POWER QUALITY

- *Introduction*
- *What's the POWER QUALITY?*
- *Why the POWER QUALITY?*
- *The standard*
- *Voltage disturbes & anomalies*
- *Quality Analysis: the importance*
- *…how analyze the POWER QUALITY ?*

POWER QUALITY

Historically, electricity has been mainly used to power mainly engines, lighting, heating systems and other "simple" uses.

In the last half century, with the growth of electronic, in particular power electronic, we have passed from “simple” uses (and users) to complex uses with a difference type of load…

electronic loads…

…highly sensitive

electronic converter…

…source of voltage disturbance

The growth of users and electricity based applications make a priority the energy efficiency, so it's necessary avoid the energy waste.

…and a no good QUALITY of ENERGY lead to its waste (…and money !)

What's the POWER QUALITY?

Power Quality has several definitions depending on different point of view.

The term "power quality" originated in 1968 from a U.S. Navy study, after specifications for the power required by electronic equipment.

Now there is no a single meaning of POWER QUALITY, depending on the perspective

…for some ones,

it means the limit within the electrical devices can grant the rated performance without any degradation,

…for other ones,

it represents the defense of energy from the passive effects due to new technologies,

…for other ones

it means the respect of the reference standards,

…other ones see

the Power Quality as the supplying and grounding of sensitive equipment in a proper way - ANSI/IEEE

What's the POWER QUALITY?

The IEC uses the term Electromagnetic Compatibility (EMC), which is not the same as power quality, but there is a strong overlap between the two terms. EMC is the ability of an equipment or system to function in the environment without introducing electromagnetic disturbances.

The IEC define also Power Quality a set of parameters of the power supply proprieties as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, and waveform).

POWER QUALITY is the study or description of both voltage and current disturbances.

It can be seen as the combination of voltage quality and current quality.

As an example, the ideal voltage and current waveform is a pure sinewave of constant magnitude and frequency (typically 50 or 60 Hz).

Any deviation from the ideal that exceeds the limits set by the Standards is a power quality issue.

Why the POWER QUALITY?

Starting the '80s Power Quality (PQ) has become an interesting issue in the power industry.

It regards electric power end-users and electric distribution utilities all over the world. The recent growth of interest in power quality can be explained by these four major reasons

- Electricity consumers are better informed about power quality issues and in addition many governments have revised their policies in order to regulate electric utilities pushing them to improve power quality within the set standards and limits.

- Modern devices equipped with microprocessor-based controls and power electronic devices are more sensitive to power quality changes than the equivalent old ones

- Attention to energy efficiency has resulted an increase of project based on high-efficiency devices, adjustable-speed motor drives and shunt capacitors for power factor correction and reduction of losses: in this was the increased harmonic levels on electrical power systems could jeopardize the operability, reliability and safety of the system.

- More systems are now interconnected in the electrical network such as solar and wind, and the so-called integrated processes. They have a lot of power quality issues that must be addressed as part of the interconnection assessment.

The Power Quality is expected to increase, as now it has direct economic impacts to equipment suppliers, utilities and the end-users.

Why the

POWER QUALITY ?

A good energy, an

energy of quality

should

- be always available
- be provided in a fixed range of frequency
- with fixed values
- with perfect sinusoidal wave form

In the **theory.**

But a lot of factors could influence the theory.

…a lot **disturbances** influences the theory.

The disturbances present on transmission networks can be thought of as divided in

- **intrinsic disturbances to the transmission network**
- **disturbances caused from the environment**
- **disturbances caused from the end users**

Why the POWER QUALITY ?

Disturbances of the transmission NETWORK

Dependent on the provider

maintenance,
service management,
network switcher,
network condition,
programmed blackout or voltage reduction in high request period

Disturbances from ENVIRONMENT

Lightning:

They can break the network or cause overvoltage. By ground they can spread to the cable network

Wind, snow:

They can break the network and create disturbance

Solar storm:

Clouds of electrically charged particles reaching the earth collide with the Earth's magnetic field and cause intensity fluctuations. These induce very low frequency currents (almost a direct current) on the network. Their effect is to saturate the transformers of the network. These overheat and disconnect automatically.

Why the

POWER QUALITY ?

Disturbances from END USERS

A user system with disturbing loads, disturbs itself and pollutes the public network, transferring the disturbances to other users. The transferred disturbances are those classified as “conducted”
About three time to four, the disturbance are inside the user’s installation:

Non-linear utilities

inverters, soft starters, rectifiers, power electronics, non-filament lighting, presses

Failures at the customer's plants,
User’s power systems,
Old installations,
Electric appliances using switching power supply,

Computers, printers, decoders, video, copy machines

Transformers,

having a no linear magnetization curve

UPS,
Lighting electronic systems,

as harmonics generators

Inverter, starter, AC / DC converters,
Microwave ovens,

using transformers and rectifiers

Hospital appliances,
Solder machines,
induction ovens,

These devices distort the absorbed current waveform and create electric disturbance

Why the

POWER QUALITY ?

...so...

