



Asean Residential School in Electric Power Engineering 2008

*“Driving Towards Optimal Performance
and Customer Satisfaction”*

*Power Quality Diagnostic
“PQ Basic”*

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February 14, 2008

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The service area of the PEA is approximately 510,000 sq.km, accounting for 99 percent of the country. There are 73 provinces in the service area. In 2003 there are 928 sub-offices scattered throughout the country, rendering service to their customers. The PEA has grouped its service area into 4 regions.

200 Ngam Wong Wan Road, Chatuchak, Bangkok 10900 Thailand



•Transmission Lines (Circuit-km.)	8,157
•H.V.Distribution Lines (Circuit-km.)	276,018
•L.V.Distribution Lines (Circuit-km.)	416,802
•Number of Customers	13,843,668
•Number of Employees	26,304
•Total Electric Energy (Million kWh.)	88,799
•Residential customers	(21.4%)
•Business and Industrial	(71.5%)
•Others purposes.	(7.1%)
•Total Maximum Demand (MW.)	15,224
•Increasing (%)	6.5

What we will cover ?

- Power Quality Basics
 - PQ Definitions
 - PQ Standards
- PQ Monitoring
- PQ Diagnostic
 - Voltage Sags and Interruptions
 - Compatibility gap managements
 - Harmonics
- Case studies





Introduction

The electrical environment in commercial and industrial is changing rapidly. End-users increasingly rely on emerging electronic technologies to meet their goals for efficiency and cost-effectiveness.

Electronic equipment offers improved performance, it also is more sensitive to power disturbances that originate from sources on both sides of the electric meter.

On the other hand, power equipment sometimes cause power distortions, typically in the form of harmonics. Such distortions can propagate through the facility's electrical power distribution system to other nearby equipment or even through electric utility distribution line to other utility customers.

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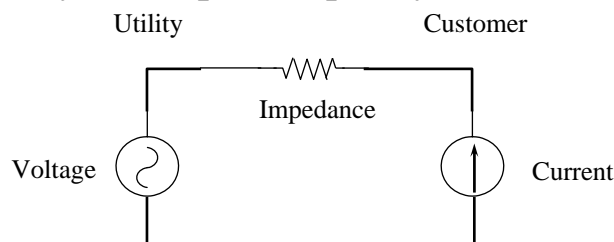
Introduction

When customers experience power disturbances, they often assume the problem is caused by utility, even though many times the problem may have occurred because of improper wiring or grounding or relay setting, overly sensitive loads, or interactions between loads within the facility.

6

Power Quality = Voltage Quality

- “Power Quality ” actually refers to the quality of the voltage supplied by the utility
- Because the system has impedance, currents outside the direct control of the utility can adversely affect power quality



7

What Is Power Quality?


Utility may define power quality as reliability and show statistics demonstrating that its system is 99.98 percent reliable.

Manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly.

In the last 50 years or so, the industrial age led to the need for products to be economically competitive, which mean that electrical machines were becoming smaller and more efficient and were designed without performance margins.

Power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment.

8



Why are we concerned about Power Quality?

The quality of power can have a direct economic impact on many industrial consumers. There has recently been a great emphasis on revitalizing industry with more automation and more modern equipment. This usually means electronically controlled, energy-efficient equipment that is often much more sensitive to deviations in the supply voltage than were its electromechanical predecessors.

Sometime momentary utility breaker operation to result in a \$10,000 loss to an average-sized industrial concern by shutting down a production line that requires 4 hours to restart. In the semiconductor manufacturing industry, the economic impacts associated with equipment sensitivity to momentary voltage sags resulted in the development of a whole new standard for equipment ride-through

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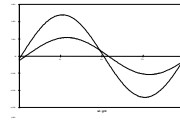


Importance of Power Quality

- What are the quality requirements?
- Customer equipment is more sensitive.
- Networks and automated processes (interconnections)
- Increasing penetration of nonlinear loads (harmonics)
- Efficiency concerns and power factor correction considerations
- The changing utility industry

10

Quality of Supply



AC power systems are designed to operate at a sinusoidal voltage of a given frequency and magnitude.

Any significant deviation in the waveform, magnitude, frequency, or purity is a potential power quality problem.

