TECHNICAL GUIDELINES FOR ELECTROMAGNETIC COMPATIBILITY
OVERVIEW OF POWER QUALITY

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Acknowledgements

List of AFSEC TC 77 (ATC 77) contributing authors to the EMC Guide on Overview of Power Quality

1. Amevi **ACAKPOVI**
   Chair – Ghana

2. Ade **OGUNSOLA**
   Former Chair & Member – Nigeria

3. Mai **ELHAFEZ**
   Secretary – Egypt

4. Sohair **FAKHRY**
   Member – Egypt

5. Chijioke **OBIEKEZIE**
   Member – Nigeria

6. Dominic **NYITAMEN**
   Member – Nigeria

7. Thelela **MYAMBO**
   Member – South Africa

8. Etienne **NTAGWIRUMUGARA**
   Member – Rwanda

9. Bwanga **MBULA**
   Member – Zambia

10. Michael **OGANGA**
    Member – Kenya

german cooperation
DEUTSCHE ZUSAMMENARBEIT

PTB
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

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Contents

1 Introduction

The ideal alternating current (ac) waveform has two important features: (1) it contains no harmonics components besides its fundamental frequency, and (2) its magnitude is consistent over a long period. A deviation from any of these characteristics results in what is known as power quality problem. Unfortunately, the ideal waveform does not exist in the real world. The non-linear characteristics of most power equipment and the switching of loads tends to distort the voltage and current waveforms. Devices such as transformers and motors can cause distortion due to the saturation of their magnetic cores. Power electronics converters can also cause distortions due to the continuous switching of their components. Cyclic load switching, such as that in sawmills and rock crushing plants, can cause flickers in voltage. Overloading distribution feeders can cause low voltage problems at customers' sites. Most electrical equipment and devices tolerate small distortions in the alternating current waveforms. However, when the distortions are large enough to affect equipment or be perceived by the public as annoyances, they are power quality problems. Although the use of modern power electronic converters cause some of the power quality problems due to their switching actions, power electronics can solve a large number of these problems as well.

Electrical power systems deal with generation, transmission and distribution and utilisation of power system in customer premises. The delivery of a reliable power that meets the necessary requirements in terms of power, voltage and frequency and the continuity of supply are the major concerns of quality and efficiency for the consumer as these aspects may affect the lifespan and effective operation of home appliances. The multiplication of complex home electronic appliances, generally termed as non-linear loads, contribute significantly to the generation of harmonics onto the power distribution network that can lead to voltage and current instability. Switching ON or OFF of the same type of devices also produce harmonics and lead to flickers and power fluctuations which are quality related matters.

The main power quality problems are related to voltage and frequency. Voltage problems include voltage flickers, voltage sags, voltage swells, stray voltages, voltage transients, and outages. Frequency problems include harmonic distortions and frequency variations. Electromagnetic interferences, whether from nearby energised circuits or from solar flares, are also considered power quality problems.

The quality of the electricity supplied to customers in a power system remains one of the most important fields of study in the power industry, because low power-quality has the potential to negatively affect the operation and life of electric equipment forming the power grid, for example power transformers and customer's devices. Suppliers and customers have differing views on the level of quality to be achieved as well as the responsibility in power quality deterioration.

This guide provides an overview of power quality from an electromagnetic compatibility perspective and describe important power quality parameters considered and controlled in the power industry. The guide further presents a summary of IEC standards dealing with the power quality issues that is highly beneficial to power service provider to ensure quality in their service delivery. Finally, the guide also presented essential reliability parameters and their method of estimation for power network with substantial examples.

2 Electromagnetic Compatibility

Any electromagnetic phenomenon that may degrade the performance of a device, equipment or system, or adversely affect life or inert matter is considered an electromagnetic disturbance. Equipment and systems performance can be adversely impacted by electromagnetic disturbances and, conversely, any electrotechnical equipment is, itself, a potential source of electromagnetic-disturbance. Disturbances cause undesirable problems, thus, avoiding electromagnetic interference (EMI) is a key objective of electromagnetic compatibility (EMC) engineering. In this sense, it is possible to consider "power quality" as a dedicated subset of electromagnetic compatibility (EMC), limited to the area of low frequency conducted phenomena.

EMC is defined as the ability of an equipment or system to function as intended in its electromagnetic environment without impacting the correct functioning of adjacent equipment. EMC therefore involves the following:

- The need to ensure that the electromagnetic disturbance of a power system does not exceed a level allowing radio and telecommunication and other apparatus to operate as intended;
- The need to ensure that the power system has an adequate level of intrinsic immunity of electromagnetic disturbance, enable it to operate as intended;

Reliable, trouble-free performance is usually equated with a supply of high quality. However, equipment performance has as much to do with its immunity to supply disturbances as it has with the actual characteristics of the supply that it operates on. There is a growing need to ensure electric service compatibility between end-user equipment and the utility power system. It is also the case that supply characteristics will be influenced by the "quality" of the load connected to it.

In the power network, electromagnetic disturbance inevitably occurs and therefore there is some overlapping between emissions and immunity levels. Voltage characteristics may be equal to or higher than the compatibility level. Planning levels may also be equal to or lower than the compatibility level - planning levels are specified by the Utility owner. Immunity test levels are specified by relevant standards or are agreed upon between manufacturers and users.

Table 1 details power quality standards published by standardization organizations such as the International Electrotechnical Commission (IEC) and IEEE.

