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Wrocław University of Technology

Control in Electrical Power Engineering

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ELECTROMAGNETIC COMPATIBILITY

Wrocław 2011

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Introduction

Have you ever though why you are requested to switch off your mobile phone and other electronic equipment before airplane take off? That is an example of a typical case of electromagnetic compatibility. Your electronics devices may interfere with the electronic system in the airplane. Your equipment may affect airplane system and can cause unsafe flight.

Electromagnetic compatibility (EMC) is the ability of a system or equipment to operate satisfactorily within design tolerances in its intended electromagnetic environment, with adjacent systems and equipment, and with itself, so that the effect of any electromagnetic disturbances produced by the systems or equipment is reduced. Electromagnetic compatibility is the part of electrical sciences including the generation, propagation and immunity of electromagnetic disturbances with reference to the unwanted effects.

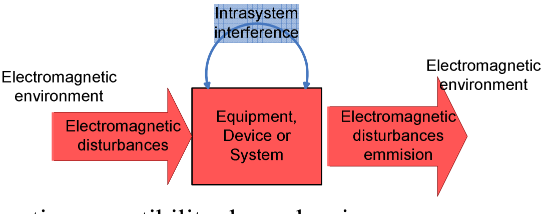


Fig.1. Electromagnetic compatibility dependencies

Electromagnetic interference (EMI) is a phenomenon in which electronic devices upset each other's operation. Computers, television receivers, telephone sets, high-fidelity sound equipment, and certain medical devices can malfunction because of strong radio-frequency fields such as those from a nearby broadcast transmitter. The EMI is usually the result of improper or ineffective shielding in the affected device or system.

The device or system should be proof to interference occurring in the environment in which it is designed to work, and should not interfere with other systems (Fig. 1). Furthermore, particular components of the device or system should not interfere with each other (intrasystem interference). The best solution is to design equipment, systems, networks, installations in a way that ensures a very high immunity to interference and the minimum emission level of disturbances.
In order to achieve this, EMC consider two different approaches (Fig. 2):

- Electromagnetic emission which is related to generation of disturbances by source, in order to reduce generation and to avoid the bad affects on external environment and working equipments operating in it.
- Susceptibility (immunity) issues, which refer to the correct operation of equipment, considered as victim, in the presence of electromagnetic disturbances.

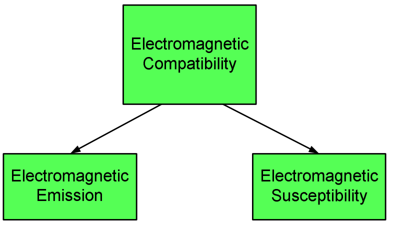


Fig.2. Electromagnetic compatibility issue

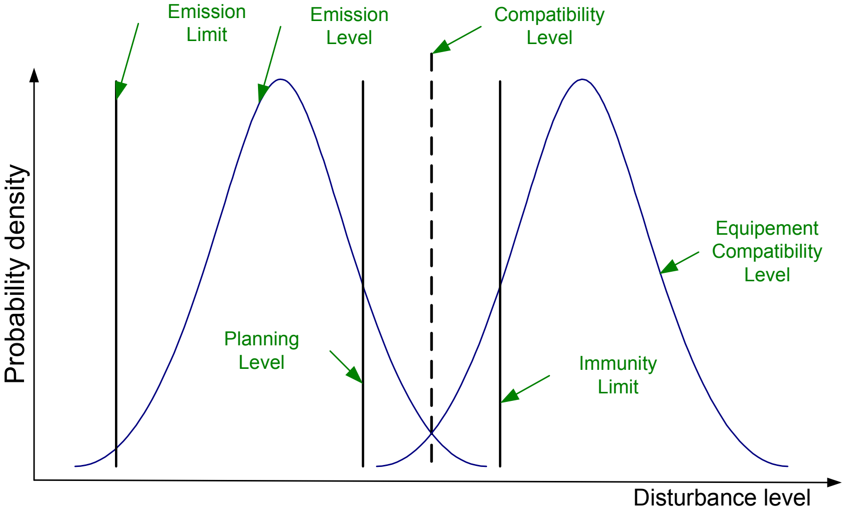


Fig.3. Relationship between emission limit, immunity limit, planning level and compatibility level – statistical approach

Figure 3 shows the probability of emission levels of particular disturbances in particular environment and probability of equipment compatibility level. They have normal distribution. To avoid electromagnetic interference the engineer should design equipment in way that the equipment distribution level is as far as away possible from emission and planning level. On the other side, the equipment emission of disturbances is limited. It is showing Figure 4.

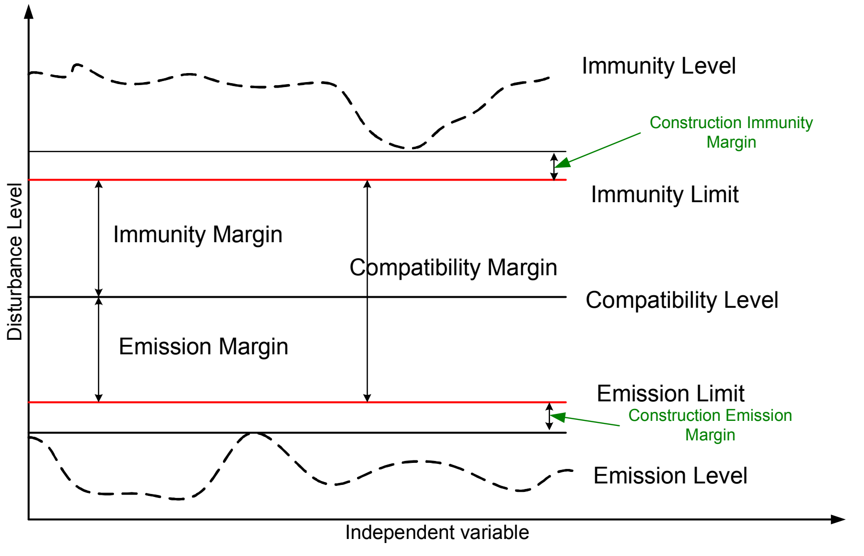


Fig.4. Relationship between emission limit, immunity limit and compatibility level

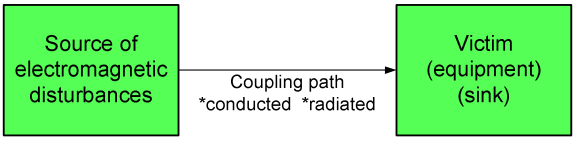


Fig.5. The electromagnetic interference (EMI) coupling channel

Disturbances coupling channels that connect sources and sinks can be classified according to different criteria. The main classification includes

a) Conducted disturbances
   - power line
   - signalling port (line)

b) Radiated disturbances
   - Magnetic field
   - Electrical field
   - Electromagnetic.

Important is also frequency range:

- DC
- Power line frequency 50,60,400 Hz
- Low frequency 50…150kHz
- High frequency >150kHz (Radio frequency)

Knowledge of the channel interference and frequency range of interference are important to take action affecting the reduction of disturbances emission (source) and increasing the level of immunity (victim).

Numerous EMC standards exist. They can be grouped as follow:
1: General: General consideration (fundamental principles).
2: Environment: Description and classification of environment compatibility levels.
3: Emission limits and immunity test levels.
4: Testing and measurement techniques.
5: Installation and mitigation guidelines.
6: Generic standards.
In accordance to the International Electrotechnical Commission (IEC) standards concerning electromagnetic compatibility are grouped as given above.
The IEC is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies — collectively known as „electrotechnics”

Table 1. Principal phenomena causing electromagnetic disturbances as classified by the IEC

Group	**Examples**
Conducted low frequency phenomena	Harmonics, interharmonics, DC in AC networks
	System signal (power line carrier)
	Voltage dips, interruption, fluctuation, imbalance
	Power frequency variation
	Induced low frequency voltages
Radiated low frequency phenomena	Magnetic fields, Electric fields
Conducted high frequency phenomena	Induced continuous wave voltage or current
	Oscillatory transients, Unidirectional transients
Radiated high frequency phenomena	Magnetic fields, Electric fields, electromagnetic fields
	Transients, continuous waves
Electrostatic discharge (ESD)	Direct discharge; indirect discharge

Nuclear electromagnetic pulse (NEMP)	a result of a nuclear explosion

Power Quality (abbreviation PQ) is a branch of electromagnetic compatibility. The domain of PQ are power grid and power system voltage parameters. Main issues of power quality are:

- equipment immunity to disturbances in power system,
- emission of disturbances to power system by equipment,
- disturbances mitigation.

Coupling path – conductive (Power Distribution System). Power quality does not consider radiated interferences caused by power grid and electrical equipment.

The IEEE standard no. 1159 provides the following definition of Power Quality - “The concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with premise wiring system and other connected equipment”.

Laboratory No. 1 – Voltage parameters of power supply

1. Aim of laboratory exercise

The purpose is assessment of low voltage characteristics of electricity supplied by utility.

The values of indices characterizing voltage are obtained from power quality analyzer and next compared with limits.

2. Measured parameters and test condition

According to EN-50160 standard and Ministry of Economy order power quality assessment is related to parameters given in Table 1

Table 1. Voltage parameters, measuring condition and limits

No	Parameter	Measurement condition	Supply voltage characteristics according to EN 50160
1.	Power frequency	10 s average value	±1% (49.5 - 50.5 Hz) for 99.5% of week -6%/+4% (47- 52 Hz) for 100% of week
2	Voltage magnitude variations	mean 10 minutes rms values	LV, MV: ±10% for 95% of week,
3.	Rapid voltage changes, Flickers	mean 10 minutes rms values	LV: 5% normal 10% infrequently $P_{lt} \leq 1$ for 95% of week MV: 4% normal 6% infrequently $P_{lt} \leq 1$ for 95% of week
4.	Supply voltage dips	10ms RMS value	0,01Unom<Urms<0,9Unominal
5.	Short interruptions of supply voltage	10ms RMS value	0,01Unom<Urms Duration < 1 minutes
6.	Long interruption of supply voltage	10ms RMS value	longer than 3 minutes

7.	Temporary, power frequency overvoltages	10ms RMS value	LV: <1.5 kV rms MV: 1.7 *Uc* (solid or impedance earth) 2.0 *Uc* (unearthed or resonant earth)
8.	Transient overvoltages		LV: generally < 6kV, MV: not defined
9.	Supply voltage unbalance	mean 10 min rms values	LV, MV: up to 2% for 95% of week up to 3% in some locations
10.	Harmonic voltage	mean 10 min rms values	LV, MV: see Table , THD<8%

Table 2. Limits for voltage harmonics defined in regulationr and standards.