■ Voltage

- System Voltage +/- 5% (Normal operation)
- System Voltage +/- 10% (Emergency operation)

■ Frequency

- System frequency +/- 1%



11

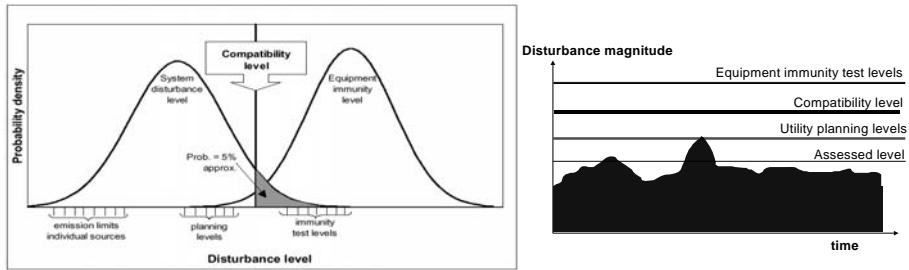
Quality of Supply

When the current passing through the impedance of the system can cause a variety of disturbances to the voltage. For example,

1. The current resulting from a short circuit causes the voltage to sag or disappear completely.
2. Currents from lightning strokes passing through the power system cause high-impulse voltages that frequently flash over insulation and lead to other phenomena, such as short circuits.
3. Distorted currents from harmonic-producing loads also distort the voltage as they pass through the system impedance. Thus a distorted voltage is presented to other end users.

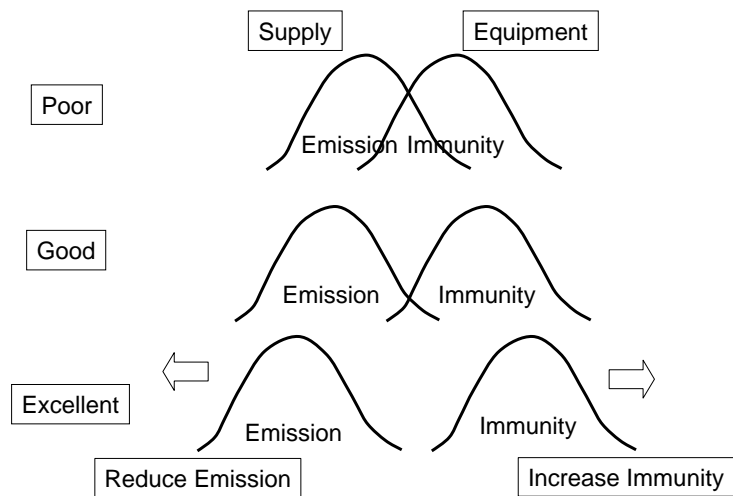
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EMC concept

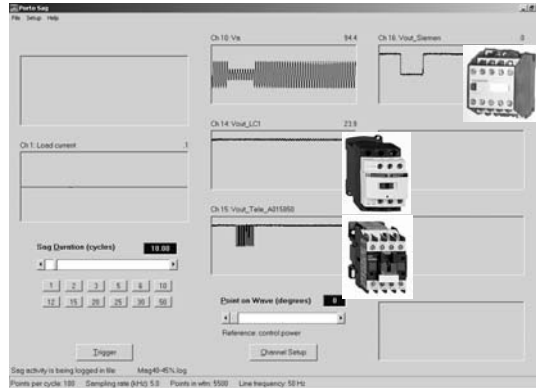


- **Compatibility Levels** – levels that should result in compatibility between the supply system and the connected equipment.
- **Voltage Characteristics** – power quality levels that are effectively promised by the supply company.
- **Planning Levels** – objectives set for planning purposes to make sure that the voltage characteristics are not exceeded.

EMC concept



Sensitive VS Power Quality



Two identical devices or pieces of equipment might react differently to the same power quality parameters due to differences in their manufacturing or component tolerance.

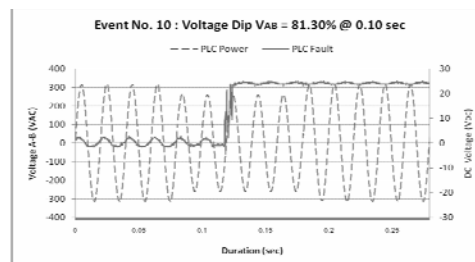
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Sensitive VS Power Quality

Pass

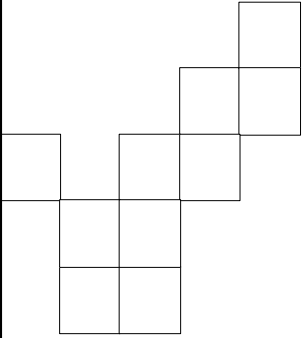


Fail




The interaction between power quality and susceptible equipment. What is “good” power for one piece of equipment could be “bad” power for another one.