Standard Number	Standard Title
IEC 62510	Standardising the characteristics of electricity
EN 50160	Voltage characteristics of electricity supplied by public electricity networks
IEC 61000-2-2	Electromagnetic compatibility (EMC). Environment. Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems
IEC. 61000-3-2	Electromagnetic compatibility (EMC). Limits. Limits for harmonic current emissions (equipment input current ≤16 A per phase)
IEC 61000-3-3	Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection
IEC 61000-3-4	Electromagnetic compatibility (EMC). Limits. Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
IEC 61000-3-5	Electromagnetic compatibility (EMC). Limits. Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A
IEC 61000-3-6	Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems
IEC 61000-3-7	Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems
IEC 61000-4-1	Electromagnetic compatibility (EMC). Testing and measurement techniques. Overview of IEC 61000-4 series
IEC 61000-4-2	Electromagnetic compatibility (EMC). Part 4-2: Testing and measurement techniques. Electrostatic discharge immunity test
IEC 61000-4-3	Electromagnetic compatibility (EMC). Testing and measurement techniques. Radiated, radio-frequency, electromagnetic field immunity test
IEC 61000-4-4	Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrical fast transient/burst immunity test. Basic EMC publication
IEC 61000-4-5	Electromagnetic compatibility (EMC). Testing and measurement techniques. Surge immunity test
IEC 61000-4-6	Electromagnetic compatibility (EMC). Part 4-6. Testing and measurement techniques. Immunity to conducted disturbances, induced by radio-frequency fields
IEC 61000-4-7	Electromagnetic compatibility (EMC). General guide on harmonics and inter harmonics measurements and instrumentation, for power supply systems and equipment connected thereto
IEC 61000-4-11	Electromagnetic compatibility (EMC). Testing and measurement techniques. Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase
IEC 61000-4-15	Electromagnetic compatibility (EMC). Testing and measurement techniques. Flickermeter. Functional and design specifications. Basic EMC publication

Standard Number	Standard Title
IEC 61000-4-30	Electromagnetic compatibility (EMC). Testing and measurement techniques. Power quality measurement methods
IEEE-Std-120	Master Test Guide for Electrical Measurements in Power Circuits
IEEE-Std-141	Recommended practice for electric power distribution for industrial plants with effect of voltage disturbances on equipment within an industrial area
IEEE-Std-142	Recommended practice for grounding of industrial and commercial power systems
IEEE-Std-213	Standard procedure for measurement of conducted emissions in the range of 300 kHz–25MHz from television and FM broadcast receivers to power lines
IEEE-Std-241	Recommended practice for electric power systems in commercial buildings
IEEE-Std-449	Standard for ferro resonance voltage regulators
IEEE-Std-465	Test specifications for surge protective devices
IEEE-Sd-519	Recommended practice for harmonic control and reactive compensation of static power converter
IEEE-Std-859	Standard terms for reporting and analysing outage occurrences and outage states of electrical transmission facilities
IEEE-Std-1159	Recommended practice on monitoring electric power quality. Categories of power system electromagnetic phenomena
IEEE-Std-1250	Guides for service to equipment sensitive to momentary voltage disturbances
IEEE-Std-1346	Recommended practice for evaluating electric power system compatibility with electronics process equipment
IEEE-Std-1453	Recommended Practice for the Analysis of Fluctuating Installations on Power Systems

Table 1: Power Quality Standards

3 Sources of Power Quality Deterioration

The term "power quality" refers to the maintenance of a near sinusoidal waveform of the power distribution voltages and currents at rated frequency and magnitude. In EMC, the term refers to a wide variety of electromagnetic phenomena that characterize voltage and current at a given time and location on the power system. IEC 61000-2-5 [9], classifies electromagnetic phenomena into several groups as shown in Table 2.

Harmonics, Inter harmonics	**Conducted low-frequency phenomena**
Signal systems (power line carrier)	
Voltage fluctuations	
Voltage dips and interruptions	
Voltage unbalance	
Power-frequency variations	
Induced low-frequency voltages	
DC in ac networks	
Magnetic fields	**Radiated low-frequency phenomena**
Electric fields	
Induced continuous wave voltages	**Conducted high-frequency phenomena**
Unidirectional transients	
Oscillatory transients	
Magnetic fields	**Radiated high-frequency phenomena**
Electric fields	
Electromagnetic fields	
Continuous waves	
Transients	
Electrostatic discharge	**Electrostatic discharge**
Nuclear electromagnetic pulse	**Nuclear electromagnetic pulse**

Table 2: Principal phenomena causing electromagnetic disturbances

Power quality relates to conducted phenomena and can be divided into three broad categories, namely:

1. Disturbance
2. Steady-state phenomena (long duration disturbances)
3. Continuity (interruptions)

It should be noted that steady-state phenomena are referenced in the stochastic sense, i.e., provides information on the normal operation of the system.

The sources of poor power quality can be categorized in two groups: (1) actual loads, equipment and components and (2) subsystems of transmission and distribution systems. Poor quality is normally caused by power line disturbances such as impulses, notches, voltage sag and swell, voltage and current unbalances, momentary interruption and harmonic distortions. The IEC (and the IEEE) classification of power quality includes loss-of-balance as a source of disturbance. The other major contributors to poor power quality are harmonics and reactive power. Solid state control of AC power using high speed switches are the main source of harmonics whereas different non-linear loads contribute to excessive drawl of reactive power from supply. It leads to catastrophic consequences such as long production downtimes, mal-function of devices and shortened equipment life.

While power-supply reliability, service quality and supply quality issues are generally discussed under the theme of power quality. It is usually sufficient to distinguish between: "voltage quality" and "continuity of supply".

Voltage quality, otherwise known as "power quality", PQ, is concerned with the technical characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters [26]. In this term, the deviations of the voltage (or the current) from the ideal are analyzed, considering electricity as a single frequency sine wave of constant amplitude and frequency. Continuity of supply is concerned with the probability of satisfactory operation of a power system over the long term. It denotes the ability to supply adequate electrical service on a nearly continuous basis, with few interruptions over an extended period of time. It is covered by reliability indices; the three most common are referred to as SAIFI, SAIDI, and CAIDI, defined in [39].

Low power-quality has an impact on the economic and industrialization growth of AFSEC Member States. While Engineers tend to view a power network technically through planning analysis and operation, the consumer is more concerned with power quality, safety and continuity of supply. This AFSEC guide therefore provides guidance on the how to ensure a reliable power quality for both consumers and service providers within Member States.