Odd harmonics				Even harmonics	
Non multiples of 3		Multiples of 3			
Harmonic order	Relative value [%]	Harmonic order	Relative value [%]	Harmonics order	Relative value [%]
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					
NOTE: Do not give a value of harmonic higher than 25, because they are usually small and largely impossible to predict due to the resonance effects					

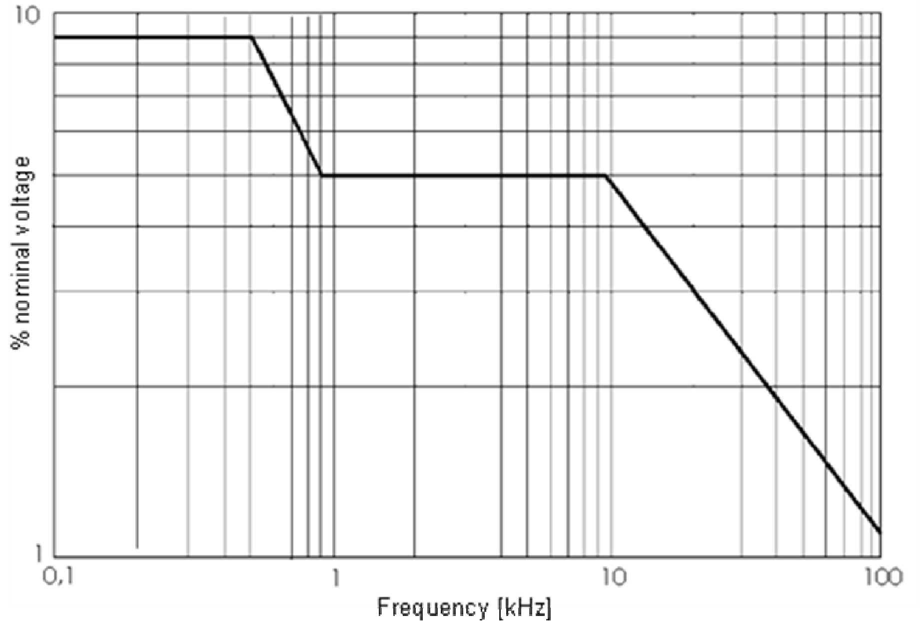


Fig.1. The level of transmission signal which is used in public network presented relative to nominal voltage in function of frequency.

3. Measuring circuit

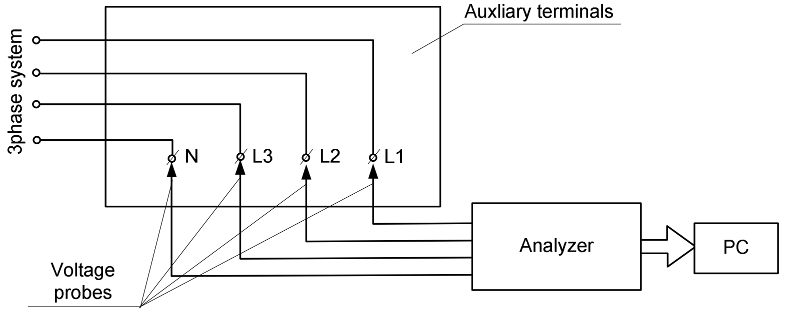


Fig. 2. Scheme of a measuring circuit

4. Measuring instruments

Analyzer MEMOBOX 686 or Mavowatt 50

5. Laboratory exercise execution and analisis of the results

Connect the circuit as shown in Figure 2.

Set the parameters of analysis as shown in Figures 3 and 4. Next program the analyzer (option write to memobox).

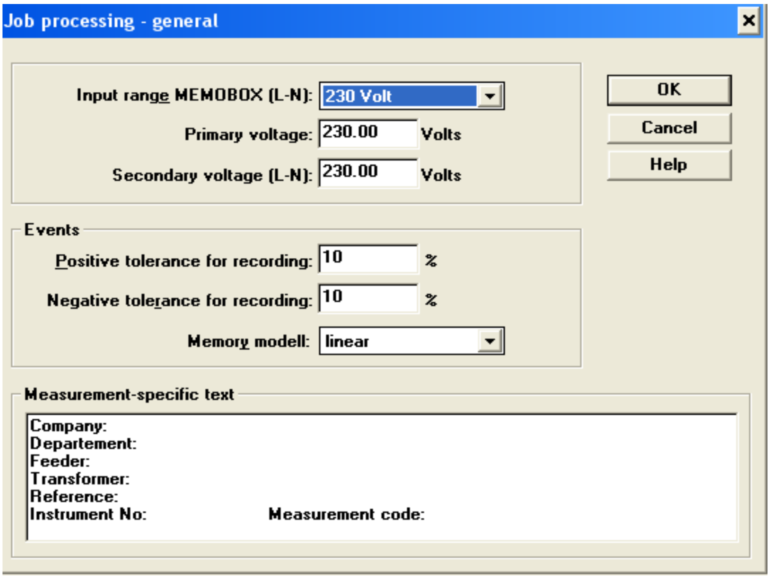


Fig. 3. Window – general settings

During the recording the LED indicator is green. The LED is red when the recording is finished or is not started.

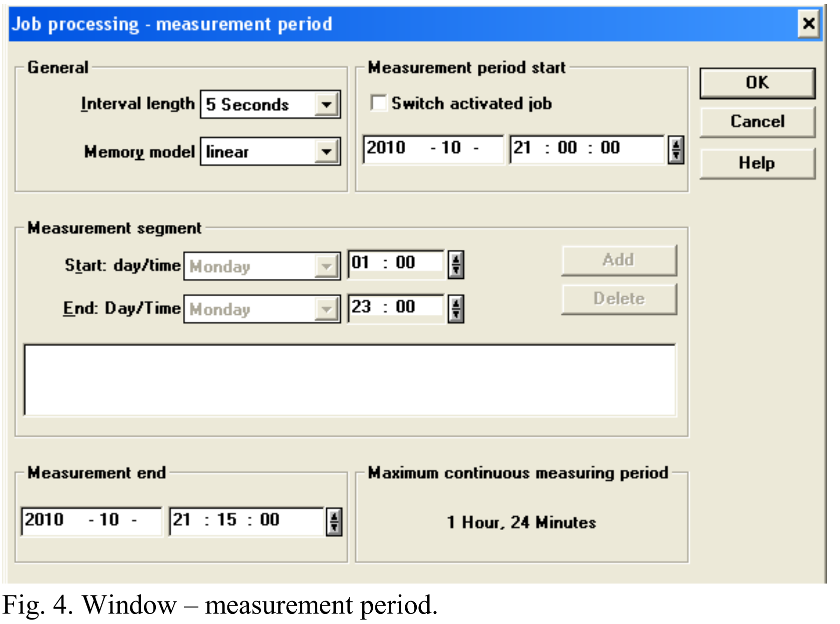


Fig. 4. Window – measurement period.

Read the results after 15..20 minutes (You don't have to wait until the analyzer finish recording).

The window "graphical summary" will open automatically after the results reading finished (Fig. 5.). The window shows values of voltage parameters compared to EN-50160 limits.

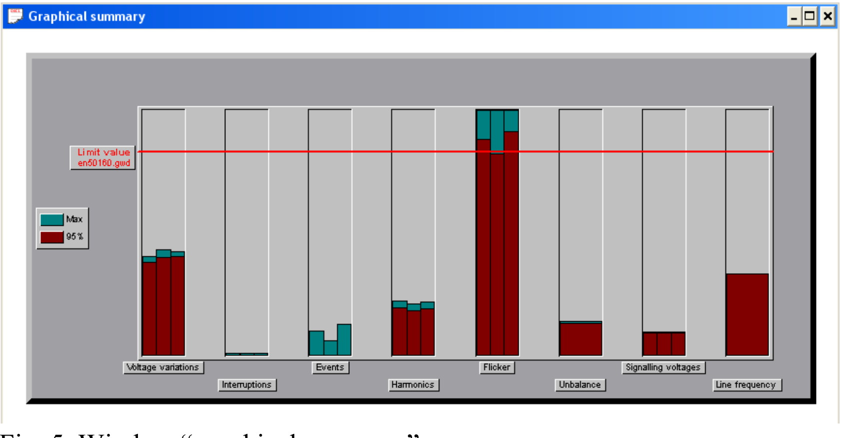


Fig. 5. Window "graphical summary"

The software of CODAM686 presents results of power quality assessment in tables. The type of table may be choosen by the user (click on „analysis" (fig. 6)).

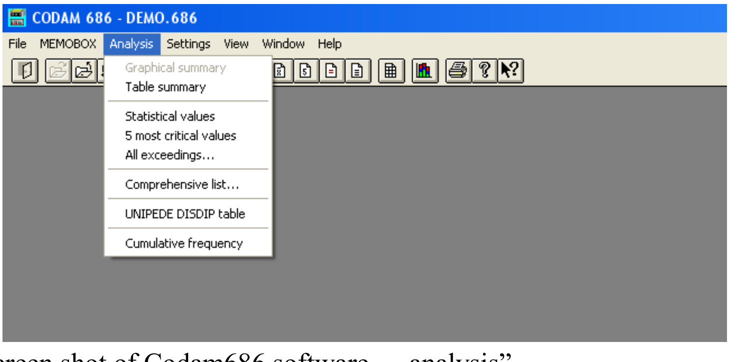
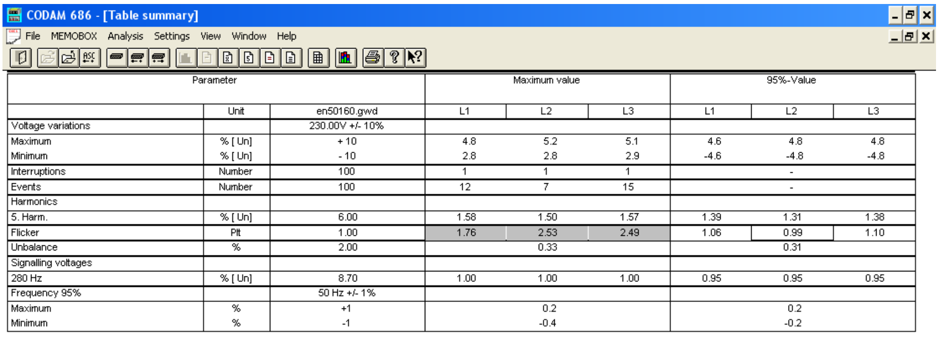


Fig. 6. Screen shot of Codam686 software – „analysis"

Option „Table summary" shows all parameters and exceeded limits (Fig. 7)



Parameter			Maximum value			95%-Value		
	Unit	en50160.gwd	L1	L2	L3	L1	L2	L3
Voltage variations		230.00V +/- 10%						
Maximum	% [Un]	+ 10	4.8	5.2	5.1	4.6	4.8	4.8
Minimum	% [Un]	- 10	2.8	2.8	2.9	-4.6	-4.8	-4.8
Interruptions	Number	100	1	1	1		-	
Events	Number	100	12	7	15		-	
Harmonics								
5. Harm.	% [Un]	6.00	1.58	1.50	1.57	1.39	1.31	1.38
Flicker	Plt	1.00	1.76	2.53	2.49	1.06	0.99	1.10
Unbalance	%	2.00		0.33			0.31	
Signalling voltages								
280 Hz	% [Un]	8.70	1.00	1.00	1.00	0.95	0.95	0.95
Frequency 95%		50 Hz +/- 1%						
Maximum	%	+1		0.2			0.2	
Minimum	%	-1		-0.4			-0.2	

Fig. 7. Screen shoot of „Table summary" – exceeded limits (third column) are marked in column "Maximum Value"

In order to present graphically recorded results are converted to CODAM604 software compatible file. Open the option „cumulative frequency" in CODAM604. Some possible presentation forms and windows are presented in Figures 8 to 11.

