08	h09	h10	h11	h12	h13	h15	h17	h19	h21	h23	h25	thd
	lim	2.0	5.0	1.0	6.0	0.5	5.0	0.5	1.5	0.5	3.5	0.5	3.0	0.5	2.0	1.5	0.5	1.5	1.5	8.0
L1	min	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
	max	0.0	0.0	0.0	3.3	0.0	1.1	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	3.6
	95%	0.0	0.0	0.0	3.1	0.0	1.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
L2	min	0.0	0.0	0.0	0.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
	max	0.0	0.0	0.0	3.9	0.0	1.0	0.0	0.0	0.0	0.7	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.0	4.2
	95%	0.0	0.0	0.0	3.7	0.0	0.9	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	4.0
L3	min	0.0	0.0	0.0	0.1	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
	max	0.0	0.0	0.0	2.6	0.0	1.6	0.0	0.0	0.0	0.1	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	3.2
	95%	0.0	0.0	0.0	2.5	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.0

Figure 22: cumulative frequency for harmonics

5.7. EN50160 report in tabular form

Figure 23 is a snapshot of the tabular form representation of a 50160 measurement. It shows the measured values for each phase and the limits defined by EN50160 standard. Table 6 shows the results form when data has been exported.

EN50160

Execute

Parameter			Max value			95% value		
	Unit	Limit	L1	L2 / tot	L3	L1	L2 / tot	L3
Voltage variations		230.00V +/- 10%						
Maximum	% Un	+ 10	1.34	0.00	4.22	-3.24	0.00	2.43
Minimum	% Un	- 10	-6.42	-8.98	-3.75	-5.36	-7.67	-2.97
Interruptions	Number	100	0	0	0	-	-	-
Events	Number	100	1	1	114	-	-	-
Flicker Plt	Plt	1.00	0.00	0.16	0.00	0.00	0.00	0.00
Frequency 95%		50Hz +/- 1%						
Maximum	%	+ 1		0.12			0.03	
Minimum	%	- 1		-0.13			-0.07	
Imbalance	%	2.00		0.51			0.35	
Harmonics								
THD	% Un	8.0	3.62	4.18	3.24	3.46	4.00	2.97
2. Harm.	% Un	2.0	0.00	0.00	0.00	0.00	0.00	0.00
3. Harm.	% Un	5.0	0.00	0.00	0.00	0.00	0.00	0.00
4. Harm.	% Un	1.0	0.00	0.00	0.00	0.00	0.00	0.00
5. Harm.	% Un	6.0	3.30	3.90	2.60	3.10	3.70	2.50
6. Harm.	% Un	0.5	0.00	0.00	0.00	0.00	0.00	0.00
7. Harm.	% Un	5.0	1.10	1.00	1.60	1.00	0.90	1.40
8. Harm.	% Un	0.5	0.00	0.00	0.00	0.00	0.00	0.00
9. Harm.	% Un	1.5	0.00	0.00	0.00	0.00	0.00	0.00
10. Harm.	% Un	0.5	0.00	0.00	0.00	0.00	0.00	0.00
11. Harm.	% Un	3.5	0.10	0.70	0.10	0.10	0.40	0.00
12. Harm.	% Un	0.5	0.00	0.00	0.00	0.00	0.00	0.00
13. Harm.	% Un	3.0	0.20	0.10	0.80	0.00	0.00	0.10
15. Harm.	% Un	0.5	0.00	0.00	0.00	0.00	0.00	0.00

Figure 23: tabular form of EN50160 report – snapshot

Table 6: tabular form of EN50160 report

	Unit	Limit	L1	L2/tot	L3	L1	L2/tot	L3
Voltage variations		*230V*						
Maximum	*% Un*	*+ 10*	*1,34*	*0,00*	*4,22*	*-3,24*	*0,00*	*2,43*
Minimum	*% Un*	*- 10*	*-6,42*	*-8,98*	*-3,75*	*-5,36*	*-7,67*	*-2,97*
Interruptions	*Number*	*100*	*0*	*0*	*0*	*-*	*-*	*-*
Events	*Number*	*100*	*1*	*1*	*114*	*-*	*-*	*-*
Flicker Plt	*Plt*	*1,00*	*0,16*	*0,23*	*0,16*	*0,00*	*0,00*	*0,00*
Frequency 95%		*50Hz +/- 1%*						
Maximum	*%*	*+ 1*		*0,12*			*0,03*	
Minimum	*%*	*- 1*		*-0,13*			*-0,07*	
Imbalance	*%*	*2,00*		*0,51*			*0,35*	
Harmonics								
THD	*% Un*	*8,0*	*3,62*	*4,18*	*3,24*	*3,46*	*4,00*	*2,97*
2. Harm.	*% Un*	*2,0*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
3. Harm.	*% Un*	*5,0*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
4. Harm.	*% Un*	*1,0*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
5. Harm.	*% Un*	*6,0*	*3,30*	*3,90*	*2,60*	*3,10*	*3,70*	*2,50*
6. Harm.	*% Un*	*0,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
7. Harm.	*% Un*	*5,0*	*1,10*	*1,00*	*1,60*	*1,00*	*0,90*	*1,40*
8. Harm.	*% Un*	*0,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
9. Harm.	*% Un*	*1,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
10. Harm.	*% Un*	*0,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
11. Harm.	*% Un*	*3,5*	*0,10*	*0,70*	*0,10*	*0,10*	*0,40*	*0,00*
12. Harm.	*% Un*	*0,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
13. Harm.	*% Un*	*3,0*	*0,20*	*0,10*	*0,80*	*0,00*	*0,00*	*0,10*
15. Harm.	*% Un*	*0,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
17. Harm.	*% Un*	*2,0*	*0,00*	*0,40*	*0,00*	*0,00*	*0,10*	*0,00*
19. Harm.	*% Un*	*1,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
21. Harm.	*% Un*	*0,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
23. Harm.	*% Un*	*1,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*
25. Harm.	*% Un*	*1,5*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*

5.8. Flicker graph

Figure 24 is a snapshot of a flicker window. Flicker severity is recorded according to IEC flickermeter standard IEC 61000-4-15*. Variations of the short-term (Pst) and long-term (Plt) flicker indicators, against time can be seen.*

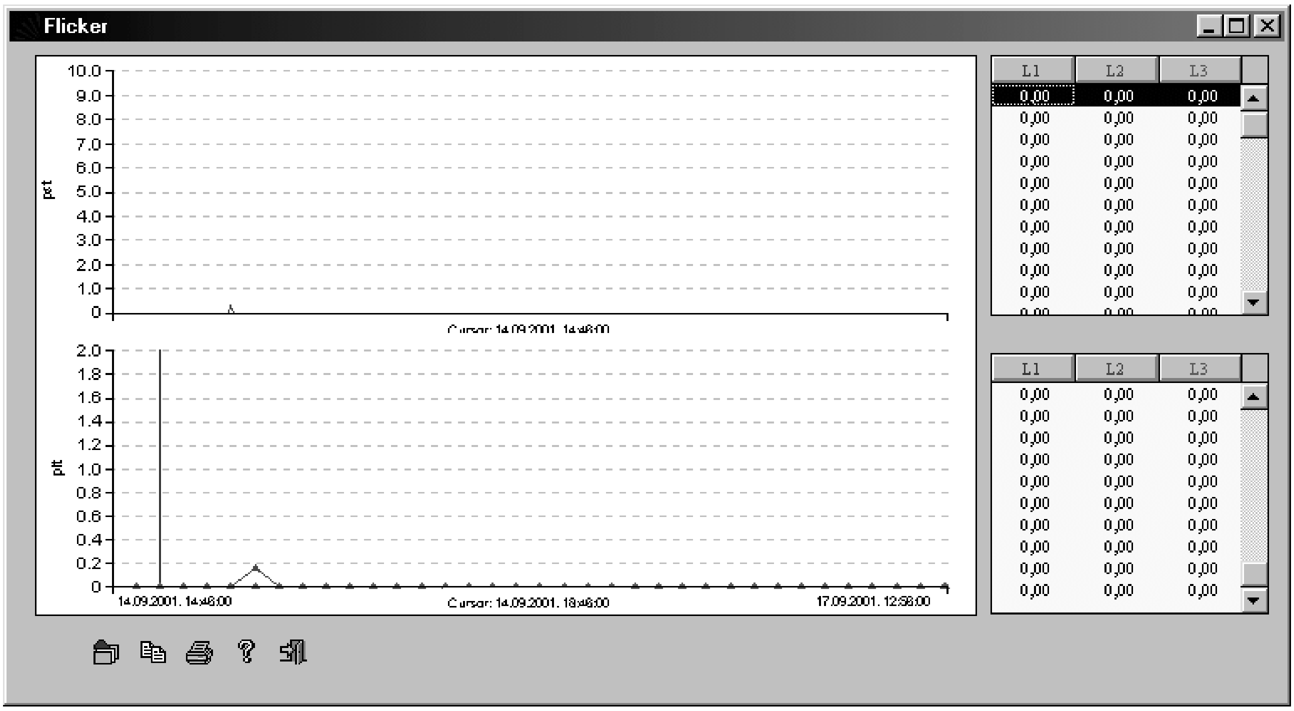


Figure 24: flicker graph

(more comments after new flickermeter's function is implemented)

5.9. <u>Dips, swells and interruptions - anomalies</u>

Dips, swells and interruptions assessed on $U_{rms1/2}$ measurement (further details: “4.4 Supply voltage dips”, page 14) for each phase voltage.

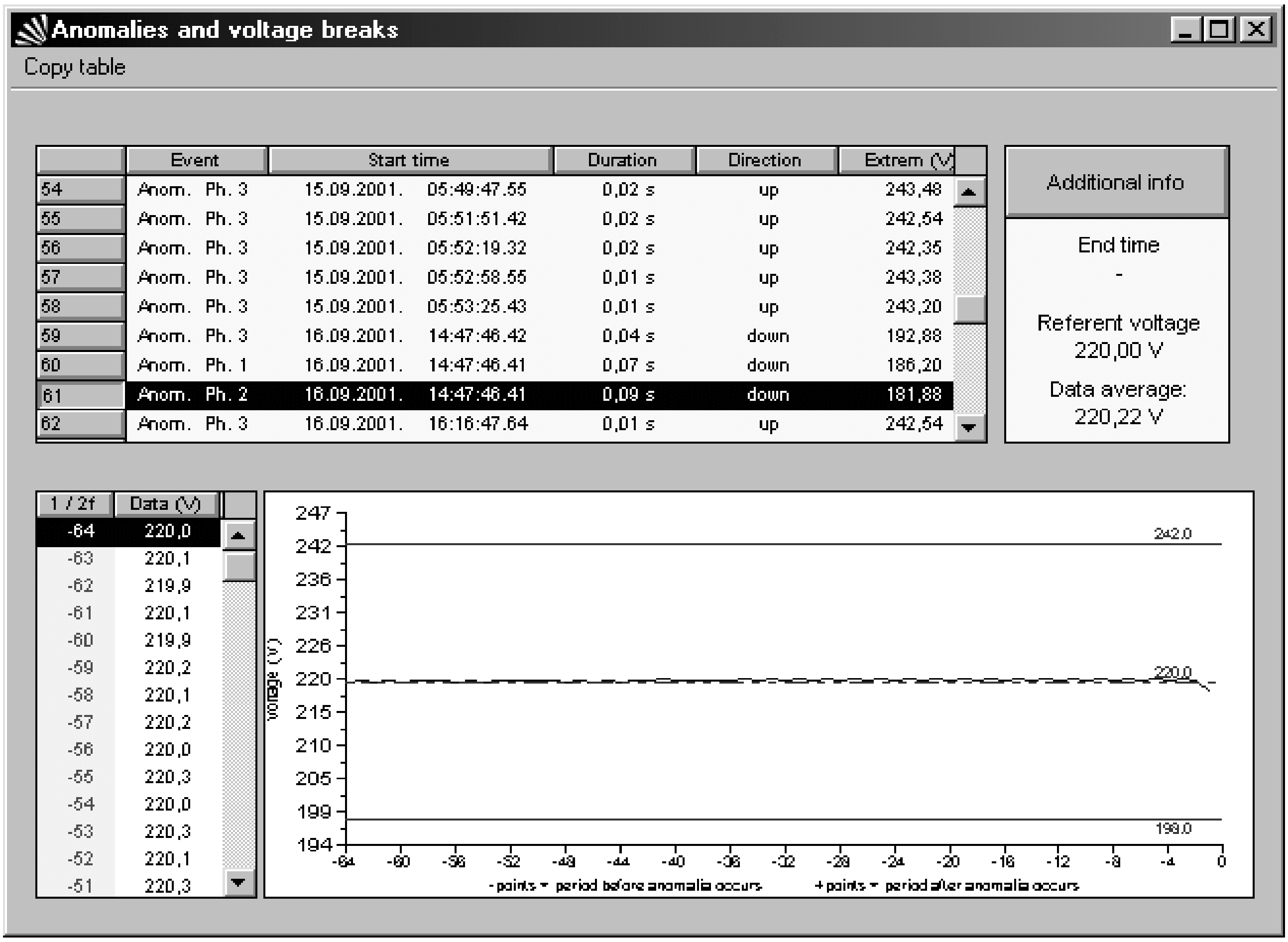


Figure 25: anomalies report

Recorded dips, sags and interruptions are reported in a common report: **anomalies**. *Figure 25 presents a snapshot of such a report. For each recorded anomaly 5 parameters are recorded:*

- Event – defines the phase that suffered the anomaly
- Start time – start of first half period with rms value ($U_{rms1/2}$) above/below the set thresholds
- Duration – duration of the anomaly
- Direction – voltage change; up-swell; down- dip, interruption; up/down – both thresholds exceeded without returning into the area within the thresholds
- Extrem – value of $U_{rms1/2}$ voltage with maximum voltage deviation from the referent voltage during the anomaly

*The type of anomaly determines the parameter “direction”: **dip->down, swell->up**. Differentiation between a dip and an interrupt is made upon parameter “extrem”. **If the ‘extrem’ is greater than 1% of the referent voltage, the anomaly is recorded as a dip otherwise it is recorded as an interruption**.*
Referent voltage is the voltage that is used for dip and swell threshold calculation. It can be fixed or variable. A variable voltage threshold can be used when measurement is performed on two different voltage levels e.g. 400V (LV) and 6kV (MV) and the transformation ratio are not constant or in areas with a significant voltage supply variation. With a fixed voltage reference the recorded anomalies cannot be adequately compared when the transformation ratio changes due to regulation. In the second case, if the voltage supply falls/rise near its thresholds, a minimal change in the voltage amplitude will cause an anomaly record to be issued and the instrument’s memory can be entirely filled before the measurement ends (linear memory) or some data can be overwritten (circular memory).