...maintaining satisfactory Power Quality is a joint responsibility for the supplier and the electricity user

So rules, standard, law must regulate the POWER QUALITY and define the parameters

VS

The standard

The reference

STANDARDS

that regulate the supply of the provider is

EN-50160

It defines, describes and specifies the main features of the voltage at the terminals of a network user's supply in public low voltage, medium voltage or high voltage AC, under normal operating conditions

It's main document dealing with requirements concerning the supplier's side and regulate the voltage parameters of electrical energy in public distribution systems.
The EN-50160 concern the supply voltage, i.e. that measured at the point of common coupling.

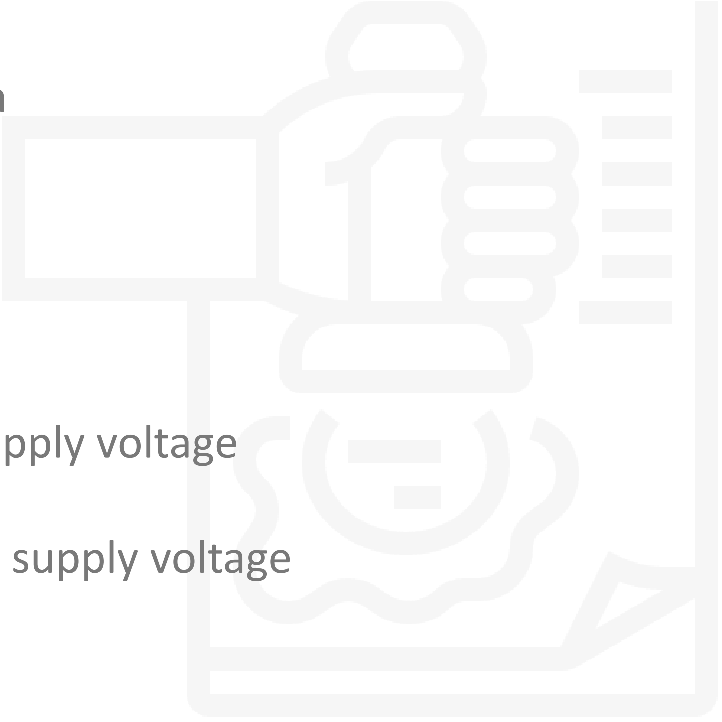
The EN-50160 define characteristics and anomalies of the main attributes of the voltage:

- Harmonic voltage
- Frequency variations
- Voltage interruptions
- Voltage Swell / Dip
- Flicker
- Unbalance

The standard

In according to the

EN 50160



The events can be divided in

CONTINUOUS PHENOMENA

- Harmonic voltages
- Frequency variations
- Slow variations in the supply voltage
- Flickers
- Unbalance of the power supply voltage

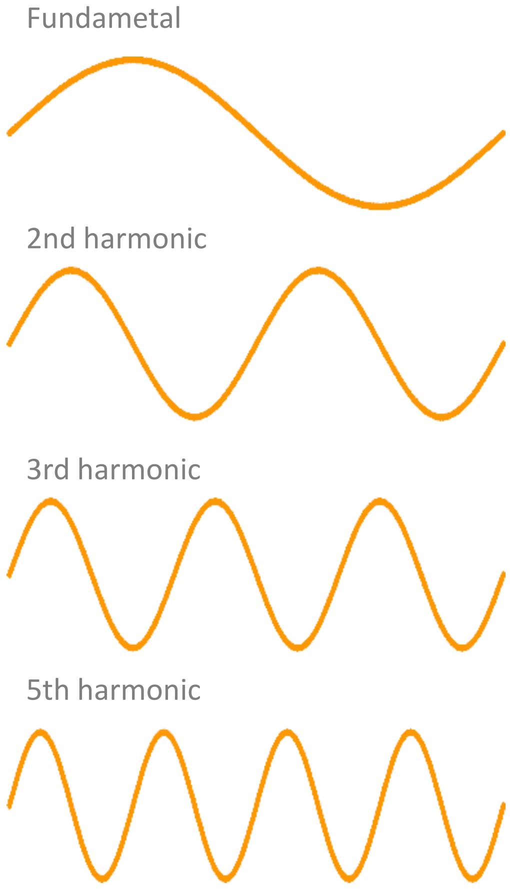
VOLTAGE EVENTS

- Voltage interruptions
- Voltage Swell / Dip

HARMONICS DISTORTION

is a **sinusoidal voltage with a frequency equal to an integer multiple of the fundamental frequency** of the supply voltage.

It can show as



Voltage disturbes & anomalies

continuous phenomena

HARMONICS DISTORTION

Harmonic voltages can be evaluated:

- individually by their relative amplitude **Un** related to the fundamental voltage U1, where **n** is the order of the harmonic
- globally, usually by the **T**otal **H**armonic **D**istortion factor THD_U, calculated using the following expression:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} U_n^2}}{U_{fund}}$$

It's the ratio of equivalent root mean square (RMS) voltage of all the harmonic frequencies over the RMS voltage of the fundamental frequency U_{fund}

Harmonics of the supply voltage are caused mainly by the non-linear loads of the network users connected to all voltage levels of the supply network. The harmonic currents flowing through the network impedance give rise to harmonic voltages.
Harmonic currents and network impedances at the supply terminals (so the harmonic voltages) vary in time

The THD of a theoretical sinusoidal signal is 0.

At increase of number of harmonic, THD also increase.

