A general review of power quality standards and terminologies

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Abstract

In the next few years, more than 80% of AC power is to be processed through power converters owing to their benefits of energy conservation, flexibility, network interconnection, and weight and volume reduction in a number of equipment such as lighting arrestors, HVAC computers, fans, and so on.This paper gives an introduction on power quality (PQ), causes and effects of power quality problems. It also deals with power quality definitions, terminologies, standards, bench-marks, monitoring requirements, financial loss, and analytical quantification. It also discusses various types of nonlinear loads, which cause these power quality problems, they are illustrated, classified, modeled, quantified, and analyzed forassociated power quality issues.

Keywords: AC Power, convertors, power quality definitions terminologies standards benchmarks, power quality problems,nonlinear loads.

1.Introduction

Power quality has become an important subject and area of research thanks to its increasing awareness and impacts on the consumers, manufacturers, and utilities. Many technical institutions, industries, and R&D organizations are offering regular and short-term courses on power quality. There are a spread of power quality problems within the present-day fast-changing electrical systems. The most causes of those problems are often classified into natural and man-made causes. Natural causes end in problems that are generally transient in nature, like voltage distortion, swell, and impulsive and oscillatory transients. The facility quality problems affect all concerned utilities, customers, and makers directly or indirectly. These problems affect the monitoring systems in much critical, emergency, vital, and dear equipment. Harmonic currents increase losses during a number of electrical equipment and distribution systems

1.1 An introduction on power quality (PQ)

1.1.1 Introduction

Electric power quality (PQ) is generally used to assess and to maintain the good quality of power at the level of generation, transmission, distribution, and utilization of AC electrical power.

Power quality is quantified in terms of voltage, current, or frequency deviation of the supply system. These power quality problems cause failure of capacitor banks, increased losses in the distribution system and electric machines, noise, vibrations, over-voltages and excessive current. The problems have become much more serious with the use of solid-state controllers.

Power quality has become an important area of study in electrical engineering. It has created a great challenge to both electric utilities and electrical distribution entities.A number of techniques have evolved for the mitigation of these problems either in existing systems or in equipment to be developed in the near future. It has resulted in a new direction of research and development (R&D) activities for the design and development engineers.

Power quality improvement techniques used in newly designed and developed systems are based on the modification of the input stage of these systems. In existing nonlinear loads, a series of power filters are used externally to mitigate power quality problems. This paper is aimed at providing an awareness of the power quality problems, their causes and adverse effects.

1.1.2 Awarenss among customers

The power quality problems have been present since the inception of electric power. However, recently the awareness of the customers toward the power quality problems has increased tremendously because of the following reasons:

•The customer's equipment have become more sensitive to power quality problems

•Solid-state controllers have increased harmonic levels, distor- tion, notches, and other power quality problems. Typical examples are ASDs and electronic ballasts, which have substantial energy savings.

•The awareness of power quality problems has increased in the customers.

•The disturbances to other important appliances such as telecom communication network, TVs,

•The deregulation of the power systems has increased the importance of power quality.

•Distributed generation using renewable energy has increased power quality problems as it needs.

•Power network contamination and power quality concerns has become an environmental concern with other implications in addition to financial concerns, similar to other types of emissions such as air pollution.

•As the law and discipline of the country, several rules and protocols are developed and implemented on consumers, producers, and utilities

1.1.3 Power Quality:Classification

In today's fast-changing electrical grids, there are a host of power quality issues. This may be categorised based on transient and steady- state occurrences and quantities like current, voltage, and frequency, or load and supply networks.

• Many transient events (e.g., impulsive or oscillatory in nature) are included in the transient forms of power quality issues, such as sag (dip), swell, short-duration voltage changes, power frequency variations, and voltage fluctuations.

•Long-duration voltage anomalies, waveform distortions, unbalanced voltages, notches, DC offset, flicker, low control factor, unbalanced load currents, load harmonic currents, and exces- sive neutral current are all examples of steady-state power quality issues.

•Voltage distortions, flicker, notches, noise, sag, swell, unbalance, undervoltage, and overvoltage are all examples of voltage distortions.

•Reactive power portion of current, harmonic currents, unbalanced currents, and excessive neutral current are all examples of current problems.

•Load current with harmonics, reactive power portion of cur- rent, unbalanced currents, neutral current, DC offset, and other power quality issues are caused by the design of the load.

•Voltage and frequency-related issues such as notches, voltage imbalance, unbalance, sag, swell, flicker, and noise are all caused by supply system issues. These may also include a mix of voltage and current-based power quality issues in the device.

•Hertz variations above or below the target base value are fre- quency-related power quality issues. These have an effect on the efficiency of a variety of loads and other devices in the delivery system, such as transformers.

1.1.4 Problems with Power Quality: What Causes Them?

In today's fast-changing electrical grids, there are a host of power quality issues. In terms of current, voltage, frequency, and soon, the key causes of these power quality issues can be categorised as normal and man-made. Faults, lightning, atmospheric hazards such as storms, system loss, and storms are the most common natural causes of low power efficiency. The man-made triggers, on the other hand, are often attributable to loads or machine operations. Nonlinear loads, such as saturating transformers and other electrical devices, as well as loads of solid-state controls, such as vapour lamp-based lighting systems, ASDs, UPSs, arc furnaces, computing power supplies, and televisions, are among the sources.

Switching of transformers, capacitors, feeders, and heavy loads are the sources of power quality issues related to system operations. Normal causes cause power quality issues like voltage sag (dip), voltage distortion, swell, and impulsive and oscillatory transients, which are all transient in nature. Man-made triggers, on the other hand, result in both intermittent and steady-state power efficiency issues. Any of the power quality issues and their causes are mentioned in Table 1.1.4(a). However, one of the more serious power quality issues is the pres- ence of harmonics, which can be caused by a variety of nonlinear loads, like transformers, electrical machines, and furnaces, as well as newer ones including power converters in vapour lamps, switched- mode power supplies (SMPS), ASDs using AC-DC converters, cyclo-converters, and AC voltage controllers.

