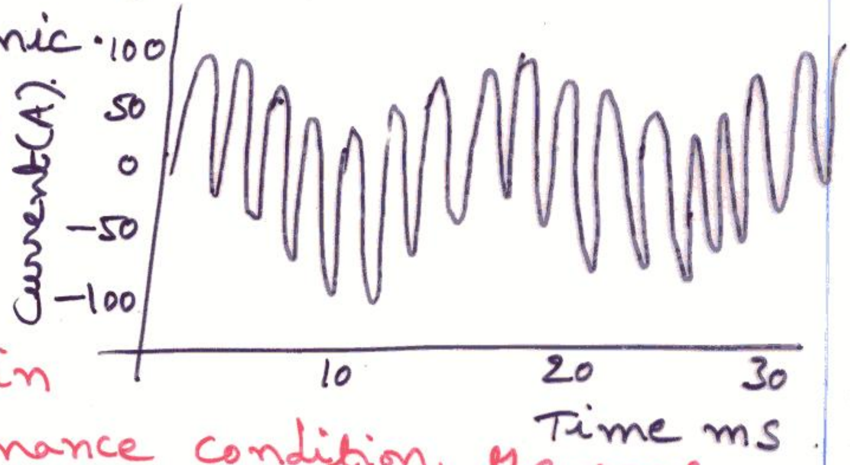
Effects of Harmonic distortion:

- Harmonic currents Produced by Non linear Loads are injected back into supply systems. These currents can interact adversely with a wide range of Power System equipment. most notably with capacitors, transformers and motors causing additional losses, overheating and overloading. These also cause interference with telecommunication lines and errors in Power metering.

①Impact on capacitors:

- A capacitor bank experiences high voltage distortion during resonance. The current flowing in capacitor is also large and rich in a monotonic harmonic.



- A current waveform of a capacitor bank in resonance with the system at 11th harmonic is shown in fig. In such a resonance condition, the rms current is higher than the capacitor rms current rating.
- The following specifies the continuous capacitor ratings.

(a) 135% of nameplate kVar (b) 110% of rated rms Voltage (Including harmonics but excluding Transients

- 180% of rated rms current (Including fundamental and harmonic current)
- 120% of Peak Voltage (Including harmonics)

(b) Impact on transformers:

- The transformers are designed to deliver the required power to the connected load with minimum losses at fundamental frequency.
- Harmonic distortion of the current, as well as of Voltage will contribute significantly to additional heating. To design a transformer to accomodate higher frequencies, designers make different design with transposed cable instead of solid conductor and putting in more cooling ducts.
- There are three effects that result in increased transformer heating.

(i) Rms current: Transformer is sized only for the KVA requirement of the load, harmonic currents may result in the transformer rms current being higher than its capacity. The increased total rms current results in increased conductor losses.

(ii) Eddy current losses: These are induced currents in a transformer caused by the magnetic fluxes. Induced currents flow in the windings, in the core and in other conducting ~~bodies~~ cause additional heating. This component of the transformer losses increases with the square of the frequency of the current causing the eddy currents, becomes important component.

(iii) Core losses: The increase in core losses in the presence of harmonics will depends on the effect of the harmonics on the applied voltage and design of the transformer core. Increasing the voltage distortion may increase the eddy currents in the core laminations. The net impact depends on thickness of the core lamination and the quality of the core steel.

(c) Impact on motors:

- Motors are significantly impacted by the harmonic voltage distortion. Harmonic voltage distortion at the motor terminals is translated into motor fluxes within the motor. These fluxes do not contribute significantly to motor torque, but rotate at a frequency different than the rotor synchronous frequency, inducing high frequency currents in the rotor.
- The effect on motors similar to that of –ve sequence currents at fundamental frequency. The additional fluxes do little more than induce additional losses. Hence decreased efficiency along with heating, vibration, and high-pitched noises are indicators of harmonic voltage distortion.
- At harmonic frequencies, motors represented by the blocked rotor reactance connected across the line. Lower order harmonics voltage components magnitudes are larger and motor impedance lower.

Guidelines for limiting harmonics :

- Harmonic distortion is Present to some degree on all Power systems. Fundamentally one needs to control harmonics only when they become Probler
- There are three common causes of harmonic Problems.