4 Power Quality

Power quality describes the variation of voltage, current and frequency in a power system. The fundamental concept of power quality is to identify the parameters and their degree of variation with respect to their rated magnitude which are the base reason for degradation of quality of electric power. Sources of power quality concerns are the regions or locations or events which have the potential to cause the unwanted variation of those parameters. The effects of poor quality of power are the effects faced by the system and consumer equipment after the occurrence of different disturbances. Through modeling and analysis, attempts are taken to configure the disturbance, its occurrence, sources and effect; mainly based on the mathematical background. For monitoring of power quality, constant measurement and instrumentation of the electric parameters are necessary. Complete solution, i.e. delivery of pure power to the consumer side is practically impossible. The target is to minimise the probability of occurrence of disturbances and to reduce the effects of power quality problems.

4.1 Classification of Power Quality

Power quality problems occur due to various types of electrical disturbances. Most of the disturbances depend on amplitude or frequency or on both frequency and amplitude. Based on the duration of existence of power quality disturbances, events can be divided into short, medium or long type. There are different classifications for power quality issues, each using a specific property to categorize the problem. Some of them classify the events as "steady-state" and "non-steady-state" phenomena. In some regulations (e.g., ANSI C84.1 [41]) the most important factor is the duration of the event. Other guidelines (e.g., IEEE-Std-519 [34]) use the wave shape (duration and magnitude) of each event to classify power quality problems. Other standards (e.g., IEC) use the frequency range of the event for the classification.

For example, IEC 61000-2-5 [9] uses the frequency range and divides the problems into three main categories: low frequency (< 9 kHz), high frequency (> 9 kHz), and electrostatic discharge phenomena. In addition, each frequency range is divided into "radiated" and "conducted" disturbances. Table 2 shows the principal phenomena causing electromagnetic disturbances according to IEC classifications . All these phenomena are considered to be power quality issues; however, the two conducted categories are more frequently addressed by the industry.

The magnitude and duration of events can be used to classify power quality events, as shown in Figure 1. In the magnitude–duration plot, there are nine different parts [5]. Various standards give different names to events in these parts. The voltage magnitude is split into three regions:

- Interruption: voltage magnitude is zero
- Undervoltage: voltage magnitude is below its nominal value
- Overvoltage: voltage magnitude is above its nominal value

	Duration of event				
Magnitude of event	Very short overvoltage	short overvoltage	long overvoltage	Very long overvoltage	110%
		Normal operation voltage			90%
	Very short undervoltage	short undervoltage	long undervoltage	Very long undervoltage	
		1-3 cycles	1-3 min	1-3 hours	

Figure 1: Classification of power quality events in a magnitude-duration plot

The duration of these events is split into four regions: very short, short, long, and very long. With the above in mind, a brief description of the disturbances causing power quality degradation arising in a power system is presented below:

- Interruption: these are very common type of disturbances. During power interruption, voltage level of a particular bus goes down to zero. The interruption may occur for short or medium or long period. Interruption occurs when the supply voltage (or load current) decreases to less than 0.1 pu for less than 1 minute, as shown by Figure 2. Some causes of interruption are equipment failures, control malfunction, and blown fuse or breaker opening. The difference between long (or sustained) interruption and interruption is that in the former the supply is restored manually, but during the latter the supply is restored automatically. Interruption is usually measured by its duration. For example, according to the European standard EN-50160 [7]:

  – A short interruption is up to 3 minutes; and

  – A long interruption is longer than 3 minutes.

However, based on the standard IEEE-1250 [37]:

  – An instantaneous interruption is between 0.5 and 30 cycles;

  – A momentary interruption is between 30 cycles and 2 seconds;

  – A temporary interruption is between 2 seconds and 2 minutes; and

  – A sustained interruption is longer than 2 minutes.

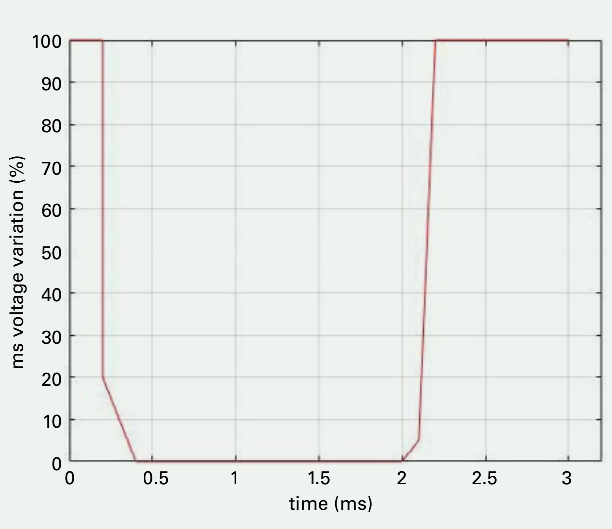

Figure 2: Momentary interruption due to a fault

- Sustained Interruption: Sustained (or long) interruption is the most severe and the oldest power quality event at which voltage drops to zero and does not return automatically. According to the IEC definition, the duration of sustained interruption is more than 3 minutes; compared to 1 minute duration definition given in IEEE. The number and duration of long interruptions are very important characteristics in measuring the ability of a power system to deliver service to customers. The most important causes of sustained interruptions are:

  – fault occurrence in a part of power systems with no redundancy or with the redundant part out of operation,

  – an incorrect intervention of a protective relay leading to a component outage, or

  – scheduled (or planned) interruption in a low-voltage network with no redundancy.