Table 1.1.4(a) Power quality issues and causes.

Power quality problems: causes and effects

Problems	Category	Categorization	Causes	Effects
Transients	Impulsive	Peak, rise time, and duration	Lightning strikes, transformer energization, capacitor switching	Power system resonance
	Oscillatory	Peak magnitude and frequency components	Line, capacitor, or load switching	System resonance
Short-duration voltage variation	Sag	Magnitude, duration	Motor starting, single line to ground faults	Protection malfunction, loss of production
	Swell	Magnitude, duration	Capacitor switching, large load switching, faults	Protection malfunction, stress on computers and home appliances
	Interruption	Duration	Temporary faults	Loss of production, malfunction of fire alarms
Long-duration voltage variation	Sustained interruption	Duration	Faults	Loss of production
	Undervoltage	Magnitude, duration	Switching on loads, capacitor de-energization	Increased losses, heating
	Overvoltage	Magnitude, duration	Switching off loads, capacitor energization	Damage to household appliances
Voltage imbalance		Symmetrical components	Single-phase load, single-phasing	Heating of motors
Waveform distortion	DC offset	Volts, amperes	Geomagnetic disturbance, rectification	Saturation in transformers
	Harmonics	THD, harmonic spectrum	ASDs, nonlinear loads	Increased losses, poor power factor
	Interharmonics	THD, harmonic spectrum	ASDs, nonlinear loads	Acoustic noise in power equipment
	Notching	THD, harmonic spectrum	Power electronic converters	Damage to capacitive components
	Noise	THD, harmonic spectrum	Arc furnaces, arc lamps, power converters	Capacitor overloading, disturbances to appliances
Voltage flicker		Frequency of occurrence, modulating frequency	Arc furnaces, arc lamps	Human health, irritation, headache, migraine
Voltage fluctuations		Intermittent	Load changes	Protection malfunction, light intensity changes
Power frequency variations			Faults, disturbances in isolated customer-owned systems and islanding operations	Damage to generator and turbine shafts

1.1.5 Users' Reactions to Issues with Power Quality.

All of the affected utilities, consumers, and suppliers suffer direct or indirect financial losses as a result of process interruptions, equipment destruction, manufacturing losses, raw material waste, and the loss of critical records, among other things. There are many instances and implementations, such as automated production systems, such as semi- conductor processing, pharmaceutical manufacturing, and banking, where even a minor voltage dip/sag triggers process delay for several hours, raw material waste, and so on.

Any power quality issues wreak havoc on security schemes, causing safety equipment to malfunction. Many activities and procedures of factories and other establishments are disrupted by these. Many types of measurement instruments and metering of different quantities such as voltage, current, electricity, and energy are also affected. Further- more, these issues have an effect on the monitoring systems in a wide range of sensitive, essential, emergency, crucial, and expensive equipment.

Harmonic currents cause energy waste, inadequate use of utility properties such as transformers and feeders, overloading of power capacitors, noise and vibrations in electrical devices, and disruption and interruption to electronics appliances and communication net- works by increasing losses in a variety of electrical equipment and distribution systems.

1.2 Standards and Monitoring of Power Quality

1.2.1 Introduction

There has been exponentially growing interest in power quality (PQ) in the past quarter century. Some of the main reasons for this have been enhanced sensitivity of equipment and increased cost of electricity globally.Power quality problems affect the customers in a number of ways such as economic penalty in terms of power loss, equipment failure, mal-operation, interruption in the process, and loss of pro- duction. Many industries are developing instruments, recorders, and analyzers to measure power quality.

This section deals with the state of the art on power quality standards and monitoring.

1.2.2 Power Quality Standards and Monitoring: A modern take

From the beginning of electric power, there have been challenges and concerns with power efficiency. The language of power efficiency, on the other hand, does not date back to the early days and has been known by a variety of other terms. Power efficiency has been a very familiar terminology and well understood over the last few decades. Similarly, as technology advances, many standards have been established, updated, recommended, and applied to ensure and measure the level of power efficiency.

List of some standards are written below-

Table 1.2.2(a) Power Quality Standards

Standards	Description
IEEE Standard 519-1992	Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
IEEE Standard 1159-1995	commended Practice for Monitoring Electric Power Quality
IEEE Standard 1100-1999	commended Practice for Powering and Grounding Sensitive Electronic Equipment
IEEE Standard 1250-1995	Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances
IEEE Standard 1366-2012	Electric Power Distribution Reliability Indices
IEC 61000-2-2	mpatibility Levels for Low-Frequency onducted Disturbances and Signaling in Public Supply Systems
IEC 61000-2-4	mpatibility Levels in Industrial Plants for Low-Frequency Conducted Disturbances
IEC 61000-3-2	its for Harmonic Current Emissions (Equipment Input Current Up to a nd Including 16 A Per Phase)
IEC 61000-4-15	Flicker Meter - Functional and Design Specifications
EN 50160	Voltage Characteristics of Public Distribution Systems
IEEE 519-1992	Permissible level of waveform distortion
IEEE Std141-1993	commended Practice for Electrical Power Distribution for Industrial Plants.
IEEE Std142-1991	commended Practice for Grounding of Industrial & Commercial Power System
IEEE Std241-1990	commended Practice for Electric Power Systems in Commercial Buildings.
IEEE Std242-2001	commended Practice for Protection and Coordination of Industrial and Commercial Power Systems
IEEE Std446-1995	ommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications
IEEE Std493-1997	commended Practice for the Design of Reliable Industrial & Commercial Power Systems
IEEE Std 1100-1999	commended Practice for Powering and Grounding Electronic Equipment
IEEE Std 1250-1995	E Equipment Disturbances. Sensitive to Guide for Service to Momentary Voltage
IEEE Std 1346-1998	commended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment
IEEE Std518-1982	E Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
IEEE C62.21-2003	E Guide for the Application of Surge Voltage Protective Equipment on AC Rotating Machinery 1000 Voltsand Greater
IEEE C62.22.1-1996 (R2003) E	Guide for the Connection of Surge Arrestors to Protect Insulated, Shielded Electric Power Cable Systems
IEEE SidC62.22.1997	E Guide for the Application of Metal Oxide Surge Arrestors for Alternating Current Systems
IEEE Std C62.41-1991	E Recommended Practice on Surge Voltage in low Voltage AC Power Circuits.
IEEE C62.41.1-2002	E Guide on the 'Surge Environment n Low Voltage (IOOOV and less) AC Power Circuits
IEEE C62.41.2-2002	E Recommended Practice on Characterization of Surges in Low Voltage (lOOOV and less) AC Power Circuits
IEEE Std C62.42-1992	E Guide for the Application of Gas-Tube and Air Gap Arrestor Low Voltage (Equal to or Less than 1000Vrrns or 1200Vdc) Surge Protective Devices