Voltage disturbes & anomalies

continuous phenomena

HARMONICS DISTORTION

….in STANDARD CONDITION…

during each period of one week, the 95 % of the true RMS of each individual harmonic voltage (averaged on a 10 minutes range) shall be less than or equal to the values given in the following table.

Resonances may cause higher voltages for an individual harmonic.

Moreover, the Total Harmonic Distortion THD of the supply voltage (including all harmonics up to the order 40) shall be less than or equal to 8%

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
Order [h]	Relative amplitude [U_h]	Order [h]	Relative amplitude [U_h]	Order [h]	Relative amplitude [U_h]
5	6,00%	3	5,00%	2	2,00%
7	5,00%	9	1,50%	4	1,00%
11	3,50%	15	0,50%	6…24	0,50%
13	3,00%	21	0,50%		
17	2,00%				
19	1,50%				
23	1,50%				
25	1,50%				

Values of individual harmonic voltages at the supply terminals for orders up to 25 given in percent of the fundamental voltage U_1

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HARMONICS DISTORTION

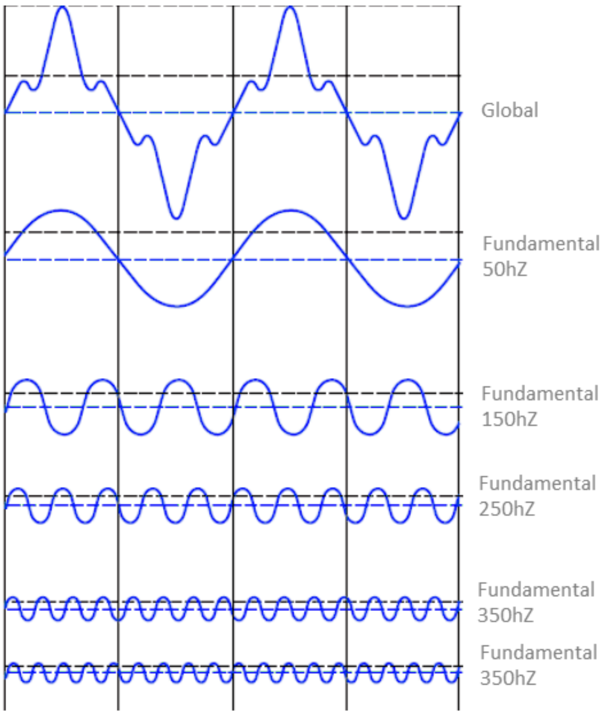
The theory: the mathematical foundations

The harmonic analysis is based on some mathematical principles:
the Fourier theorem and the Fourier series

The
FOURIER THEOREM
states:

any periodic wave
(or regularly repeating),
however complicated,
can be described in terms of
an infinite number of sines
waves (of various amplitudes
and phases) added together.

The sine waver series
is the
FOURIER SERIES



HARMONICS DISTORTION

The main HARMONIC issue is the wave form distortion compared to the theorical sinusoidal wave form. You could have the sinusoidal wave form only with linear load

However the resulting waveform is still periodic, so it’s possible represent the waveform by the function

$$f(t+T)=f(t)$$

Where T is the period

and so the pulsation is $\omega = 2\pi/T$

The Fourier serie can be described by the function

$$y(t) = Y_0 + \Sigma_{n=1}^{n=\infty} Y_n * sen (n*\omega*t - \Phi_n)$$

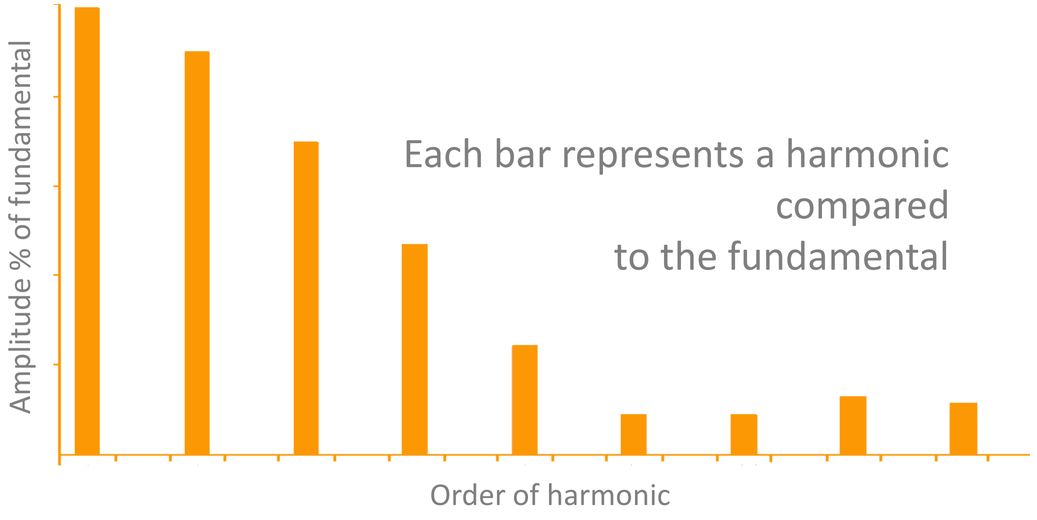
Where
Y_0 = value of the continuous component if it exists
Yn = effective value of the n^{th} component (harmonic of order n)
n = order of harmonicity
ω = pulsation of the fundamental frequency ($\omega = 2\pi f$)
Φn = phase shift of the harmonic component with t = 0