18



Power Quality Definitions

19



Power Quality

- **Steady State Variations**
- **Disturbances**

20

Type of Power Quality Disturbances

Frequency events

- frequency variation

Voltage events

- Short term variation
- Long term variation
- Interruption
- Unbalance
- Fluctuation

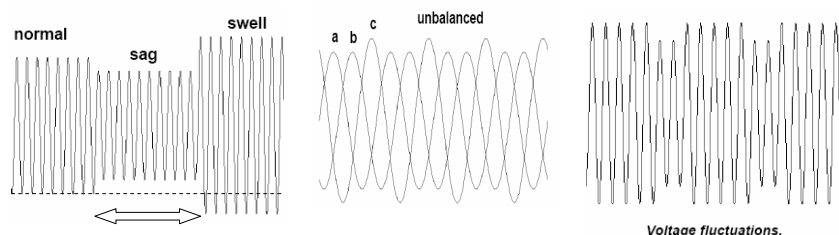
Waveform events

- Harmonics
- Inter-harmonics
- Transients
- Notching
- Noise

21

Voltage events

- Short term variations of duration less than 1 minute. These are called **Sags** (voltage between 10% to 90% of nominal) or **Swells** (voltage greater than 110% of nominal)
- Long term variations of duration more than 1 minute. These are called **Undervoltages** (voltage between 10% to 90% of nominal) or **Overvoltages** (voltage greater than 110% of nominal)
- Voltage unbalance where the voltage on each phase conductor is different.
- Interruptions where supply is lost completely (**Momentary** < 1 min., **Sustained** > 1 min.)



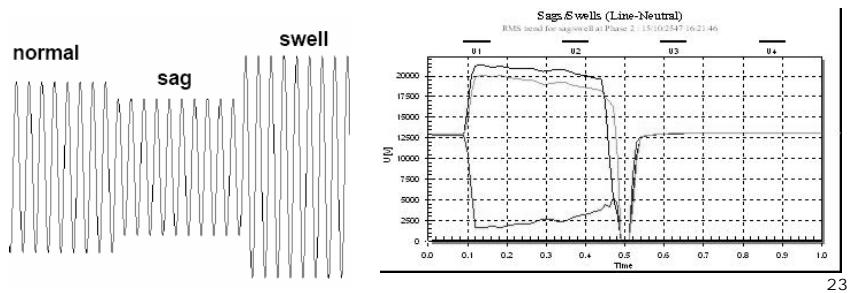
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Sags (dips)

A *sag* is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.

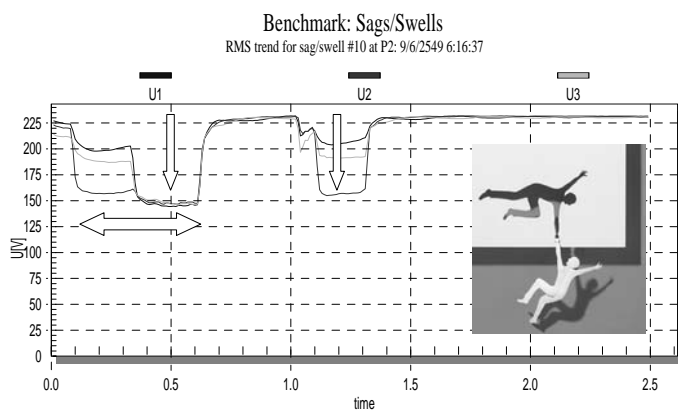
Swells

A *swell* is defined as an increase to between 1.1 and 1.8 pu in rms voltage at the power frequency for durations from 0.5 cycle to 1 min.



23

Severity of Voltage sag

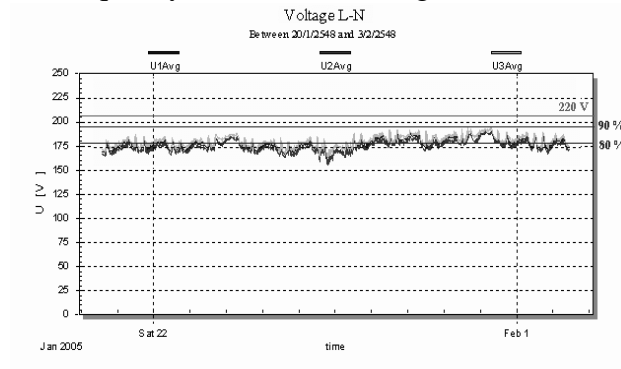


Voltage sags and interruptions are related power quality problems. Both are usually the result of faults in the power system and switching actions to isolate the faulted sections.

24

Undervoltage

Undervoltage is a decrease in the rms ac voltage to less than 90 % at the power frequency for a duration longer than 1 min.