5.10. Examination of recorded data

In the presented measurement a large number of events occurred (report on figure 21). An anomaly report discovers that the great majority of recorded events are swells with duration of 0.01 or 0.02 seconds and extreme up to 244 V. All of them happened on phase 3 during the weekend. Just one dip, presented on figure 25, was recorded during the measurement.
The reason for such distribution of anomalies can be found by examination of the recorded data. Each signal’s average, minimum and maximum can be examined by using the “RECORDING” function. &4 signals are recorded during EN56150 measurement.
Figure 26 presents detail of a recording: 10-minute voltage averages during a weekend. The magnitude of the supply voltage rose over the weekend causing an increase of swells. Just phase 3 voltage exceeded the swell threshold (unbalance).
Advanced measurement techniques that can be used in troublesome situations will be presented in the next chapter.

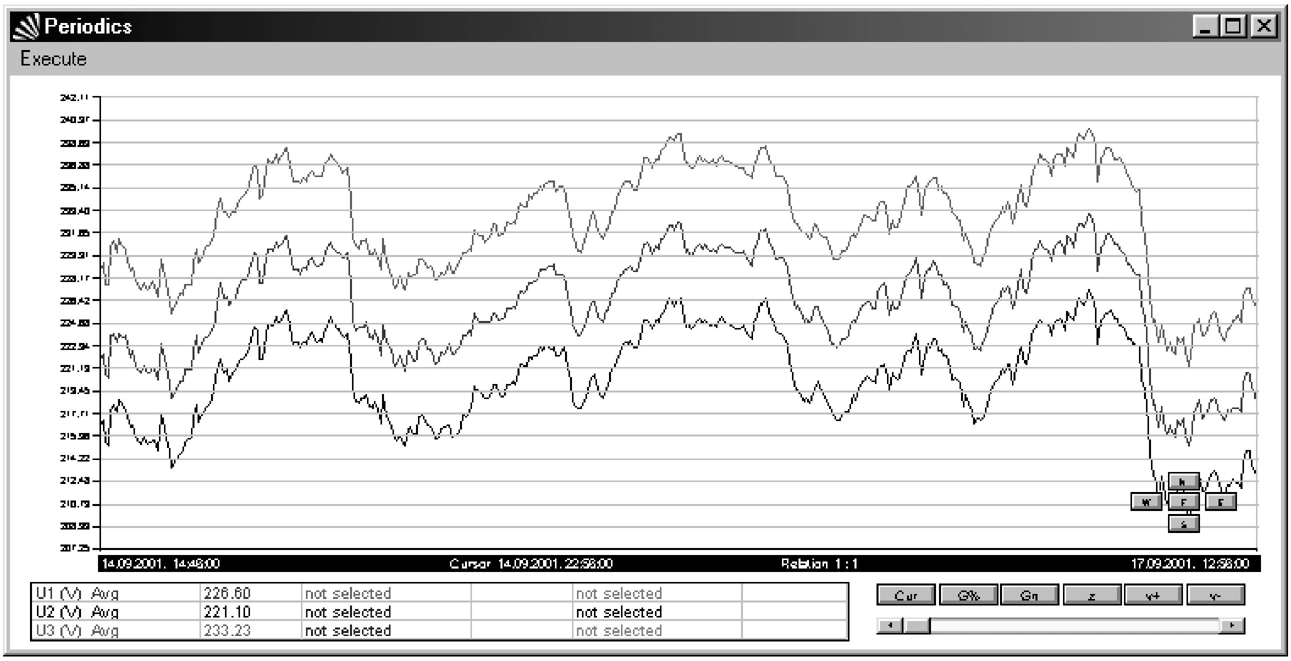


Figure 26: detail of recorded data – voltage averages

6. Advanced measurement with Metrel Power Harmonic Analyser

The Metrel Power Harmonic Analyser MA 2092 has 5 types of recording:

- EN50160
- periodics recording (registration)
- waveform recording
- fast logging
- transient recording

The first measurement type, EN50160, measures, stores and evaluates power quality events against limits defined by the EN50160 standard. The other four types of measurement implements additional recording techniques and combined with current inputs can be used for advanced monitoring, statistical or troubleshooting purposes and will be presented in the following chapters in more detail.

Three current inputs and sufficient processing power provide the facility for the advanced measurement and analysis of current, power and energy. A fast sampling rate, large of memory, graphical display and serial link to PC enables fast troubleshooting.
A measurement in the field usually starts with an inquiry from a customer or other department with a short description of a problem. Common occasions that initiate such inquiries are:

- ***a new high-powered piece of equipment (variable speed regulator, welding machine or similar) is to be connected into a system that has already experienced problems with IT equipment***
- ***a power conditioning device (active or passive filter) is added to a system and its performance is to be confirmed***
- ***unexplainable, strange and infrequent malfunctions of a customer's equipment occurs causing a significant financial loss. Authorised service personnel have examined the device and were not able to solve the problem. Usually during service the faulty situation cannot be reproduced***
- ***frequent complaints from the local network operator indicating that something in the system is not working properly***
- ***system benchmarking, optimising and tracing the source of disturbance generators.***

Excluding the measurement for EN50160 as described in the previous chapter, the Power Harmonic Analyser provides four types of measurement methods:

- periodic recording (periodics)
- waveform recording
- fast logging
- transient recording

Each type will be described on the following pages. In addition, some examples of troubleshooting measurements will be presented. The intent is not to give solutions, but to give some ideas on how the instrument can be exploited in troublesome situations.

6.1. Periodic recording (registration)

Periodic registration is a measurement that incorporate 3 measurement methods:

- periodic recording (periodics)
- dip-swell-interruption measurement (anomalies)
- statistics

6.1.1. Periodic recording

Periodic recording *is the base for power quality measurement. In fact the EN50160 measurement is a periodic measurement with the recording parameters set to EN50160 standard's requirements.*
Measuring period *is the time period between which the measurement begins and ends.*
Signal *is a value that can be selected for recording. This value is obtained by measurement (sampling techniques) followed by a calculation (rms calculation, DFT, power and energy calculation). A subset of 64 channels from a set of 308 (98 channels per phase and 14 channels for 3-phase system) can be selected in a single periodic recording.*
The main purpose of the periodic recording is the concentration of signal data. For example, there are 90,000 values for voltage rms in a 10-minute period for a 3-phase system. In addition the current can be monitored and up to 40 harmonics can be recorded on each current or voltage input. The measurement of power and energy per phase or in total may also be required.
Because of the large amount of data produced with real-time measurement an **integration period (IP)** *(terms* averaging *or* aggregating *period are also used) is introduced in measurement. The signal value is updated every half-period (10 ms for 50 Hz system) for voltage and current signals, full-period (20 ms) for power signals and every 8th period (160 ms for 50 Hz) for harmonic and THD signals. The* **average** *of all signal values in a period and* **minimum** *and* **maximum** *values are stored in the instrument's memory at the end of the integration period for each signal selected for recording. The recording of minimum values for harmonic and THD does not have any practical use and is not stored in memory.*
The selection of signals and integration time period greatly depends on the purpose of a measurement. If the measurement is performed for the evaluation of power (voltage) quality, then the IP and signals that are selected for recording are usually predefined and only the CP95 value is used. Minimum and maximum values of rms voltage and frequency are also taken into consideration for the complete measurement period. However, maximum and minimum values for each IP are also available for examination and often disclose some heavy loads influence that could cause problems.
If the measurement is performed for troubleshooting purposes the current inputs are also used and the IP is usually kept to as low a measurement period as the number of selected signals and instrument memory will allow. Such measurement discovers the dynamics of the system and is usually valuable for extending fast logging and waveform measurements.

Examples of periodic measurement are presented in EN50160 measurement and also in the presentation of exported data.

6.1.2. Anomalies

If confirmed by the "Anomalies" checkpoint in the Power Link program or as an option in the registration menu on the instrument, the detection of voltage dips, swells and interruptions is performed during a measurement period. The characteristics of each event is acquired and stored in memory. An example of a voltage dip is presented on figure 28.

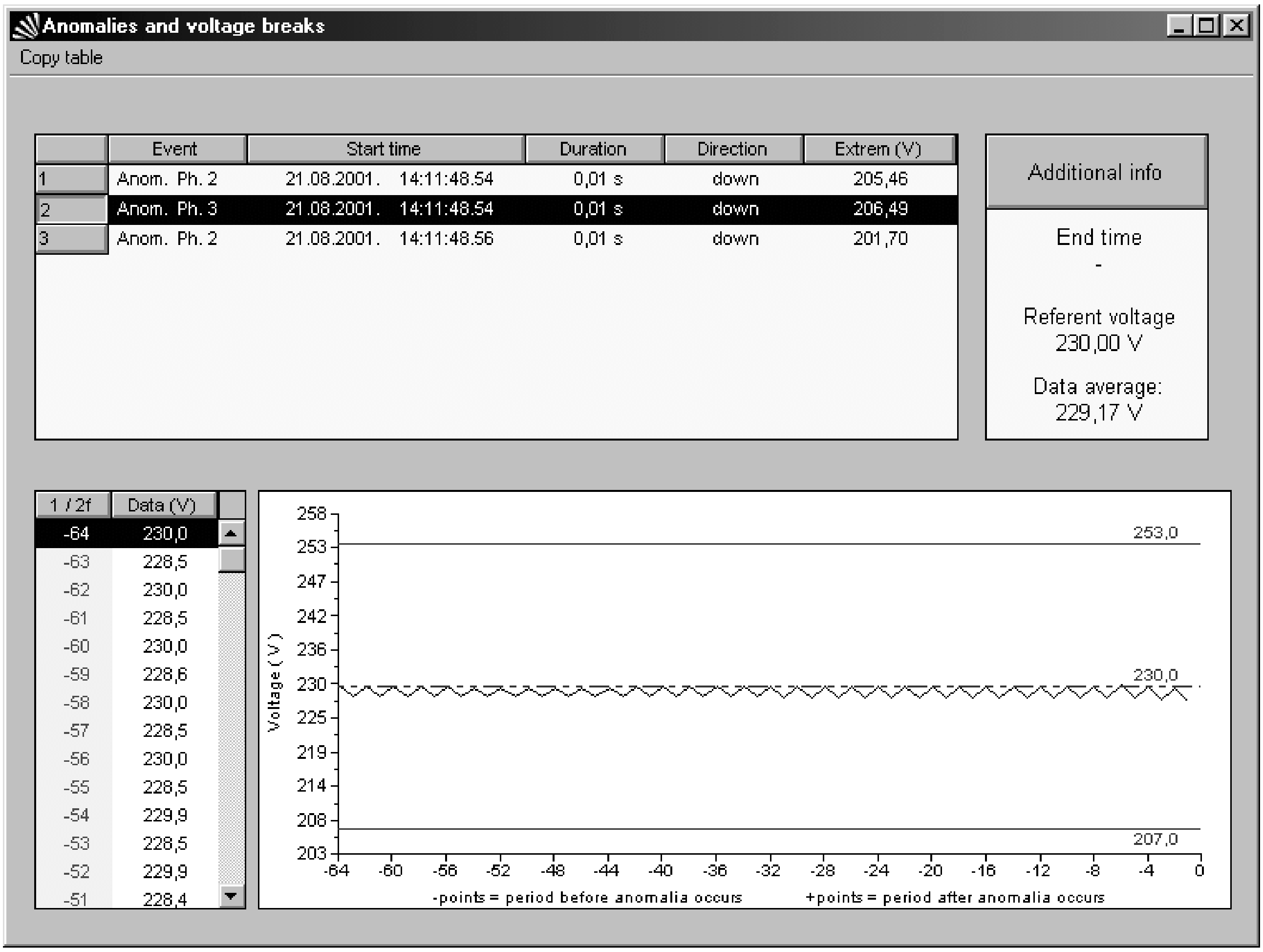


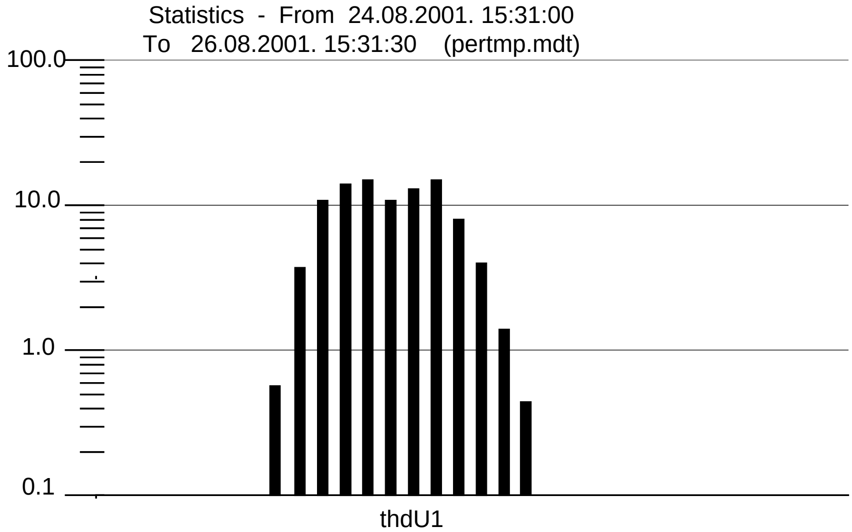
Figure 27: Anomalies and voltage breaks

Voltage dips and swells are characterised with retained voltage and duration (see chapter on power quality events). The last 64 $U_{RMS(1/2)}$ values prior to the start of an event are added as additional attributes to a record. This information can be used for the determination of event's origin. A referent voltage and data average are necessary information when dealing with a sliding voltage reference.