Voltage disturbes & anomalies

continuous phenomena

HARMONICS DISTORTION

Plotting the function in a chart,
where on
abscissa:
frequency of each terms of serie
ordinate:
amplitude
we obtain the **spectrum of harmonic**



The harmonic spectrum is reached at infinity, however for analysis instruments it is limited the 50th harmonic: above the 50th harmonics they are negligible

HARMONICS DISTORTION

key indicator

There are some KEY INDICATOR to evaluate the HARMONICS DISTORTION

Power factor
Crest factor
Power distortion
Frequency spectrum
Harmonic distortion rate

Knowing the key indicator value you can determinate the corrective action

Power factor

It's defined as the ratio:

FP= P / A where P= active power, A= apparent power

Defining

Cosϕ= P_1 / A_1 where P_1= active power of the fundamental, A_1= apparent power of the fundamental

So Cosϕ is referred ONLY to the fundamental. In case of harmonics Cosϕ and FP are different

HARMONICS DISTORTION

key indicator

Crest factor

It's defined as the ratio:

Current crest factor	Voltage crest factor
kI= Im / Irms	**kV= Vm / Vrms**
Im= peak current value Irms= Root Mean Square current	Vm= peak voltage value Irms= Root Mean Square voltage

It is used, in particular the current one, to understand if the current absorbed by the system can create problems at the power sources.

It can take values from 1.5 to 5
(e.g. IT users often have 3 < K < 5)

A pure sinusoidal signal k= √2

Voltage disturbes & anomalies

continuous phenomena

HARMONICS DISTORTION

key indicator

Power distortion

Considering the **Apparent power** S as

S= $V_{rms} * I_{rms}$ and in case of harmonic $S=\Sigma_{h=1}^{\infty} V_h * I_h$

so the relation $S^2= P^2 + Q^2$ isn't valid.

So that, **POWER DISTORTION D** is the defined as
$S^2= P^2 + Q^2 + D^2$ where **S= apparent power Q= reactive power**

Frequency spectrum

It shows each harmonic as percentage of the fundamental one. It represents the frequency decomposition of the signal and allows the graphic display of the harmonics as well as their intensity. Offers a quick assessment of deformation

Total Harmonic Distorsion

It gives an evaluation the degree of distortion of the signal.
Knowing this factor, you can evaluate the analysis of the disturbances introduced into the network as well as for understanding the cause

HARMONICS DISTORTION

Effects

The problems of the Power Quality aren't only due HARMONIC EFFECT: there is a wide variety of phenomena and aspects not only electrical: it is only a portion of the aspects that does not allow the system to be the ideal solution in a system connected to the network.

But in any case it's a main issue

The main effects of harmonics on a power system can be different but the most important ones are losses in the various electrical components.

As electric current circulates in the conductors, there is a voltage drop due to the resistance of the conductor.
The active power transmitted at a load depends on the fundamental current. When the current absorbed by the load contains harmonics, the effective value of the current is higher than that of the fundamental.

HARMONICS DISTORTION

Effects

One of the effects of harmonic currents is that they cause an increase in **Joule losses** in all conductors so there will be a further increase in temperature in transformers, cables and equipment.

The presence of harmonics also provoke over-heating of the neutral conducto: In a three-phase balanced system, the 50hz fundamental component of the current is cancelled in the neutral wire as the sum of 3 current is zero. In single phase no linear loads the harmonics are not cancelled but on the contrary, they are added in the neutral conductor

FREQUENCY VARIATION

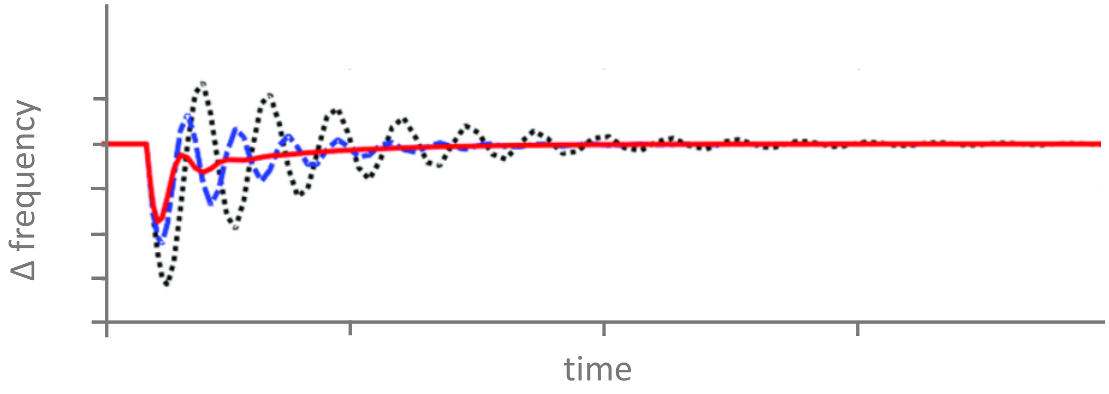
is a **deviation of the system operating frequency** compared its nominal value (50 Hz or 60 Hz).