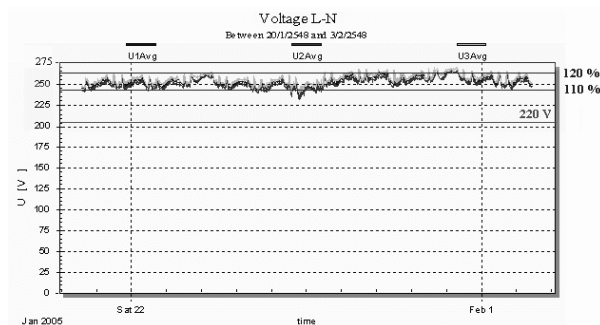


- Load switching on.
- Capacitor bank switching off
- Overloaded circuits.

25

Overvoltage

Overvoltage is an increase in the rms ac voltage greater than 110% at the power frequency for a duration longer than 1 min.



- Switching off a large load or energizing a capacitor bank.
- The system is too weak for the desired voltage regulation or voltage controls are inadequate.
- Incorrect tap settings on transformers.

26

Capacitor switching

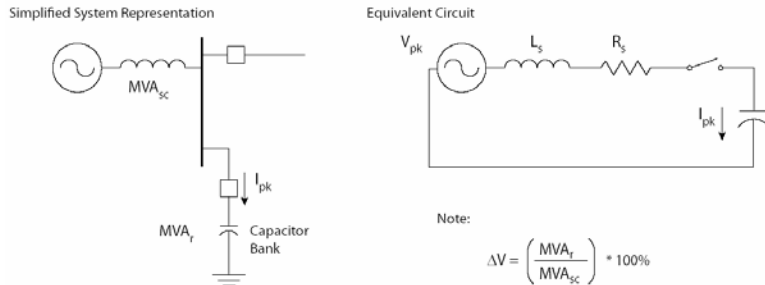


Figure 15 – Equivalent circuit for capacitor energizing

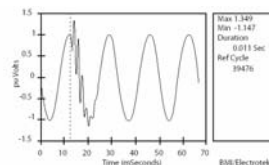
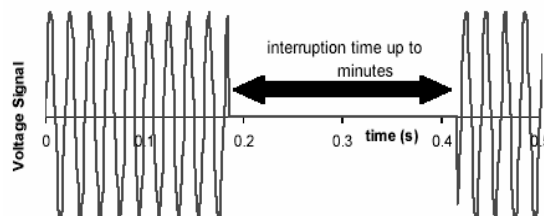


Figure 16 – Typical distribution bus voltage during capacitor energizing

27

Sustained interruptions

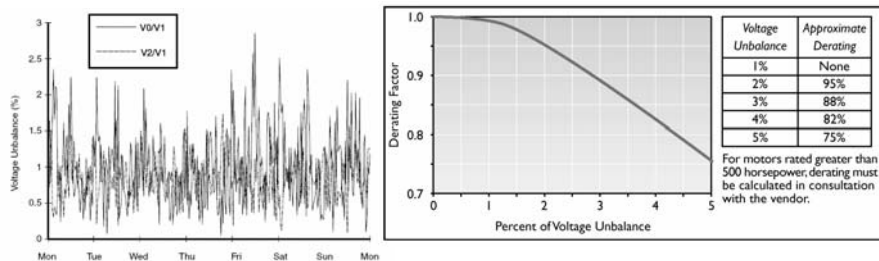
When the supply voltage has been zero for a period of time in excess of 1 min, the long-duration voltage variation is considered a *sustained interruption*.



28

Voltage Imbalance

(*Voltage unbalance*) is sometimes defined as the maximum deviation from the average of the three-phase voltages, divided by the average of the three-phase voltages, expressed in percent. And ratio of Zero sequence or Negative sequence to Positive sequence



29

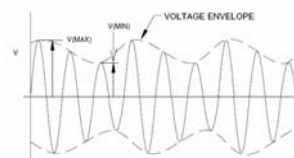
Voltage fluctuation

Flicker (or light flicker) is a low-frequency phenomenon in which the magnitude of the voltage or frequency changes at such a rate as to be perceptible to the human eye.