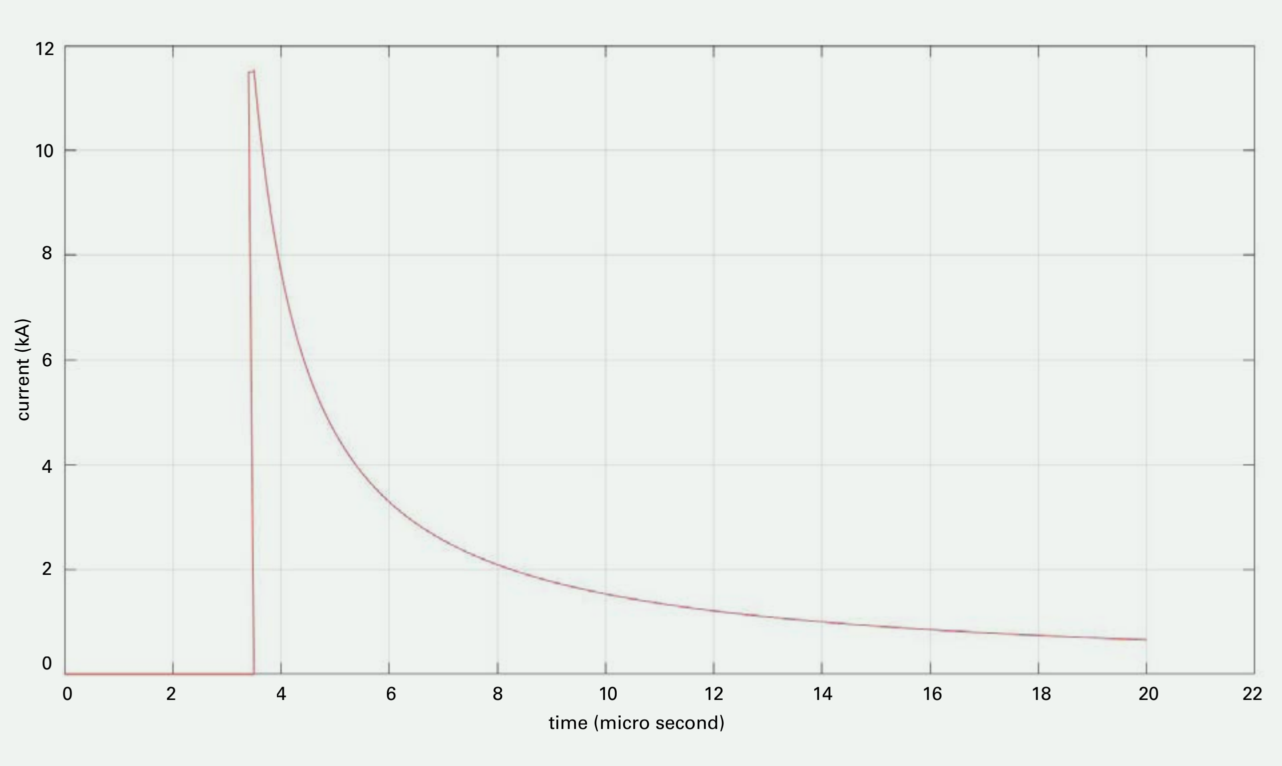

Figure 3: Impulsive transients current caused by lightning strike

- Under Voltage/Over Voltage: Under voltage and over voltage are fall and rise of voltage levels of a particular bus with respect to standard bus voltage. Sometimes under and over voltages of little percentage is allowable; but when they cross the limit of desired voltage level, they are treated as disturbances. Such disturbances increase the amount of reactive power drawn or delivered by a system, insulation problems and voltage stability. The undervoltage condition occurs when the rms voltage decreases to 0.8–0.9 pu for more than 1 minute; where Overvoltage is defined as an increase in the rms voltage to 1.1–1.2 pu for more than 1 minute. There are three types of over voltages:

  – Over voltages generated by an insulation fault, Ferro resonance, faults with the alternator regulator, tap changer transformer, or overcompensation;

  – Lightning overvoltages; and

  – Switching over voltages produced by rapid modifications in the network structure such as opening of protective devices or the switching on of capacitive circuits.

- Transients: Power system transients are undesirable, fast- and short-duration events that produce distortions. Their characteristics and waveforms depend on the mechanism of generation and the network parameters (e.g., resistance, inductance, and capacitance) at the point of interest. "Surge" is often considered synonymous with transient. Transients can be classified with their many characteristic components such as amplitude, duration, rise time, frequency of ringing polarity, energy delivery capability, amplitude spectral density, and frequency of occurrence.

  Transients are usually classified into two categories: impulsive and oscillatory. An impulsive transient is a sudden frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity (Figure 3). The most common cause of impulsive transients is a lightning current surge. Impulsive transients can excite the natural frequency of the system. An oscillatory transient is a sudden frequency change in the steady-state condition of voltage, current, or both that includes both positive and negative polarity values. Oscillatory transients occur for different reasons in power systems such as appliance switching, capacitor bank switching, fast-acting overcurrent protective devices, and Ferro resonance.

- Voltage/Current Unbalance: voltage and current unbalance may occur due to the unbalance in drop in the generating system or transmission system and unbalanced loading. During unbalance, negative sequence components appear. This hampers system performance and in some cases, it may hamper voltage stability.

- Harmonics: Harmonics are the alternating components having frequencies other than the fundamental present in the voltage or current signals. Harmonics have adverse effects on the generation, transmission and distribution system as well as on consumer equipment. With a fundamental of 50 Hz (or 60 Hz), harmonics re of frequencies 50n Hz (where n is an integer). Fourier series informs that any practical periodical signal; can be expanded into a linear combination of multiple sinusoidal and dc components. The relative amplitudes and phases of harmonics determines the shape of periodic signals. To evaluate the sinusoidal degree of signals, the Total Harmonics Distortion (THD) is used. THD is defined as the ratio of the root-sum-square of harmonics and fundamental component. Harmonics are classified as integer harmonics, subharmonics and inter harmonics. Integer and inter harmonics are the most common in power system. Harmonics are also classified in terms of time and space.

  – Integer harmonics: integer harmonics have frequencies which are multiple of the fundamental frequency.

  – Subharmonics: Subharmonics have frequencies below the fundamental frequency. There are rarely sub- harmonics in power systems. However, due to the fast control of electronic power sup- plies of computers, inter- and subharmonics are generated in the input current [42]. Resonance between the harmonic currents or voltages with the power system (series) capacitance and inductance may cause subharmonics, called sub-synchronous resonance [43]. They may be generated when a system is highly inductive (such as an arc furnace during start-up) or when the power system contains large capacitor banks for power factor correction or filtering.

  – Inter-harmonics: The frequency of inter-harmonics are not integer multiples of the fundamental frequency. Inter-harmonics appear as discrete frequencies or as a band spectrum. Main sources of inter-harmonic waveforms are static frequency converters, cyclo-converters, induction motors, arcing devices, and computers. Inter-harmonics cause flicker, low-frequency torques, additional temperature rise in induction machines, and malfunctioning of protective (under-frequency) relays. Inter-harmonics is addressed in a number of international standards such as the IEC 61000-4-7 [23] and the IEEE-519 [34].