6.1.3. Statistics

The statistic *option can be used in a recording where more statistical information is required.*
If statistics is enabled for the measurement it will provide an insight of the data spread within each IP. A statistical record for each signal is allocated in the instrument's memory. A statistical record consists of 256 classes of the same width covering the full range (0-100%). For harmonics and THD signals, 255 classes cover the range 0-40% and the 256th range is used for cumulating values over 40%.
For EN50160 measurements the CP95 curve is calculated upon each 10 minutes average of the signal after the data has been downloaded to a PC. Statistic recording groups each *calculated value of a selected signal into the appropriate class during measurement.*

Figure 28 presents the statistical record for THDU1 in a period of one working day. It has obvious bimodal characteristics of THD. First group representing time from 15:00 till 00:30 is approx. 2.5. Other peak represents time from 00:30 till 15:00 with THD approx. 1.9. **Figure 28: statistics window**



thdU1	
1,28 - 1,44	0,56%
1,44 - 1,60	3,50%
1,60 - 1,76	10,94%
1,76 - 1,92	14,86%
1,92 - 2,08	15,35%
2,08 - 2,24	10,74%
2,24 - 2,40	13,07%
2,40 - 2,56	15,57%
2,56 - 2,72	8,80%
2,72 - 2,88	4,77%
2,88 - 3,04	1,51%
3,04 - 3,20	0,28%
3,20 - 3,36	0,05%

Figure 28: statistics window

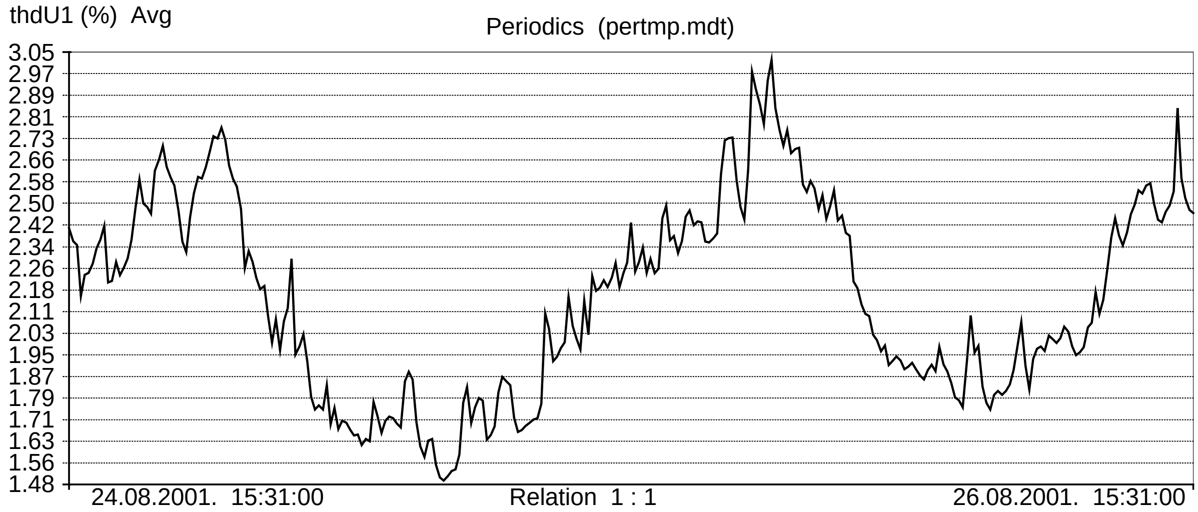


Figure 29: correspondent graph of 10 minutes THD average

6.2. Waveform measurement

Waveform measurement is a powerful tool for troubleshooting and capturing the current and voltage response in a switching situation.
The waveform method records waveforms of selected inputs on a trigger occurrence. The trigger can be set manually, by timer or when half-period rms value of selected trigger input rises/falls above/below a trigger level. Selected pre- and post- trigger periods expressed in periods of power frequency or in seconds are stored in the instrument's memory. Each saved period in the waveform record consists of 128 sampled values.

Figure 30 shows an example of a waveform recording. A 4 kW DC motor powered via a 3-phase auto-transformer and rectifier bridge drives a synchronous generator. The generated voltage is used for testing AVRs, diesel engine regulators and synchronism circuitry. The DC motor speed is regulated by the auto-transformer's voltage output. In this example, a 30 V step voltage is applied to a system. The voltage and current of phase 1 on the output of the auto-transformer are recorded and plotted.
A 1-second pre-trigger and 4-second post-trigger period with a single shot rise level triggering on 18 V phase 1 voltage. The upper part of the display (scope) shows the recorded waveforms. The width of a scope is 10 periods. The lower part (rms graph) is a graphical presentation of rms values calculated on a period basis. By setting the scope width to 128 (one period) the whole transition period can be examined period-by-period. Figure 31 shows a period with peak voltage (U_{1rms} = 31.3V, U_{1THD} = 298%, I_{1rms} = 48.9A, I_{1THD} = 8.5%). Figure 32 shows the last period in the record (U_{1rms} = 28.4V, U_{1THD} = 50.4%, I_{1rms} = 6.6A, I_{1THD} = 24.8%).

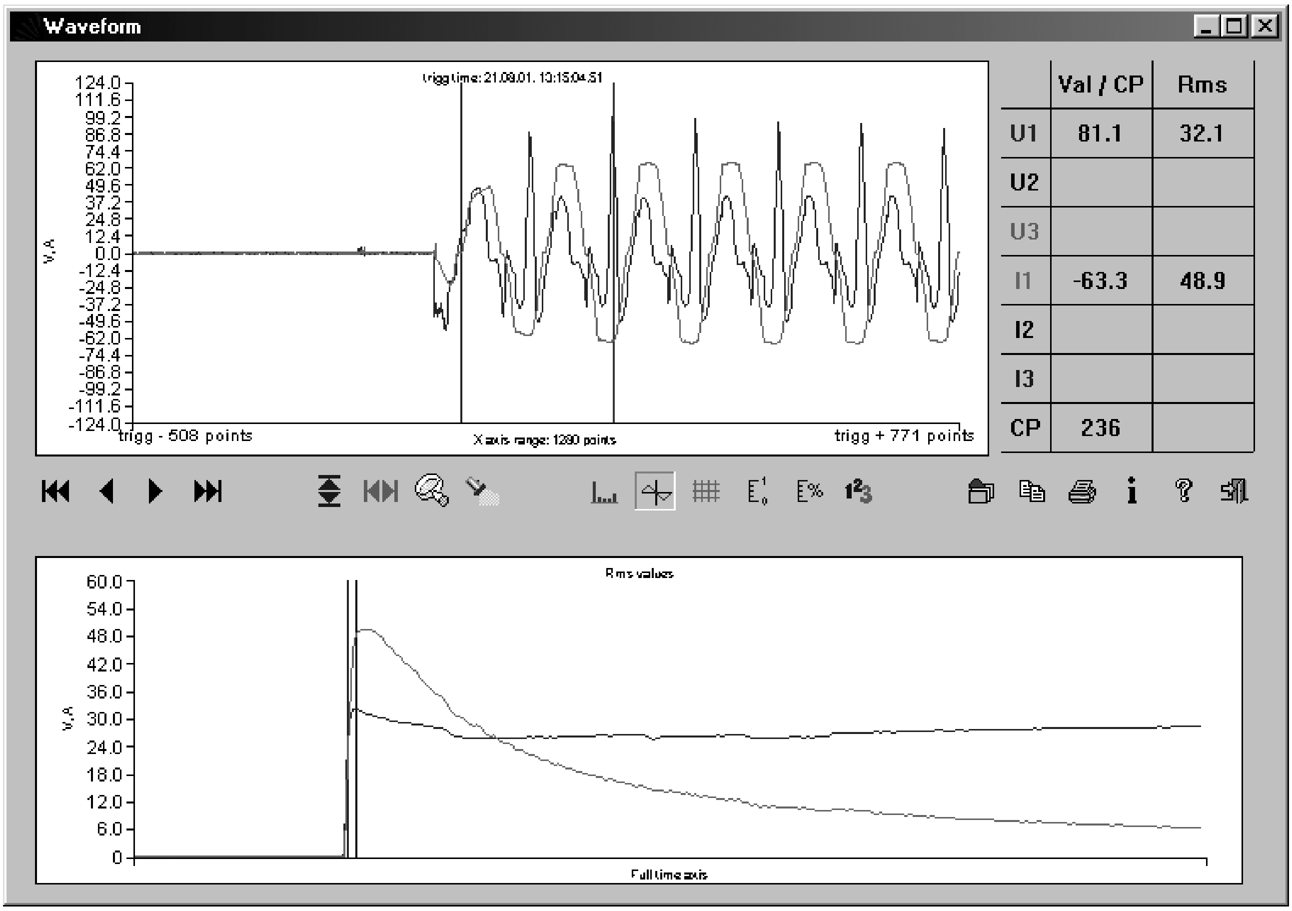


Figure 30: waveform example

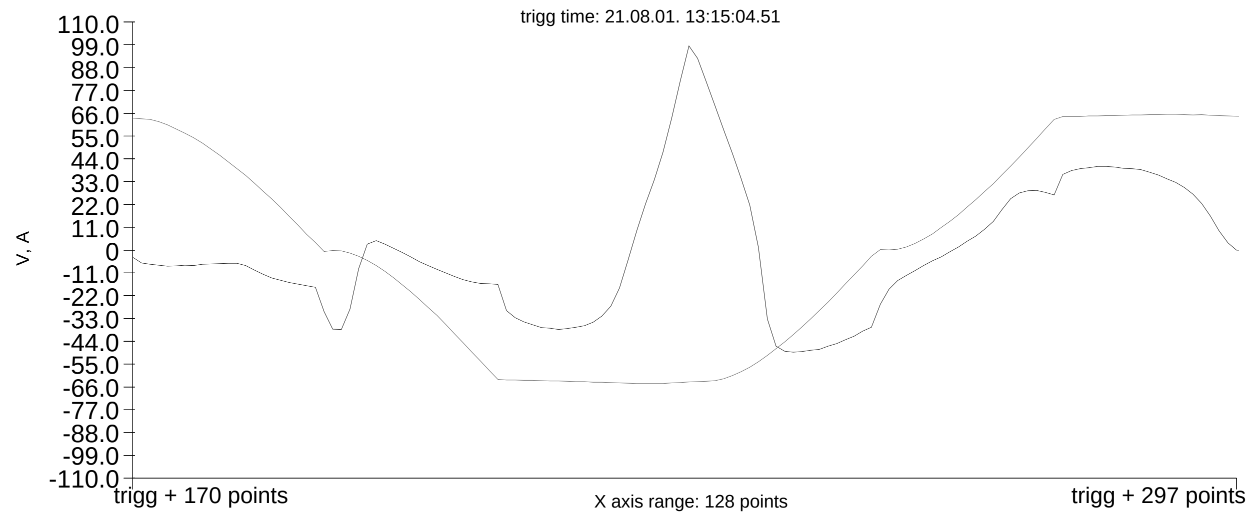


Figure 31: period with maximum rms value

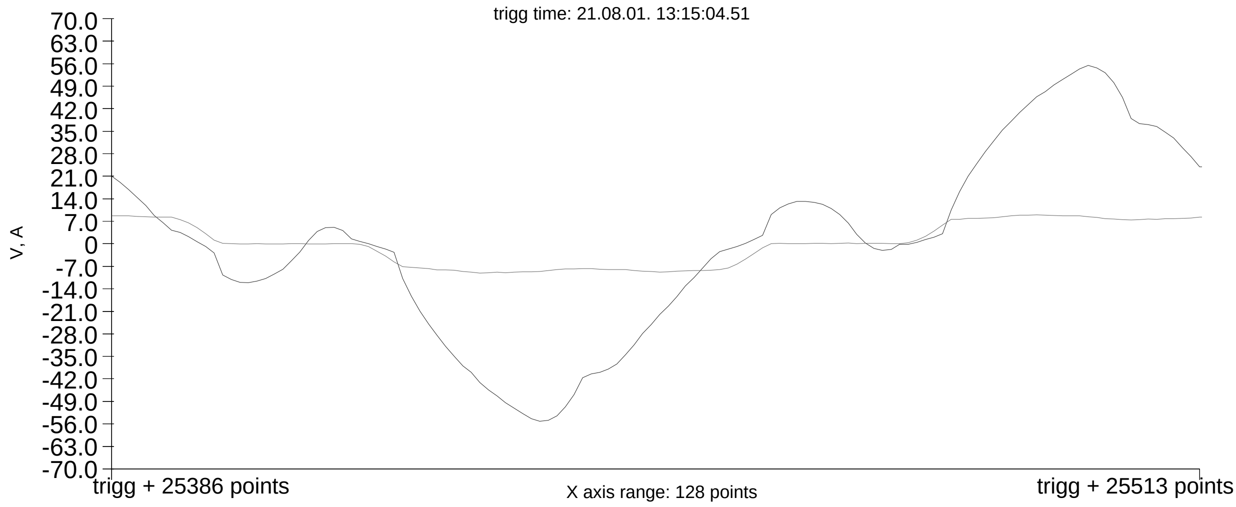


Figure 32: last recorded period

*Although very useful, waveform records consume a large amount of instrument memory. In the presented example the record lasts 5 seconds. This is 5*50=250 periods i.e. 250*128=32000 points per input channel. Since there are 2 signals (U1 and I1) 64000 points are saved. Each point needs 2 bytes and the total length of the record is 126kbytes. For some situations this is a waste of memory and fast logging can be used instead*

6.3. Fast logging

Fast logging is a measurement similar to a waveform recording but instead of storing 64 points in a wave half-period only the rms value of a particular half-period is saved. In this case just 1/64 of memory is spent on record data. Triggering and signal selection are the same as for waveform recording.

Figure 33 shows a fast logging measurement performed on the same equipment as in the waveform-recording example. The difference between the voltage curves on the rms graph on figure 31 and the fast logging graph on figure 34 is quite noticeable. A rms graph represents rms values of a period while a fast logging curve represents half-period rms (64 samples). Figure 33: fast logging example

shows detail of diagram that explains the reason of the saw like signal. There is a 2.5 V difference between positive and negative $U_{rms(1/2)}$. Similar graph is characteristic for $U_{rms(1/2)}$ before voltage dip.