1.2.3 Terminologies for Power Quality

Because power quality challenges, recognition, and mitigating strate- gies have been reported to a high degree of concern, different termi- nologies to measure power quality problems have been developed.

See the terminology and definitions mentioned below, which are specified in detail in IEEE Standards [24]:

• Flicker: Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

• Fundamental (component): The component of order 1 (e.g., 50 Hz, 60 Hz) of the Fourier series of a periodic quantity.

• Imbalance (voltage or current): The ratio of the negative- sequence component to the positive sequence component, usu- ally expressed as a percentage. Syn: unbalance (voltage or current).

• Impulsive transient: A sudden non-power frequency change in the steady-state condition of voltage or current that is unidirectional in polarity (primarily either positive or negative).

• Instantaneous: When used to quantify the duration of a short- duration root-mean-square (rms) variation as a modifier, it refers to a time range from 0.5 to 30 cycles of the power fre- quency.

• Interharmonic (component): A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is operating (e.g., 50 Hz, 60 Hz).

• Long-duration rms variation: A variation of the rms value of the voltage or current from the nominal value for a time greater than 1 min. The term is usually further described using a modi- fier indicating the magnitude of a voltage variation (e.g., under- voltage, overvoltage, and voltage interruption).

• Momentary interruption: A type of short-duration rms voltagevariation where a complete loss of voltage (<0.1 pu) on one or more phase conductors is for a time period between 0.5 cycle and 3 s.

• Root-mean-square variation: A term often used to express a variation in the rms value of a voltage or current measurement from the nominal value. See sag, swell, momentary interruption, temporary interruption, sustained interruption, undervoltage, and overvoltage.

• Short-duration rms variation: A variation of the rms value of the voltage or current from the nominal value for a time greater than 0.5 cycle of the power frequency but less than or equal to 1 min. When the rms variation is voltage, it can be further described using a modifier indicating the magnitude of a

• voltage variation (e.g., sag, swell, and interruption) and pos- sibly a modifier indicating the duration of the variation (e.g., instantaneous, momentary, and temporary).

- Sustained interruption: A type of long-duration rms voltage variation where the complete loss of voltage (<0.1 pu) on one or more phase conductors is for a time greater than 1 min.

- Temporary interruption: A type of short-duration rms varia- tion where the complete loss of voltage (<0.1 pu) on one or more phase conductors is for a time period between 3 s and 1 min.

- Voltage change: A variation of the rms or peak value of a voltage between two consecutive levels sustained for definite but unspecified durations.

- Voltage fluctuation: A series of voltage changes or a cyclic vari- ation of the voltageenvelope.

- Voltage interruption: The disappearance of the supply voltage on one or more phases. It is usually qualified by an additional term indicating the duration of the interruption (e.g., momen- tary, temporary,and sustained).

- Waveform distortion: A steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation.

- Accuracy: The quality of freedom from mistake or error, that is, of conformity to truth or to a rule (as in instrumentation and measurement). The accuracy of an indicated or recorded value is expressed by the ratio of the error of the indicated value to the true value. It is usually expressed in percent. See accuracy rating of an instrument (as indicated or recorded value).

- Calibration: The adjustment of a device to have the designed operating characteristics, and the subsequent marking of the positions of the adjusting means, or the making of adjustments necessary to bring operating characteristics into substantial agreement with standardized scales ormarking.

- Comparisonof the indication of the instrument under test, or registration of the meter under test, with an appropriate standard (as in metering).

- Common-mode voltage: The voltage that, at a given location, appears equally and in phase from each signal conductor to ground.

- Coupling: The association of two or more circuits or systems in such a way that power or signal information may be transferred from one system or circuit to another.

- Current transformer (CT): An instrument transformer designed for use in the measurement or control of current (as in metering).

- Dropout: A loss of equipment operation (discrete data signals) due to noise, voltage sags, or interruption.

- Electromagnetic compatibility (EMC): A measure of equip- ment tolerance to external electromagnetic fields. The ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

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• Electromagnetic disturbance: An electromagnetic phenomenon that may be superimposed on a wanted signal. Any electro- magnetic phenomenon that may degrade the performance of a device, a piece of equipment, or a system.

• Equipment grounding conductor: The conductor used to con- nect the noncurrent-carrying parts of conduits, raceways, and equipment enclosures to the grounding electrode at the service equipment (main panel) or secondary of a separately derived system.

• Failure mode: The manner in which failure occurs; generally categorized as electrical, mechanical, thermal, and contamina- tion.

• Frequency deviation: An increase or decrease in the power fre- quency from the nominal value. The duration of a frequency deviation can be from several cycles to several hours.

• Ground: A conducting connection, whether intentional or acci- dental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth. Grounds are used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting ground currents to and from earth (or the conducting body).

•Ground loop: A potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential.

•Harmonic: A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. For example, a component having a frequency twice the fundamental frequency is called a second harmonic.

•Harmonic components: The components of the harmonic con- tent expressed in terms of the order and rms values of the Fourier series terms describing the periodic function.

• Harmonic content: The function obtained by subtracting the DC and fundamental components from a non-sinusoidal periodic function. The deviation from the sinusoidal form, expressed in terms of the order and magnitude of the Fourier series terms describing the wave. Distortion of a sinusoidal waveform characterized by indication of the magnitude and order of the Fourier series terms describing the wave.