- Voltage Sag: Sags, also known as dips, are a short duration reduction in the rms voltage between 0-1 and 0.9 pu. Voltage sags are caused by:

  – Energisation of heavy loads

  – Starting of large induction motors

  – Single line to ground cults; and

  – Load transferring from one power source to another

Sags are main reasons for malfunctions of electrical low-voltage devices. Uninterruptible power supply (UPS) or power conditioners are mostly used to prevent voltage sags.

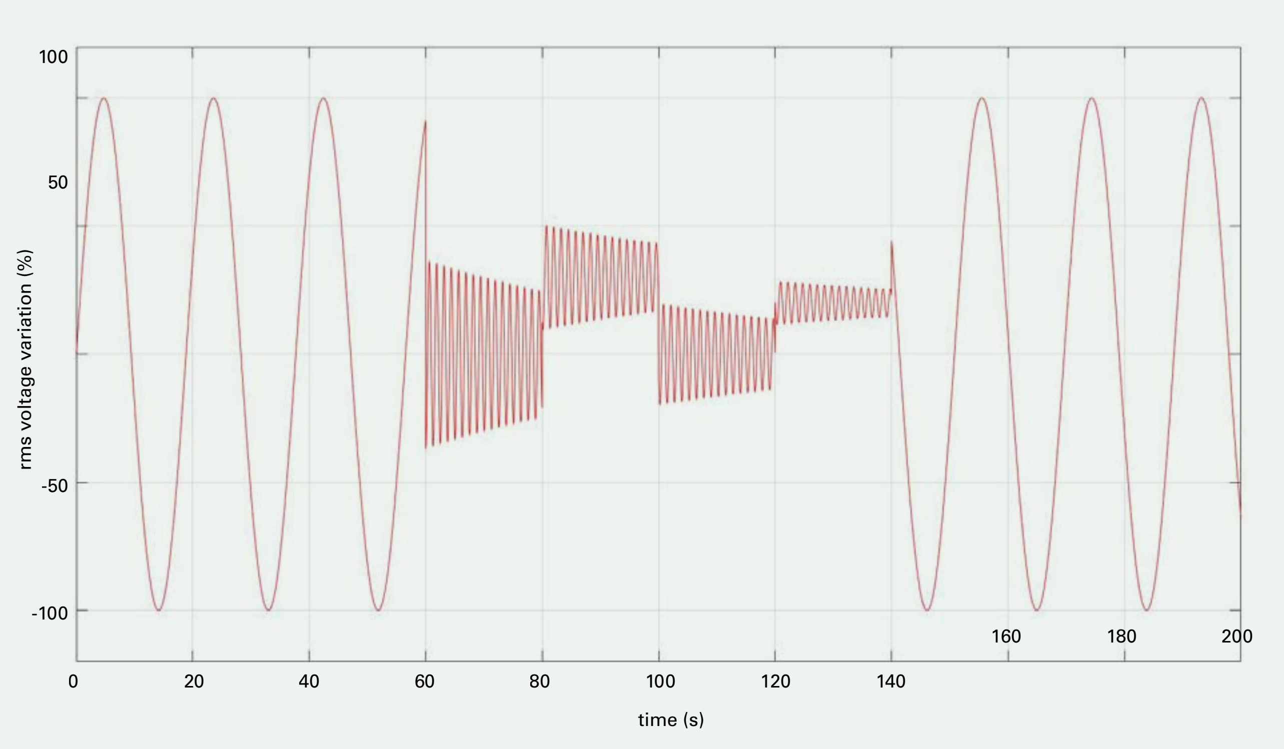

Figure 4: Voltage sag caused by a single line-to-ground fault

- Notching: Notching is a periodic voltage disturbance caused by the normal operation of power electronics devices when current is commutated from one phase to another. Voltage notching represents a special case that falls between transients and harmonic distortion. Since notching occurs continuously (steady state), it can be characterized through the harmonic spectrum of the affected voltage.