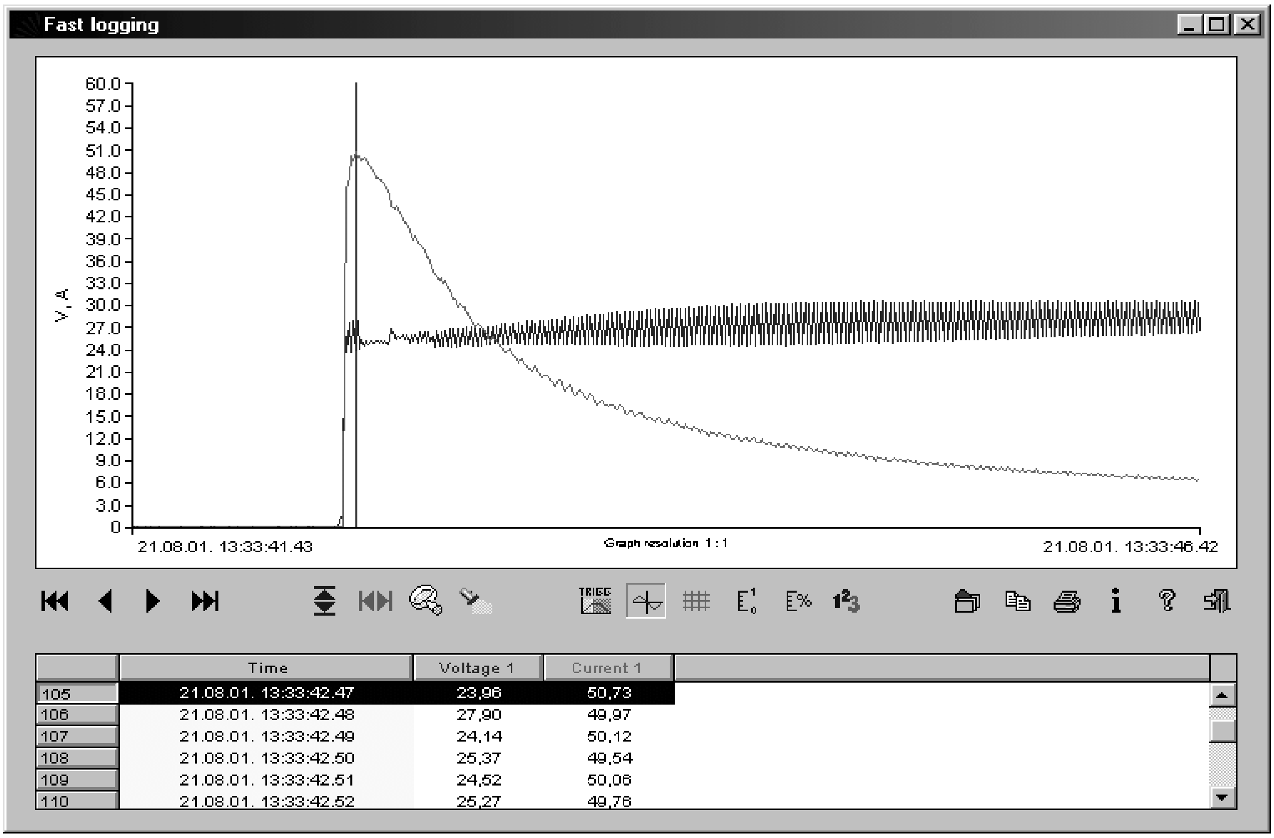


Figure 33: fast logging example

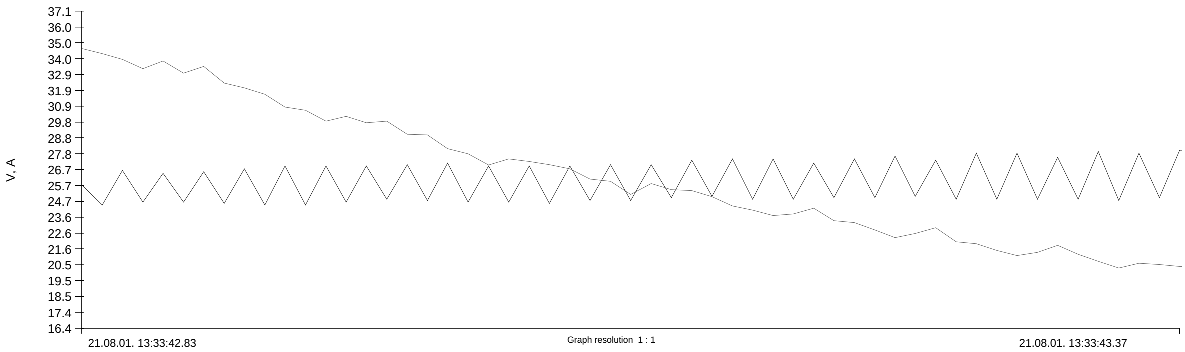


Figure 34: a detail of fast logging graph

6.4. Transient recording

Transient recording is the measurement method with the fastest sampling rate that the instrument can provide. Up to 25 kHz signals can be captured within this mode of operation.

The principle of measurement is similar to waveform recording, but with a higher sampling rate. For a single signal enabled for capturing, there are 1000 samples in a 50 Hz signal period. When all six signals are enabled, 400 samples per period, per signal are stored in the instrument memory. Figure 37: transient – charged capacitor

Table 7 specifies the sampling times in relation to the number of channels chosen for the recording.
Triggering is performed in the same manner as in waveform recording but with a new triggering mode (a difference between two samples). The difference between the two samples is that a signal's slope and trigger is set if the slope is higher than the set threshold (du/sample or di/sample).

Figure 35 is a snapshot of a transient window. A discharged 4 μF capacitor is connected to a 230V line. Capacitor current is measured with 1000 A current clamps (I1). The voltage of 230V line is also recorded (U1). Trigger settings: I1, level, 30A. Sampling interval: 40 μs (see table 6). Five periods pre-trigger and five periods post-trigger window is recorded.
A zoom function is used for showing detail of the recorded inrush current. Figure 36 shows that detail. Current peak was 99A, voltage dropped from 286V to 70V.
The peak current greatly depends on the precise moment when the metallic contact in the switch makes, on the loop resistance and the capacitors charge.

Figure 36: inrush current detail

: shows another transient record. In this case the capacitor had been fully charged before the circuit was closed. This time the current peak of 175 A and voltage change from –287V to 130V were recorded.

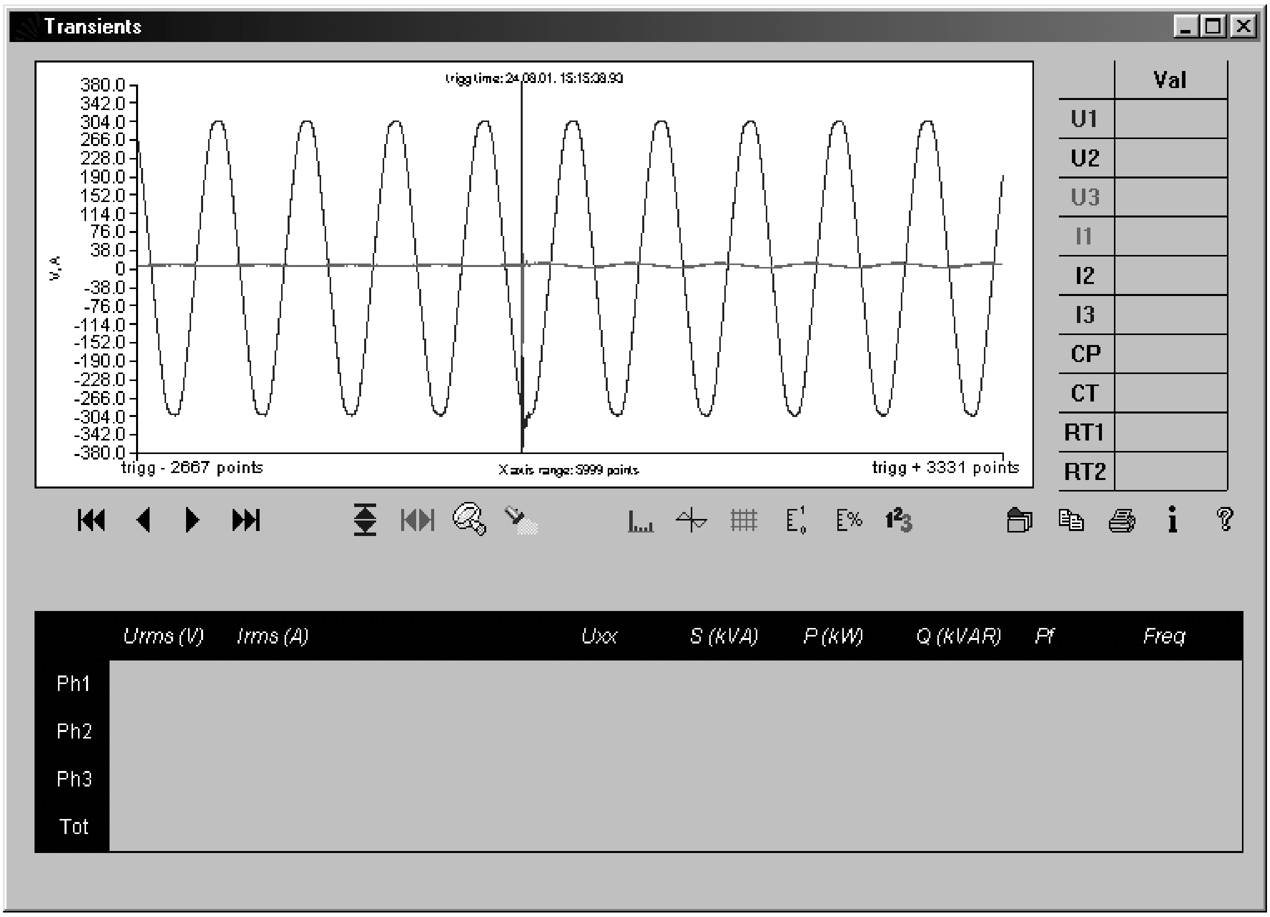


Figure 35: transient example

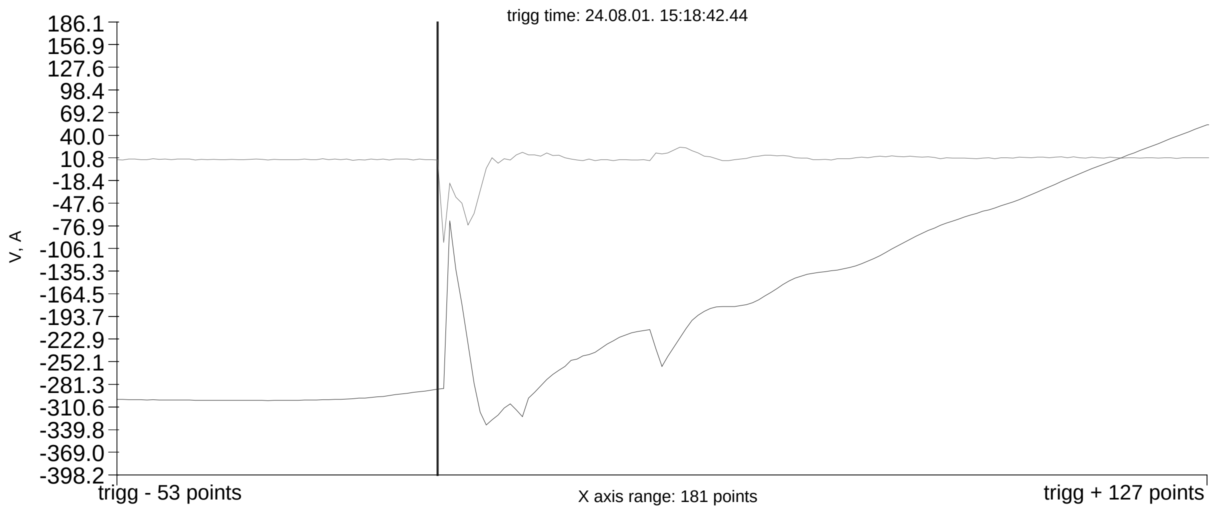


Figure 36: inrush current detail

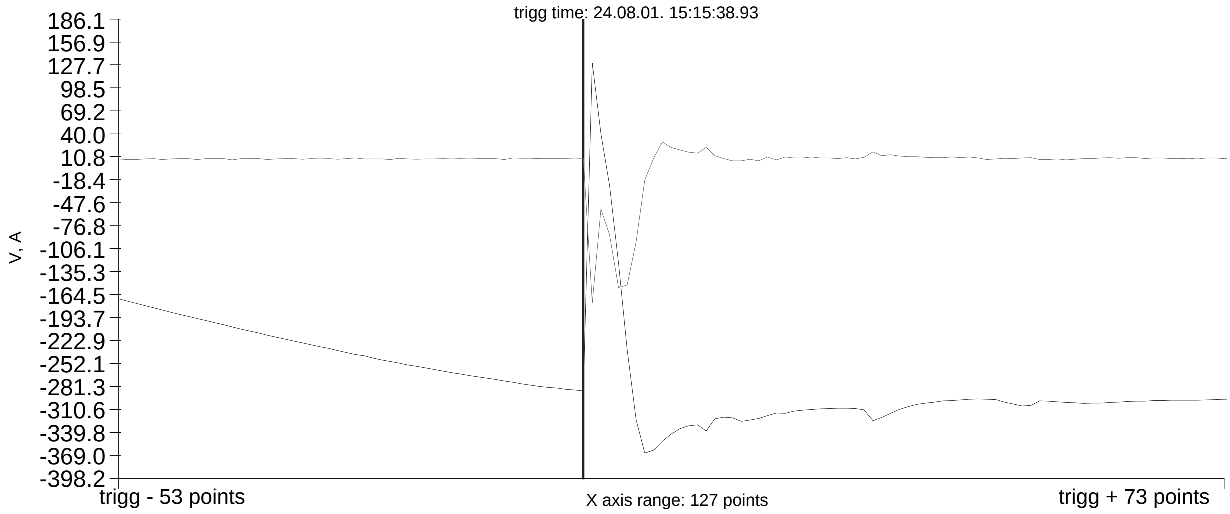


Figure 37: transient – charged capacitor

Table 7: sampling times

Selected signals	*No. of inputs*	*Sampling time*
single voltage input	*1*	*20 μs*
single current input	*1*	*20 μs*
all voltage inputs (U_1, U_2, U_3)	*3*	*30 μs*
all current inputs (I_1, I_2, I_3)	*3*	*30 μs*
one voltage and one current input	*2*	*40 μs*
U_1, U_2, U_3, I_1, I_2, I_3	*6*	*50 μs*

7. Direct Link

Direct link is a program for on-line connection between the instrument and PC. Colour coded signals, zoom, spectral analysis and printing are used for quick examination, saving or simple reports.