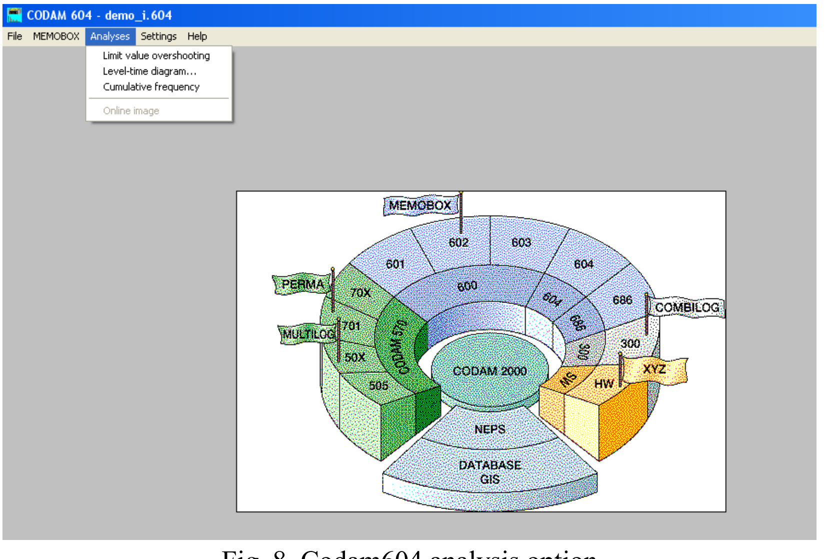


Fig. 8. Codam604 analysis option

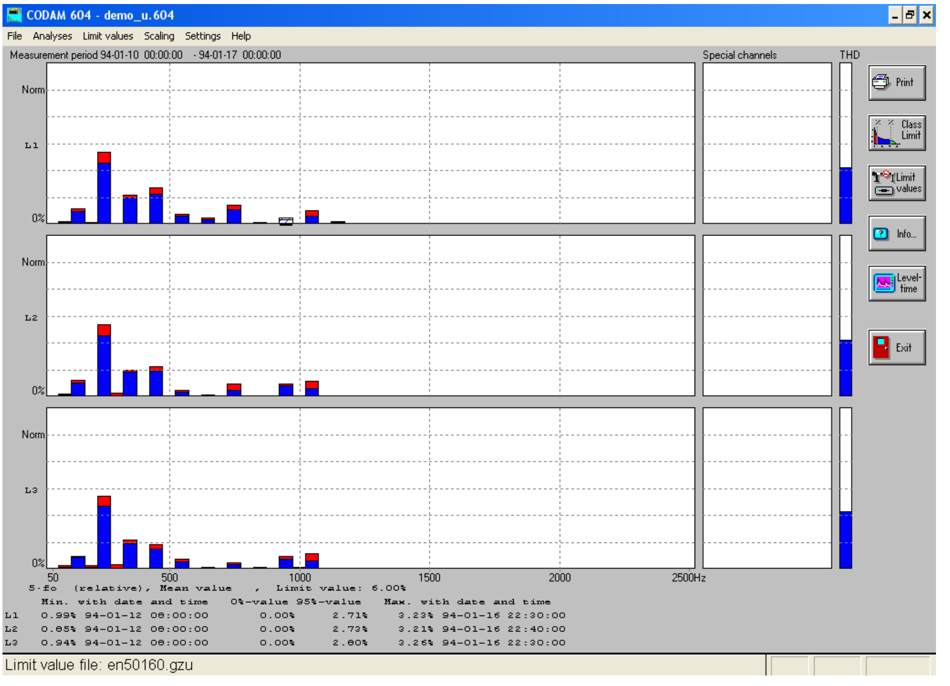


Fig. 9. Window – “analysis of voltage harmonics”

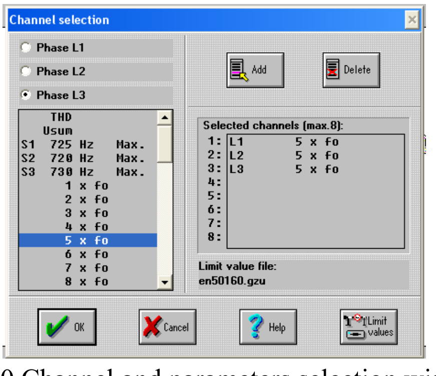


Fig. 10 Channel and parameters selection window

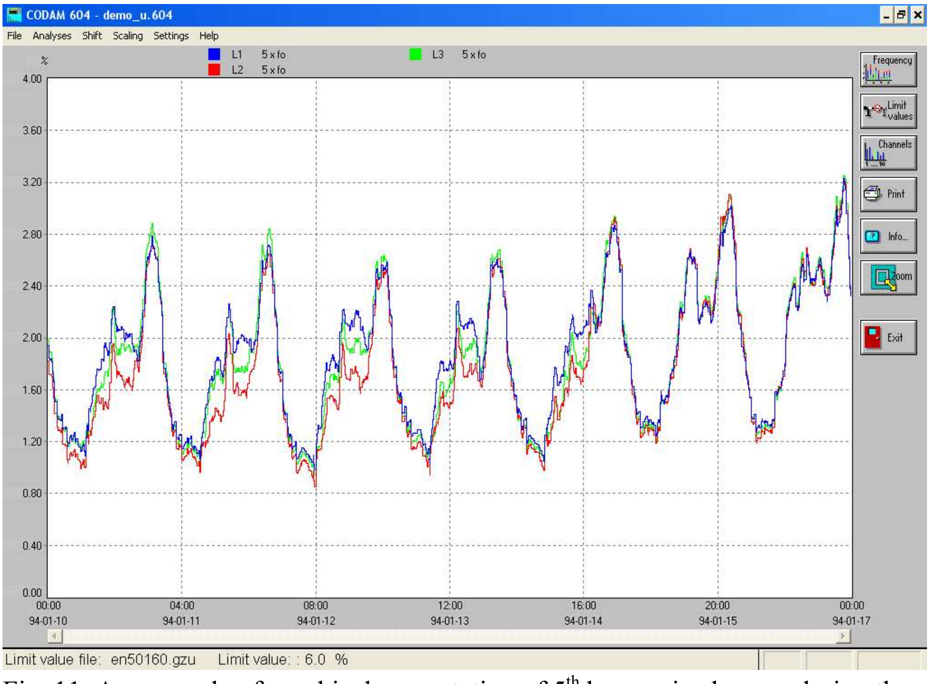


Fig. 11. An example of graphical presentation of 5th harmonic changes during the recording time.

6. Summary

Present the final assessment of power quality according to standard requirements and use „Guidelines on the Reporting of Compliance with Specification"

7. References

User manual of MEMOBOX 686 analyzer
User manual of Mavowatt 50 analyzer
User Guide of CODAM 686 software
User guide of CODAM 604 software
EN 50160:2002 - Voltage characteristics of electricity supplied by public distribution
ILAC-G8:03/2009 Guidelines on the Reporting of Compliance with Specification

Laboratory No. 2 – current waveform harmonics analysis of nonlinear load

1. Aim of laboratory exercises

The purpose is to determine harmonics emission levels of particular loads. Then compare them with limits for equipment with input current lower then 16A per phase.

2. General requirements and test conditions

General requirements and test conditions regarded to harmonic current emissions measurement; limits described in EN 61000-3-2.

Various electrical devices with different characteristics are the source of harmonics emissions with very different amplitudes, frequencies and phase angles. The standard gives a rule for classification of equipment and limits for classes in order to reduce mutual interferences.

Class A – balanced three-phase equipment, household appliances, dimmers for incandescent lamps,

class B – portable tools,

Class C – lighting equipment,

Class D – Equipment with a specified power according to point 6.2.2 in standard 61000-3-2. TV- receiver, PC, computer monitors, equipment with power consumption less than 600W.

For proper classification equipment under test use the diagram on figure 1. (That diagram is not presented in new issue of the standard but is helpful for equipment classification)

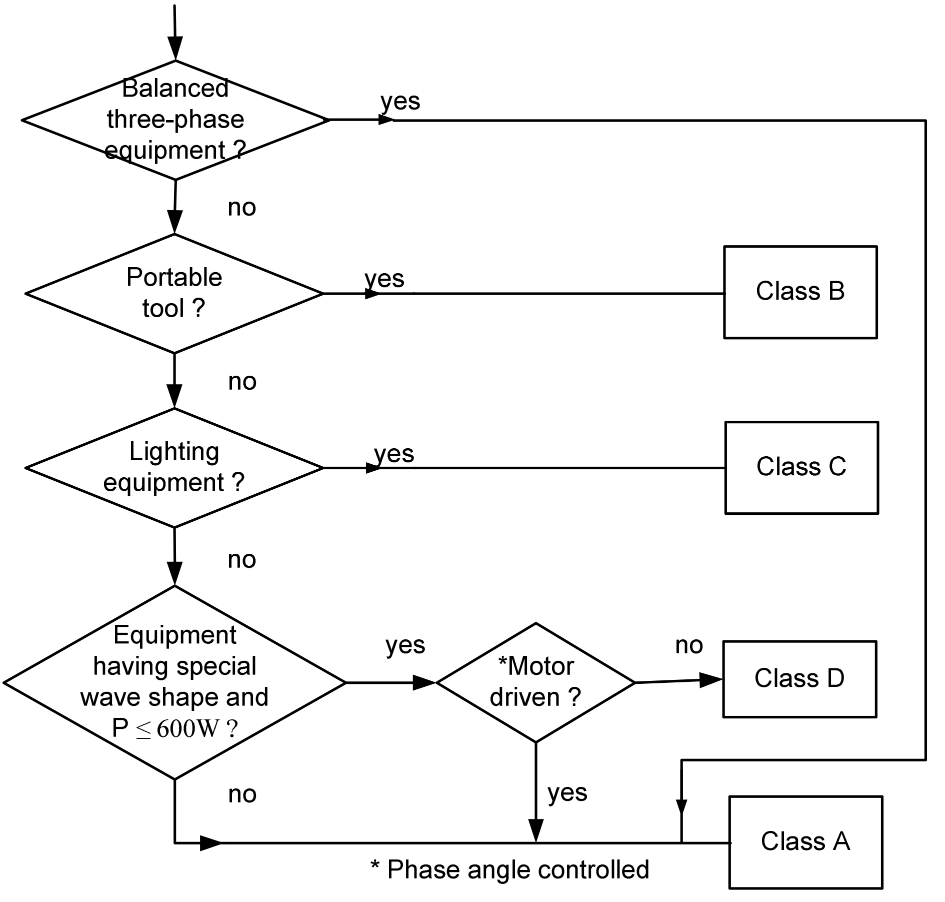


Fig. 1. Classification of equipment.

The standard defines requirements of supply source for voltage harmonics content, voltage maintain value (2% of nominal value),and unbalance in case Three phase systems.

Supply source – requirements for harmonic ratio which shall not exceed:

- 0,9% for harmonic of order 3
- 0,4% for harmonic of order 5
- 0,3% for harmonic of order 7
- 0,2% for harmonic of order 9
- 0,2% for even harmonics of order from 2 to 10
- 0,1% for harmonics of order from 11 to 40.