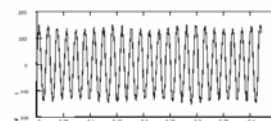
Voltage Change	Changes/Second
1 volt	4
2 volts	2
4 volts	1

Flicker is expressed as:

$$fv = 100 \times (V_{\max} - V_{\min}) / V_{\text{nom}}$$

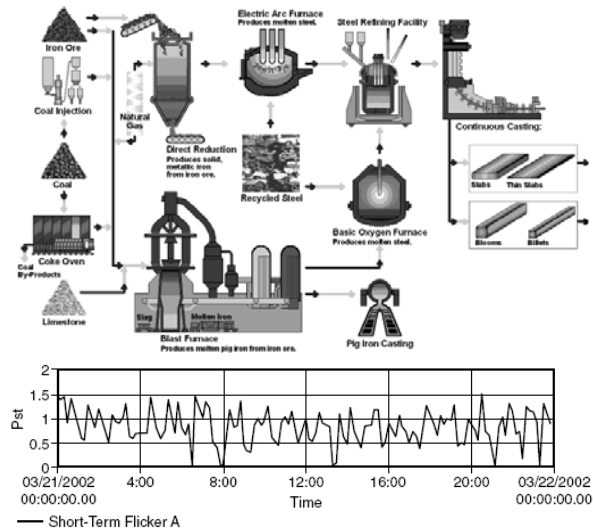


Flicker



30

Voltage fluctuation



31

Waveform Distortion

Waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation.

There are five primary types of waveform distortion:

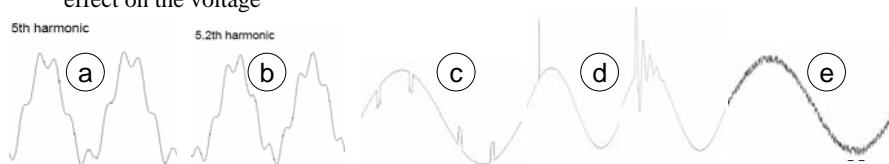
- DC offset
- Harmonics
- Interharmonics
- Notching
- Noise

32

Waveform events

These events result in distortion of normal sinusoidal waveshape of the mains voltage

- a) **Harmonics** are additional frequencies present in the mains voltage or current that are integral multiples of the mains frequency. Their effect can be distorted in waveform. Each cycle is distorted but identical.
- b) **Interharmonics** are additional frequencies that are non-integral multiples of the mains frequency. Neighbouring cycles are not identical.
- c) **Notching** results from the normal operation of 3-phase electronic switching devices such as AC to DC converters.
- d) **Transients** are generally large, short duration voltage change usually resulting from lightning strikes or switching operations on the network. They last for less than one half cycle of the mains voltage.
- e) **Noise** is a disturbance with a broad frequency distribution up to about 200,000 Hz. Its effect on the voltage



Harmonics

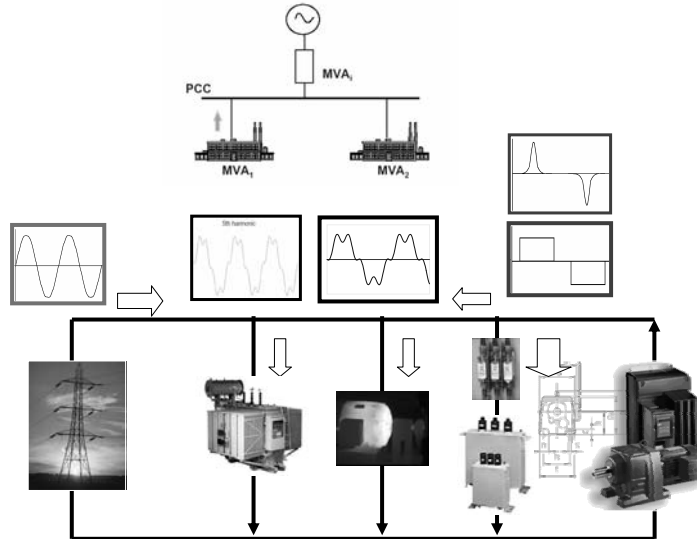
Are additional frequencies present in the mains voltage or current that are integral multiples of the mains frequency(50/60 Hz.). Their effect can be distorted in waveform. Each cycle is distorted but identical.