The **system operating frequency** is strictly related to the rotation speed of the generators supplying the system.

The **deviations magnitude** and its duration are affected by the connected load:

short circuit
unpowered loads
no working generation system
can be causes of **frequency deviation**

In **modern system** the frequency deviations are uncommon and minimal



Voltage disturbes & anomalies

continuous phenomena

SLOW VOLTAGE CHANGE

In standard condition, except for switch off time, voltage variation should

< +-10%

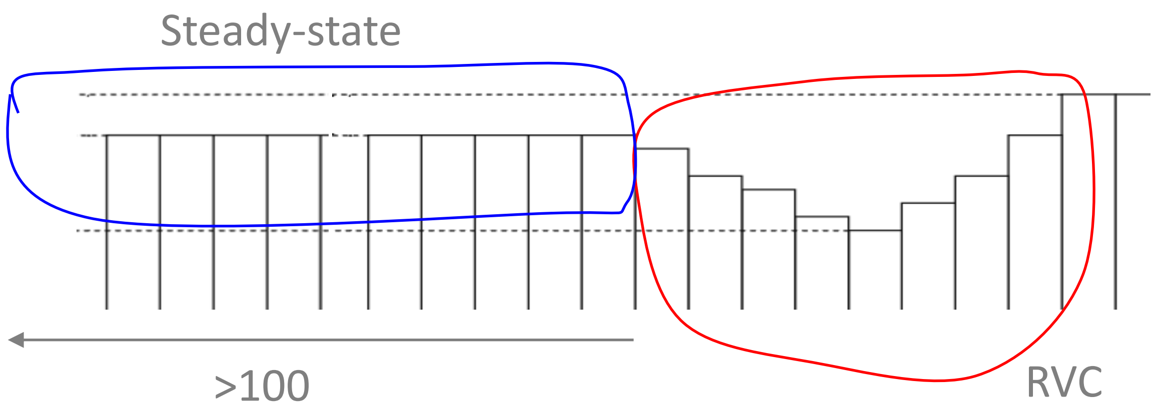
For exceptional case (long distance between user and the network) the variation can be +10%... -15%

RAPID VOLTAGE CHANGE

Voltage is in a steady-state condition when

all the immediately preceding 100 Urms1/2 values remain in a RVC thresholds.

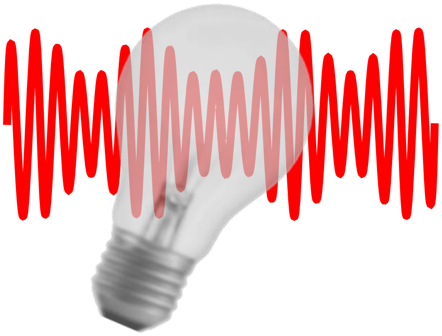
If the measured voltage is out of the fixed threshold you have a Rapid Voltage Change event



Voltage disturbes & anomalies

continuous phenomena

FLICKER



is a **human perception** of **voltage fluctuation** on incandescent lamps and other electrical lighting devices. This effect can be perceived by the human eye, with a maximum sensitivity of between 8 and 10 Hz

How objectively measure a human sensation?
Indicating the level of the visual sensation that the human subject would feel, if a reference lamp (230 V, 60W) is powered by the network in question. The measurement of the flicker is expressed through the disturbance indices Pst (short term flicker severity) and Plt (long term flicker severity)

Pst measurement:
A variation on the power emitted for 10 minutes is applied to the bulb: it was found when the 50% of a sample people group detected the presence of variations in brightness intensity. The value Pst = 1.0 has been assigned to this disturbance value.

Plt measurement:
It's calculated in according to

$$Plt = \sqrt[3]{\sum_{i=1}^{n} \frac{Pst_i^3}{n}}$$

calculated starting from a sequence of n values (usually 12) of Pst (Psti in the formula) over an interval of 12x10min = 2 hours, but the required specifications may vary

Voltage disturbes & anomalies

continuous phenomena

FLICKER

causes

- Arc furnaces
- Arc welders
- Boilers
- Elevators

How to fix

Removing the offending load, relocating the sensitive equipment, or installing power line conditioning or UPS devices

results

High flicker levels cause an increase in maintenance and faults on electronic equipment.

Employees become tired, irritable and to lose concentration, particularly at workstations in office buildings. The continual adjustment of the optic nerve to the changing lighting conditions causes tiredness quickly and finally transfers to the person‘s overall sensitivity.

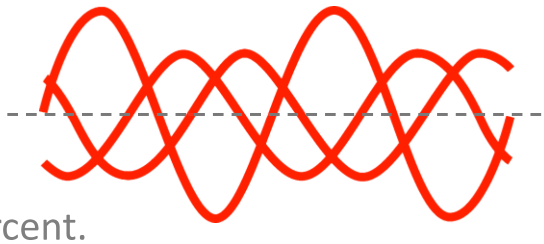
Voltage disturbes & anomalies

continuous phenomena

UNBALANCE

is a **diversity of the amplitudes** of the phase voltages or the normal 120 degree phase shift between phases, so the three-phase system isn't symmetrical.

Voltage unbalance can be estimated as the maximum deviation from the average of the three-phase voltages divided by the average of the three-phase voltages, expressed in percent.