3. Measuring circuit

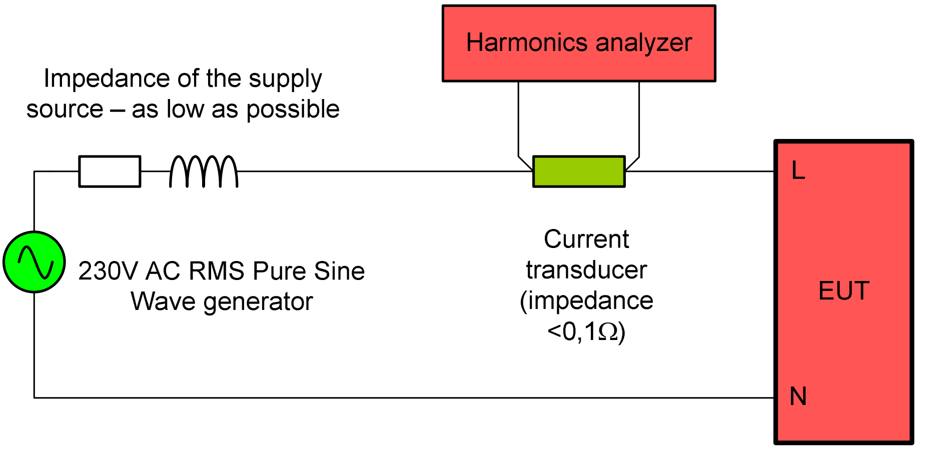


Fig.2 Measurement circuit for single phase equipment according to standard

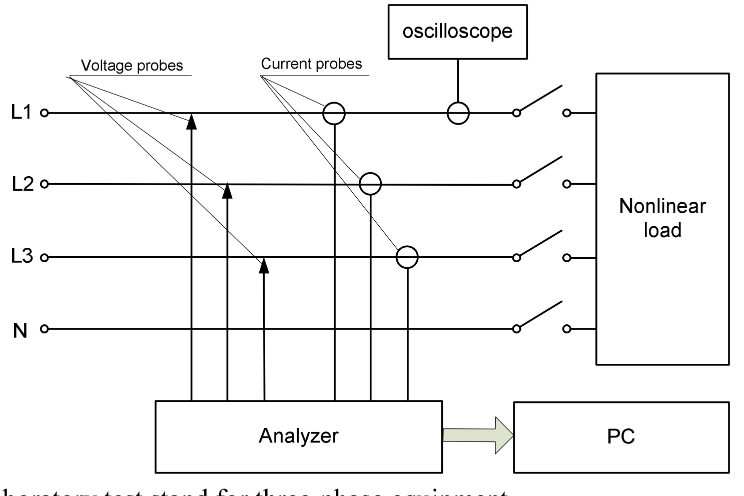


Fig. 3. Laboratory test stand for three-phase equipment

4. Measuring instruments

Oscilloscope - optional

Current and voltage harmonics analyzer.

AC power source 6834B or 6813 or voltage autotransformer- optional

5. Laboratory exercise execution

5.1. Control of the power source

The power source must meet the requirements from section 2.

If the source 6834B or 6813 is used than requirements of the standard are met.

If the network supply is used, then a check of voltage harmonics is needed in final assessment of harmonic current emission.

Make a research on the voltage quality using the analyser Memobox604 or Mavowat50.

Program the memobox604 as shown on Figures 4 and 5. Connect the voltage probes to the analyzer and start the recording for 15..20 minutes period.

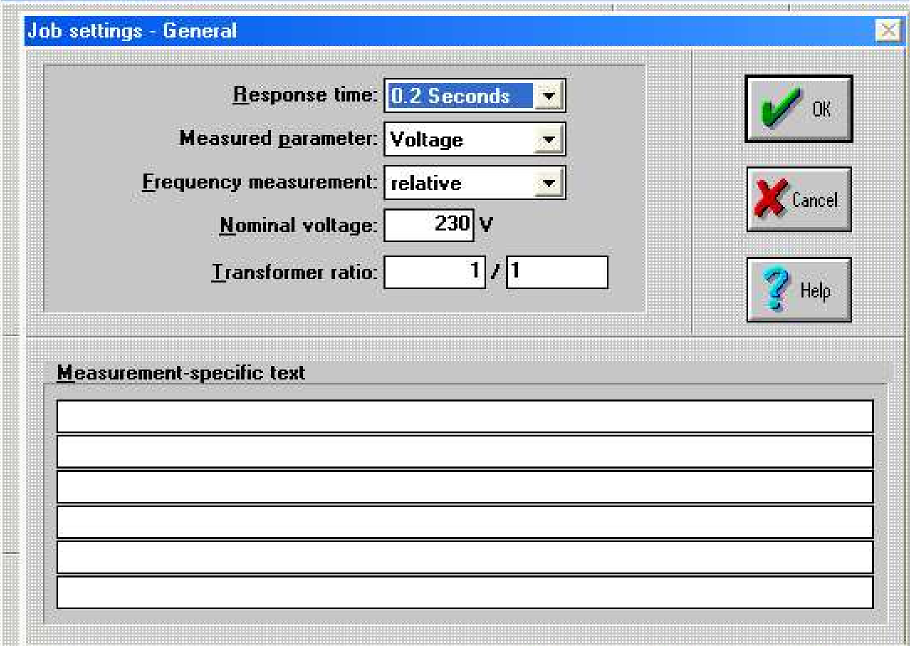


Fig. 4. Window – general settings with selected voltage as measurement parameter

Test observation period (recording period) should guarantee repeatability of the measurement better then 5%. For quasi stationary equipment behaviour time of measurement can be short but it is recommended to measure longer than 15 minutes.

For short periodic behaviour (T cycle < 2,5 minutes) observation time must be longer then 10 cycles.

For long periodic behaviour (T cycle> 2,5 minutes) or for program cycle. Observation time must cover the representative 2,5 minutes period consider by manufactures as the operating period with highest total harmonic distortion of current.

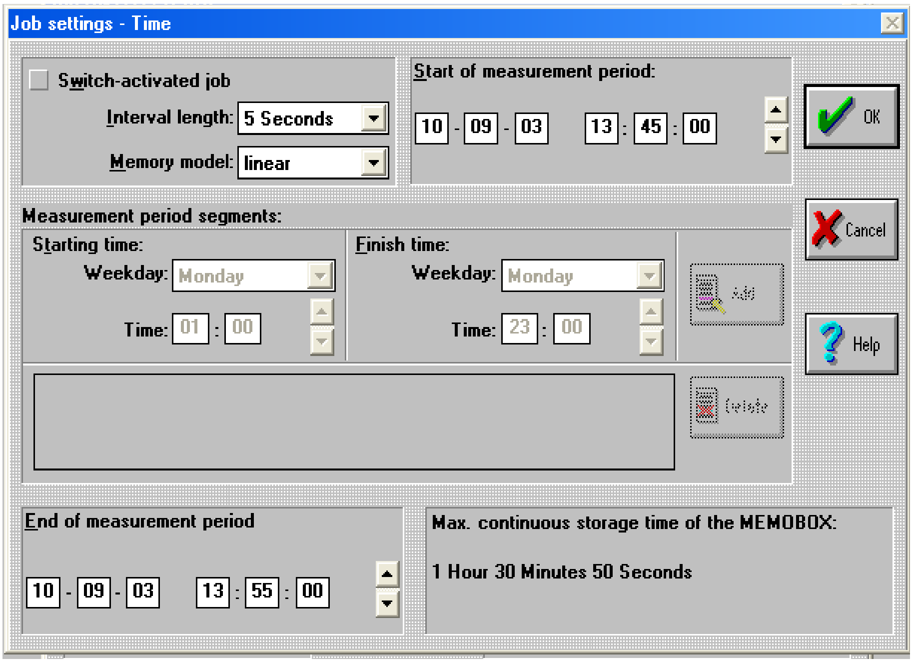


Fig. 5. The CODAM 604 window – Setting time of recording

The LED indicator blinks shortly during the recording. Read results from analyzer. Select the harmonics analysis and check the harmonic values (Fig. 6-7)

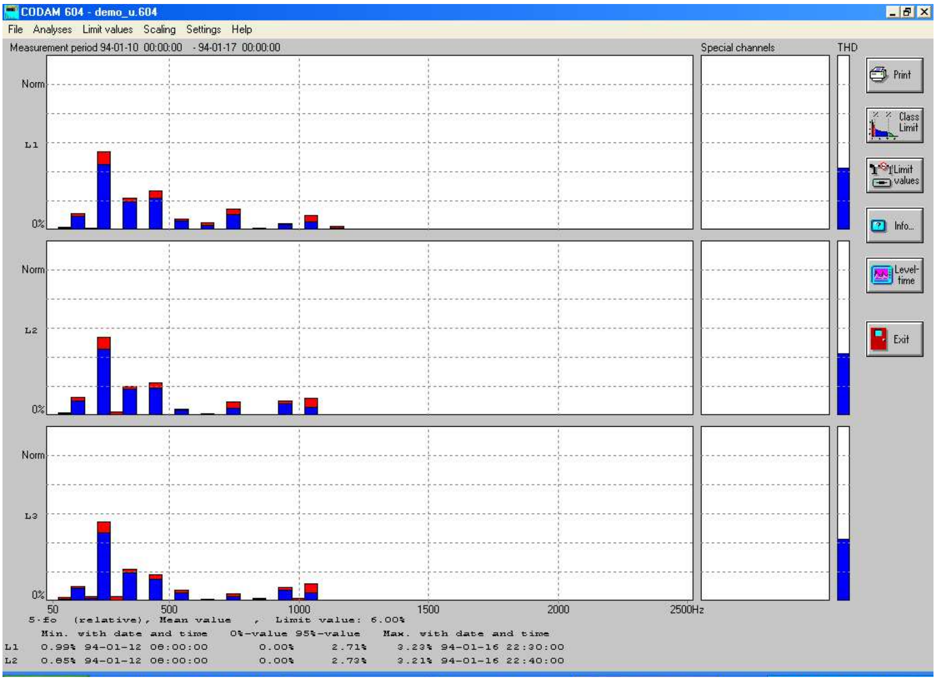


Fig. 7. The CODAM 604 - window “Harmonic analysis”

5.2 Determination of current harmonic emission.

Change the measured parameter for current in the general settings window (Fig. 8)

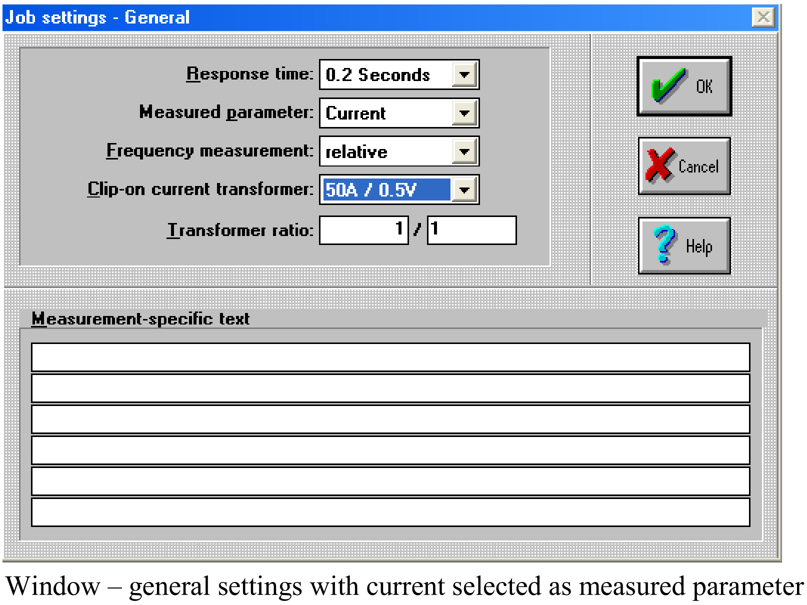


Fig. 8. Window – general settings with current selected as measured parameter

Similarly to voltage analysis (fig. 5) set the time of recording. Program the analyzer and read the results after 20 minutes.

6. Assessment of harmonic emission in current.

Compare values of current harmonics with limits (Table 1) for selected Class of equipment under test.

Harmonic currents less than 0,6% of the input current measured, or less than 5mA, whichever is greater, are disregard.

Table 1. Limits for harmonic current emission

Harmonic	Class A [A]	Class B [A]	Class C	Class D	Class D
2	1,08	1,62	2%	-	-
3	2,3	3,45	30%*PF	3,4mA/W	2,3
4	0,43	0,645	-	-	-
5	1,14	1,71	10%	1,9mA/W	1,14
6	0,3	0,45	-	-	-
7	0,77	1,155	7%	1mA/W	0,77
9	0,4	0,6	5%	0,5mA/W	0,4
11	0,33	0,495	3%	0,35mA/W	0,33
13	0,21	0,315	3%	0,296mA/W	0,21
15≤n≤39 (odd)	0,15*15/n	0,225*15/n	3%	3,85/n [mA/W]	0,15*15/n
8≤n≤40 (even)	0,23*8/n	0,345*8/n	-	-	-

7. References

EN- 61000-3-2 – Limits for harmonic current emissions – equipment input current <= 16A per phase

User guide of MEMOBOX 604 software

Laboratory No. 3 – Voltage, current and power waveform harmonics analysis of nonlinear three phase and one phase loads.