•Immunity (to a disturbance): The ability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance.

•Impulse: A pulse that begins and ends within a time so short that it may be regarded mathematically as infinitesimal, although the area remains finite. An impulse is a surge of uni-directional polarity

•Isolated equipment ground: An isolated equipment grounding conductor run in the same conduit or raceway as the supply conductors. This conductor may be insulated from the metallic raceway and all ground points throughout its length. It origi- nates at an isolated ground-type receptacle or equipment input terminal block and terminates at the point where neutral and ground are bonded at the power source.

•Isolation: Separation of one section of a system from undesired influences of other sections.

•Maximum demand: The largest of a particular type of demand occurring within a specified period.

•Momentary: When used as a modifier to quantify the duration of a short-duration variation, it refers to a time range from 30 cycles to 3 s.

•Momentary interruption: A type of short-duration variation.The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time period between 0.5 cycle and 3 s.

•Noise: Electrical noise is unwanted electrical signals that pro- duce undesirable effects in the circuits of the control systems in which they occur.

•Nominal voltage: A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (as 208 V/120 V, 480 V/277 V, 600 V).

•Nonlinear load: A load that draws a nonsinusoidal current wave when supplied by a sinusoidal voltage source.

•Normal-mode voltage: The voltage that appears differentially between two signal wires and that acts on the circuit in the same manner as the desired signal.

•Notch: A switching (or other) disturbance of the normal power voltage waveform, lasting less than a half cycle, which is initially of opposite polarity to the waveform and is thus subtracted from the normal waveform in terms of the peak value of the disturbance voltage. This includes complete loss of voltage for up to a half cycle.

•Oscillatory transient: A sudden, non-power frequency change in the steady-state condition of voltage or current that includes either positive or negative polarity value.

•Overvoltage: When used to describe a specific type of long- duration variation, it refers to a measured voltage having a value greater than the nominal voltage for a time greater than 1 min. The typical values are 1.1-1.2 pu.

•Phase shift: The displacement in time of one waveform relative to another of the same frequency and harmonic content.

•Point of common coupling (PCC): The point at which the elec- tric utility and the customer interface occurs. Typically, this point is the customer side of the utility revenue meter.

• Potential transformer (PT): An instrument transformer that isintended to have its primary winding connected in shunt with a power supply circuit, the voltage of which is to be measured or controlled.

- Power disturbance: Any deviation from the nominal value (or from some selected thresholds based on load tolerance) of the input AC power characteristics.

- Power quality: The concept of powering and grounding elec- tronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment.

- Pulse: A wave that departs from an initial level for a limited duration of time and ultimately returns to the original level.

- Sag: A decrease in rms voltage or current for durations of 0.5 cycle to 1 min. The typical values are 0.1-0.9 pu.

- Shield: A metallic sheath, usually copper or aluminum, applied over the insulation of a conductor(s) for the purpose of pro- viding means for reducing electrostatic coupling between the conductor(s) so shielded and others that may be susceptible to or that may be generating unwanted (noise) electrostatic fields.

- Shielding: The process of applying a conductive barrier between a potentially disturbing noise source and electronic circuitry. Shields are used to protect cables (data and power) and elec- tronic circuits. Shielding may be accomplished by the use of metal barriers, enclosures, or wrappings around source circuits and receiving circuits.

- Sustained: When used to quantify the duration of a voltage interruption, it refers to the time frame associated with a long- duration variation (i.e., greater than 1 min).

- Sustained interruption: A type of long-duration variation. Thecomplete loss of voltage (<0.1 pu) on one or more phase con- ductors for a time greater than 1 min.

- Swell: An increase in rms voltage or current for durations from
0.5 cycle to 1 min. The typical values are 1.1-1.8 pu.

- Temporary interruption: A type of short-duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time period between 3 s and 1 min.

- Total demand distortion (TDD): The total rms harmonic cur- rent distortion, in percent of the maximum demand load current (15 or 30 min demand).

- Total harmonic distortion (THD) (HF: harmonic factor): The ratio of the rms value of the harmonic content to the rms value of the fundamental quantity, expressed as a percent of the fundamental.

- Transient: Pertaining to or designating a phenomenon or a quantity that varies between two consecutive steady states during a time interval that is short compared to the timescale of interest. A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occur- ring in either polarity.

• Undervoltage: When used to describe a specific type of long- duration variation, it refers to a measured voltage having a value less than the nominal voltage for a time greater than 1 min. The typical values are 0.8-0.9 pu.

• Voltage distortion: Any deviation from the nominal sine wave form of the AC line voltage.

• Voltage imbalance (unbalance): The ratio of the negative- or zero-sequence component to the positive- sequence component, usually expressed as a percentage in polyphase systems.

• Voltage regulation: The degree of control or stability of the rms voltage at the load. Often specified in relation to other parameters, such as input voltage changes, load changes, or temperature changes.

1.2.4 Definitions for Power Quality

Power quality is defined in many sources, which give different meaning to different people. It is used synonymously with supply reliability, service quality, voltage quality, quality of supply, and quality of consumption. In general, power quality is related to disturbances in voltage, current, frequency, and power factor. Any deviation in the voltage or current from the ideal value is a power quality disturbance. The definition of power quality has not been universally agreed upon. International Electrotechnical Commission (IEC) provides a description of power quality in IEC 61000-4-30 which states power quality as "Power quality is the principle of powering and grounding sensitive equipment in a manner that is appropriate for the operation of that equipment," and according to the Institute of Electrical and Electronics Engineers(IEEE)dictionary power quality means "Characteristics of the energy at a specified point on an electrical grid, measured against a set of reference technical parameters"

1.2.5 Standards for Power Quality

When power quality issues reach a point where they begin to affect not just those that are causing them, but also other customers, it becomes a cause for concern. A number of organisations, including the International Electrotechnical Commission (IEC), the American National Standards Institute (ANSI), British Standards (BS), European Norms (EN), Computer Business Equipment Manufacturers Association (CBEMA), and the Information Technology Industry Council (ITIC), have established standards to specify the permissible limits of various performance indices to mitigate power pollution.

