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SOME ASPECTS OF THE ELECTRICAL POWER QUALITY

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Abstract: The paper presents basic definitions, terms and indicators of the quality of electricity. Higher harmonics and their consequences are presented. Degradation of basic voltage parameters (effective value, frequency, phase shift, symmetry, etc.) as well as waveform distortion, ie short-term or long-term deviations from the sinusoidal shape (higher harmonics, short-term interruptions, voltage failures, impulse overvoltages and others) represents a low-frequency part of the conduction disturbances that most affect the voltage quality as part of the electromagnetic compatibility problem. Basic standards and recommendations for controlling higher harmonics in electrical networks are given.
Keywords: electrical power quality, higher harmonics, standards

INTRODUCTION

The concept of quality of electricity is complex [1-4], because in addition to user, ecological and commercial quality it implies technical quality as a synonym for the quality of electricity, which includes problems of reliability and security of power supply, overall stability of system operation, numerous disruptions as well as the rental ratio of the electric power system - consumer and vice versa.

The problem of the technical quality of electricity is any phenomenon that is reflected in the disturbance of the basic parameters of the voltage in the established or transient states, disturbing the waveforms of the voltage and the current, their phase shift as well as the deviation of the frequency [1-4].

Ideally, the voltage of the electrical network should be the sine waveform, the nominal frequency, the nominal effective value, while the ideal current is also sinusoidal, without harmonic distortion and in the phase with voltage [1-4]. In reality, however, the quality of the delivered electricity is impaired by various irregularities, such as: overvoltages, undervoltage, short-term voltage abnormalities, voltage peaks, flickers, higher harmonics, etc.

Non-linear consumers (electrical energy devices, electric machines, electric furnaces and others) have a dominant influence on the physical voltage quality, transient phenomena due to commutations in the system with switches, automatic re-switch, switching on / off of large consumers etc.).

The switching nature of the operation of the power electronics device and the consumption of non-ionic currents causes the appearance of higher harmonics, deforms the waveform of the network voltage, a weak power factor, causes electromagnetic interference, and hence degrades the quality of electricity.

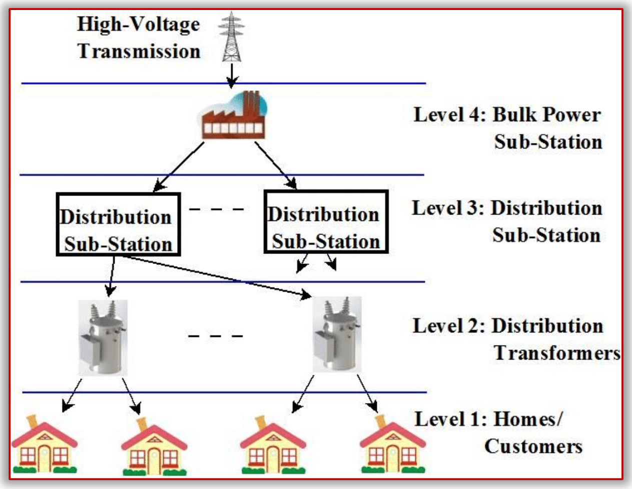
Degradation of basic voltage parameters (effective value, frequency, phase shift, symmetry, etc.) as well as waveform distortion, ie short-term or long-term deviations from the sinusoidal shape (higher harmonics, short-term interruptions, voltage failures, impulse overvoltages and others) represents a low-frequency part of the conduction disturbances that most affect the voltage quality as one part of the EMC problem [1-4].

Today there are extensive research of quality parameters, continuous testing and supplementation of technical regulations for limitations of harmonics and flicker levels, more stringent standards for connecting non-linear consumers are introduced. Based on the large number of research papers, and in particular the recommendations of the working groups, the relevant organizations relevant to the EMC, international and national standards are continuously updated, adjusted and improved.

BASIC DEFINITIONS, TERMS AND INDICATORS OF THE QUALITY OF ELECTRICITY

Many answers apply to this simple question. They all depend on your perspective. From the utility perspective, Power Quality has been defined as the parameters of the voltage that affect the customer's supersensitive equipment. From the power user perspective, Power Quality may be defined as any electrical parameter or connection that affects the operation of the equipment. This includes all electrical parameters, connections and grounds, whether the source from the utility, local equipment or other users. From the Power Quality market or industry perspective, it is any product or service that is supplied to users or utilities to measure, treat, remedy, educate engineers or prevent Power Quality issues, problems and related items.