1. Aim of laboratory exercises

Assessment of distortions and harmonics emission levels caused by one phase and three phases rectifier bridges. Introducing the phenomenon of harmonic summation in neutral wire three-phase connection with neutral wire (wye-connection). Current harmonics compensation effect gained through simultaneous connection of different loads. One of the compensation methods is based on the knowledge of harmonic phase related to the fundamental. The aim of power harmonic analysis is the determination of disturbances sources (loads which inject harmonic currents into the supply system). Current harmonic causes voltage distortion.

2. Description of the laboratory stand

2.1. The laboratory set of instruments, equipments and three phase loads for current, voltage and power harmonics analysis.

2.1.1. The diagram of the stand

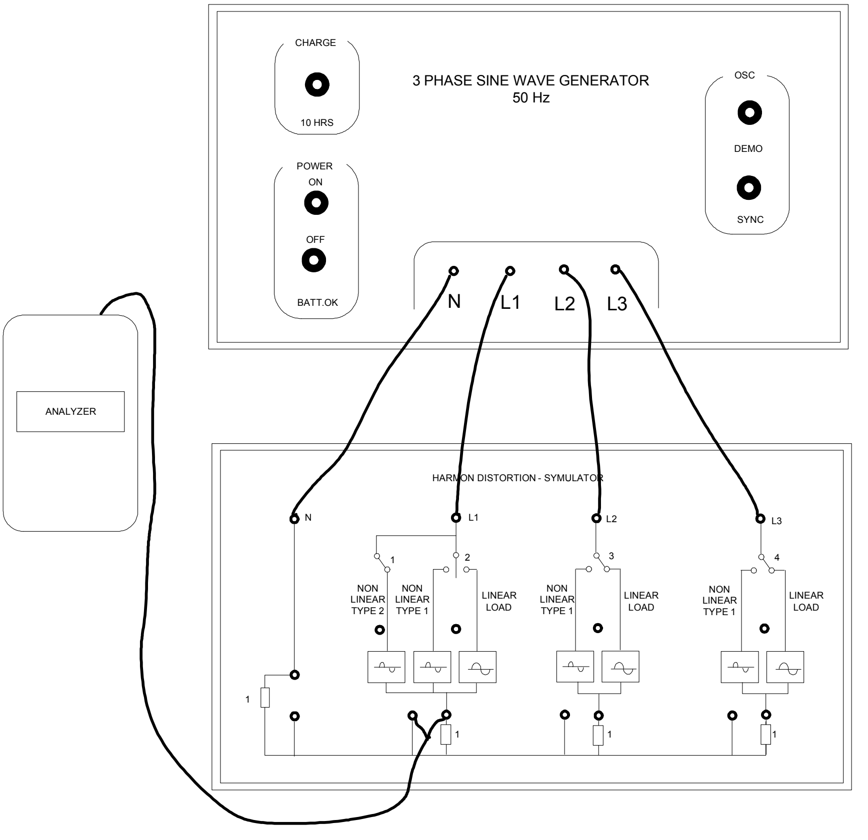


Fig. 1. The scheme of connections

2.1.2. Measuring instruments

Fluke 41 Analyzer, ammeter-optional

2.1.3. Laboratory exercise execution and phenomena description

Connect terminals N, L1, L2 and L3 of three-phase sine generator with the same terminals of harmonic distortion simulator (Fig.1). Set the switches number 2,3 and 4 in linear load position. The switch number 1 set in neutral position (the nonlinear load type 2 is off). Connect the BNC conductor to analyzer current probe input (instead of current clamp). The second end of the conductor will be connected during the exercise to current shunt terminal on the harmonic distortion simulator.

Observe the wave shape of currents on the scope display. Write down: the phase and neutral currents parameters: RMS value, THD, 3rd harmonics content.

The currents in all phases are nearly identical and sinusoidal. The current in neutral wire is nearly zero. That value is results from symmetric and linear load.

Set the switches number 2, 3 and 4 in non linear load position. The switch number 1 is set in neutral position (the nonlinear load type 2 is off)

Observe the shape of currents on the scope display. Write down: the phase and neutral currents parameters: RMS value, THD, 3rd harmonics content and K-factor of phase current shape. Important is fundamental frequency of neutral wire current. Notice the phase harmonic angle relative to fundamental.

That part of the exercise shows the summation effect of harmonic in neutral wire (all odd harmonic of order three multiplied, 3,9,15...). Crest factor is involved overheating of power distribution transformers.

Connect the analyser to the terminal of L1 phase. Ones again observe the waveform. Make research when a nonlinear load ii switched on

a) Nonlinear Load 1,

b) Nonlinear Load 2

c) Nonlinear Load 1 and Nonlinear Load 2.

Write down: the phase currents parameters: RMS value, THD, 3rd harmonics content and third harmonic phase, Crest factor of current shape.

Notice that for a, and b loads third harmonic has different phase. When the both loads are switched on the third harmonic is distinctly lower (partially compensated). The THD is also decreased.

That effect of harmonics compensation without harmonic filter can proceed for higher harmonics either.

2.2. The laboratory set of instruments, and one phase loads for current, voltage and power harmonics analysis.

2.2.1. The scheme of the stand

The connection scheme harmonic analyzer is shown on the Figure 2.

Attention! Shock hazard. Make all connections only if power is off.

Connect voltage input of the analyzer to voltage terminal located on the left part of the box. Use the current clamp to measure the current. If the power calculated by the analyzer is negative then change the clamp orientation. The load selection is done by switching adequate switches and putting the ammeter wires to terminal. Ammeter is used to measure output current of power supply. The analyzer measures the input current. When the lighting equipment is selected, then both apparatus measure the same current.

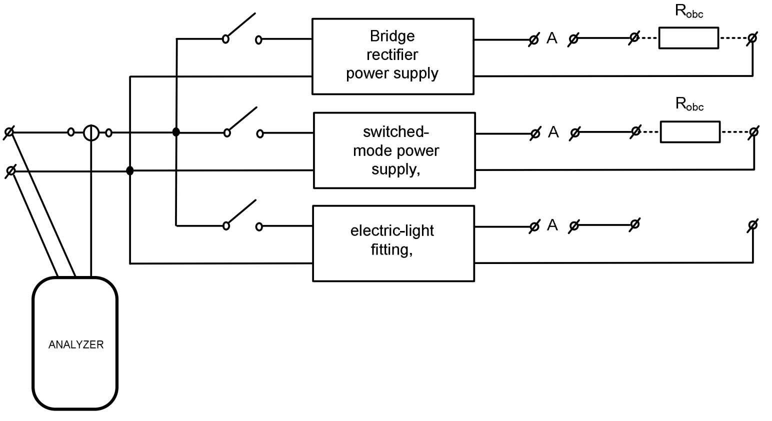


Fig. 2. The diagram of measurement circuit

2.2.2. Measuring instruments
FLUKE-41 analyzer, ammeter

2.2.3. Laboratory exercise execution and phenomena description

Select the load and observe the waveform of current, voltage and power. Write down: voltage and current RMS value, active, reactive and apparent power, Power Factor, Fundamental Power Factor, THD, voltage and current harmonics content, crest factor for current. The sign of power harmonic is important. The negative sign of power harmonic means that the load emits harmonic into power supply network. The sign of power harmonic is the simplest indicator of disturbances source.

Make the investigation of power supplier for two values of output current.

3. Summary

The laboratory report should contain the assessment of harmonic current emission by loads. Tables with results will be helpful. Mark harmonics injected to power network. Present the harmonic summation in neutral wire and harmonic compensation.

4. References

FLUKE 41 User guide

Laboratory No. 4 - Immunity tests – part 1: voltage dips and interruptions

1. Aim of laboratory exercise

The purpose of this exercise is to familiarize the students with the phenomena of voltage dips and short interruptions affecting electrical equipment. During the exercise selected equipment is tested. The test waveform can be edited by student or downloaded from files.

2. Dip definition

Voltage dip is a sudden decrease of RMS of line voltage to a value between 90% and 1% of the nominal voltage followed by a voltage rise to the given limits within a short period. Conventionally, the duration of a voltage dip is from 10 ms to 1 minute. The dip depth is defined as a difference between nominal voltage and minimum value of 10 ms RMS measured during the dip. The difference is defined in relative units. Voltage dip to value grater then 90% of nominal voltage are not considered as .voltage dips. According to standard EN 50160, short interruption may be consider as a 100% dip. Examples of voltage dips are presented in Figure 1. Voltage dips and short supply interruptions are unpredictable, random, arising mainly from electrical faults in power supply system. Voltage dips duration time usually ranges from half a period to1s. The dips duration time resolution is 10 ms.

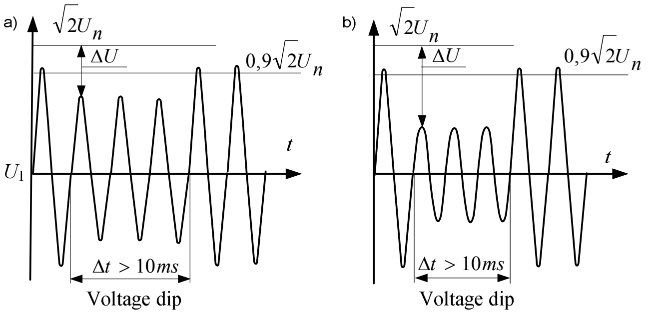


Fig. 1. Examples of voltage dips; U_N – nominal voltage, a) shallow dip, b) severe dip

3. Test conditions

The standard EN 61000-4-11 recommends the test levels and dips duration. Values are given in Table 1. The equipment must be tested for each selected combination of test level and duration with a sequence of three dips with minimum

10 seconds between. For voltage dips, changes in supply voltage shall occur at zero crossing of the voltage and at additional angles. Angles are preferably selected from 45°, 90°, 135°, 180°, 225°, 270°, and 315°. For class x any dips duration and level can be used.

For a three-phase system dip can be seen in one phase only or in three phases simultaneously.

Table 1. Preferred test levels and durations for voltage dips and interruptions (50Hz system).

<table>
<tr><td></td><td>Class 2</td><td>Class 3</td><td>Class x</td></tr>
<tr><td rowspan="5">Test level and duration for voltage dips</td><td>0% during 1/2cycle</td><td>0% during 1/2cycle</td><td>X</td></tr>
<tr><td>0% during 1cycle</td><td>0% during 1cycle</td><td>X</td></tr>
<tr><td rowspan="3">70% during 25cycle</td><td>40% during 10cycle</td><td>X</td></tr>
<tr><td>70% during 25cycle</td><td>X</td></tr>
<tr><td>80% during 250cycle</td><td>X</td></tr>
<tr><td>Test level and duration for short interruption</td><td>0% during 250cycle</td><td>0% during 250cycle</td><td>X</td></tr>
</table>

X – to be defined by product committee. For equipment connected to the public network, the levels have to be class 2 or higher.

For dip duration equal half of fundamental period (10ms) the test must be done for two different phases (polarisation): 1 – dip occurs at 0^o , 2- dip occurs at 180^o

The levels and duration must be given in the product specification. A test level of 0% corresponds to total supply voltage interruption. A test level from 0% to 20% of nominal voltage may by considered as an interruption.