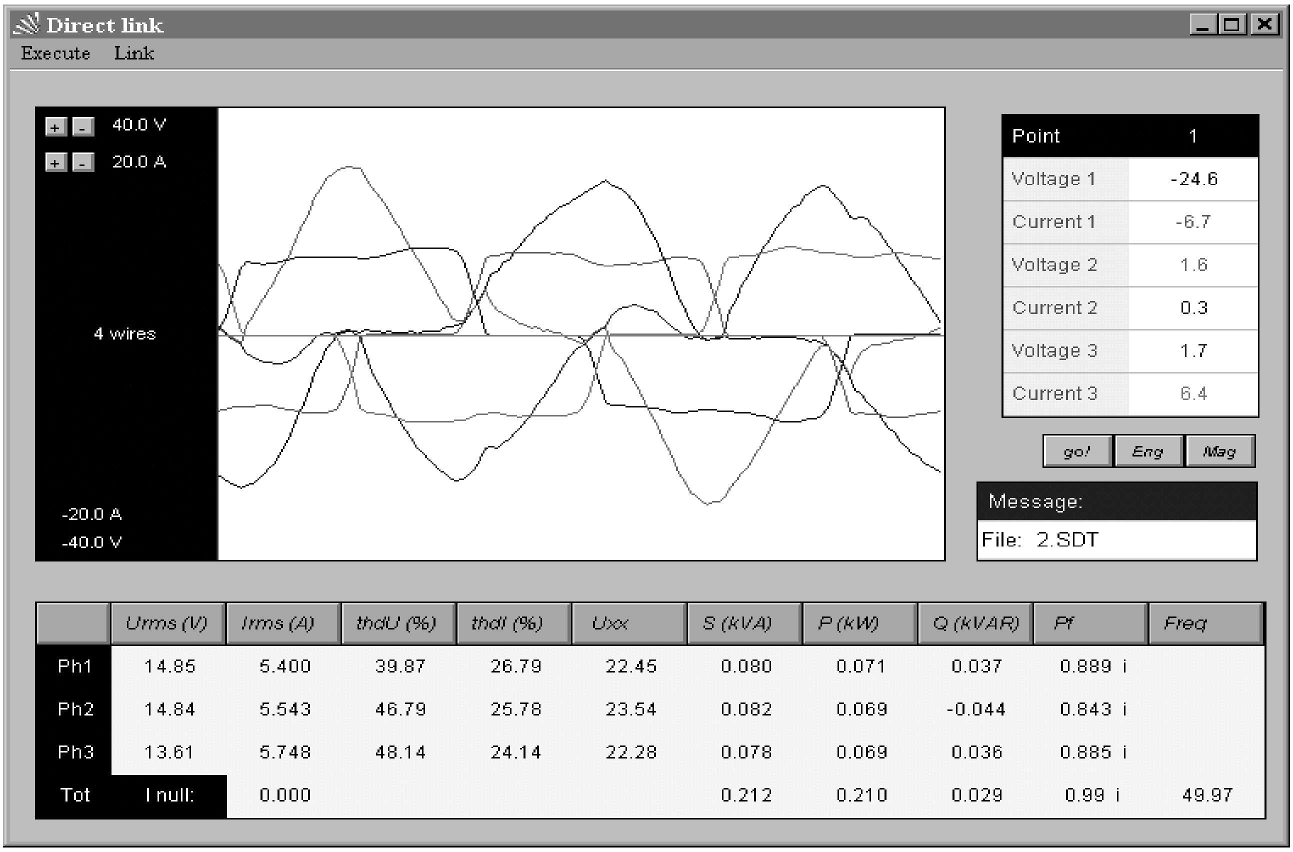


Figure 38: DC motor run for 15V on auto-transformer output – current and voltage (see waveform recording)

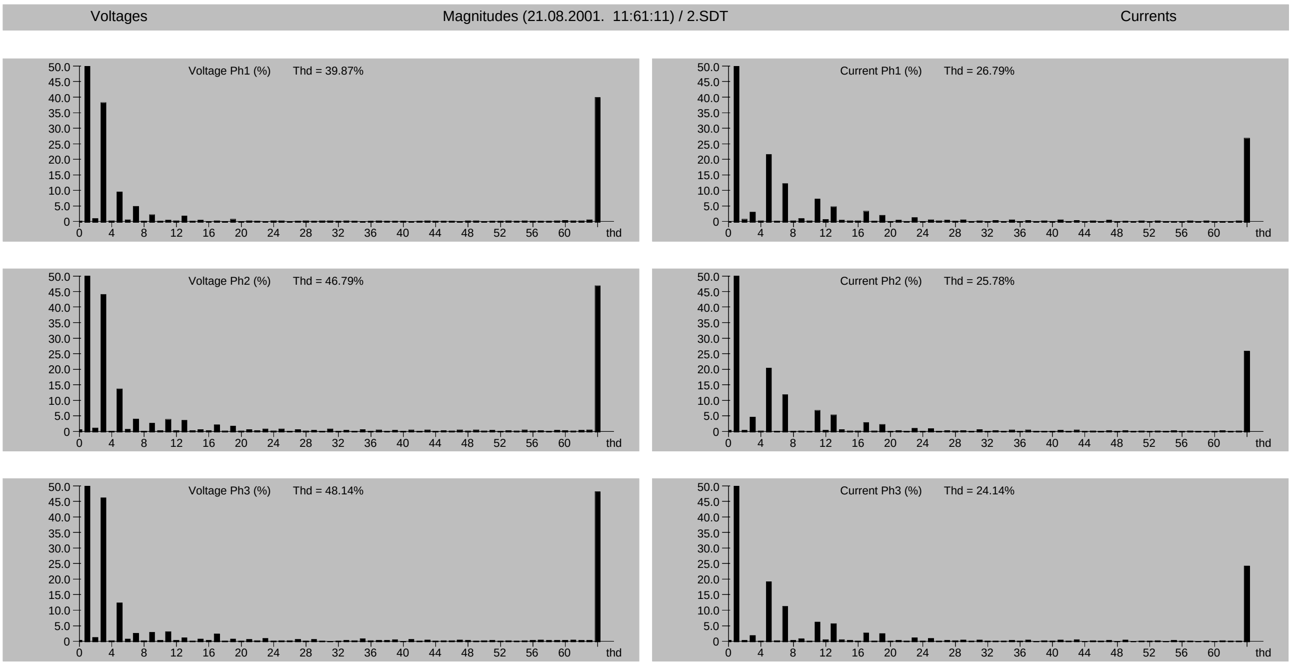


Figure 39:spectral analysis for inputs on figure 38

8. Export of recorded data

The advanced techniques that were briefly presented in the previous chapter can be used as a stand-alone tool or as a part of a more complex survey. Also the data captured with the MA 2092, especially in complex studies, must be presented concisely. This powerful facility of the instrument can be exploited for capturing large amounts of data on a specific event in order to perform additional calculations with specialised software. All of this can be achieved with exportation of recorded data. Export can be made to a clipboard or to a text file. Here are some examples on how data captured with the Power Harmonic Analyser can be used.

8.1. Power measurement – cutting power peaks

One of the simplest and the most efficient way to decrease the electricity power bill is by lowering peaks of consumed power (peak demand). This can be achieved by:
reorganisation of production processes
embedded generation
The first solution can be implemented in systems where some tasks can be stopped or rescheduled. The second solution can be implemented in systems with generators that are often used as a back-up power supply. Both solutions require additional monitoring and control systems that are designed upon previously conducted measurement and analysis of the situation in the field.
Another possibility to increase efficiency is by increasing the power factor using corrective techniques.
Power measurement over a one-week period is presented on figure 41. The recording of one-week's power consumption and power factor is exported to and processed with a dedicated program on a PC. The contract power price, generated power price, amortisation costs and other relevant factors are considered during the design phase of the system and algorithm that provide the lowest costs for the consumed energy.

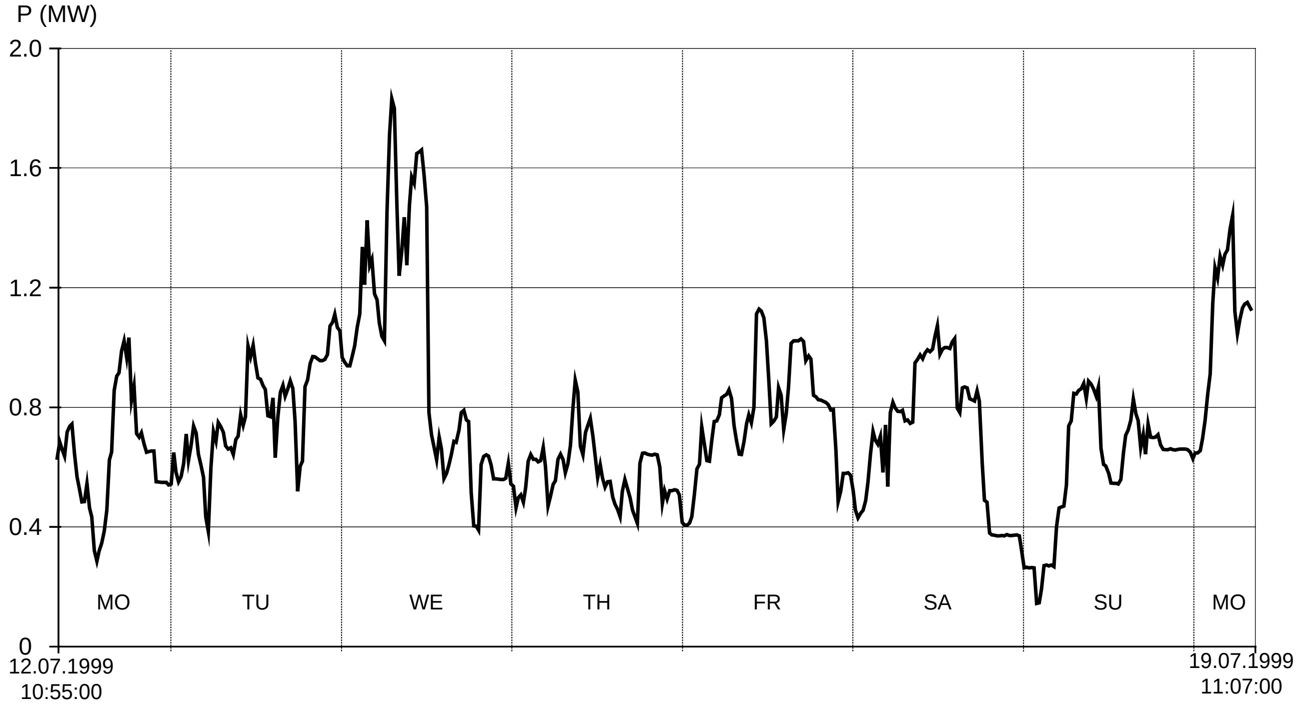


Figure 40: power consumption during a one week period

8.2. Capacitor Banks – Influence of harmonics

Capacitor banks are the devices most susceptible to the presence of harmonics.
Since consumers' loads usually have inductive characteristics, capacitor banks are used for compensation of inductive currents. This feature allows:

- ***better overall system performance***
- ***increased availability of active power***
- ***decreased transmission loses***
- ***increasing voltage***
- ***decreasing financial penalty because of poor power factor***

The presence of harmonics causes several problems connected with capacitor banks:

- ***volt-ampere-watt-meter measurement cannot be used for calculating the capacitor bank size***
- ***a capacitor bank impedance decreases with frequency ($Z_C=1/j\omega C$) and n^{th} harmonic current percentage will be n times higher then n^{th} harmonic voltage percentage***
- ***a capacitor bank will sink current harmonics causing harmonic voltage drop on a supply line. The resulting voltage THD will be higher than without a capacitor bank and the capacitor bank can be damaged by increased current***
- ***a resonance problem may occur causing high voltages that can degrade capacitor dielectric.***

Confusing situations arise with power factor correction in the presence of harmonics. Examples with linear and non-linear load will be described for comparison.

Figure 41 (a) shows the voltage, current and instantaneous power waveform for a typical linear load (pF=0.8, R_L : X_L = 1 : 0.75) and the same load with compensation X_C=-X_L (b). For simplicity the supply voltage is considered as ideal (THDU=0, Zs=0).

Used formulas:

Voltage RMS: $$U = \sqrt{\frac{1}{T}\int_0^T u^2(t)\,dt} \quad [\mathrm{V}]$$ (10)

Current RMS: $$I = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt} = \sqrt{I_R^{\,2} + I_L^{\,2}} \quad [\mathrm{A}]$$ (11)

Apparent power: $$S = U \cdot I \quad [\mathrm{VA}]$$ (12)

Active power: $$P = \frac{1}{T}\int_0^T u(t)\,i(t)\;dt = U \cdot I \cdot \cos(\phi) = U \cdot I_R = S \cdot \cos(\phi) \quad [\mathrm{W}]$$ (13)

Reactive power:

$$Q = \sqrt{S^2 - P^2} = U \cdot I \cdot \sin(\phi) = U \cdot I_L = S \cdot \sin(\phi) \quad [\mathrm{VAr}]$$ (14)

Power factor: $$PF = \frac{P}{S} = \frac{P}{U \cdot I} = \frac{I_R}{I}$$ (15)

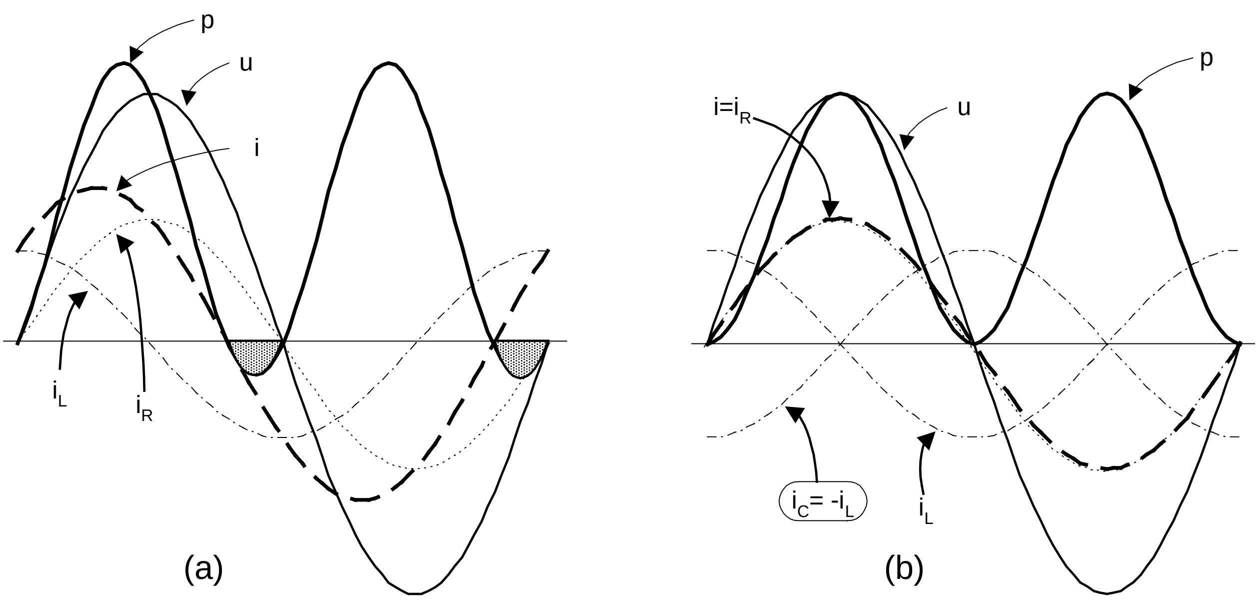


Figure 41: Linear load waveforms

A typical load current can be divided into *resistive* (I_R) and *reactive* (I_L) components. I_R is in phase with the voltage and contributes to *active power* i.e. power transformed into mechanical movement and heat. Active power represents the power of consumed coal, water, oil or other fuels. The instantaneous product of u(t) and i_R(t) is always positive.