Some of those limits are defined below.

Table 1.2.5(a). IEEE Standard 519-1992: current distortion limits for general distribution systems (120-69 000 V)

Maximum harmonic current distortion (in percet of I_l)						
I_{sc}/I_l	h<11	11 6 h < 17	176h < 23	236h < 35	356h	TDD(%)
<20	4.0	2.0	1.5	0.6	0.3	5.0
20 to<50	7.0	3.5	2.5	1.0	0.5	8.0
50 to<100	10.0	4.5	4.0	1.5	0.7	12.0
100to<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

*I*sc=maximum short-circuit current at PCC and;
Il=maximum demand load current (fundamental frequency component) at PCC.
h=harmonic order with respect to fundamental frequency.

Table 1.2.5(b) IEEE Standard 519-1992: current distortion limits forgeneral distribution systems (>161 kV), dispersed generation and cogeneration

Maximum harmonic current distortion (in percent of I_l)						
I_{sc}/I_l	h<11	11 6 h < 17	176h < 23	236h < 35	356h	TDD(%)
<50	2.0	1.0	0.75	0.3	0.15	2.5
>50	3.0	1.5	1.15	0.45	0.22	3.75

Table 1.2.5(b) IEEE Standard 519-1992: voltage distortion limits

voltage at PCC	ividual voltage distortion (%)	al voltage distortion(%)
69kV and below	3.0	5.0
69.001 to 161kV	1.5	2.5
161.001 and above	1.0	1.5

Table 1.2.5(c) IEC 61000-2-4: voltage distortion limits in industrialplant (class 2)

Odd harmonics		Even harmonics		Triplen harmonics	
h	V_h(pu)	h	V_h(pu)	h	V_h(pu)
05	6.0	02	2	03	5
07	5.0	04	1	09	1.5
11	3.5	06	0.5	15	0.3
13	3.0	08	0.5	>21	0.2
17	2.0	10	0.5		
19	1.5	>12	0.2		
23	1.5				
25	1.5				
>29	0.2+12.5lh				

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Table 1.2.5(d) . IEC 61000-2-4: voltage distortion limits
in industrial plants (class 3)

Odd harmonics		Even harmonics		Triplen harmonics	
h	V_h(pu)	h	V_h(pu)	h	V_h(pu)
05	6.0	02	2	03	6.0
07	5.0	04	1	09	2.5
11	3.5	>06	0.5	15	2.0
13	3.0			21	1.75
17	2.0			>27	1
19	1.5				
23	1.0				
25	1.5				
>29	5 (11/h)				

1.2.6 Monitoring of Power Quality

PQ incidents are haphazard in nature and occur at random. As a result, tracking the PQ phenomenon becomes almost inevitable for vital and expensive equipment where PQ issues are likely to result in a significant loss of revenue. If these recording/measuring instru- ments are correctly chosen to record PQ events, the monitoring device used for evaluating PQ events which provide enough data to decide on curing and minimising power quality problems. There are several guidelines and texts dedicated solely to PQ tracking. Only a brief explanation is given here to explain and raise awareness of PQ surveillance.

PQ monitoring requires the right selection of monitoring equip- ment, the method of collecting data, and so on. The recorded information needs to meet only the monitoring objectives in order for the monitoring to be successful. The objective of the monitoring may be to diagnose incompatibilities between the supply and the consumer loads. In other cases, it is used to evaluate the electrical environ- ment at a particular location for the required machinery or equipment.

Preventive and predictive monitoring may require recorded volt- ages and currents to quantify the existing level of power quality. Measurement of PQ includes both time- and frequency- domain vari- ables. PQ monitoring may be provided by the utility, customers, or any other personnel such as energy auditors.

Table 1.2.6(a) shows some important parameters that can be determined using suitable algorithms from the voltage and current waveforms.

Table 1.2.6(a) IEEE-519: parameters that can be determined fromacquired voltage and current data

ANSI transformer derating factor	rharmonic rms current	True power factor
hmetic sum power factor	rharmonic rms voltage	Unsigned harmonic power
hmetic sum displacementpower factor	Current-time product	Vector sum displacement factor
hmetic sum volt-amperes	Negative-sequence current	Vector sum power factor
Current crest factor	Negative-sequence voltage	Vector sum volt-amperes
Current THD	Net current	Voltage crest factor
Current THD (rms)	Positive-sequence current	Voltage THD
rent total interharmonic distortion (TID)	Positive-sequence voltage	Voltage THD (rms)
Current TID (rms)	Residual current	Voltage TID
Current imbalance	rms current	Voltage TID (rms)
placement power factor	current individual harmonics	tage telephone nterference factor (TIF)
Frequency	rms harmonic current (total)	Voltage TIF (rms)
frequency arithmetic sum volt-amperes	rms voltage	Voltage imbalance
d frequency vector sum volt-amperes	rms voltage individual harmonics	Watt-hours
Harmonic power (sum)	Total fund frequency reactive power	Zero-sequence current
IEEE 519 current TDD	nsformer K-factor	Zero-sequence voltage

1.3 Loads that wreak havoc on power quality

1.3.1 Introduction

Most of the electrical loads have nonlinear behavior at the AC mains. Many fluctuating loads such as furnaces, electric hammers, and frequently switching devices exhibit highly non linear behavior as electrical loads. These loads are known as nonlinear loads.

Solid-state control of AC power using diodes, thyristors, and other semiconductor switches is widely used to feed controlled power to elec- trical loads. These AC loads consisting of solid-state converters draw non-sinusoidal currents from the AC mains and behave in a nonlinear manner.

Nonlinear loads cause low system efficiency, poor power factor (PF), mal- operation of protection systems, AC capacitors overloading and nuisance tripping. They also cause distortion in the supply voltage.

Nonlinear loads exhibit different behavior thereby causing dif- ferent power quality problems, and they are therefore often classified according to their performance. The devices used for power quality improvements of such mixed nonlinear loads are connected in shunt with the loads to supply locally all their current components other than the fundamental active power component of load current. The mixed non linear loads consist of several several current fed type and voltage type of nonlinear load.