$V_{unbalance}$= Max Deviation from Average Voltage / Average Voltage

causes

The main sources of unbalance are the unbalanced partition of the single-phase loads on the low voltage and the single-phase loads powered phase-phase on the medium and low voltage

results

Voltage unbalances are one of the most common problems in three-phase systems, and can cause severe damage to equipment: for example, a 2.3% voltage imbalance on a 230V motor results in a current imbalance of nearly 18%, causing a temperature rise of 30 ° C., degrading motor insulation causing cumulative and permanent damage to the motor

Voltage disturbes & anomalies

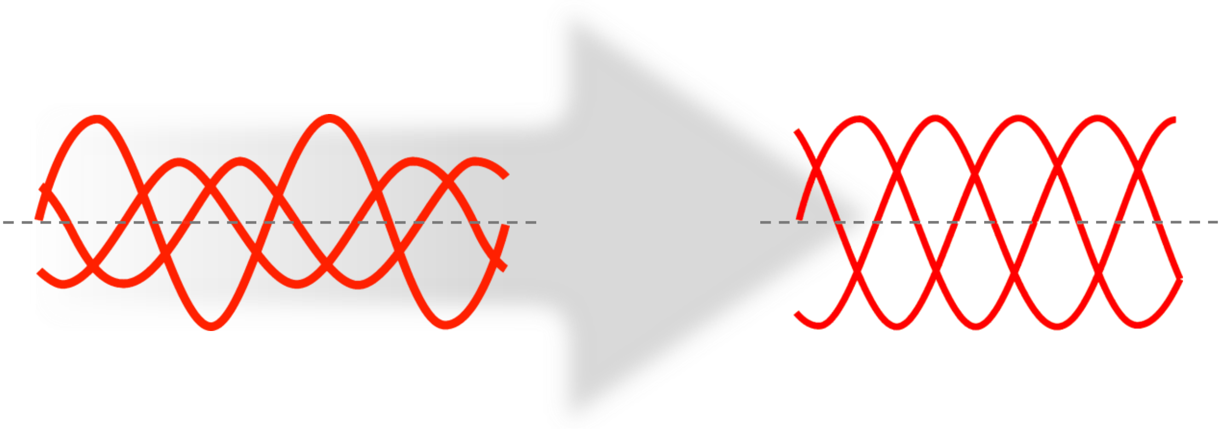
continuous phenomena

UNBALANCE

How to fix

For the utility, it is just a matter of repairing malfunctioning equipment or redistributing loads to reduce the unbalance. For the end-users, proper testing and communication with the utility would help locate and resolve the problems.

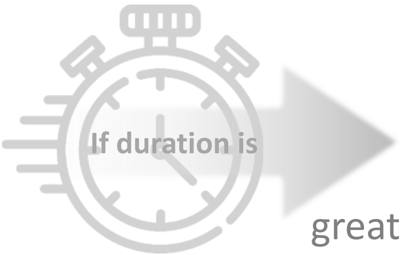
Adjustable speed drives can be equipped with AC-line reactors and DC link reactors to mitigate the effects of unbalance



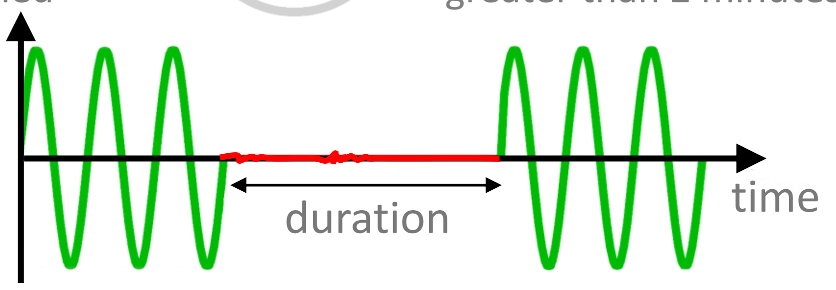
Voltage disturbes & anomalies

VOLTAGE INTERRUPTION

is a **supply voltage loss** below the 5% of nominal voltage.
It can be



Instantaneous	0.5 to 30 cycles
Momentary	30 cycles to 2 seconds
Temporary	2 seconds to 2 minutes
Sustained	greater than 2 minutes