(i) The Source of harmonic currents is too great.
(ii) The Path in which the currents flow is too long resulting in either high Voltage distortion or telephone interference.
(iii) The response of the system magnifies one or more harmonics to a greater degree than can be tolerated.

- when a Problem occurs, the basic options for controlling harmonics are

(i) Reduce the harmonic currents Produced by the load.
(ii) Add filters either siphon the harmonic currents off the system, block the currents from entering the system, or supply the harmonic currents locally.
(iii) modify the frequency response of the System by filters, inductors or capacitors.

Reducing harmonic currents in loads:

- Little can be done with existing load equipment to significantly reduce the amount of harmonic current. The over excited Transformer brought back to normal operation by lowering the applied Voltage to the correct range. But arcing devices and electronic Power converters are locked into designed characteristic.
- PWM drives that charge the dc bus capacitor directly from line without any intentional impedance is one exception. Adding a line reactor or transformer in series will significantly reduce harmonics, as well as transient Protection benefits.
- Transformer connections can employed to reduce harmonic currents in three-phase systems. phase shifting half of the 6 Pulse Power Converter in a Plant load by 30° can benefits of 12-Pulse loads by reducing 5th and 7th harmonics. Delta-connected transformers block the flow of zero-sequence harmonics (triplen) from the line. Zig-Zag and grounding transformers shunt the triplens off the line.
- Purchasing specifications go a long way toward Preventing harmonic Problem by Penalizing bids from vendors with high harmonic content. This is Particularly important for loads as high-efficiency lighting.

Filtering:

- Shunt filter works by short circuiting harmonic currents as close to the source of distortion. This most common type of filtering applied because of economics and also tends to correct the load pf as well as removing the harmonic current.
- Another approach is a series filter, that blocks the harmonic currents. A Parallel tuned circuit offers a high impedance to the harmonic currents. It is not often use because, it is difficult to insulate and Load Voltage is very distorted.
- Active filters work by electronically supplying the harmonic component of the current into a non linear load.

Modifying the system frequency response:

- There are many number of methods to modify the system responses to harmonics.

(i) Add a shunt filter, which not only does this shunt a troublesome harmonic current off the system, but it completely change system response.

(ii) Add a reactor to detune the system. Harmful resonances occur between system inductance and shunt Power factor correction capacitors. Reactor must be added between capacitor and Supply Source. one method is to simply put a reactor in series with capacitor. Another is to add reactance in the Line.

(iii) change the capacitor size. one of the least expensive for both utilities and industrial customers.

(iv) Remove the capacitor, accept higher losses, lower Voltage, pf Penalty. Technically feasible, this a a best economic choice.

Harmonic distortion Evaluations:

- Harmonic currents produced by non linear loads can interact adversely with the utility supply system.
- This interaction gives rise to voltage and current distortion observed in the system.
- To limit both voltage and current distortion IEEE standard 519-1992 proposes to limit harmonic current injection from end users, so that overall levels on the PS will be acceptable. This approach required participation from both end users and utilities.

(i) End users:

- Harmonic problems are more common at end-user facilities than on the utility system. Most non-linear loads within end-user facilities and highest voltage distortion levels occur close to harmonic sources.
- The most problems occur when there are non-linear loads and pf correction capacitors result in resonant conditions.

$V_n \leq 69\,kV$

I_{sc}/I_L	$h < 11$	$11 \leq h \leq 17$	$17 \leq h \leq 23$	$23 \leq h \leq 35$	$35 \leq h$	T_{DD}
< 20	4	2	1·5	0·6	0·3	5
20 – 50	7	3·5	2·5	1	0·5	8
50 – 100	10	4·5	4	1·5	0·7	12
100 – 1000	15	7	6	2·5	1·4	20

$69\ kV \leq V_n \leq 161\ kV$

< 20	2	1	0.75	0.3	0.15	2.5
20 – 50	3.5	1.75	1.25	0.5	0.25	4.
50 – 100	5.0	2.25	2	0.75	0.35	6
100 – 1000	6	2.75	2.5	1	0.5	7.5

Harmonic current distortion limits in % of I_L

- I_h is magnitude of individual harmonic component (rms amps).
- I_{sc} short circuit current at PCC
- I_L fundamental component of the max. demand load current at PCC.
- TDD is expressed interms of max. demand load current $TDD = \frac{\sqrt{\sum_2 I_h^2}}{I_L} \times 100\%$.
- Load consists of Power converters with Pulse number q higher than 6, the limits are increased by a factor equal to $\sqrt{q/6}$.