I_L represents current that generates a magnetic field in a load. It is out-of-phase with the supply voltage causing energy bouncing over transmission lines between load and network. Twice per a period an instantaneous power caused with I_L is delivered to a load, stored in inductance and then returned to the network. Although there is no power consumption, that current causes additional losses on the transmission line by increasing the total current and power demand.

The capacitor connected in parallel to the load has a current I_C with an opposite direction than the inductive component of the load (phase angle between currents is 180°). If the capacitor's current I_C equals $I_{L,}$ then the complete reactive energy circulates just between the load inductance and the capacitor. As a result:

- ***load's current is in phase with voltage***
- ***total current RMS is lower***
- ***instantaneous power is never negative (no energy bouncing)***
- ***minimal power is transmitted over the line thereby minimising losses and network load.***

(a) shows a current that is in phase with the supply voltage and consists of the fundamental (I_1) current and a third harmonic current (I_3). The ratio between the fundamental and the 3^{rd} harmonic is 1:0.75 (i_3=75%). Voltage, current and instantaneous power waveforms are presented. The part of the power created by the harmonic current (p_3) can be seen on the picture. Active power can be calculated as the sum of the active power of each harmonic. The active power of each harmonic can be calculated by formula (16).

n^{th} harmonic active power: $P_{h_n} = U_n \cdot I_n \cdot \cos(\phi_n)$ (16)

$\cos(\phi_n)$ - phase angle between n^{th} harmonic voltage and current.

Since there is no 3rd voltage harmonic (u_3=0), the active power of the 3rd harmonic equals zero. This can be explained by examining the area below the p_3 curve on figure (a). The average value of p_3 over a fundamental frequency period is 0. Negative value of p_3 represents power returned back to the supply network. The effect of this is that measurements with volt- ampere- and wattmeter and a calculation using formula (14) result with a power factor PF=0.8 as in the previous example.

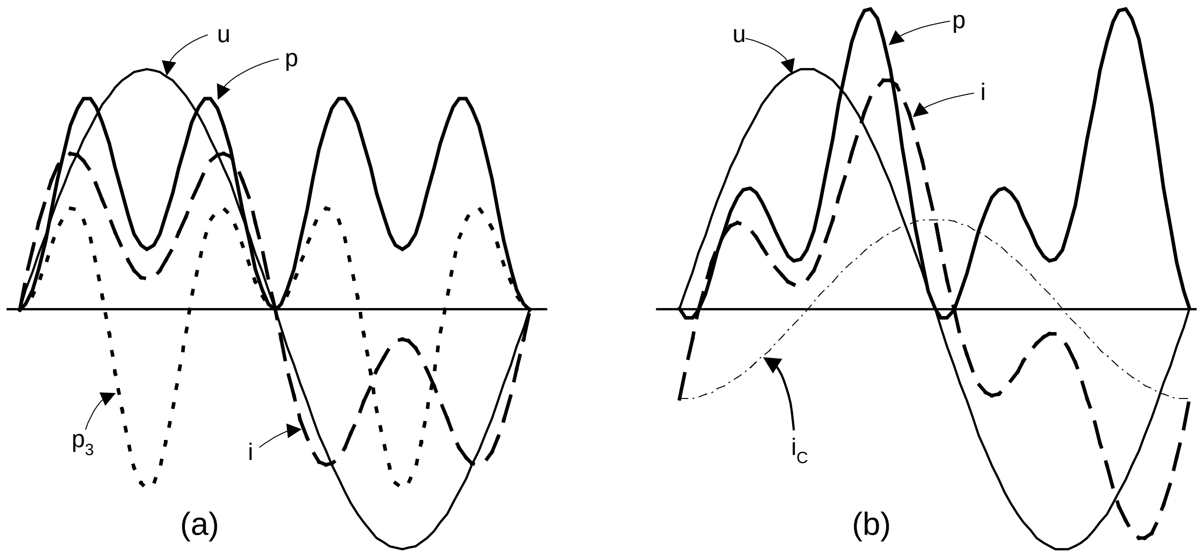


Figure 42: nonlinear current PF

If the same capacitor exampleused in the previous example is added in parallel to the load in order to improve power factor, then the situation shown on figure 43(b) arises. Because of the ideal supply voltage and that Xs=0, no change occurs on the capacitors terminals and the capacitor currents in both instances are the same.
Additional capacitor current causes:

- ***increased current rms value***
- ***increased power demand***
- ***leading phase shift between voltage and current (negative reactive power)***

The current is increased by 16% and power factor (PF=P/S) is decreased from 0.800 to 0.686. It can be concluded that the additional capacitor just deteriorated the systems performance. Figure 43 explains the influence of current harmonics on a power factor for an ideal supply voltage.
The total load current can be broken down to the fundamental and the sum of all other harmonic currents. The fundamental current can be further broken down to an active (resistive load) and reactive (inductive load) component.

$$I_{rms}^2 = I_1^2 + \sum_{k=2}^{\infty} I_k^2 = (I_1 \cos\phi_1)^2 + (I_1 \sin\phi_1)^2 + I_{harm}^2 \qquad (17)$$

A power diagram can be drawn using current vectors with the opposite direction for power caused by the reactive component. This is because inductive current lags behind the supply voltage and is presented in a negative mathematical direction. Reactive power is considered as positive and is drawn in a positive mathematical direction. Only power caused by the inductive component of the fundamental current (Q) can be compensated with a capacitor. Power factor defined with formula (15) and its compensation are not uniquely correlated, so new definitions are introduced. Namely apparent power factor that equals the power factor defined with (15), apparent power factor that can be used for compensation purposes and distortion power factor that stands for the influence of harmonics.

Apparent power factor: $$PF = \frac{P}{U \cdot I} = \frac{P}{S} \qquad (18)$$

Displacement power factor:

$$RF = \cos(\phi_1) = \phi_{U1} - \phi_{I1} \qquad (19)$$

ϕ_{U1}, ϕ_{I1} – *fundamental frequency voltage and current angles calculated with DFT*

Distortion power factor: $$DPF = \sqrt{1 - PF^2 - RF^2} \qquad (20)$$

Distortion power:

$$D = \sqrt{S^2 - P^2 - Q^2} \quad [\text{dVA}] \qquad (21)$$

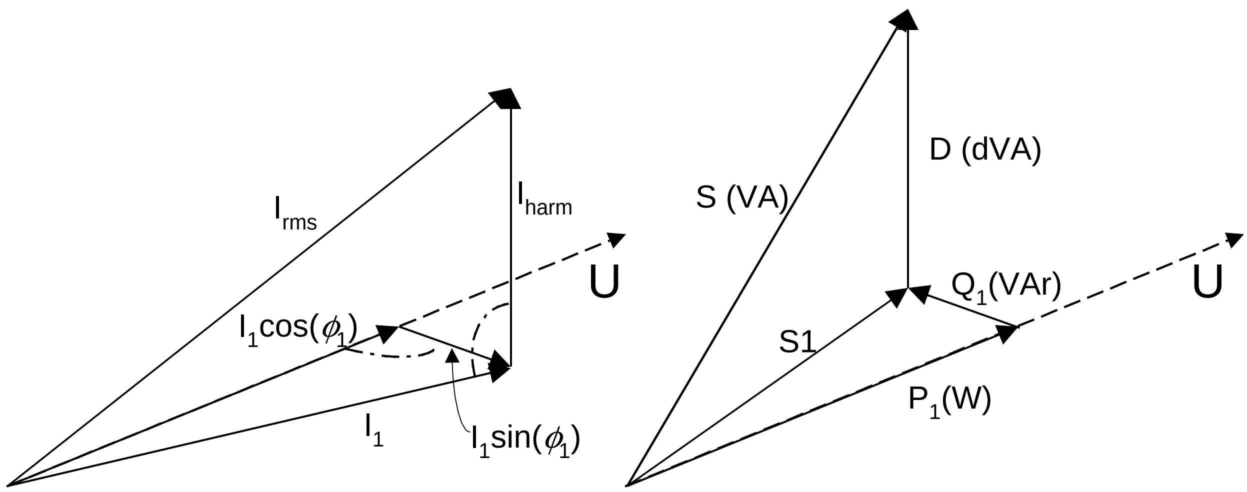


Figure 43:graphical presentation of a power caused by harmonics

This simplified example is based on an ideal voltage supply. In reality the situation becomes more complex because of the influence of non-linear loads (Xs) and the presence of harmonics in the supply voltage (THDU>0).
The measurement of power quality parameters influenced by a capacitor bank will be briefly presented on the following pages.
A customer has a point of common coupling (PCC) on a 35 kV system. A 6 kV network with 3 steam powered generator sets is the basis of the customer's energy system. In a normal situation, power through the PCC is –0.5..-1MW i.e. the generators cover the system's reactive power and there is 0.5-1 MW reserve in generated power. A three-stage capacitor bank on the 6 kV network is switched off. The aim of the measurement was the evaluation of the capacitor bank's influence on the voltage and current in a PPC.
In order to perform the measurement, reactive power generation must be stopped. When a capacitor bank is switched on to provide the generator's compensation, the voltage on a 35 kV system increases significantly. The measurement period was divided into the following sub-periods:
normal operation (system reactive power is cancelled by generators)
generators stop producing reactive power
1st stage of compensation switched on
2nd stage of compensation switched on
3rd stage of compensation switched on
normal operation
Voltage and current waveforms are sent to a portable PC through the serial connection. The recording is performed with a 5 second integration time.

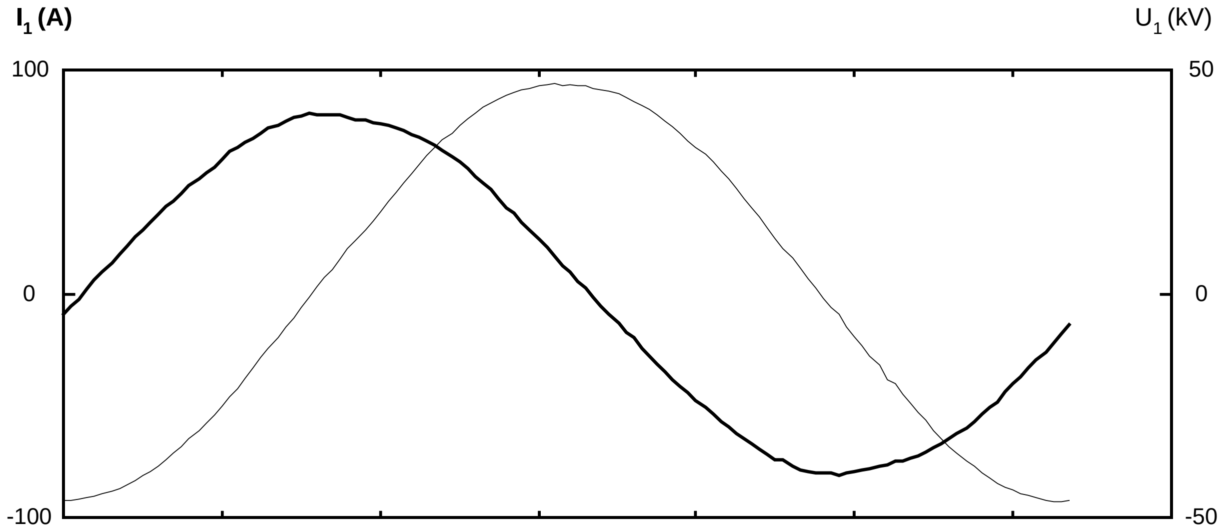


Figure 44: current during step (b) – no compensation

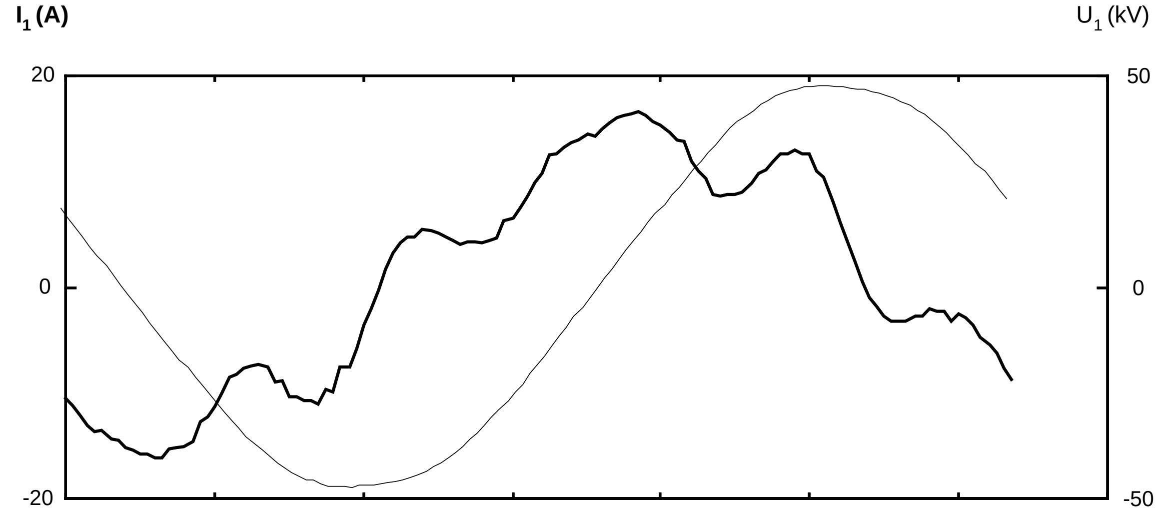


Figure 45: a current during step (e) – all stages of capacitor banks are switched on

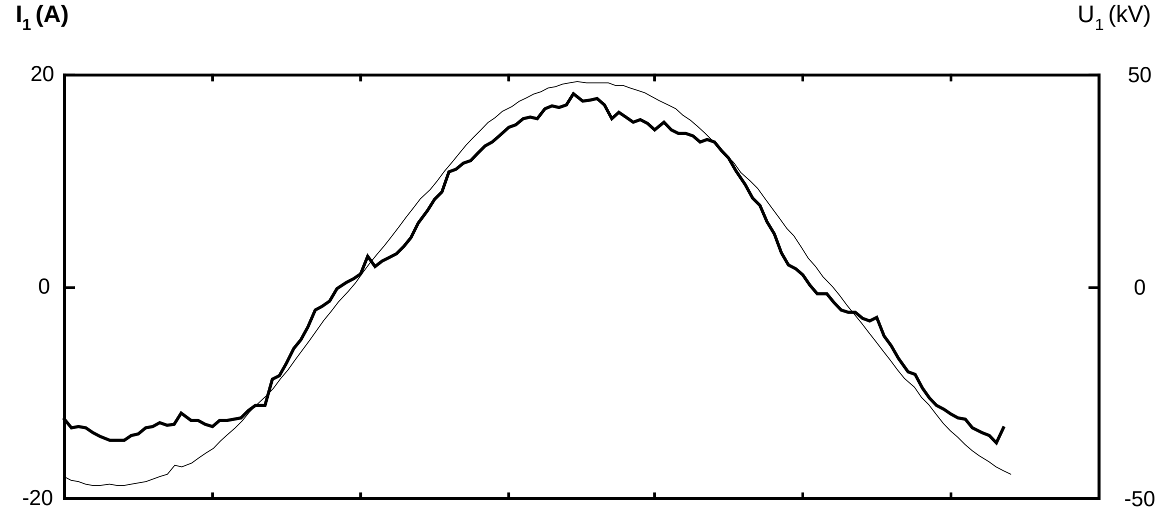


Figure 46: current during step (f) – normal situation – compensation by generation