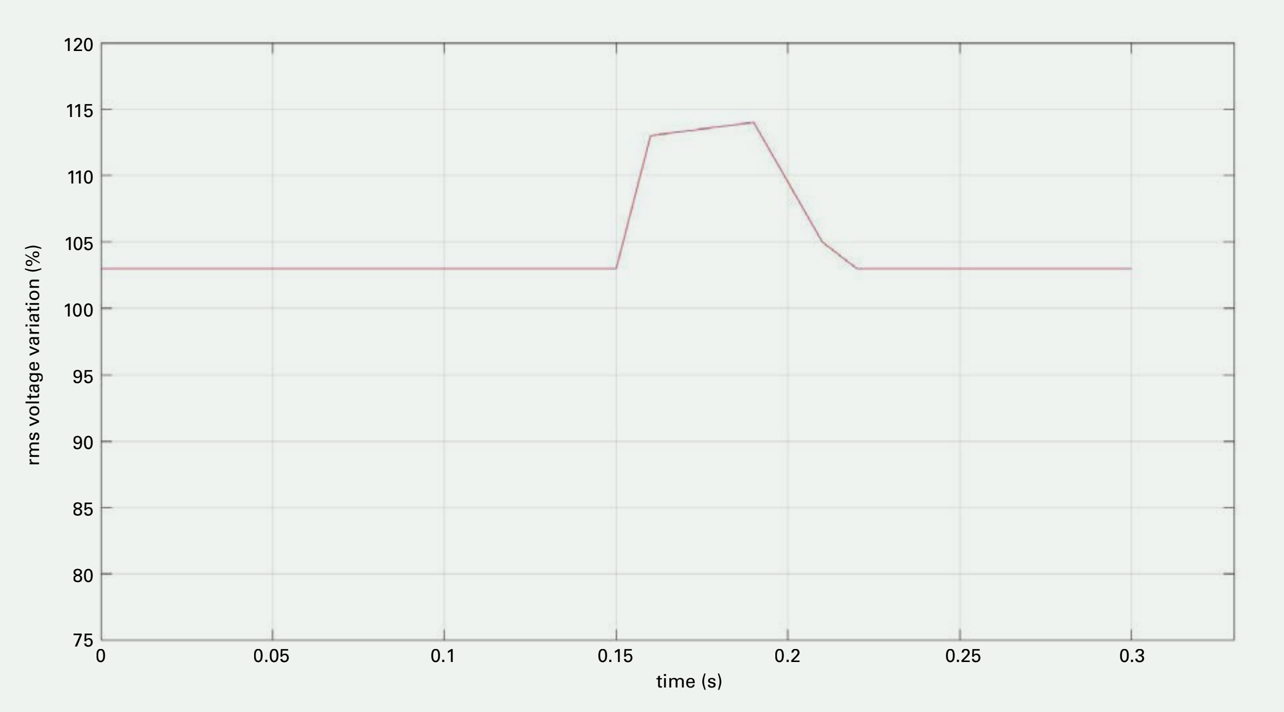

Figure 5: Examples of voltage notching

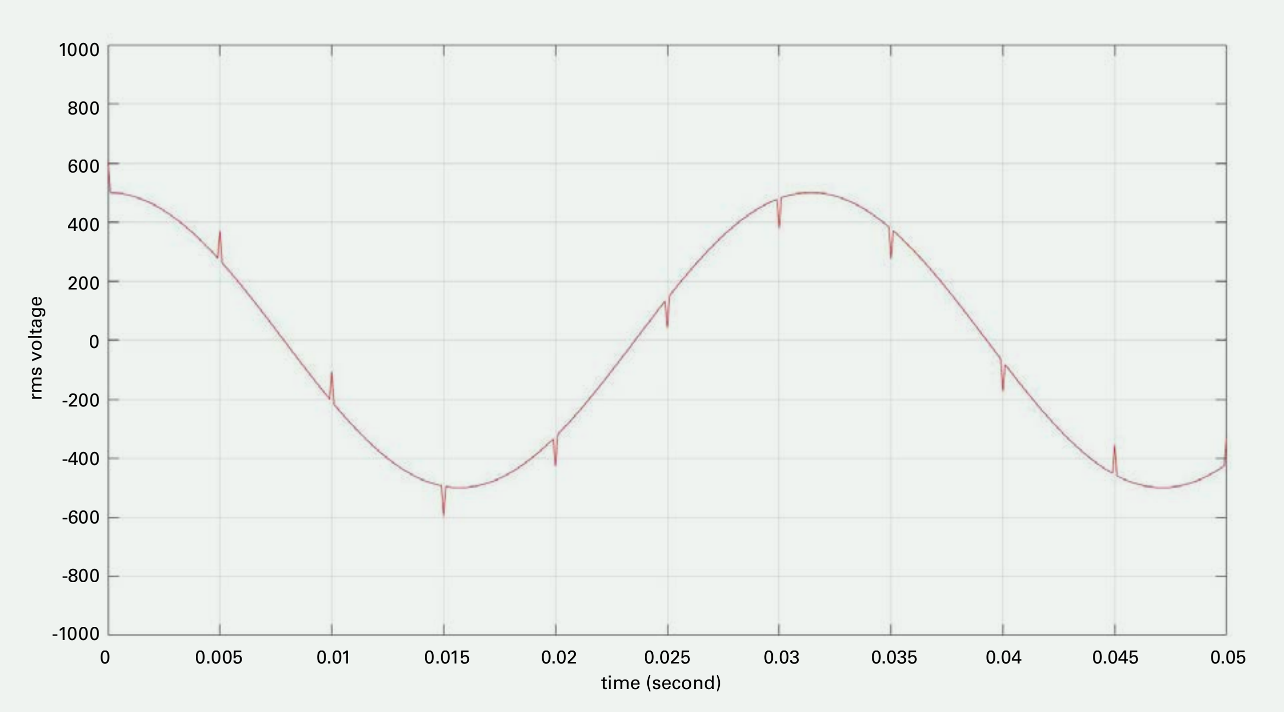

Figure 6: Instantaneous voltage swell caused by a single lime-to-ground fault.

- Voltage Swells: Swells are short duration increase in the rms voltage between 1.1 and 1.8 pu. Swell are caused by:
  - Switching off a large load;
  - Energizing a capacitor bank; or
  - Voltage increase of the unfaulted phases during a single line to ground fault.

- Voltage Fluctuation: Voltage fluctuations are systemic variations of the voltage envelop or random voltage changes, the magnitude of which does not normally exceed specified voltage ranges:
  - Step-voltage changes, regular or irregular in time; and
  - Cyclic or random voltage changes produced by variations in the load impedances.