5th harmonic



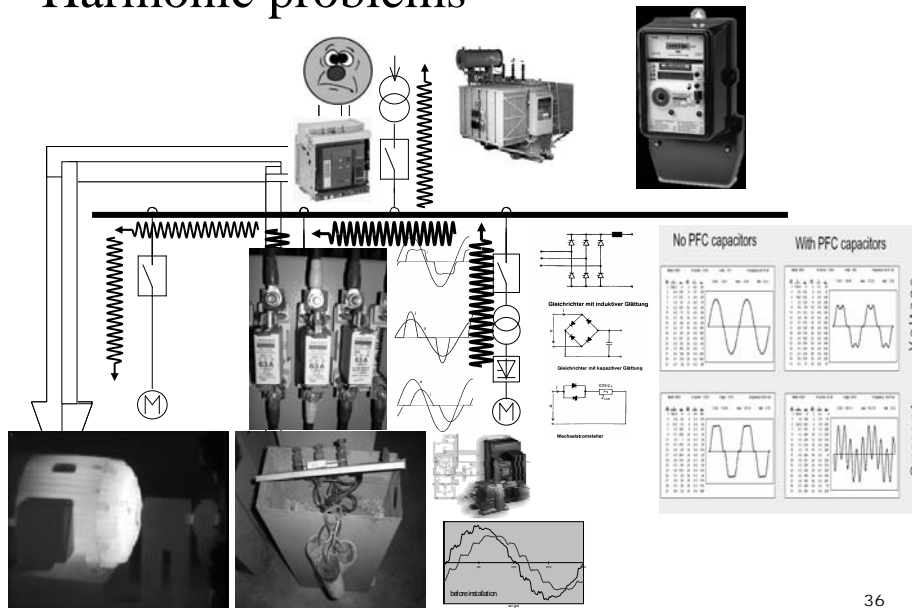
Periodically distorted waveforms Harmonics orders = 2, 3, 4, ..., n₃₄

Voltage quality and Current Quality



35

Harmonic problems



36

Interharmonics

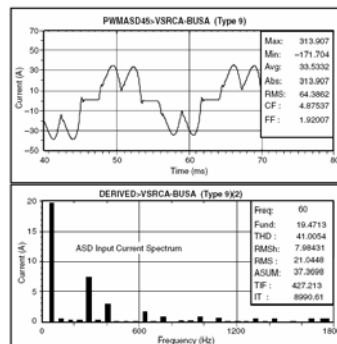
Are additional frequencies that are non-integral multiples of the mains frequency. Neighbouring cycles are not identical.



37

Total Harmonic Distortion (THD)

Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. It is also common to use a single quantity, the *total harmonic distortion* (THD)



38

Total Harmonics Distortion : THDi

Determine the total current of load consisting of 60 A of fundamental, 20 A of 3rd harmonics, 15 A of 5th :

$$\text{Total RMS current (I}_{\text{rms}}) \quad I_{\text{rms}} = \sqrt{(60^2 + 20^2 + 15^2)} = 65 \text{ A}$$

$$I_{\text{H}} = \sqrt{(I_2^2 + I_3^2 + I_4^2 + I_5^2 + I_6^2 + I_7^2 + \dots)}$$

$$\text{THD} = (I_{\text{H}}/I_1) \times 100\%$$

$$I_{\text{H}} = (20^2 + 15^2)^{0.5}$$

$$I_{\text{H}} = 25 \text{ A}$$

$$\text{THD}_i = 25/60 \times 100\%$$

$$\text{THD}_i = 41 \%$$

39

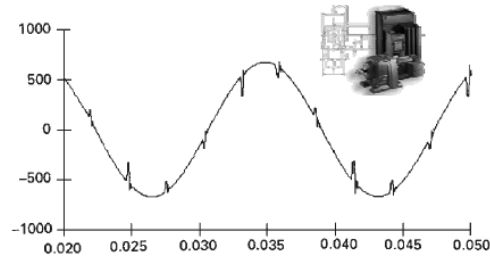
Total Demand Distortion (TDD)

IEEE Standard 519-1992 defines another term, the *total demand distortion* (TDD). This term is the same as the total harmonic distortion except that the distortion is expressed as a percent of some rated load current rather than as a percent of the fundamental current magnitude at the instant of measurement.

40

Notching

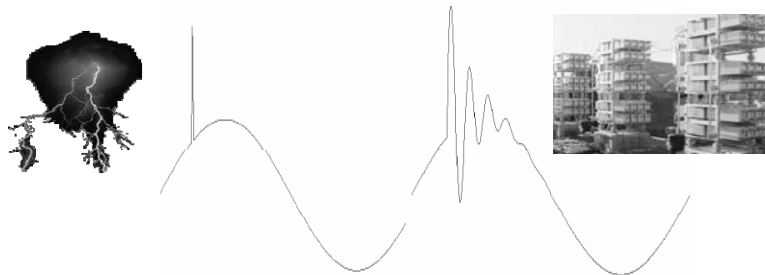
Notching is a periodic voltage disturbance caused by the normal operation of 3-phase power electronic devices such as AC to DC converters when current is commutated from one phase to another.



41

Transients

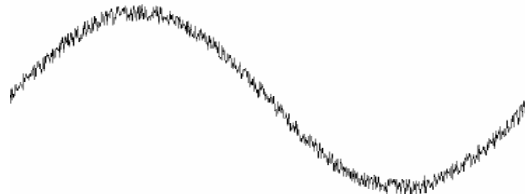
Are generally large, short duration voltage change usually resulting from lightning strikes or switching operations on the network. They last for less than one half cycle of the mains voltage.