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy with a clean sinusoidal voltage at the contracted voltage level (110kV, 30kV, 10kV, 415V) and frequency (50Hz) (Fig.1). However, in practice, power systems, face a variety of challenges either from generation, transmission and distribution or even within a customer facility which impacts the quality of power. These power quality issues can affect the uninterrupted operation of customer loads, but the safety-related issues can reduce the life of the connected loads and electrical equipment. A customer having numerous nonlinear loads can also affect the quality of power supply and the purity of the voltage waveform is lost which can affect other loads within the facility or even outside the customer facility. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality (PQ) problems.



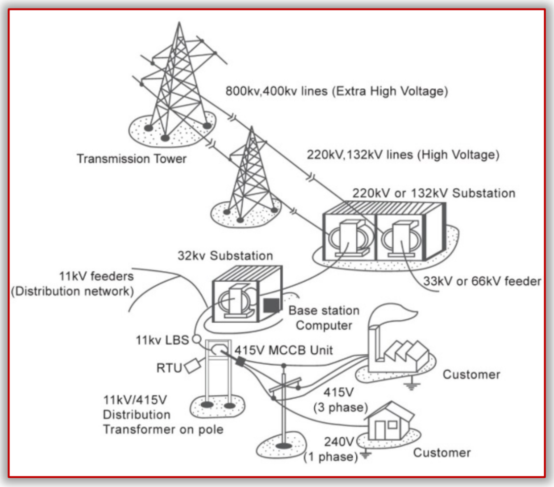


Figure 1. Typical electricity distribution hierarchy.

The quality of electricity is mostly related to the quality of voltage and frequency, i.e. their deviation from the nominal value as well as the comparison of the waveforms of the current and voltage relative to the ideal sinusoid.

The basic parameters and deformation of waveforms, among others, are two groups of factors that determine the quality of the used voltage [2]. The basic parameters of the used voltage include the variation of the effective value of the voltage, frequency and the occurrence of an asymmetry in the supply. The deformation of the waveforms of the voltage includes the following states: stable states of the system (harmonics, voltage notches, flickers and noise), transient regime of the system (overvoltages, undervoltage, voltage failure, voltage overload, short-circuit breaks) and transient states (impulses and oscillations). On Fig.2 gives an overview of the factors of the quality of the used voltage.

Harmonics are sinusoidal voltages and currents at frequencies that are integers of the basic network frequency. Distorted waveforms consist of a fundamental component and components with frequencies up to 5 kHz (Fig.3).

Voltage cutouts are periodic intermittent faults that last less than 1 ms, typically 0.3 ms. The result is commutations with a network of switched converters. Typical values are in the range 10 -90% of the nominal voltage.

Noise (electromagnetic interference): corresponds to high frequency electromagnetic noise, which can, for instance, be produced by the fast switching of electronic power converters (Fig.4).

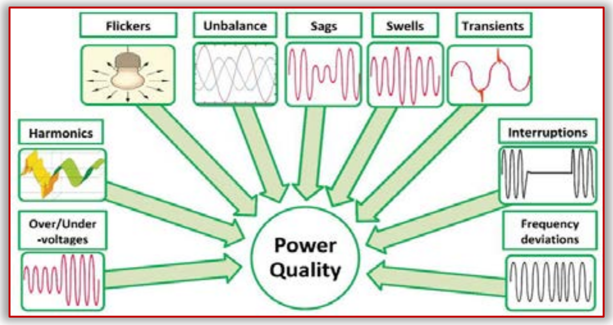


Figure 2. The common power quality problems

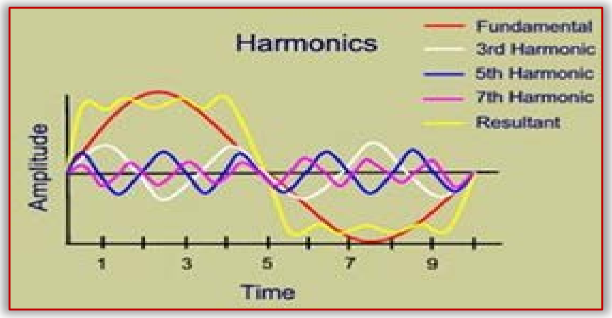


Figure 3. Decomposition example of a complex distorted signal, as addition of 50Hz fundamental and 3rd, 5th and 7th harmonics (150Hz, 250Hz, 350Hz respectively).