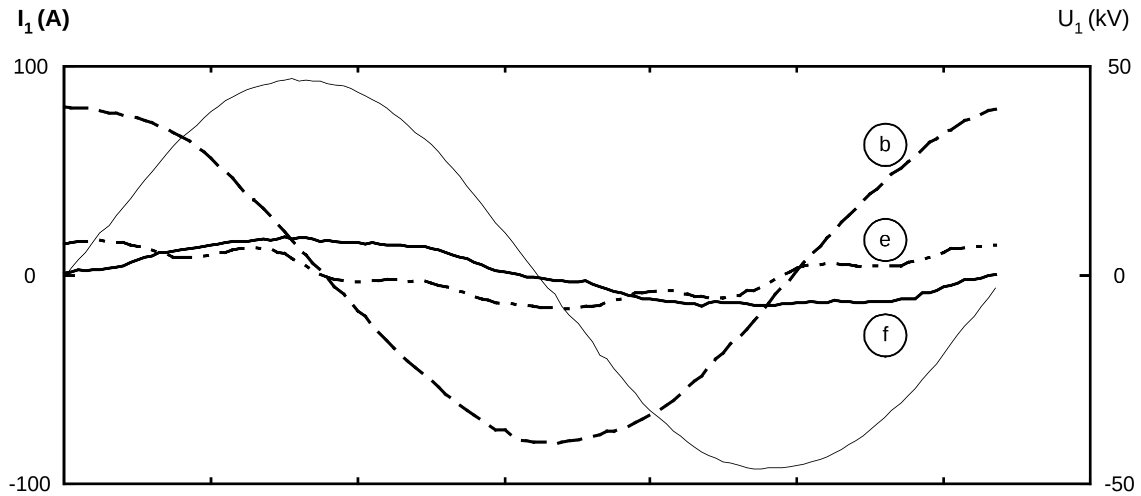


Figure 47: concentrated plot

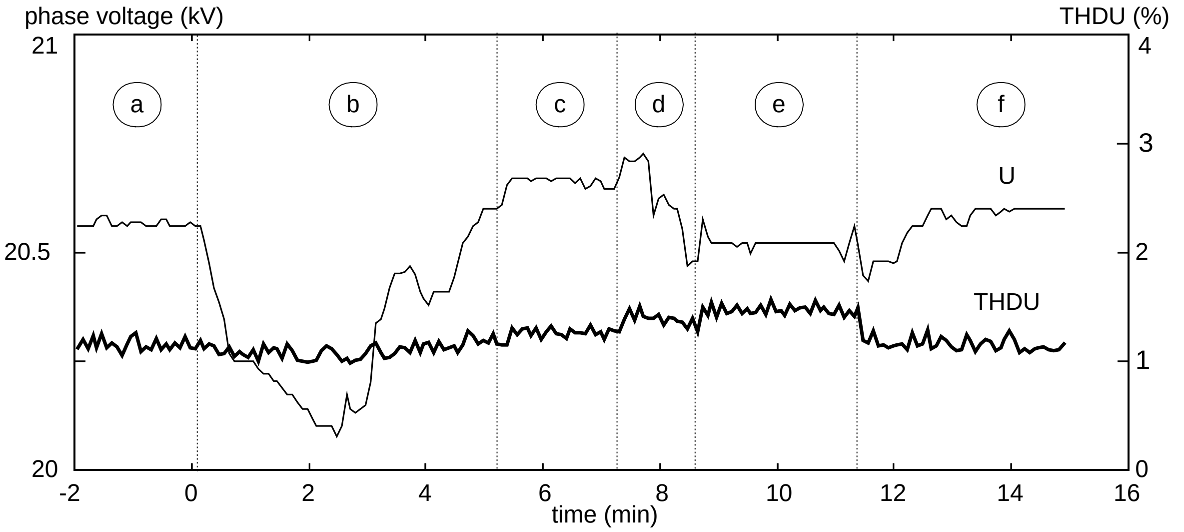


Figure 48: PCC voltage and THDU

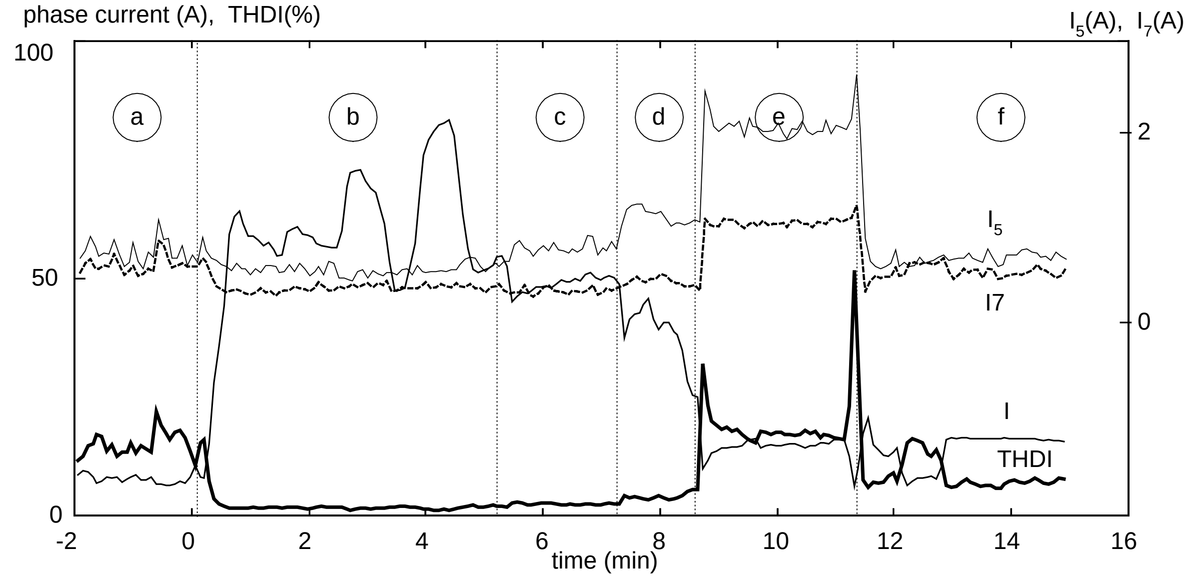


Figure 49: PCC voltage and THDU

The data on figures 45, 46 and 47 is captured from the instrument and figure 48 is made with post processing of the captured data. Figure 49 and 50 show the recording results. In conclusion: voltage THD arises when the 3rd stage of a capacitor bank is switched on. Current THD is decreased in 0-I-II compensation stages, mainly because of the increased reactive current through the PCC. When the 3rd stage of the capacitor bank is switched on, THDI arises significantly because of the decreasing current rms and the increase of harmonics. Current harmonics are rather constant. A significant increment occurs when the 3rd stage is switched on (figure 48).

8.3. Fast logging – motor start current

Figure 50 illustrates how fast logging can be used in monitoring a motor start-up. A pump motor has to be started with star-delta switching. A time between star and delta connection must be set according to the manufacturers recommendations and measurement must confirm that the pumps automatic control is properly adjusted.

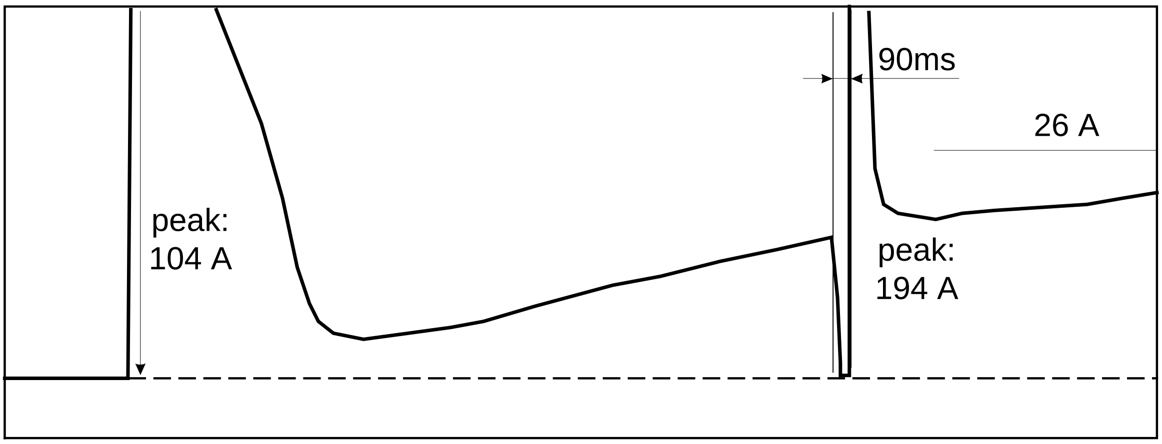
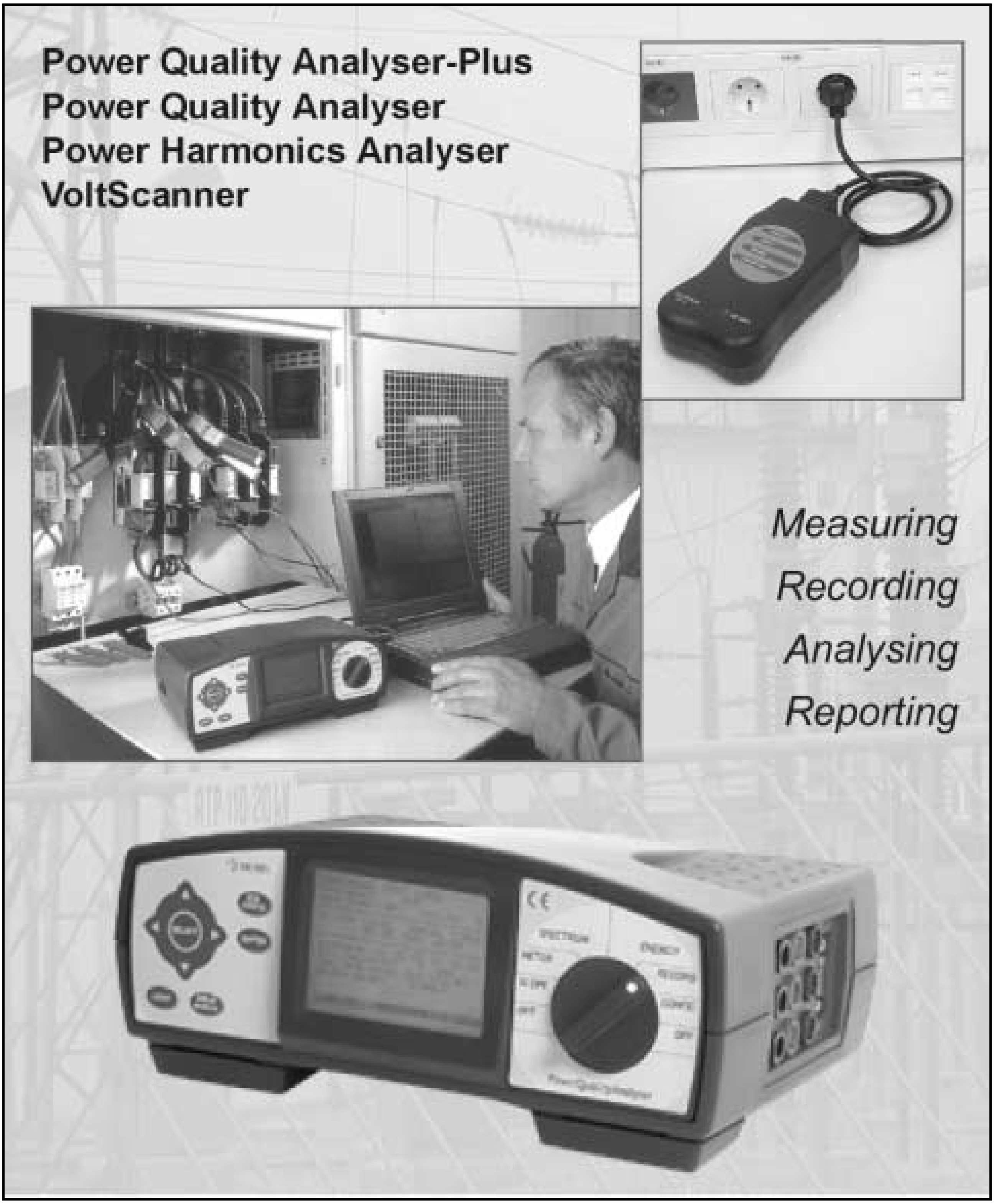
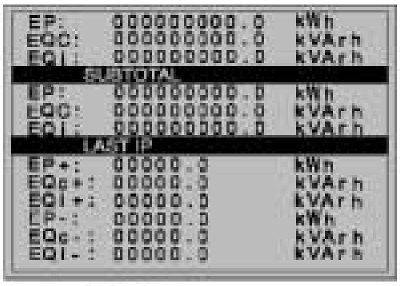


Figure 50: a motor start

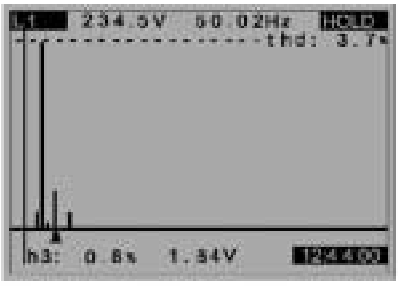
9. Recommended measurement instruments



9.1 Power Harmonics and Power Quality Analysers



Accurate Energy Measurement
Active & Reactive
Import & Export
Inductive & Capacitive
Separate registers for total, Sub-total & Last Integration Period

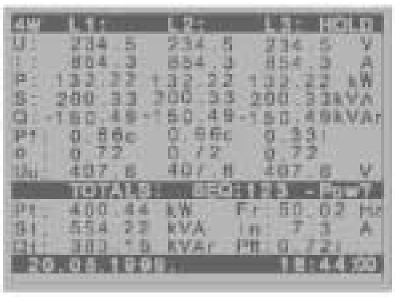


Voltage and Current Harmonic Analysis
Harmonics up to 63[th] component

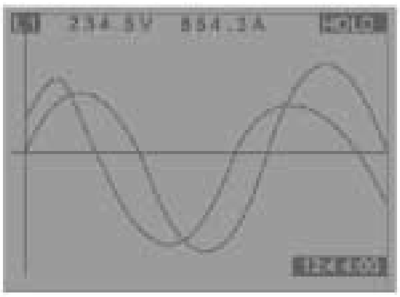
True Real-Time operation for capturing anomalies, voltage interruptions and power breaks.
2 Mb of memory allows data logging up to several months.