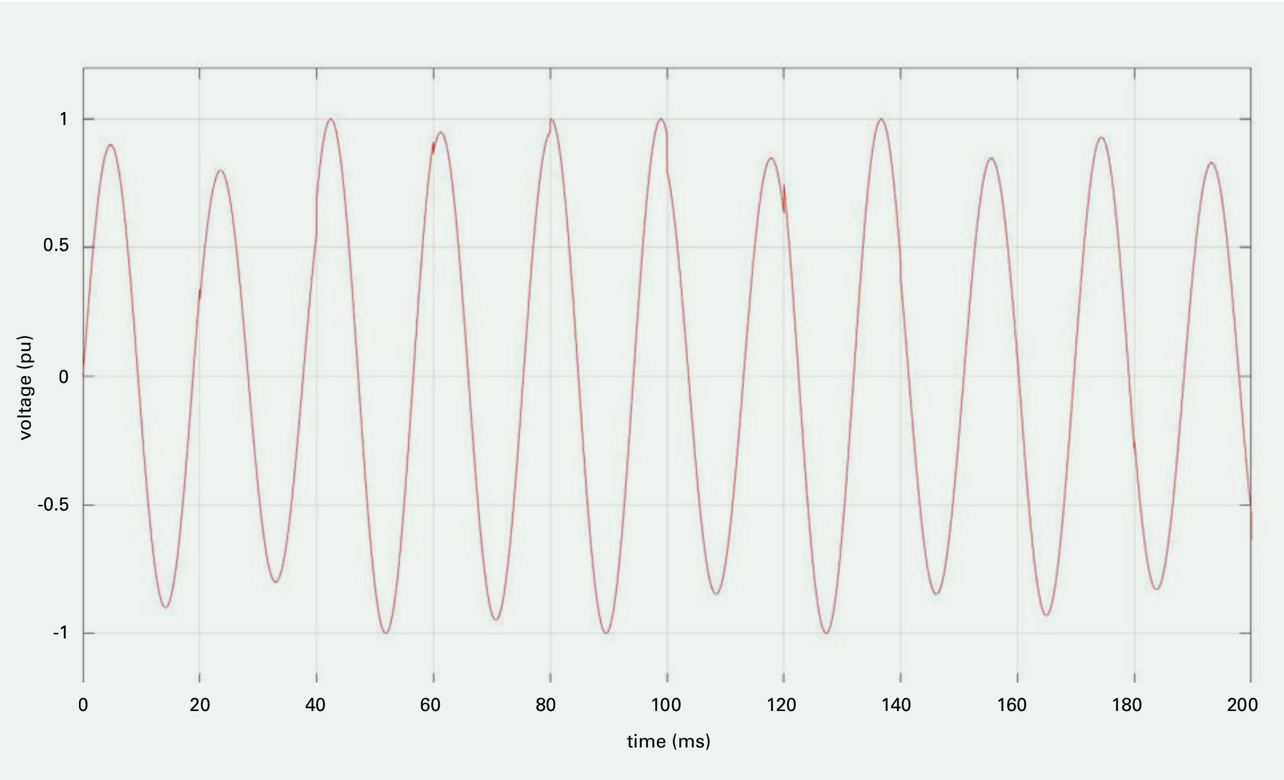

Figure 7: Voltage flicker caused by arc furnace operation

Voltage fluctuations degrades he performance of the equipment and causes instability of the internal voltages and currents of electronics equipment. Voltage fluctuations off less that 10%, however, do not affect electronics equipment. The main uses of voltage fluctuations are pulsed-power output, resistance welders, start-up of drivers, arc furnaces, drivers with rapidly changing loads, and rolling mills.

- Flicker: the term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived to flicker by thee human. eye. This may be caused by an arc furnace, one of the most common causes of voltage fluctuations in utility transmissions and distribution systems.

- Power frequency Variations: The deviation of the power system fundamental frequency from its specified nominal value its defined as power frequency variation. If the balance between the generation and demand (load) is not maintained, the frequency of the power system will deviate because of changes in the rotational speed of electromechanical generators. The amount of deviation and its duration of frequency depends on the load characteristics and response of the generation control system to load changes. Faults of the power transmission system can also use frequency variations outside of the accepted range for normal steady-state operations off the power system.

5 Reliability Indices

Power outages disrupt more business than any other factor. Reliability in general is a possibility a system will be able to function as intended for a certain period of time. Distribution reliability can be expressed as how often the system experienced a blackout, how long the outage occurred and how much time is required to recover from the outage occurred. The system with a high reliability will be capable of providing electrical power required at any time, while the system with a low reliability will lead to frequent outage. Reliability statistics, based on long-duration interruptions, are the primary benchmark used by utilities and regulators to identify service quality. Faults on the distribution system cause most long-duration interruptions; a fuse, breaker, reclose, or sectionalized locks out the faulted section.

Many utilities use reliability indices to track the performance of the utility or a region or a circuit. Regulators require most investor-owned utilities to report their reliability indices. The regulatory trend is moving to performance-based rates where performance is penalised or rewarded based on quantification by reliability indices. Some utilities also pay bonuses to managers or others based in part on indices. Some commercial and industrial customers ask utilities for their reliability indices when locating a facility.

Reliability indices, also called quality indices, measures the performance of a power systems. Poor reliability on the part of the electrical utility is penalized based on quantification by reliability indices. Some utilities also pay bonuses to utility personnel, based on outstanding performance. Commercial and industrial customers inquire about reliability indices when locating a new facility. Most regulatory bodies have established targets for reliability indices. If utilities do not fulfil them (have figures higher than those defined), they can be penalized. The most important indices to measure the reliability performance are the following:

5.1 System Average Interruption Frequency index (SAIFI)

SAIFI is defined as the average number of times that a customer is interrupted during a specific time period, which also is a year. It is calculated by dividing the total number of customers interrupted in that time period by the average number of customers served. (This means outages per customer, not the number of interruptions.)

The resulting unit is "interruptions per customer". Typically, a utility's customers average between one and two sustained interruptions per year. SAIFI is also the average failure rate, which is often labelled λ. Another useful measure is the mean time between failure (MTBF), which is the reciprocal of the failure rate: MTBF in years = 1/λ. Also useful with SAIFI is customer interruptions (CI), the part that adds to the numerator of SAIFI.

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} \qquad (1)$$

5.2 System Average Interruption Duration Index (SAIDI)

SAIDI is defined as the average interruption duration for customers served specific time period, which normally is a year. It is calculated by summing the customer minutes off for each interruption during a specified time period and dividing the sum by the average number of customers served during the period. The unit is minutes.

SAIDI quantifies the average total duration of interruptions. SAIDI is cited in units of hours or minutes per year. Also useful with SAIDI is customer-minutes of interruption (CMI), the part that adds to the numerator of SAIDI. The index enables the utility to report the time (normally in minutes) customers would have been out of service if all customers were out at one time.

$$SAIDI = \frac{Sum\ of\ all\ customer\ interruptions\ durations}{Total\ numbet\ of\ customer\ served} \qquad (2)$$

5.3 Customer Average Interruptions Duration Index

CAIDI is the "apparent" repair time (from the customers' perspective). It is generally much shorter than the actual repair time because utilities normally sectionalize circuits to reenergise as many customers as possible before crews fix the actual damage.

CAIDI is the ratio of the SAIDI over the SAIFI and is defined with the following expression:

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{Sum\ opf\ all\ customer\ interruption\ durations}{Total\ number\ of\ customer\ interruptions} \qquad (3)$$

5.4 International Category Index and Values

A summary of reliability index for SAIFI and SAIDI are shown in Table 3.