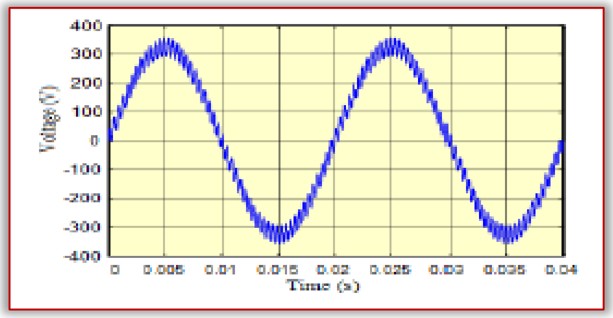


Figure 4. Noise (electromagnetic interference) [6]

Momentary interruption: occurs, for instance, when the electrical system has automatic reset circuit breakers, that opens when a fault occurs, closing automatically after some milliseconds (and is kept closed if the short-circuit is extinguished) (Fig.5.).

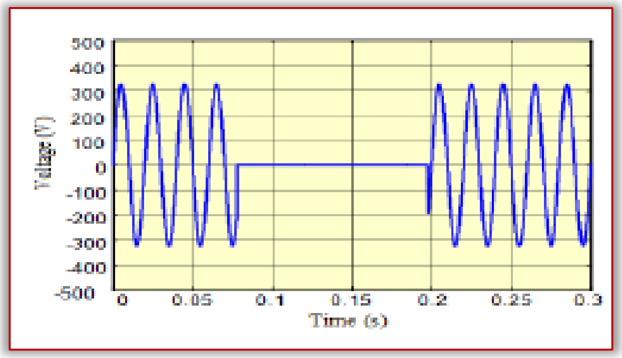


Figure 5. Momentary interruption

Voltage sag: can be caused, for instance, by a momentary short-circuit at another branch of the same electrical system, which is eliminated after some milliseconds by the opening of the branch circuit breaker (Fig.6.).

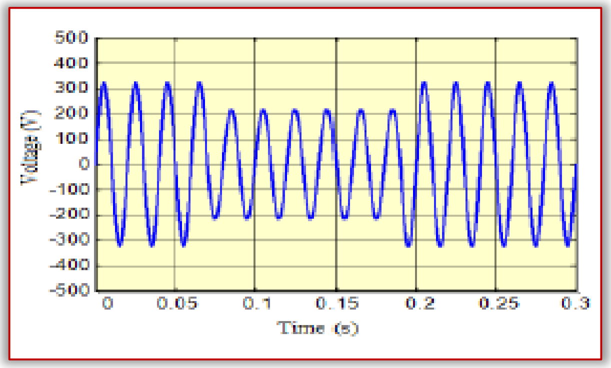


Figure 6. Voltage sag [6]

Voltage swell: can be caused, amongst other cases, by fault situations or by commutation operations of equipments connected to the electrical grid (Fig.7).

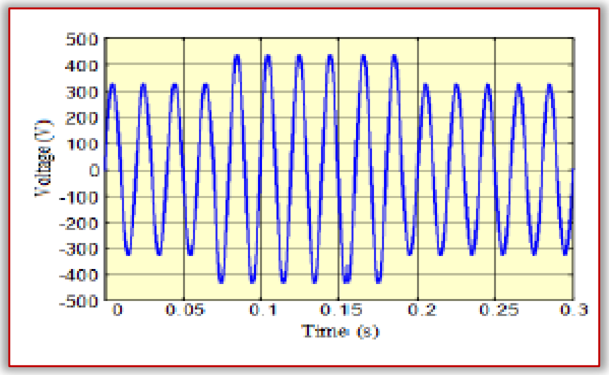


Figure 7. Voltage swell

Flicker: it happens due to intermittent variations of certain loads, causing voltage fluctuations (which results, for instance, in oscillations on electric light intensity) (Fig.8).