causes

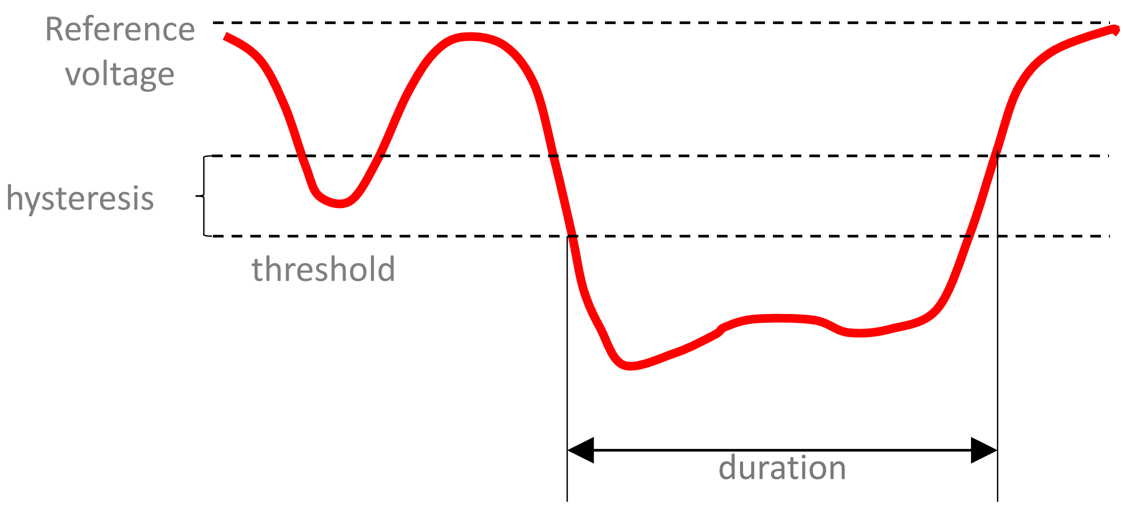
Electrical supply grid damage,
- lightning strikes,
- animals,
- trees,
- vehicle accidents,
- destructive weather (high winds, heavy snow or ice on lines, etc.),
- equipment failure

VOLTAGE DIP also known as “sags” (*)

(*) In the international context, "sag" was used for many years to describe a generic short duration voltage drop.
Although the term has not been formally defined, it has been accepted and used by distributors, manufacturers and end users. **The term used by the IEC** for describing this phenomenon **is "dip“:** in any case, the two terms (“voltage sag ”and“ voltage dip ”) are considered interchangeable.

is a **rapid** and **temporary decrease** of the voltage at **90%** in half cycle of one or all supply phase voltages without any supply interruption.

The dip starts when one of the supply voltages becomes lower than a set thresholds and ends when all the voltages goes up the threshold.



VOLTAGE DIP

causes

They are caused by switching on of high-current equipment such as air conditioners, microwave, furnace fans, hair driers, motors, mills, welding machine or could be caused by weather condition.

Similarly, the starting of large motors inside an industrial facility can result a voltage drop, causing a significant voltage drop to the rest of the circuit

How to fix

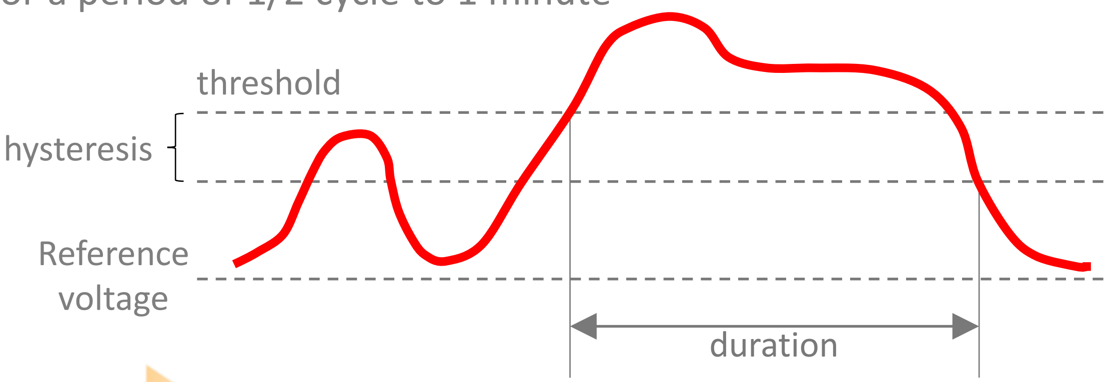
- alternative power starting sources that do not load the rest of the electrical infrastructure at motor startup
- adjustable speed drives (ASDs), which vary the speed of a motor in accordance with the load
- Some techniques used to fix interruptions issues: UPS equipment, motor generators, system design techniques

results

Sometimes the damage being caused by sags is not apparent until the results are seen over time (damaged equipment, data corruption, errors in industrial processing).

VOLTAGE SWEL

is the opposite of DIP: in according to the standard it's defined as a momentary **increase** in voltage of 10% or more of nominal voltage for a period of 1/2 cycle to 1 minute



causes

- high-impedance neutral connections,
- sudden (especially large) load reductions,
- single-phase fault on a three-phase system

How to fix

- Power line conditioners, UPS
- Ferro resonant "control" transformers (constant voltage transformers)
- Magnetically controlled regolators

results

The result can be data errors, flickering of lights, degradation of electrical contacts, semiconductor damage in electronics devices, insulation degradation. Swells may not be apparent until their results are seen.

Quality Analysis: the importance

Bad Power Quality: **costs** & **impacts**

The industry is every day more and more careful to the Power Quality

The consumer needs (and wants) an energy with a certain quality

…he pays…so he require!

…**but a bad quality directly also impacts to the cost!**

Cost for Personnel's no productive time due to the sudden interruption of the production cycle.

Costs for raw materials lost

Cost for not carried out work or lost

Costs to fix the negative effects (overtime work, …)

Machinery reparation cost and temporary rent to replace them

Penalties due contractual breaches.