4. The scheme of measurement circuit

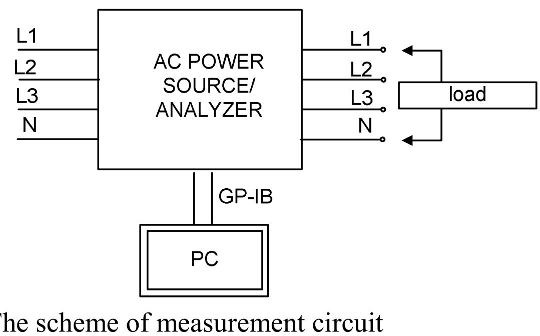


Fig. 2. The scheme of measurement circuit

5. Test instrumentation

The AC POWER SOURCE 6834B or 6813.

The requirements for test generator:

- Voltage change with load connected at the output of the generator less than 5%
- Output current capability of
    - Peak inrush current capability at least 500A for 230V mains
- Instantaneous peak overshoot/undershoot of the actual voltage
- Zero crossing control of the generator
- Output impedance must by predominantly resistive and less then 0,4+j0,25Ω
- Voltage rise and fall time during abrupt change less then 5us.

The mentioned requirements for test generator are difficult to fulfil by an electronic generator for loads and current. The standard allows to use generator with lower current capability if low power equipment is tested.

6. Laboratory exercise execution

A) Start the AC-Source GUI program and set the most important parameters. Set the RMS voltage 230V and frequency 50 Hz. Set the current limit (default =1A) to maximum value (13A for 6813B, 5A for 6834B in three phase mode). Then push the button "output on"

B) Chose the test level, duration and number of repetitions. In order to perform the test select the edition window of output transient. Next edit the voltage variation shape using one of the three techniques (1. editing table with value of RMS and time, 2. editing points of decreasing and increasing voltage dragging mouse. 3 chose the Tests/Surge/Sag). The data can be saved to a file for future use or the test can be started by clicking start transient button. You can use files located in the folder "test61000-4-11".

C) Classify the immunity

While the transient is running observe the equipment under test and finally classify the immunity

Loading the transient waveform from library

. You can use ready files located in the folder "test61000-4-11"

In the" output transient editor" window click the open button and choose a file. In the library are 216 files. The file name represents the dip parameters.

Z_XYZ_ABCDE_IJK

Where:

Z – voltage dip,

XYZ – value of dip depth,

ABCDE – dip duration in ms,

IJK – phase angle in degree.

Example Z_060_01000_270 represents 60% dip depth (40% test level), dip duration is equal 1000ms=1secound, the dip starts at 270°.
The folder contains files with dips depth 100%; 60%; 30%,dip duration :10; 25; 50; 1000; 2000; 3000 and phase angle 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°.

Test procedure and assessment of immunity

After the transient shape is edited or loaded from file push the button "start transient". While the transient is running observe the equipment under test and finally classify the immunity

According to standards EN 61000-4-11, the tests results must be classified in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

a) Normal performance within limits specified by the manufacturer, requestor or purchaser;

b) Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under tests recovers its normal performance, without operator intervention;

c) Temporary loss of function or degradation of performance, the correction of which requires operator intervention;

d) Loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer's specification may define effects on the EUT which may be consider insignificant and therefore acceptable

7. References

Quick start guide of Agilent Technologies AC Source/Power Analyzer Graphical User Interface
Standard EN 61000-4-11

Laboratory No. 5 – Calculation and measurement of voltage changes, voltage fluctuation and flicker in supply system

Reasons for voltage variation

Repetitive low frequency voltage fluctuation in range +-10% of nominal voltage (for 230V the range is from 207V to 253V) produces flicker – temporal variation of luminance in incandescent lamps and fluorescent lamps. Light flickering has negative impact on people for certain range of frequency and magnitude. Flickering light affects the optical perceptive ability of the human eye.

The IEEE 1159-2009 standard definition is as follows „*Flicker: impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuation*".

Active and reactive power variations and repetitive changes in the current are the main reasons for voltage variation. The flicker may be produced by repeatable starting induction motors (example: cranes, elevators), welders, boilers, power regulators, pumps and compressors.

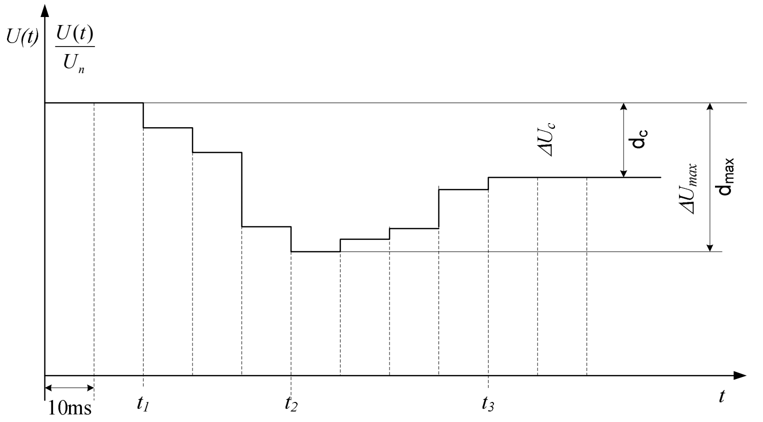


Fig. 1. Relative voltage change characteristic [EN 61000-3-3]

Assessment method of the short-term flicker value Pst

A good engineering practice to mitigate flicker is to design equipment with limited level of voltage variation.

Calculation and measurement methods of voltage variation and flicker are presented in the standard EN 61000-3-3. Essential information relevant to equipment designing are also given in that standard.

The short term flicker is defined in EN 61000-4-15 standard. The meters (measuring equipment) calculate the Pst value directly. Alternative assessment methods for Pst evaluation are in the Table 1.

Table 1. Assessment method

Types of voltage fluctuations	Methods of evaluation Pst
All voltage fluctuations	Direct measurement
All voltage fluctuations where d(t) is defined	Simulation Direct measurement
Voltage change characteristics according to figures 5 to 7 of standard with occurrence rate less than 1 per second	Analytic method Simulation Direct measurement
Rectangular voltage change at equal intervals	Use of the Pst=1 curve Direct measurement

In the next part of the exercise the analytic method description and the Use of the Pst=1 curve will be given.

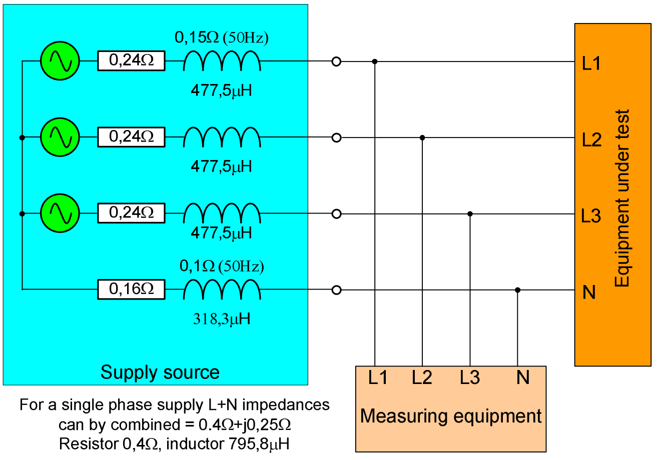


Fig. 2. Reference network for single phase and three phase supplies equipment

Example 1 – Heat sealing machine

One phase heat sealing machine with heater rated power equal 2650 Watts is switched on and off twice a minute. Heating consumption time is 100ms. The result of this current is voltage droop on source impedance and voltage decrease in point of coupling. The equivalent scheme is presented in Figure 3. The voltage and current changes during the machine working scheme are shown in Figure 4.

The task: calculate the short term flicker value.

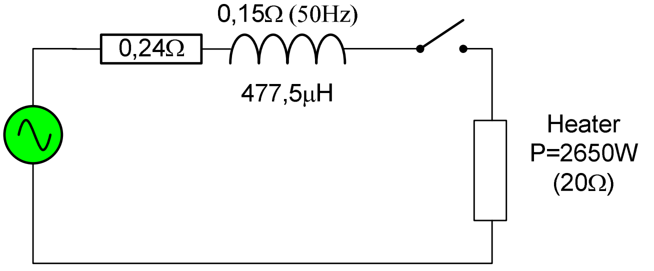


Fig 3. The scheme of heat sealing machine connected to reference network.

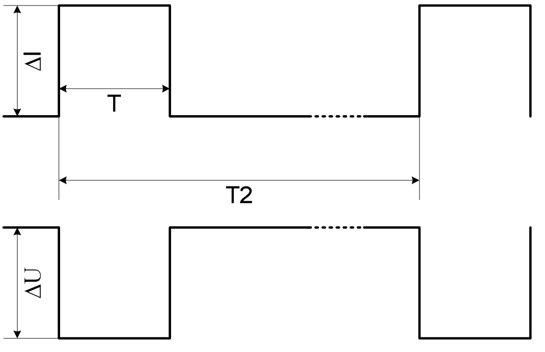


Fig. 4. The current and voltage changes during heat sealing machine work.

Assuming that rms value of current (when heater is switched on) is equal I=230V/20,4Ω (imaginary part of source impedance is omitted) the increase of current is equal ΔI=11,275A , from here voltage drop is ΔU=4,51V. Maximum value of relative voltage change is equal dmax=ΔU/U=4,51V/230V=1.96%. Flicker impression time t_f in seconds are expressed by formula

$$t_f = 2{,}3\left(F \cdot d_{max}\right)^{3{,}2},$$

Where the shape factor F is associated with the shape of voltage change characteristic. The value of F is taken from figure 5 (F=1.35).

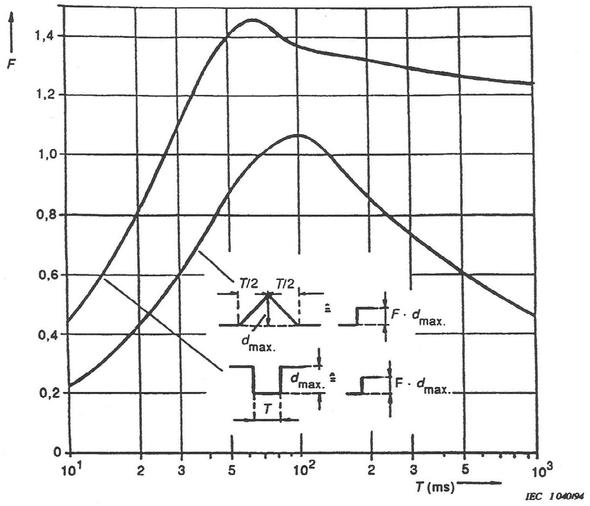


Fig. 5.Shape factor F for rectangular and triangular voltage characteristics (Fig. 6 of standard 61000-3-3)

After inserting the F and d_{max} values into formula the result is t_f=51,76s.
If the t_f is known the Pst can be calculated using formula

$$Pst = \left(\frac{\sum t_f}{Tp} \right)^{3,2},$$

Where Tp is the total interval length in seconds. The result is Pst=1,18, value exceeding limit. The Equipment Under Test (heat sealing machine) must not be connected to the public supply network.
An easy solution is increasing time of heater work and simultaneously decreasing rated power (increasing heater resistance). The energy value stays constant.
Example increasing heater resistance to 30Ω and setting heating time to 150ms cause current change ΔI=7,56A, and voltage drop ΔU=3,03V. Value of maximum voltage change dmax=1.316%. Flicker impression time is equal t_f =5,535s and finally, the value of short term flicker is Pst=0,5897. The heat sealing machines meets the requirements of the 61000-3-3 standard.