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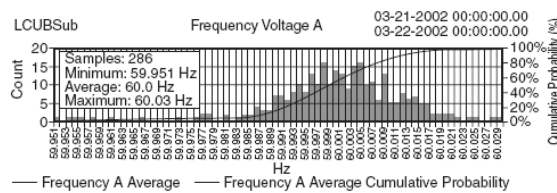
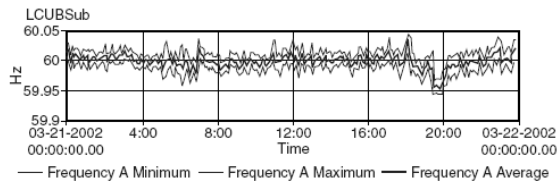
Noise

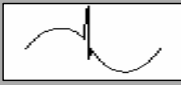

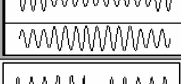
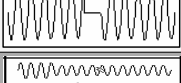
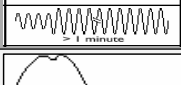
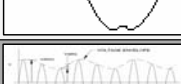
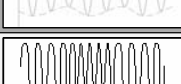
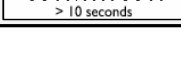
Is a disturbance with a broad frequency distribution up to about 200,000 Hz. Its effect on the voltage



Power Frequency Variations

Power frequency variations are defined as the deviation of the power system fundamental frequency from its specified nominal value (e.g., 50 or 60 Hz).



Waveshape

Causes

Impulsive
(Transients disturbance)

Oscillatory 0-8 p.u.

Sags/Swells 0.1-0.9 p.u.
(RMS disturbance) / 1.1-1.8 p.u.

Interruptions < 0.1 p.u.
(RMS disturbance)

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5-ns rise	<50 ns	
1.1.2 Microsecond	1-μs rise	50 ns-1 ms	
1.1.3 Millisecond	0.1-ms rise	>1 ms	
1.2 Oscillatory			
1.2.1 Low frequency	<5 kHz	0.3-50 ms	0-4 pu
1.2.2 Medium frequency	5-500 kHz	20 μs	0-8 pu
1.2.3 High frequency	0.5-5 MHz	5 μs	0-4 pu
2.0 Short-duration variations			
2.1 Instantaneous			
2.1.1 Interruption		0.5-30 cycles	<0.1 pu
2.1.2 Sag (dip)		0.5-30 cycles	0.1-0.9 pu
2.1.3 Swell		0.5-30 cycles	1.1-1.8 pu
2.2 Momentary			
2.2.1 Interruption		30 cycles-3 s	<0.1 pu
2.2.2 Sag (dip)		30 cycles-3 s	0.1-0.9 pu
2.2.3 Swell		30 cycles-3 s	1.1-1.4 pu
2.3 Temporary			
2.3.1 Interruption		3 s-1 min	<0.1 pu
2.3.2 Sag (dip)		3 s-1 min	0.1-0.9 pu
2.3.3 Swell		3 s-1 min	1.1-1.2 pu
3.0 Long-duration variations			
3.1 Interruption, sustained		>1 min	0.0 pu
3.2 Undervoltages		>1 min	0.8-0.9 pu
3.3 Overvoltages		>1 min	1.1-1.2 pu
4.0 Voltage unbalance		Steady state	0.5-2%
5.0 Waveform distortion			
5.1 DC offset		Steady state	0-0.1%
5.2 Harmonics	0-100th harmonic	Steady state	0-20%
5.3 Interharmonics	0-6 kHz	Steady state	0-2%
5.4 Notching		Steady state	
5.5 Noise	Broadband	Steady state	0-1%
6.0 Voltage fluctuations	<25 Hz	Intermittent	0.1-7%
7.0 Power frequency variations		<10 s	0.2-2 Pst

0.8-0.9 p.u.
/ 1.1-1.2 p.u.

0-20%

<25 Hz.

0.001-0.07 p.u.