Human care and environmental safety

Quality Analysis: the importance

Good Power Quality**: the advantages**

On the contrary…

the advantages of good Power Quality bring **benefits** that have a positive effect on the overall performance of the company

Reduction of line currents and losses on equipment,

Reduction of investments,

Power factor improvement,

Reduction of the required power,

Improvement of the current waveform (→ consequent more efficient operation of the power equipment)

Reduction of harmonic distortion (→ consequent reduction of losses in copper, in the core and for stray currents);

Elimination of sudden and unplanned production stop,

Elimination or reduction of equipment failures due to a low electrical and thermal stress;

High affidability and durability of the equipment thanks to the low operating temperature for lower losses.

...how analyze the

POWER QUALITY ?

...IME can help you !!!

IME has in its production range the

NEMO QUALITY ANALYZER

NEMO 96EA

The Network analyzer for LOW - MEDIUM – HIGH voltage geared for energy quality

The NEMO 96 EA is more than an unit of measurement, **it allows to control the quality of the network that it measures and to record the events that can happen**. It will help you manage and guarantee the reliability and energy efficiency of your installation in order to minimize losses due to disturbances in the distribution networks.

NEMO 96 EA is supplied as standard with the RS485 Modbus RTU/TCP communication module.

NEMO 96 EA has an 8Mb internal memory for the recording of real time data (current, voltage, powers, frequency,…) and integrated data (energies). It can also save the energy quality events (voltage holes, overvoltage, quick variations and interruptions of the voltages). It calculates the instantaneous flicker intensity

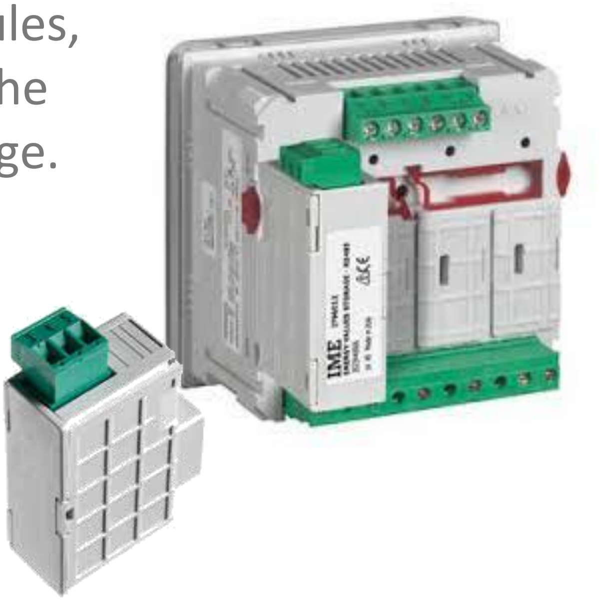
...how analyze the

POWER QUALITY ?

...IME can help you !!!

...plug in module.... Too add functions

NEMO 96 EA can be equipped with up to 4 additional modules, including those normally in the catalog for the NEMO 96 range.



RS485 communication
RS232 communication
Ethernet communication
Pulse output
Pulse input
Allarms
Neutral current
Relay
Temperature measurement

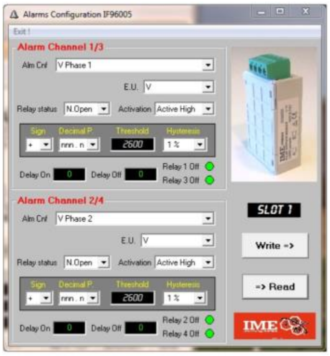
...how analyze the

POWER QUALITY ?

...IME can help you !!!

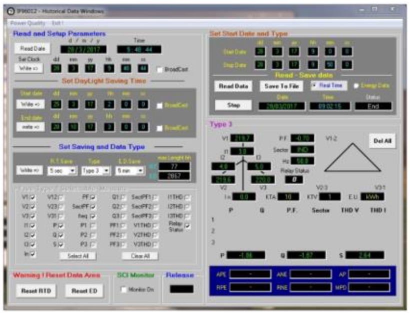
Thresholds and alarm management

NEMO 96 EA is able to display all network parameters and setting alarm thresholds.



Embedded memory

It's possible choose what parameters to store and keep track of for the future analysis.



FREE SOFTWARE

to remotely view the power quality parameters of your Network

and to complete the configuration of the device and the connected modules

...how analyze the

POWER QUALITY ?

...IME can help you !!!

STANDARDS:

Energy measuring

IEC 62053-22 class 0.5

IEC 61557-12 PMD

Monitoring of network quality

IEC 62586-1/2 PQIs class S

EN 61000-4-30 EN 61000-4-15

POWER QUALITY FUNCTIONS:

Harmonics (U&I) to 40th

Overvoltages

Network holes

Network interruptions

Rapid voltage change

Flickers

Memory embedded (8Mb)

RTC (Real time clock)

…how analyze the

POWER QUALITY ?

…IME can help you !!!

DISPLAY:

- Phase and linked voltage
- Min. and max. phase voltage
- THDV
- Voltage harmonic analysis
- Voltage crest factor
- Phase angle between voltage
- Neutral and phase current
- Current demand and max. current demand
- Average current
- THDI
- Current crest factor
- Phase angle between current and voltage
- Active, reactive phase power
- Power demand and max. power demand
- Positive and negative active and reactive energy
- Apparent energy
- Power factor
- Frequency
- Run hour meter, count start with voltage or power present

...how analyze the

POWER QUALITY ?

...IME can help you !!!

More information about how IME can help you?

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