Procedure to find short circuit ratio:

- Determine the 3-φ short circuit duty I_{sc} at the PCC. This value may be obtained at utility. If short circuit duty given in MVA, use the following to convert it to an ampere value expression.

$$I_{sc} = \frac{1000 \times MVA}{\sqrt{3} \times KV}\ Amp.$$

MVA & kV represent s/c 3-φ capacity in MVA & Line to line Voltage at PCC in kV.

- Find Load average KW demand T_D over the most recent 12 months. This can be found from billing Information.
- Convert average KW demand to the average demand current in amperes using the following

$$I_L = \frac{KW}{PF \times \sqrt{3}\ KV} \text{ Amp.}$$

where PF is the average billed Power factor.

- The short circuit ratio now determined by

$$\text{short circuit ratio} = \frac{I_{sc}}{I_L}$$

This s/c ratio used to determine the limits on harmonic currents.

(ii) Harmonic evaluations on the utility system:

- This involves procedures to determine the acceptability of the voltage distortion for all customers. If voltage distortion exceed the recommanded level, corrective actions to be taken to limit.

Bus Voltage at PCC, V_n (kV)	Individual harmonic Voltage distortion (%)	Total Voltage distortion, THD V_n (%)
$V_n \leq 69$	3.0	5.0
$69 < V_n \leq 161$	1.5	2.5
$V_n > 161$	1.0	1.5

Harmonic Voltage distortion limits in % of Nominal fundamental frequency Voltage.

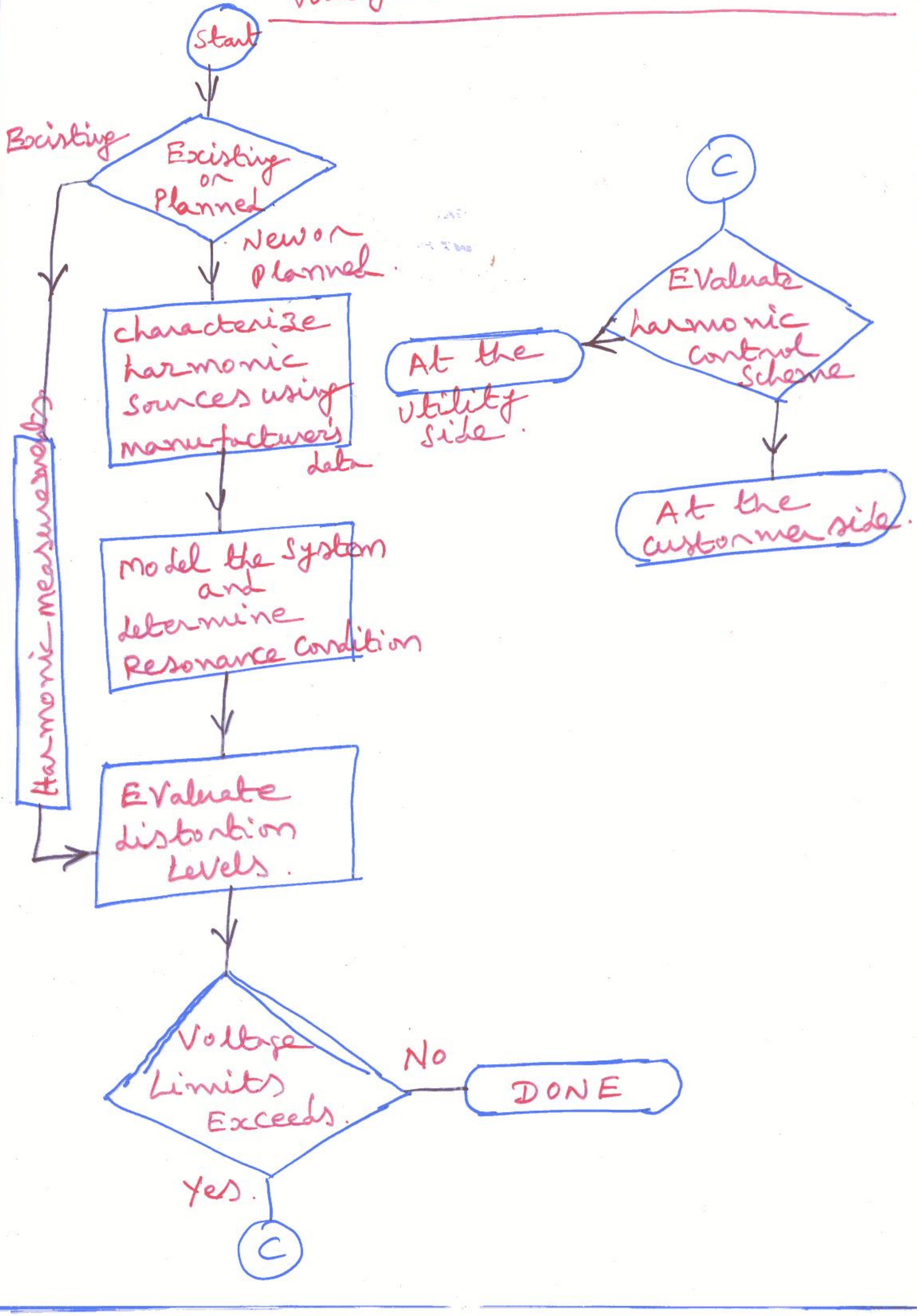
- Two important components for limiting Voltage distortion levels on the overall utility system.