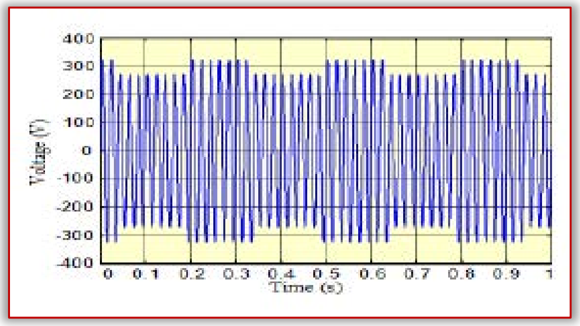


Figure 8. Flicker

Notches: Consist in small periodic cuts on the voltage waveform, which result from voltage drops on the line inductances of the electrical system. These occur due to loads which consume currents with abrupt periodical variations (like rectifiers with capacitive or inductive filter) (Fig.9).

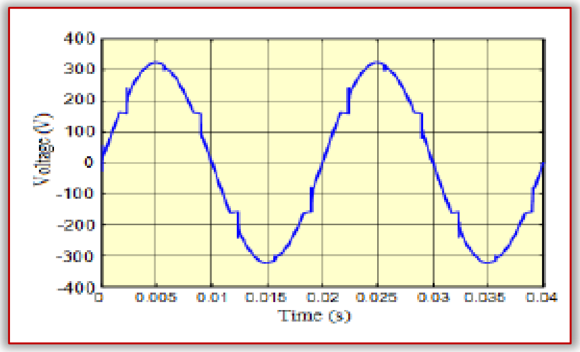


Figure 9. Notches [6]

Transients: occur as a result of transitory phenomena, such as capacitor bank switching or atmospheric discharges (Fig. 10).

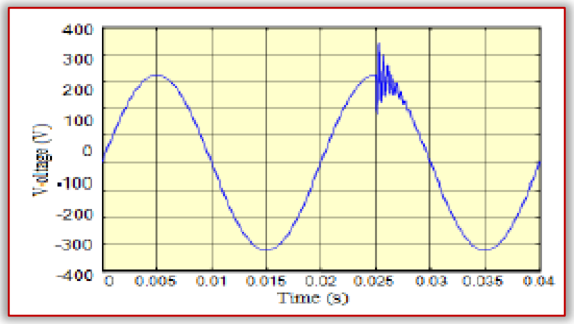


Figure 10. Transients

HARMONICS AND THEIR CONSEQUENCES

One of the definitions of harmonics is that it represents a periodic oscillation present in a complex function, the value of which is an integer multiplication of the basic frequency [2-4]. Similarly, in electrical engineering according to the IEC vocabulary, the term harmonics is a component of a Fourier order of some periodic size whose order is greater than one. Harmonics occur even in the process of electricity generation, transmission and by individual consumers.

The development of powerful semiconductor components, and a series of new topologies of power converters, have led to their widespread use. The non-linear (switching) nature of these devices is the cause of higher harmonics of voltage and current in the network to which they are connected, and when it comes to the high power of these devices or a larger number of devices, less power makes them the main cause of the disruption of the quality of electricity.

Higher harmonics cause a variety of side effects. These are interruptions in the operation of computers, faults in the operation of protective equipment, measurement errors, overvoltages, interference with communication and signaling devices, additional heating of electrical machines, etc. All of these effects can have very serious technical and economic consequences, so today special attention is paid to the problem of eliminating higher harmonics from the network.

The current modern electrical and electronic equipment should be designed to work reliably even under "polluted" conditions, since any limitation of the higher harmonics level must respect real technical, technological and economic conditions, since the complete elimination of higher harmonics is practically impossible [2-5].

For complete processing and analysis of higher harmonics, it is necessary to gain insight into different aspects of their appearance, influence, measurement (measuring size, places and methods of measurement), monitoring methods, standardization (standards, recommendations, instructions, harmonization of regulation) and, ultimately, effective elimination of harmonics [2-4]. All these aspects of higher harmonics are processed as part of a comprehensive topic of electromagnetic compatibility (EMC).