Example 2.
Wave solder is equipped with 3000 Watts heater. Calculate the maximum number switchovers per minute with respect to standard limitation.
Switching on the heater causes a decrease in current ΔI=13A, and a voltage drop ΔU=5,22V. The value of maximum voltage change is dmax=2,26%. Number of

changes per minute taken from Curve for Pst = 1 for rectangular equidistant voltage change should be maximal 2.

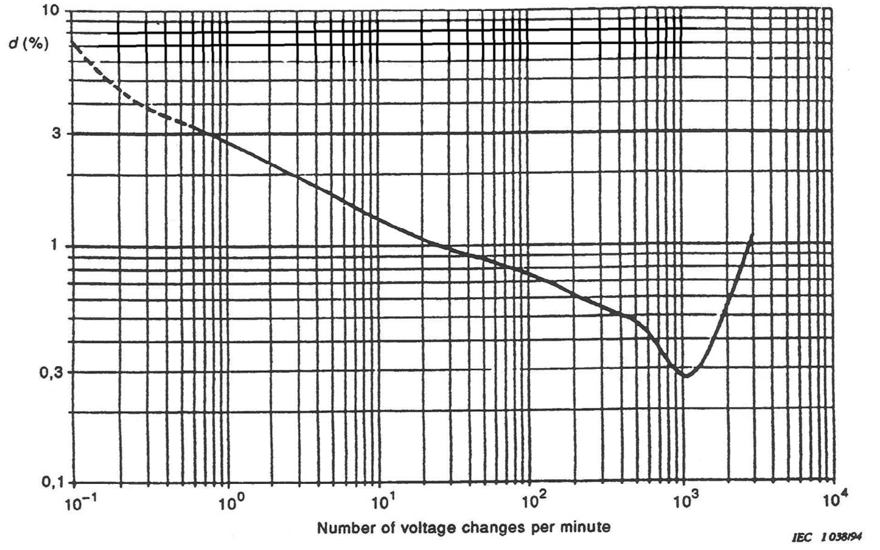


Fig 6. Curve for Pst = 1 for rectangular equidistant voltage change[EN 61000-3-3].

The needed number of switchovers for proper soldering pot temperature control is 20. The solution is to equip the wave solder with heater working in parallel and independently controlled. For example 3 heaters 1000W rated power. Switching on one heater causes the increase of current ΔI=4,35A and voltage drop ΔU=1,74V. Maximum voltage change value is dmax=0,756%. Number of changes per minute read from Curve for Pst = 1 should be lower then 30. Second condition – simultaneous heaters may by switched on and switch off only at the start and the end of work.

3. Test of equipment

Connect the external impedance to ac power supply source in order to achieve the impedance source Zref=0,4Ω+j015Ω.

Parallel to loads connect voltage recorder/analyzer and oscilloscope. Switch on the supply of load. Read the inrush current and maximum and minimum current value during the recording time. Calculate the Pst value – analytical method. The first Pst value measured directly by analyzer appears after 10 minutes. Reject that value. Take the second Pst value to compare with Pst obtained with analytical method.

4. Test of measurement equipments.

Program the AC6834 power source for generation of sinusoidal voltage with variations and Pst=1. To do that open the file from folder „pst_emmision” or edit the variation table yourself. Connect to the source terminal flickeretters (power quality analyzers) and voltmeter. Connection of external impedance is not necessary. Program the analyzers. Switch on the source – transient. Compare the results obtained from flicker meters.

Laboratory No. 6 - Immunity tests – part 2 : harmonics, power frequency, voltage variation

1. Aim of the exercise execution

The purpose of this exercise is to familiarize the students with negative effects of interferences occurring in power distribution network and electrical loads.

Conducted disturbance can be divided into temporary and long-lasting. The exercise is considered with long-term and low-frequency impact of the phenomena:

- Harmonics,
- Voltage variation,
- Power frequency variation.

Tests are performed on a test stand equipped with a controlled generator and optionally an oscilloscope, voltmeter and spectrum analyzer (Fig. 1).

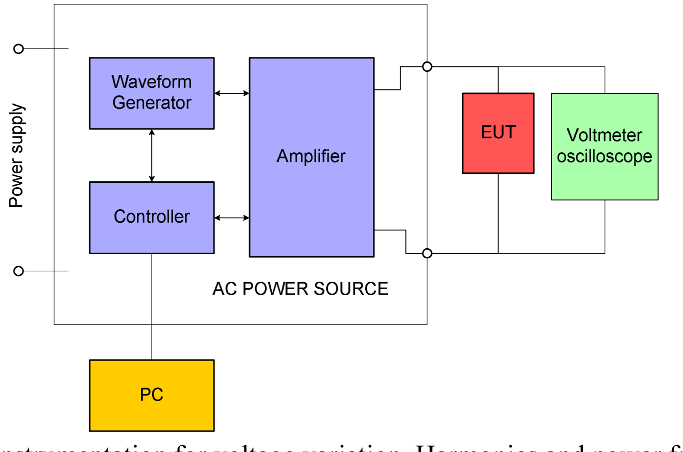


Fig 1. Test instrumentation for voltage variation, Harmonics and power frequency variation immunity tests.

The waveform shape can be defined by user or loaded from files (library of waveforms for immunity tests) and send to test generator.

According to standards [2-4], the tests results should be classified in terms of loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

a) normal performance within limits specified by the manufacturer, requestor or purchaser;
b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under tests recovers its normal performance, without operator intervention;
c) temporary loss of function or degradation of performance, the correction of which requires operator intervention;
d) loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

2. Harmonics at AC power port, frequency immunity tests

Harmonic disturbances are generally caused by nonlinear loads which draw non sinusoidal current or by periodic and line synchronised switching loads.
Depending on the type of power network, its parameters and the order of harmonics, some harmonics are propagated in the network and interact negatively with other equipment connected to it. In order to reduce mutual interference of loads, the harmonics emission level is limited (standard EN 61000-3-2) and the immunity to the harmonic (EN 61000-4-13) increased.
The test conditions and the test procedure are described in details in the standard [2].
In this exercise only selected tests will be carried out. The harmonic value can be set according to recommendation for equipment class or arbitral.

Test – Harmonic combination – „over swing".
Supply voltage contains harmonic 3 in phase and 5 in antiphase. Values for each class are given in Table 1.
Table 1. Harmonic combination, „over swing"

Class	3rd % of U1 /angle	5th %of U1/angle
1	4%/180^o	3%/0^o
2	6%/180^o	4%/0^o
3	8%/180^o	5%/0^o
X	X%/180^o	x%/0^o

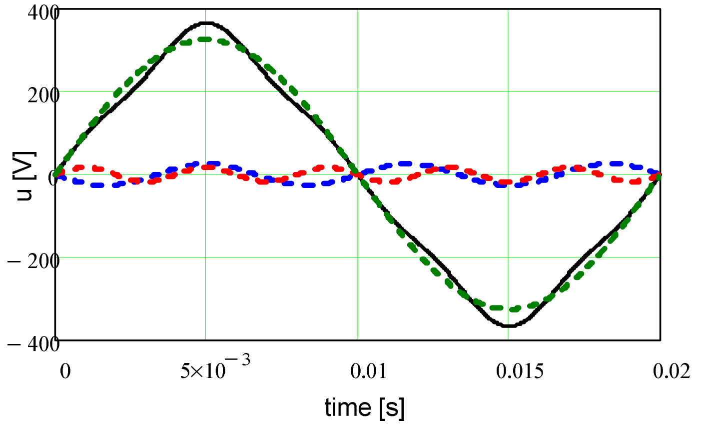


Fig. 2. „over swing" waveshape

Test harmonic combination – "Flat curve"

The „Flat curve" waveshape is a sinusoidal wave with flat cut peaks. That waveshape is shown in the Figure 3. The software allows you to select the percentage of amplitude clipping or cutting height is adjusted automatically to the desired level of THD. (Note that THD does not exceed 35%)

Table 2. Cutting height in „Flat curve" test

Class	function
1	0≤|sinωt|≤0.95
2	0≤|sinωt|≤0.9
3	0≤|sinωt|≤0.8
X	0≤|sinωt|≤X

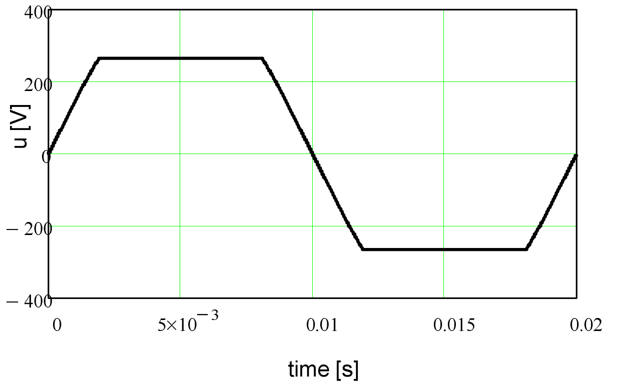


Figure. 3. „Flat curve" waveshape

In order to perform the test choose the edition window of arbitrary waveform. Next edit the waveform using one of the three techniques (1. editing table with value of amplitude and harmonics phase, 2. editing points in time domain, 3. Dragging mouse). Than save the waveshape and send to the test generator.
You can use ready files located in the folder "test61000-4-13". Set the rated voltage to 230V and turn on voltage ("output on"). Observe the test equipment under test and finally classify the immunity.

4. Voltage variation immunity test

In accordance with the requirements of the EN 50160 standard, the RMS value of supply voltage should be in range from 90% to 110% of nominal value. Voltage fluctuations in this range can affect equipment. A detailed description of the voltage fluctuation immunity test procedure is in the standard EN 61000-4-14. Figures 6 and 7 show a sequence of voltage changes during the test.

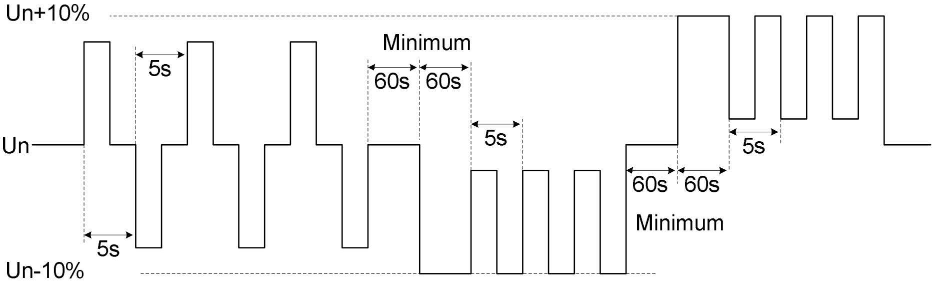


Fig 6. Voltage changing sequence during test.

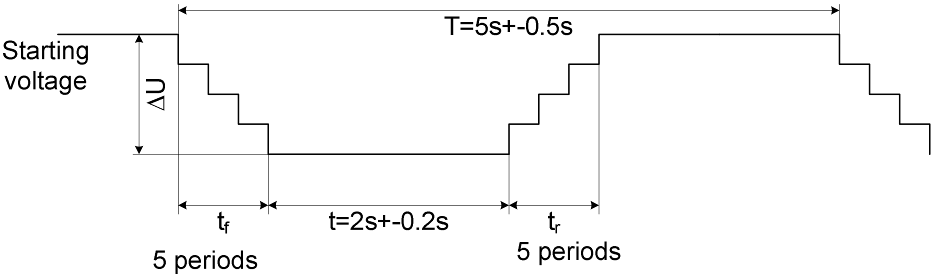


Fig. 7. Details of voltage decreasing and increasing

In order to perform the test, set the sinusoidal waveshape, 230Vrms and frequency 50Hz. In the program open "output transient" window then load the file with voltage variation shape and send it to test generator. Start the voltage variation sequence – click "start transient" button. Observe the equipment under test and finally classify the immunity.