AC powered and battery powered
Battery Pack provides full operation for up to 5 hours.

Modern Remote Control by using GSM or standard type of communication.



Meter Menu for display of all measured parameters

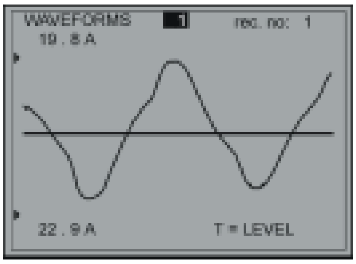


Scope function allows viewing of current and voltage waveforms.

Configuration menu for setting measuring method, integration period, current scaling factor, and selection of signals.

9.2 Special SW Tools

Special tools enable a detailed, time domain based signal analysis. They represent a powerful, modern troubleshooting tool for solving of all kinds of problems which are appearing in power distribution systems. The user can choose between three modes, differing in terms of sampling speed, trigger possibilities and recording time:



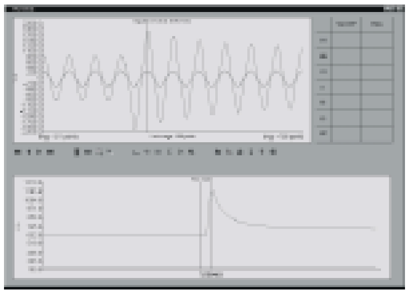
• *WAVEFORMS*

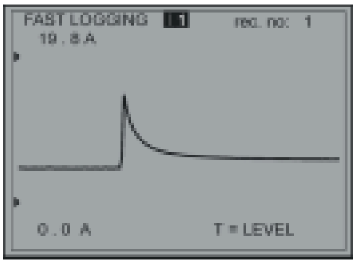
Recording of voltages and currents with 128 samples/period. Half period RMS values of recorded quantities are also calculated and shown in this mode. Best suited for:

- monitoring of switching phenomena,
- locating of noise and disturbance sources,
- defining disturbance type,
- locating excessive harmonics sources.

Typical problems that can be solved by WAVEFORM analysis:

- capacitor banks switch over,
- transformer overheating,
- UPS problems,
- SMPS failures etc.





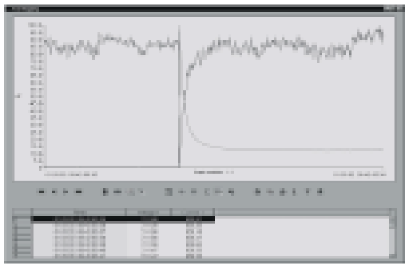
• *FAST LOGGING OF SIGNALS*

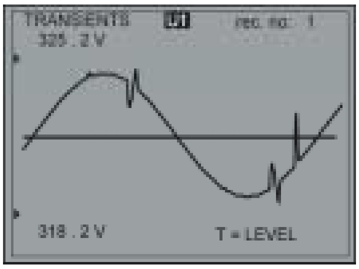
Recording of half period RMS voltage and currents values. Recommended when record length is critical and signal's details are not of importance. Best suited for:

- observing start up and inrush events,
- locating impedance problems,
- long term analysing of unstable mains.

Typical problems that can be solved with FAST LOGGING analysis:

- too high inrush currents of large motors,
- undersized fuses and installation wiring,
- too weak voltage source etc.





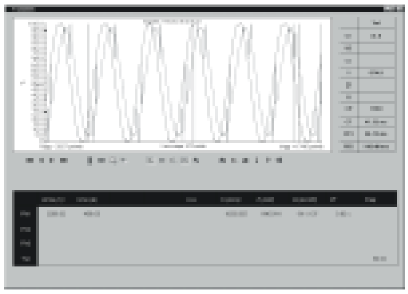
• *TRANSIENTS*

The recording mode with fastest sampling rate that the instrument can provide. Up to 50 kHz transient detect ability in this mode. Best suited for:

- monitoring atmospheric discharging,
- analysing switching problems,
- detailed analysis of high frequency noise and notching.

Typical problems that can be solved with TRANSIENT analysis:

- frequency noise,
- voltage spikes caused by switching of capacitor banks etc.



9.3 Technical Specifications

AC VOLTAGES

Three-phase AC voltage input
(3 differential inputs, L_1 - N_1, L_2 - N_2, L_3 - N_3)

Input voltage range:	10 - 550 Vrms L-N, 900 Vrms L-L 600 Vrms L-N (over load 10 s)
Optional on request:	10 - 750 Vrms L-N, 1000 Vrms L-L 800 Vrms L-N (overload 10 s)
Resolution:	0.1 V
Accuracy:	± 0.5 % of reading ± 2 digits
Crest factor max.	1.4
Frequency range:	43.-.68 Hz fundamental

AC CURRENTS

Three-phase AC input for connection to current transducers wit voltage output

Input current (voltage range): 0.02 - 1 Volt rms (from 0.02 x I_n to I_n) input

Resolution:	0.3 mV (0.3 Amp with 1000 A / 1 V)
Accuracy:	± 0.5 % of reading ± 6 digits plus current transformer accuracy
Crest factor:	2.5

Max. permissible overload: 150 % I_n (sinusoidal current)

Maximum input voltage: 1 Vrms

PHASE ANGLE

Consider Phase angle data of used current transformer.

Range	Limits of error		Resolution
I_{range} U_{range}	THD Total Harmonic Distortion	HD Harmonic Distortion	on LCD and
2…100 %	0.2 % x U_r/U (I_r/I)	0.2 % x U_r/U (I_r/I)	0.1 %

ENERGY

Displayed. Quantities from integration of calculated power as:
- cumulative values (TOTAL);
- partly cumulative (resettable by user request) (SUB TOTAL);
- values related to last integration period (LAST IP).

Quantities. Active energy (EP), capacitive energy (EQC), inductive energy (EQI)

Basic accuracy:	± 1 % of reading
Resolution:	0.1 of displayed value

RECORDER

Periodics integration period:1 s – 900 s
Selected signals: max. 64
Statistics values: each period divided in 200 parts (0.1 ms)
Voltage anomalies: based on half period, start, duration and extrems of voltage

EN 50160 ANALYSIS MODE

Voltage dips, swells, sags and breaks, resolution 10 ms, no gaps
Voltage unsimetry, Voltage RMS values, Frequency

Harmonics:	up to 43th component
Flickers Plt Pst:	no gap

FLICKER MEASUREMENT

The instrument computes flickers according to IEC 61000-4-15

WAVEFORMS

Sampling rate:	128 scans / period
Trigger:	level, manual, timer
Buffer:	min. 10 periods of pre / post size, up to 7812 periods can be recorded
Channels:	3 x U, 3 x I, U lines, Min / Max rms values: Avg

Pf, cosφ, Crest faktor, THD U, I Frequency
Harmonics / direction: magnitudes / positive / negative

FAST LOGGING

Sampling rate:	128 scans / period, min, max, Avg recorded each halfperiod
Trigger:	level, manual, timer
Buffer:	pre / post size, up to 166 minutes of recording
Channels:	3 x U, 3 x I, Single or multichannel mode

TRANSIENTS

Capturing:	>20 µs transient detect ability
Trigger:	Level, slope, manual
Buffer:	min. 10 periods of pre / post size, up to 1000 periods can be recorded
Channels:	3 x U, 3 x I, Single or multichannel mode

9.4 VoltScanner

Easy and smart solution to measuring the quality of the line voltage in accordance with EN 50160 - event or periodics mode

Maintaining a high-quality electric power supply is essential for your daily work and life.

For a proper operation of computers and other electrical and electronic equipment you want to know whether the contracted level is being met and when and how often the limit values are exceeded.

Set-up of event recording or periodics recording mode

RS 232 communication port

LED and BUZZER indicate a wrong polarity connection on the outlet.

A flashing LED indicate that events have been captured

LED lamp indicate when the memory capacity is over.

Low-battery indication

- **A flashing LED indicate that events have been captured**
- **Memory capacity of up to 3500 events**

Simple plug-in and automatic start of monitoring

OPERATING PROCEDURE

- **Set-up limit values**
  - Custom or
  - EN 50160 auto-mode
- **Plug-in**
- **Measure & Record**
  - **Events mode**
    - Dips/Sags, Swells
    - Voltage interruptions
    - Frequency fluctuations
    - Transients overvoltage
  - **Periodics mode**
    - Power frequency
    - Supply voltage
    - EN 50160 auto-mode
- **Download**
- **Analyse**
  - Periodics (max., min., or average values) - table or graph
  - Statistics of
    - All the events by character, apparent and duration time,
    - Events selected by period of time (divided in day by day periods or divided period within a day).

TECHNICAL SPECIFICATION

Measurement

Phase to Neutral

Range	Accuracy	Resolution
0 to 265 V	± 2 V	1 V

Neutral to Ground

Range	Accuracy	Resolution
0 to 155 V	± 2 V	1 V

Frequency

Range	Accuracy	Resolution
47 - 52 Hz,	± 0.1 Hz	0.1 Hz
57 - 62 Hz	± 0.1 Hz	0.1 Hz

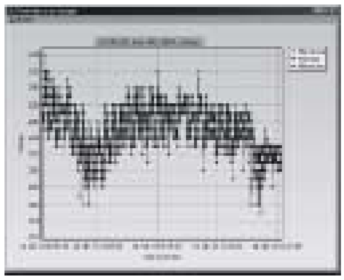
Transients

Range	Accuracy	Resolution
50 to 2700 V	± 10 %	5 V

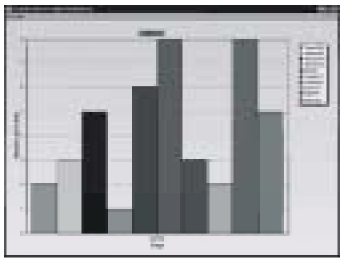
Minimum width: 1 µs

General

- Nominal Supply Voltage: 230 V or 120 V
- Nominal Frequency: 50 / 60 Hz
- Communication: RS 232 serial interface, fully opto isolated, 9 pin D-type connector
- Memory: 32 kB, 3500 events
- Battery: 6 V DC (4 x 1.5 V AA) Rechargable
- Overvoltage category: CAT III 300 V



Periodics analysis of voltage variationfor the past 3 weeks

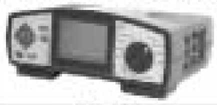
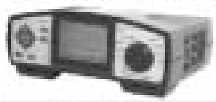
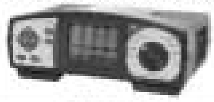
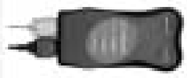


Statistics of the campured events

ScanLink Windows 95/98 software for analysing and print-outs with a complete history of campured events in a table or graphic form (statistics).

By analysing periodics it enables review of voltage quality against the set limits (Custom or EN 50160 auto-mode).

9.5 Comparison table

Main features:	Power Quality Analyser-Plus 	Power Quality Analyser 	Power Harmonics Analyser 	VoltScanner 
Order No.:	MI 2292	MI 2192	MI 2092	MI 2130
Power Quality Testing				
RMS Voltages, Currents (average, min., max.)	✔	✔	✔	
THD Harmonics Analysis	✔	✔	✔	
Power Active, Reactive, Apparent Cos Φ Character, sign	✔	✔	✔	
Voltage Events (dips, sags, interruptions)	✔	✔	✔	✔
Periodic Analysis	✔	✔	✔	✔
Statistical Analysis	✔	✔	✔	✔
Anomalies (Events) Analysis	✔	✔	✔	✔
Neutral current (calculated)	✔	✔	✔	✔
On Line monitoring				
Meter mode - tabelaric results	✔	✔	✔	
Scope mode - osciloscope	✔	✔	✔	
Spectrum Analysis mode	✔	✔	✔	
EN 50160 compliant testing				
Fast Set Up - Auto mode	✔	✔		✔
Voltage	✔	✔	✔	✔
THD & Harmonics	✔	✔	✔	
Dips, Sags, Interruptions	✔	✔	✔	✔
Flicker	✔			
Frequency	✔	✔	✔	✔
Interharmonics / Signalling	✔			
Unbalance	✔	✔		
EN 50160 Test Report	✔	✔		
Special tools				
FAST LOGGING mode	✔(168 minutes)	✔(8,4 minutes)		
WAVEFORM mode	✔(7812 periods)	✔(390 periods)		
TRANSIENT mode	✔(1000 periods)	✔(50 periods)		✔
Energy				
Total	✔	✔	✔	
Subtotal counters	✔	✔(50 periods)	✔	
SW - package for modem	✔	optional	optional	

UNIVERSITY OF MARIBOR

FACULTY OF ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE
2000 Maribor, Smetanova ul. 17
SLOVENIA

icem

infrastrukturni center za energetske meritve – power measurement center

EVALUATION OF APPLICABILITY OF POWER QUALITY ANALYSER PLUS MEASUREMENT INSTRUMENT VERSION 4

No: 02 I - 13

Applicant: Metrel d.d.
Horjul 188
1354 Horjul, Slovenija

Summary:
Power Quality Analyser is one of the most advanced measurement instruments for measuring the quality of electrical power in compliance with the EN60150.
It incorporates a number of different measurement instruments for calculating various electrical parameters which is based on current and voltage measurements. Although the Power Quality Analyser has a very wide operating range it is a clear, robust and user-friendly instrument. It enables easy handling when performing standard measurements, but it also gives the user enough room for manoeuvre when locating faults and disturbances in the power distribution system or when performing other uncommon measurements. Optional accessories, available for the Power Quality Analyser, ensure voltage and current measurements in a very wide range, as well as the use of other measurement adapters. Therefore, the only thing that limits the user is his own knowledge and skill.

Maribor, 10.10.2002

Evaluated by: Darko Koritnik, univ. dipl. inž

Head of Power Laboratory:

izred. prof. dr. Jože Voršič

Dean:

red. prof. dr. Ivan Rozman

☎ (386 2) 220 70 50 • TELEFAX (386 2) 25 25 481 • E-mail:vorsic@uni-mb.si