Power quality issues are caused by nonlinearloads, especially those that use solid-state controllers. To determine the appropriate power quality control instruments, it is necessary to characterise and eval- uate their behaviour.

Part 1.3 of this paper examines the classification and analysis of single-phase and three-phase nonlinear loads, as well as their results, with a focus on power quality issues. The state of the art for these non- linear loads, their classification, interpretation, modelling, and simula- tion of results and illustrations.

1.3.2 Nonlinear Loads: A modern take

To supply reactive power locally and reduce the pressure of reactive power on the AC mains, AC power capacitors and synchronous con- densers were used. Voltage deviation at the neutral terminal, increased losses, and harmonic voltage at the point of normal coupling arise from these harmonics and neutral current (PCC) These voltage imbalanceand fluctuation problems also affect good linear loads like AC motors, particularly induction motors, with negative sequence currents and subsequent rotor heating and increased losses, resulting in motor der- ating.

The following are few examples of nonlinear loads:

- Fluorescent lighting and other vapor lamps with electronic ballasts
- Switched mode power supplies
- Computers, copiers, and television sets
- Printer, scanners, and fax machines
- High-frequency welding machines
- Fans with electronic regulators
- Microwave ovens and induction heating devices
- Xerox machines and medical equipment
- Variable frequency-based HVAC (heating ventilation and air-conditioning) systems
- Battery chargers and fuel cells
- Electric traction
- Arc furnaces
- Cycloconverters
- Adjustable speed drives
- Static slip energy recovery schemes of wound rotor induction motors
- Wind and solar power generation
- Static VAR compensators (SVCs)
- HVDC transmission systems
- Magnet power supplies
- Plasma power supplies
- Static field excitation systems

Harmonic currents and the reactive power part of the current are drawn from the single-phase AC mains by nonlinear loads. This higher currents result in higher losses, a lower power factor, and interference with other users, networking networks, safety systems, and other electronic equipment.

1.3.3 Nonlinear Load Classification

The use of non-solid-state or solid-state systems can be used to clas- sify nonlinear loads. The presence or absence of a power electronics converter in nonlinear load circuits is also important.. Few of the classification are explained below:

•Nonlinear Loads of Solid-State Device (SSD) Form-Many separate circuits in solid-state devices are used in electrical equip- ment to process AC power for various applications. They are nonlinear loads that draw non-sinusoidal current from the AC mains. Domestic and industrial machines are examples of single- phase non- linear loads. Single-phase distributed loads on all three stages, such as electrical ballast-based lighting systems, device loads in high-rise buildings, and all other single-phase loads, put a strain on the power supply.

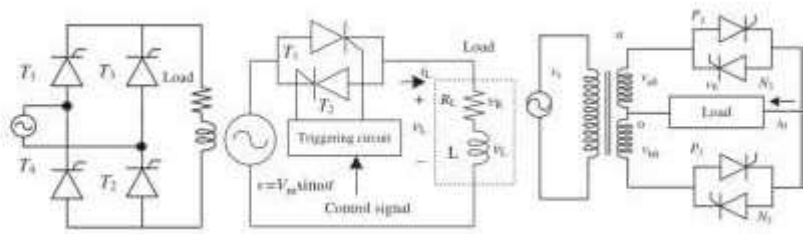

Fig1.3.3(a) Various types of non linear loads(SSD).

- Nonlinear Loads using an AC-DC Converter-The power level of AC-DC converters ranges from a few watts to a megawatt. At the AC mains, the behaviour of the filters used to filter the rec- tified DC varies depending on the type of filter used. Microwave ovens, SMPS, printers, fax machines, battery chargers, and HVDC transport devices are examples of nonlinear loads.
- Nonlinear Loads Using AC Controllers-To control the physical operation, some nonlinear loads use AC voltage regulators to control the AC rms voltage through the electrical loads. They draw harmonic currents as well as reactive power, resulting in a low power factor. They often induce unnecessary harmonic currents in single-phase spread loads on three-phase supply systems.
- Nonlinear Loads Using Cycloconverters- Cycloconverters are used in a variety of applications to transform AC voltage at a fixed frequency to variable voltage at a variable frequency or vice versa. Nonlinear loads include cyclocoversed large- rating synchronous motor drives in cement mills, for example.
- Nonlinear Loads using current feeding-Nonlinear loads that are stiffly current fed have a fixed pattern of harmonics which can often put a reactive power strain on the AC mains. They have a low crest factor and a smooth current waveform drawn from the AC mains. AC-DC converters feeding DC motor drives, magnet power supplies, alternator field excitation systems, operated AC-DC converters used to derive DC current source for feeding current source inverter supplying large-rating AC motor drives, HVDC transmission systems, and so on. Figure 1.3.3(b) depicts a current-fed nonlinear load of this kind.

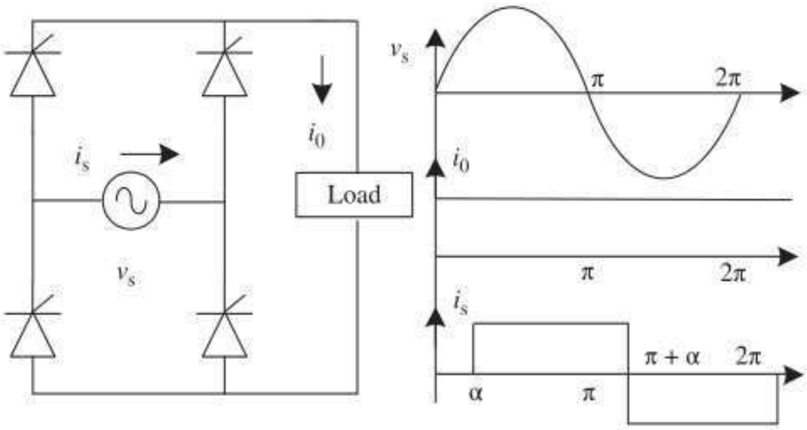

Figure 1.3.3(b) A current fed type non linear load.