6. Power frequency variation immunity test of equipment

Public power supply systems have the frequency maintained as close as possible to the nominal frequency. The dynamic changes of generator loads affect the power frequency. In small power grids especially island supply systems the voltage frequency variation can influence susceptible apparatus.

The detailed test procedure of frequency variation immunity test is described by the EN 61000-4-28 standard. The power frequency changing sequence during the test is shown in Figure 9.

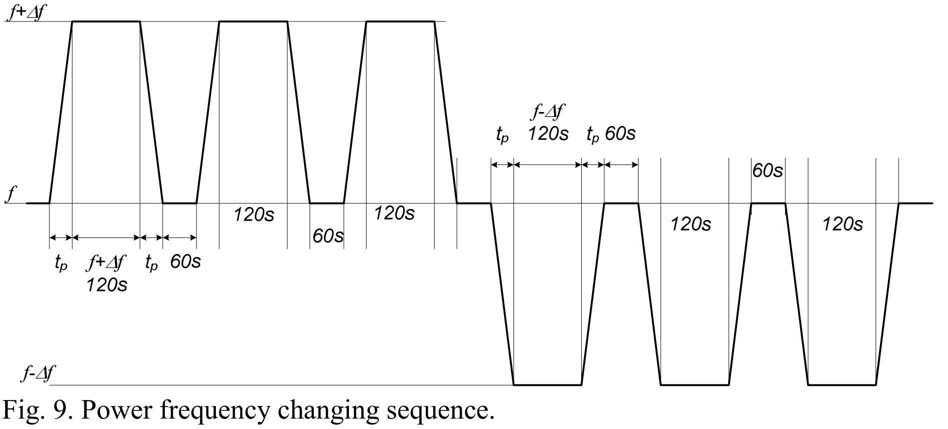


Fig. 9. Power frequency changing sequence.

Table 3. Measuring Level in frequency variation test.

Measuring Level	Frequency variation	Transient time tp
Level 1	No obligation	No obligation
Level 2	±3%	10 s
Level 3	+4% -6%	10 s
Level 4	±15%	1 s

In order to perform test set the sinusoidal waveshape, to 230Vrms and the nominal frequency to 50Hz. In the program open “output transient” window then load the file with frequency variation shape and send it to test generator. Start the frequency variation sequence – click “start transient” button. Observe the test equipment under test and finally classify the immunity.

7. References

[1]. Quick start guide of Agilent Technologies AC Source/Power Analyzer Graphical User Interface.
[2]. EN 61000-4-13
[3]. EN 61000-4-14
[4]. EN 61000-4-28

Laboratory No. 7 - Spectrum analyzer

1. Aim of exercise execution

The purpose of this exercise is to familiarize the students with the superheterodyne spectrum analyzer measurement using the example of spectral analysis and modulated fundamental signal.

2. Superheterodyne spectrum analyzer

Modern tuned spectrum analyzers function similarly to the superheterodyne radio receiver (range of long and medium wave AM modulated). Simplified block diagram of spectrum analyzer is shown in Figure 1.

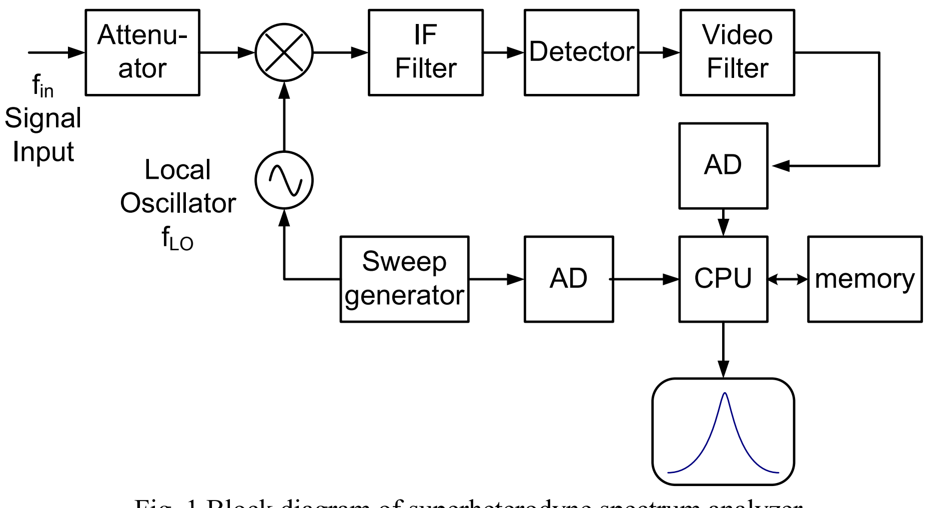


Fig. 1 Block diagram of superheterodyne spectrum analyzer

The input signal - f_{IN}, is converted to an intermediate frequency - f_{IF}, using the mixer and a tuneable local oscillator f_{LO}. The conversion of the input frequency to an intermediate frequency f_{IF} is made by mixer. The equation

$$f_{in} = f_{LO} - f_{IF},$$

determines the measurement frequency range of the analyzer. The top frequency is smaller then frequency of local oscillator. User can choose the input frequency range, set parameters: start frequency, stop frequency, centre frequency which affects on sweep time, frequency resolution and bandwidth intermediate filter. Mention parameters are interrelated. Increasing the frequency resolution causes narrowing filter bandpass and the time sweep is getting longer. To shorten the time sweep at high resolution a multi-stage-frequency conversion is used.

3. Basic modulations

AM – Amplitude Modulation

Amplitude modulation is variation of the amplitude of carrier signal $c(t) = E_c \cos(\omega_c t)$ by modulating signal $x(t) = U \cos(\Omega t)$. The result is a waveform $s(t) = E_c(1 + m\cos(\Omega t))\cos\omega_c t$ in which the symbol m marked amplitude modulation $m = \dfrac{E\max - E\min}{E\max + E\min}$.

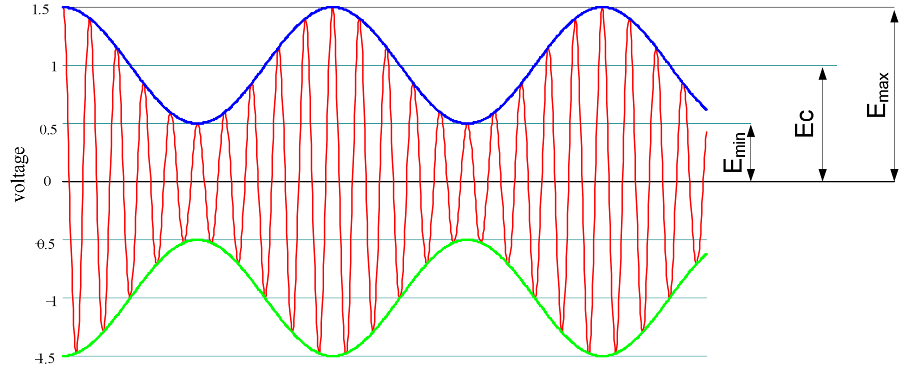


Fig. 2. Amplitude modulation

Figure 3 shows the spectrum of modulated signal.

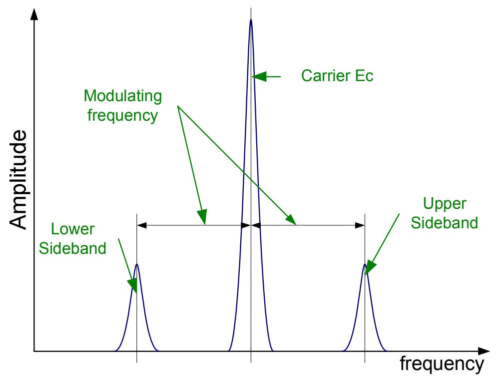


Fig. 3. The spectrum of AM modulated sin wave.

FM and FSK Modulation

Frequency modulation is a change in the carrier frequency depending on the modulating signal. This type of modulation is immune to interference. It is used widely in broadcasting. The frequency range of changing is called deviation of frequency.

The FSK - Frequency Shift Keying Modulation (Fig. 4) is the variation of FM modulation in which the carrier is modulated by square waveform (digital signal). Two frequencies represent two logical states 1 and 0.

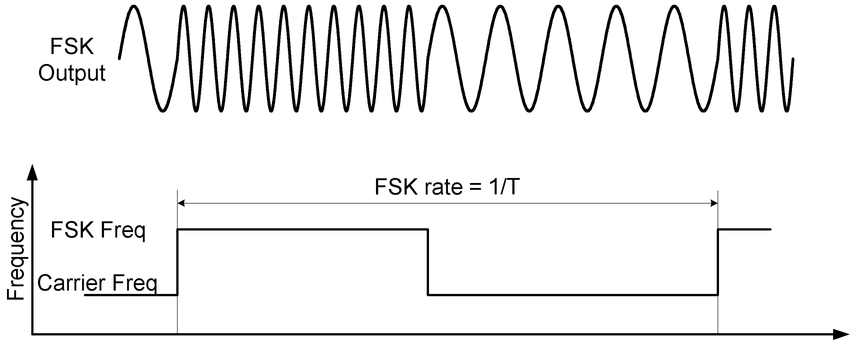


Fig. 4. Frequency Shift Keying Modulation

4. Laboratory exercise execution

Laboratory exercise take places at the stand consising of a waveform generator with internal modulation ability, an oscilloscope and the MS2651B spectrum analyzer. The oscilloscope is used to observe the signal in time domain, spectrum analyzer in frequency domain. Use of the generator and the oscilloscope is intuitive. In case of problems read the instruction manual of the instruments. Detailed manual MS2651B analyzer is at stand. During laboratory exercise use the 5^{th} chapter of the manual, volume 1 – „Basic operations procedure". The analyzer frequency range is from 9kHz to 3GHz. Set frequency upper 100kHz on generator if it is possible.

4.1. The spectrum of Basic signals

Set for the generator: waveform – sinusoid; frequency 1MHz, amplitude less then 1V. Set for the analyzer frequency range. Push the button "frequency". Set „start frequency" and „stop frequency". Set the logarithmic scale of amplitude – push the button „amplitude" and choose log option. If it is necessary set the reference level.

Observe the signal spectrum.

Change the waveform shape. Choose square shape. Observe spectrum when the duty is changing. Similarly do for triangle waveform and changing asymmetry using the same option "duty"

4.2. Spectrum of modulated signals

AM modulation

Set for the generator: waveform – sinusoid; frequency 1MHz, amplitude less then 1V. Press the button modulation and set the modulation type AM.

Set the analyzer frequency range. Push the button “frequency”. Set „start frequency” and „stop frequency”. You can also set the centre frequency value to 1MHz. Set the logarithmic scale of amplitude. If it is necessary set the reference level.
Observe the signal spectrum when parameters of modulation are changing:
a) frequency of modulation signal,
b) modulation depth,
c) modulation waveform.
Compose a conclusion.
FSK Modulation

Set for the generator: waveform – sinusoid; frequency 1MHz, amplitude less then 1V. Press the button modulation and set the modulation type FSK . Observe influence of „Hoop frequency” and „FSK Rate” on signal spectrum.

Other modulation types
Depending on the generator model available at the stand switch to other modulation types and observe the spectrum.

5. References

[1]. Spectrum analyzer MS2651B user manual
[2]. Arbitrary waveform generator user uanual
[3]. Oscilloscope user manual
[4]. Agilent spectrum analisys basics – application note 150 - www.agilent.com