According to the frequency range, four types of harmonics are distinguished:

1. subharmonic - the frequency that is part of the basic, i.e $f_n = f_1 / n$ where:

f_1 - basic frequency (50 or 60 Hz),

n - natural number (2, 3, 5 ...)

The effect of the subharmonic is reflected in the flicker of light (flicker). The biggest "producers" of the subharmonic are the electric furnace furnaces.

2. low-frequency harmonics-frequencies that are multiply basic, i.e. $f_n = nf_1$

In this case, the value is usually less than 100. Low-frequency harmonics are those most commonly called "higher harmonics". In the analysis, most often go to the 25th harmonica, and recently to 50. Their most common source is rectifiers, inverters, cyclone converters, saturated transformers, rotary electric machines, electric furnaces, etc.

3. interharmonic - fractional harmonics or asynchronous harmonics, frequencies that are not integer multiples of the basic frequency (f_1), f_n less than 10 kHz. They are mainly connected to the operation of the electric motor drive with speed control by means of a converter coupler adapter - inverter. Negatively affect systems for tone-frequency command and telemetry, which use power lines for signal transmission.

4. high-frequency harmonics - often called radio interference, frequencies exceeding 10 kHz. The result of commutation transitions in energy switching components and negatively affect telecommunication signals as well as the operation of microcircuits in computer systems.

Higher harmonics are one of the main parameters of the quality of electricity, and most often appear as a result of the work of a large number of non-linear consumers. Since equipment and consumers need to show a certain degree of tolerance or immunity to multiple harmonics, from this aspect higher harmonics appear as part of the problem of electromagnetic compatibility, as high-frequency conductive disturbances [2-5].

The vast majority of the problems that occur on electrical systems have its origins on the excessive distortion of the currents or voltages near the final consumer. The main cause for this phenomena, which can be regarded has a sort of electromagnetic environment pollution, is due to the growth of the usage of electronic equipment fed by the electrical grid, such as computers, printers, television sets, electronic ballasts for gas-discharge lamps, electronic controllers for different varieties of industrial loads, etc. Almost every electronic equipments, single-phase or three phase, embodies a rectifier circuit at its entrance, followed by a commuted converter of the type DC-DC or DC-AC. One of the most usual rectifiers for low-power equipments is the single-phase full wave rectifier with capacitive filter, which has a highly distorted current consumption, as it can be seen on figures 11 and 12.

The current's high harmonic content distorts the voltage on the loads due to the voltage drops in the electrical systems impedances. Phase fired controllers, widely used to control power consumption of heating systems and to adjust luminous intensity of lamps (dimmers), also consume currents with substantial harmonic content and with high-frequency electromagnetic interference. Even the ordinary fluorescent lamps contribute significantly for the presence of harmonics in the electrical grid, due to the non-linear behavior of the electrical discharges on the gaseous environment, and also to the ballast's magnetic circuit, that can operate on the saturation region.

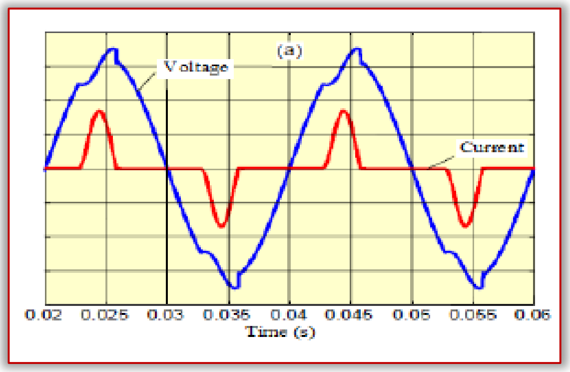


Figure 11. Voltage and current in a single phase rectifier with a capacitive filter [6]