A review of the reliability index for SAIFI and SAIDI in place in some European Countries is shown in Table 4.

Country	SAIFI	SAIDI
Austria	0.9	72
Denmark	0.5	24
France	1.0	62
Germany	0.5	23
Italy	2.2	58
Netherlands	0.3	33
Spain	2.2	104
United Kingdom	0.8	90

Table 4: Reliability indices for some European Countries for 2013/2014 [48]

	SAIFI			SAIDI		
	25%	50%	75%	25%	50%	75%
IEEE Distribution Reliability Working Group [44]						
No MEDs, 2.5	0.96	1.16	1.55	1.76	2.38	2.85
Distribution only, No MEDs	0.83	1.05	1.35	1.57	2.12	2.65
All events	1.33	1.64	2.20	3.37	5.17	10.33
NRECA 2001, no MEDs	0.90	1.29	1.88	1.30	2.07	3.17
EEI [45]						
Excludes storms	0.92	1.32	1.71	1.16	1.74	2.23
With storms	1.11	1.33	2.15	1.36	3.00	4.38
CEA (with storms) [46]	1.093	1.95	3.16	0.73	2.26	3.28
IP&L Large City Comparison [47] (Indianapolis Power & Light, 2000)	0.72	0.95	1.15	1.02	1.64	2.41

Table 3: Standard Reliability Indices

6 Summary

Power Quality is an important topic in power systems that often do not get proper attention due to operational pressures, i.e. ensuring all customers have power is more important than ensuring good power quality. Power quality phenomena is divided into categories depending on the duration of the deviation as well as the type of impact on end customers. These categories are:

- Disturbances (events);
- Steady-state phenomena (long-duration disturbances); and
- Continuity (interruptions).

It is to be noted that SAIFI and SAIDI are weighted performance indices. They stress the performance of the worst-performing circuits and the performance during adverse weather conditions. SAIFI and SAIDI are not necessarily good indicators of the typical performance that customers have. Reliability-based incentives and penalties directly affect a distribution business, so understanding the variability in year-to-year reliability indices is essential for man- aging the financial risk for a distribution utility.

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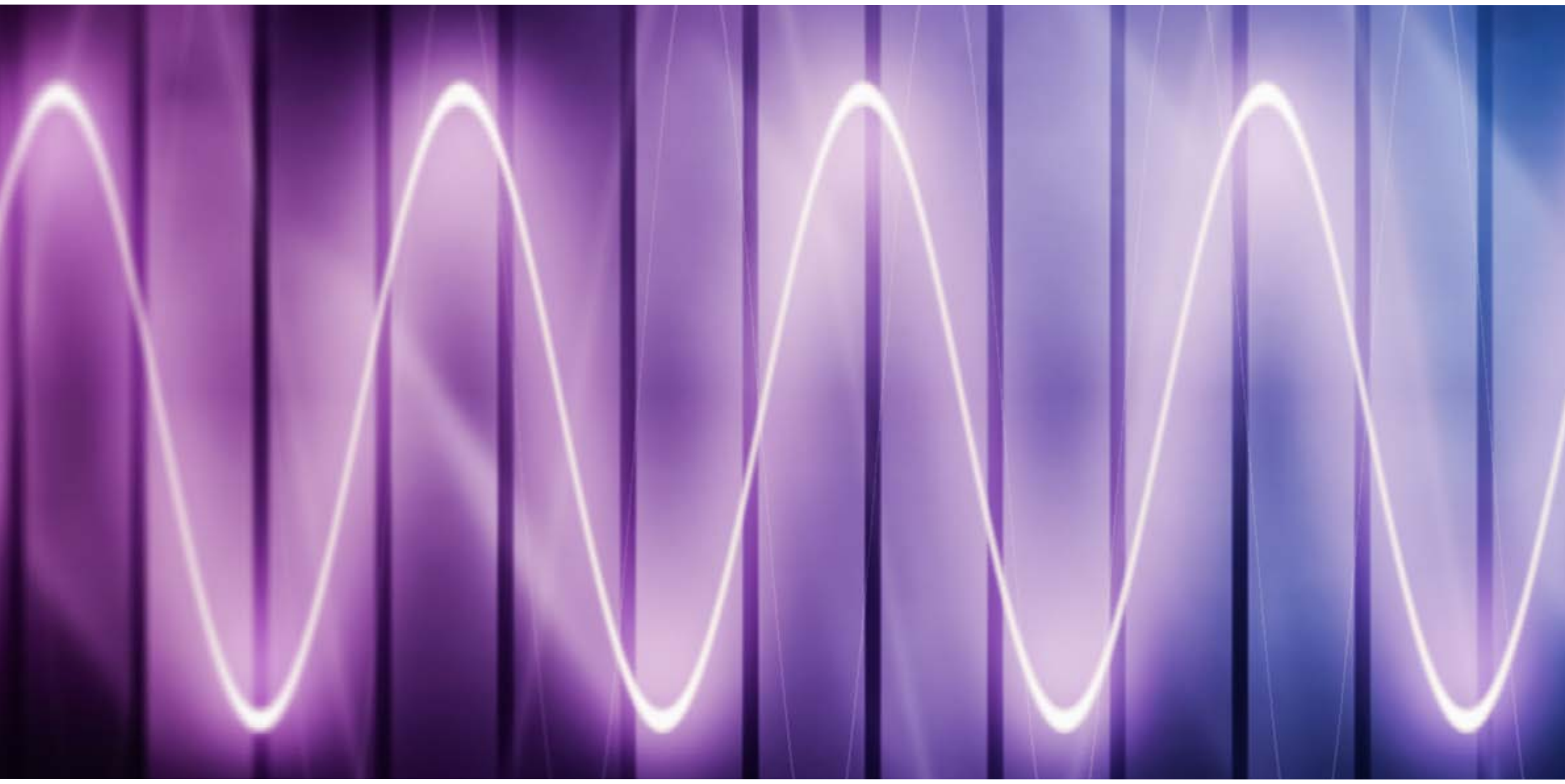

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