• Non linear loads using voltage feeding-The rigid voltage forms of the nonlinear loads function as the drain of the harmonic currents. Typical example of this load is an AC-DC converter with a large DC capacitor on its DC bus to provide the perfect DC voltage supply for the remaining solid-state conversion operation and to draw peak current from the AC mains. Strong peak factor (as seen in Figure 1.3.3(c)). In general, they do not have a reactive power criterion, but They have a significantly larger number of harmonic currents drawn from the AC mains. Examples of loads like this include SMPS, battery chargers, front-end converters of the AC powered inverter voltage source, Electronic ballasts and other electronic equipment.

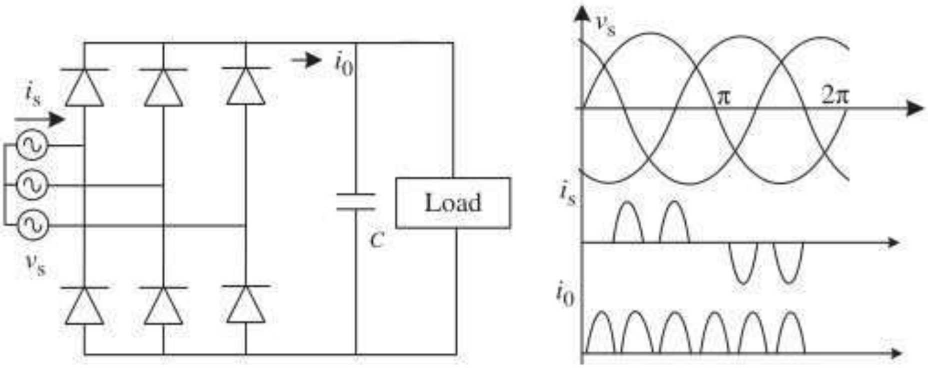

Figure1.3.3.(c) A voltage fed type non linear load.

•Mix of current Fed and Voltage Fed Nonlinear Load Types- Mixed nonlinear loads are a hybrid of current fed and voltage fed load types. This grouping includes a group of nonlinear loads and a mixture of linear and nonlinear loads. Most electrical loads consisting of solid-state converters function as nonlinear loads of this kind.

Two-Wire Non-linear Loads-A very significant number of single- phase non-linear loads are supplied by the two-wire single- phase AC mains. All of these loads, consisting of single-phase diode rectifiers, semiconverters and thyristor converters, act as non-linear loads. They pull harmonic currents and often reactive power from the AC mains as well. Typical examples of such loads are power supplies, electronic ventilator controllers, electronic ballasts, laptops, television sets, and traction. Figure 1.3.3(d) indicates the kind of voltage fed by nonlinear load

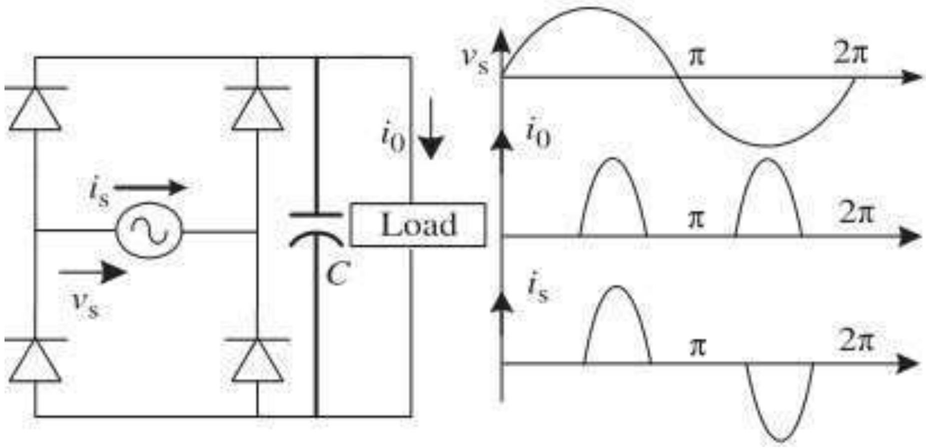

Figure 1.3.3(d) A two wire non linear load .

- Three-Wire non linear loads-Three-phase, three-wire, non-linear loads inject harmonic currents, and sometimes they pull reactive power from the AC mains, and sometimes they even have unbalanced currents. These non-linear loads are in huge numbers and absorb a large volume of electrical energy. Typical examples are ASDs using DC and AC engines, HVDC trans- mission systems, and wind power conversion. Figure 1.3.3(e) indicates the latest form of nonlinear load being fed.

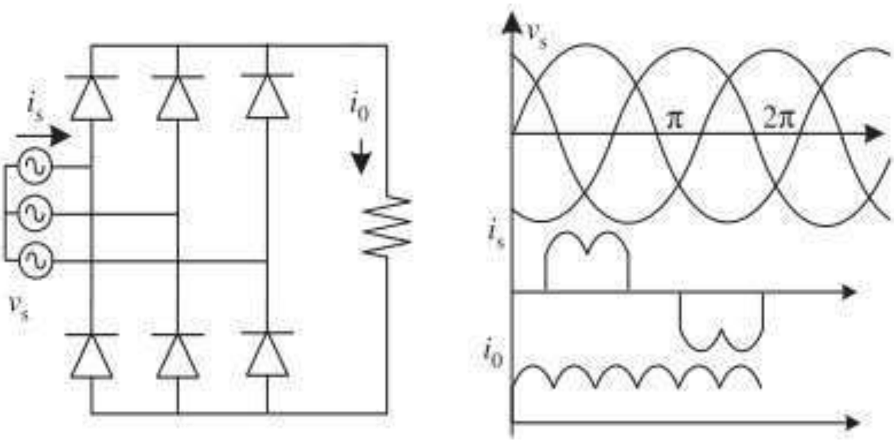

Figure 1.3.3(e) A three wire non linear load.