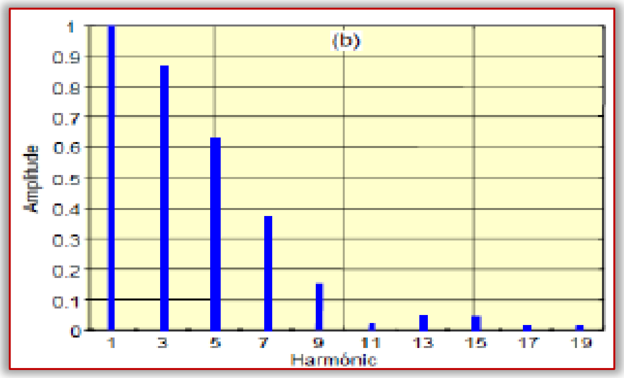


Figure 12. Harmonic of the current in input [6]

OVERVIEW OF IEC STANDARDS ON HARMONICS

The International Electrotechnical Commission (IEC), currently with headquarters in Geneva, Switzerland, has defined a category of electromagnetic compatibility (EMC) standards that deal with power quality issues. The term electromagnetic compatibility includes concerns for both radiated and conducted interference with end-use equipment. The IEC standards are broken down into six parts [7]:

- **Part 1: General.** These standards deal with general considerations such as introduction, fundamental principles, rationale, definitions, and terminologies. They can also describe the application and interpretation of fundamental definitions and terms. Their designation number is IEC 61000-1-x.
- **Part 2: Environment.** These standards define characteristics of the environment where equipment will be applied, the classification of such environment, and its compatibility levels. Their designation number is **IEC 61000-2-x** [7]:.
- **Part 3: Limits**. These standards define the permissible levels of emissions that can be generated by equipment connected to the environment. They set numerical emission limits and also immunity limits. Their designation number is **IEC 61000-3-x.**
- **Part 4: Testing and measurement techniques**. These standards provide detailed guidelines for measurement equipment and test procedures to ensure compliance with the other parts of the standards. Their designation number is **IEC 61000-4-x.**
- **Part 5: Installation and mitigation guidelines**. These standards provide guidelines in application of equipment such as earthing and cabling of electrical and electronic systems for ensuring electromagnetic compatibility among electrical and electronic apparatus or systems. They also describe protection concepts for civil facilities against the high-altitude electromagnetic pulse (HEMP) due to highaltitude nuclear explosions. They are designated with **IEC 61000-5- x.**
- **Part 6: Miscellaneous**. These standards are generic standards defining immunity and emission levels required for equipment in general categories or for specific types of equipment. Their designation number is **IEC 61000-6-x**.
- Unlike the IEEE standards on harmonics where there is only a single publication covering all issues related to harmonics, IEC standards on harmonics are separated into several publications. There are standards dealing with environments and limits which are further broken down based on the voltage and current levels. These key standards are as follows:
- **IEC 61000-2-2 (1993):** Electromagnetic Compatibility (EMC). Part 2: Environment. Section 2: Compatibility Levels for Low-Frequency Conducted Disturbances and Signaling in Public Low-Voltage Power Supply Systems [7].
- **IEC 61000-3-2 (2000):** Electromagnetic Compatibility (EMC). Part 3: Limits. Section 2: Limits for Harmonic Current Emissions (Equipment Input Current Up to and Including 16 A per Phase).
- **IEC 61000-3-4 (1998):** Electromagnetic Compatibility (EMC). Part 3: Limits. Section 4: Limitation of Emission of Harmonic Currents in Low-Voltage Power Supply Systems for Equipment with Rated Current Greater Than 16 A.
- **IEC 61000-3-6 (1996):** Electromagnetic Compatibility (EMC). Part 3: Limits. Section 6: Assessment of Emission Limits for Distorting Loads in MV and HV Power Systems. Basic EMC publication.

CONCLUSION

The quality of electricity is mostly related to the quality of voltage and frequency, i.e. their deviation from the nominal value as well as the comparison of the waveforms of the current and voltage relative to the ideal sinusoid. There are a number of electrical devices that have nonlinear operating characteristics i.e. even when the applied voltage is sinusoidal in nature, the current drawn by the device is nonsinusoidal in nature. These nonlinear devices used in power distribution circuits create nonlinear currents and which subsequently causes voltage distortions. These nonlinear currents and voltages have been generally referred to as harmonic currents and voltages. The proliferation of electronic switching devices in modern equipment has resulted in a significant increase in the amount of harmonic pollution in the electrical distribution systems. Harmonic currents and voltages can cause many unfavorable effects on the power system itself and the connected loads.

Note:

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