Voltage sag performance index

System average rms frequency index voltage (SARFI_x)

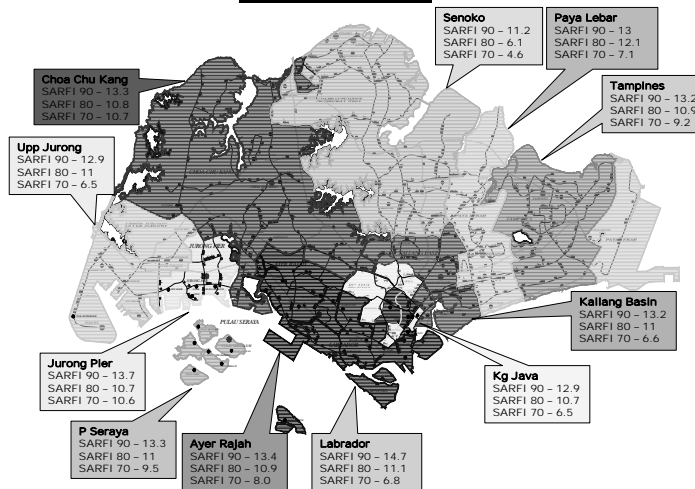
SARFI-X	< 10	< 50	< 70	< 80	< 90	> 110	> 120	> 140	IIIC 1996	SEMI F47	CBEMA 1977
NPL01	-	6	14	20	79	-	-	-	16	9	13
NPL02	-	6	14	20	79	-	-	-	16	9	13
ค่าเฉลี่ย	-	6.000	14.000	20.000	79.000	-	-	-	16.000	9.000	13.000

SARFI_x the specified disturbances are those rms variations with a voltage magnitude less than x for voltage drops or a magnitude greater x for voltage increase.

Where x = rms voltage threshold ;
possible values 140, 120, 110, 90, 80, 70, 50, 10

Voltage sag performance in Singapore – SARFI Map

22kV SARFI MAP



Comparison of major benchmarking projects

Voltage sag performance on medium voltage systems

Benchmarking Project	SARFI-70	SARFI-80	SARFI-90
Power Grid – Singapore	7.8	10.6	13.2
United States (DPQ Project)	17.7	27.3	49.7
Europe – Mixed Systems (UNIPEDA)	44.0	NA	103.1
Europe – Cable Systems (UNIPEDA)	11.0	NA	34.6
South Africa (NRS-048 indicative levels)	47.0	78.0	153.0
PEA	9	15	38

49

4.1 Voltage Events

Disturbance	Effect
Overvoltage	Overstress insulation
Undervoltage	Excessive motor current
Unbalance	Motor heating
Neutral-ground voltage	Digital device malfunction
Interruption	Complete shut-down
Sag	Variable speed drive & computer trip-out
Swell	Overstress insulation
Fluctuations	Light flicker

4.2 Waveform Events

Harmonics	Motor, transformer & neutral conductor overheating, instrumentation malfunction
Notching	Zero-crossover device malfunction
Transients	Electronic device failure or malfunction; drive trip-out
Noise	Fast-running clocks; zero-crossover device malfunction

50

What Needs to be Evaluated?

Transmission System Evaluations	<ul style="list-style-type: none"> Harmonic limits for interconnections Voltage sag/interruption performance calculations Evaluating flicker from arc furnaces Capacitor bank application evaluation
Distribution System Evaluations	<ul style="list-style-type: none"> Harmonic distortion on the distribution system Voltage sag/interruption performance calculations Voltage regulation/unbalance evaluations Capacitor bank application evaluation Ferroresonance
End User System Evaluations	<ul style="list-style-type: none"> Good grounding practices Power factor correction evaluation Motor starting voltage variations Harmonic limits (ASDs and other nonlinear loads) Voltage sag/interruption impacts Capacitor switching transients impacts Voltage variation/unbalance impacts including high efficiency motors

51

Power Quality Standards – IEC, EN

- **EN50160**
- **IEC**
 - IEC 61000-2-2 Compatibility Levels on Public Networks (LV)
 - IEC 61000-2-12 Compatibility Levels on Public Networks (MV & HV)
 - IEC 61000-2-4 Compatibility Levels in Industrial Plants
 - IEC 61000-2-8 Voltage Dip Performance
 - IEC 61000-4-15 Flicker Measurement
 - IEC 61000-4-7 Harmonics Measurements
 - IEC 61000-4-11 and IEC 61000-4-34 Voltage Dip Measurements
 - IEC 61000-4-30 PQ Monitoring Guidelines

52

Power Quality Standards – IEEE

■ IEEE Standards

- IEEE 1159 Power Quality Definitions and Monitoring
- IEEE 1366 Reliability Indices
- IEEE 519 Harmonics
- IEEE 1250 Voltage Quality Issues
- IEEE 1346 Voltage sags and equipment compatibility
- IEEE 1453 Flicker (coordinated with IEC 61000-4-15)
- IEEE 1546 Voltage sag indices
- IEEE C62.41 Transients and Surge Suppressors
- IEEE 1409 Custom Power
- IEEE 1100 Guidelines for Supplying Sensitive Equipment

53



Thank you for your attention...

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54