- Four-Wire Nonlinear Loads-A significant number of single- phase non-linear loads with a neutral conductor can be supplied from the three-phase AC mains. Apart from the harmonic cur- rents, the reactive power and the unbalanced currents, they also induce excessive neutral current due to the harmonic currents and the unbalancing of these three phase loads. Typical exam- ples are machine loads and mechanical ballast-based steam lighting systems. They often induce voltage deviation and voltage imbalance at the PCC and some potential at the neutral terminal. Figure 1.3.3(f) indicates the latest form of nonlinear load beingfed.

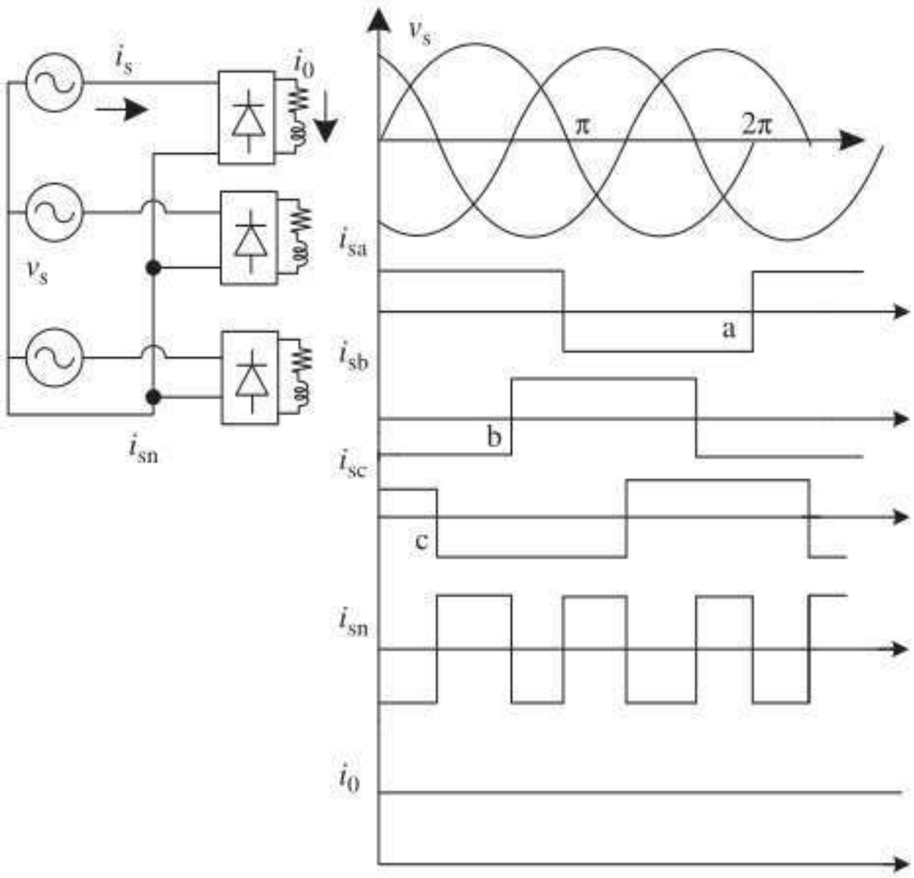

Figure 1.3.3(f) A four wire non linear load.

1.4 Power quality problems caused by non-linear loads

Nonlinear loads create a host of issues with the consistency of power in the delivery system. They are injecting harmonic currents into the AC mains. These harmonic currents increase the rms value of the supply current, increase losses, causing low usage and heating of the delivery system components, and often cause distortion and notching of the voltage waveforms at the point of normal coupling due to a voltage decrease in the source impedance. Any effects are as follows:

- Increased rms value of the supply current
- Increased losses
- Poor power factor
- Poor utilization of distribution system
- Heating of components of distribution system
- Derating of the distribution system
- Distortion in voltage waveform at the point of common coupling, which indirectly affects many types of equipment
- Disturbance to the nearby consumers
- Interference in communication system
- Mal-operation of protection systems such as relays
- Interference in controllers of many other types of equipment
- Capacitor bank failure due to overload, resonance, harmonic amplification, and nuisance fuse operation
- Excessive neutral current
- Harmonic voltage at the neutral point Some of these nonlinear loads, in addition to harmonics, require reactive power and create unbalancing,which not only increases the severity of the above-mentioned problems but also causes additional problems.
- Voltage regulation and voltage fluctuations
- Imbalance in three-phase voltages
- Derating of cables and feeders

2 Literature review

By means of a comprehensive literature study of more than 200 jour- nals and books, the paper is published after researching papers from almost 45 years of ago. This paper contains studies and publications on virtually every related topic since the onset of power quality issues. This paper is planned in a new and different way from previous papers on the topic. It consists of unusual material for easy under- standing of the subject matter and a significant number of basic derivations are used in a simpler mathematical form to solve most of the problems of power quality in analytical form. Apart from this, the paper includes basic theory accompanied by drawings, waveforms and phasor diagrams. In addition to undergraduate and postgrad- uate students in the field of power efficiency, this paper would also

prove useful to scholars, teachers and field engineers. The future spectrum of work can be everything from resolution of the above-mentioned problems to innovative guidelines for solving and implementing power quality corrective devices.

Result

There are a host of economic and reliability problems related to the satisfactory service of electrical appliances. Research and development in energy quality reduction strategies is also becoming significant and critical in limiting the emissions of the supply chain.

A variety of organizations, such as IEC and IEEE, have issued various standards that define the acceptable limits of power efficiency. Many manufacturers with different brands, such as power quality analyzers and sensors, have created a range of tools for measuring and evaluating power quality indices.

Nonlinear loads are divided into various groups, taking into account the severity of the issues. An empirical analysis of the different performance indices of these nonlinear loads is conducted in depth with an aim of studying the degree of power quality they may inflict in the system.

Conclusion

Research and design of efforts to address energy quality is becoming increasingly important and crucial. IEC and IEEE have issued stan-dards that establish acceptable limits for energy efficiency. A number of manufacturers of various names have proposed a set of instruments for calculating power quality indices.

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