(i) Harmonic currents injected from individual end user must be limited. These currents Propagate toward source through impedance creating Voltage distortion. Thus by limiting injected harmonic currents, the voltage distortion can be limited.

(ii) The overall Voltage distortion levels excessively high even, if the harmonic current injections are within limits. This occurs, when one of the harmonic current frequency is close to a system resonance frequency. result in unacceptable Voltage distortion level at some locations. The highest Voltage distortion occur at a capacitor bank that Participates in the resonance. This location is remote from the point of injection.

(a) characterization of harmonic sources:
(b) System modelling (c) system frequency response (d) Evaluate expected distortion levels. (e) Evaluate harmonic control scheme.

Voltage limit Evaluation Procedure.



Power Quality Monitoring

- PQ monitoring is the Process of gathering, analyzing and interpreting raw measurement data into useful information.
- The Process of data gathering is usually carried out by continuous measurement of V & I over an extended Period.
- The Process of analysis and interpretation traditionally Performed manually, but recent advances in signal Processing and AI to automatically analyze and interpret data into useful information. with minimum human intervention.
- PQ monitoring Programs are often driven by the demand for improving the system wide Power Quality Performance.
- Many industrial and commercial customers have sensitive equipment & is sensitive to Power disturbances. Hence it is more important to provide Quality of Power.
- Examples of these facilities include Computer networking, telecommunications facilities, semi conductor and electronics manufacturing facilities, biotechnology and pharmaceutical Laboratories, and financial data Processing centres.

The objectives & Procedures for Performing Monitoring.

- The monitoring objectives often determine the choice of monitoring equipment, triggering thresholds, methods for data acquisition and storage and analysis, interpretation requirements. The main objectives of PQ monitoring are summarized here.

(i) Monitoring to characterize system Performance:

This is most general requirement. A Power producer find this objective is important, if it has need to Understand its system Performance and then match with the needs of customers. system characterization is a Proactive approach to PQ monitoring.

(ii) monitoring to characterize specific Problems:

many PQ service departments solve Problems by Performing short-term monitoring at specific customer site or at difficult loads. This is a reactive mode of PQ monitoring.

(iii) monitoring as a Part of an enhanced PQ service:

many Power Producers are considering additional services to offer customers. one of these services would be to offer differentiated levels of PQ to match the needs of specific customers. A Provider and customer can together achive this goal by modifying PS or by installing equipment within the customer's Premices. Monitoring becomes essential to establish the bench marks.

(iv) Monitoring as a Part of Predictive or Just-in-Time maintenance :

PQ data gathered over time can be analyzed to prodive information relating to specific equipment performance. Equipment maintenance can be quickly ordered to avoid failure, thus preventing major PQ disturbances which ultimately will impact overall PQ performance.

Power Quality measuring Instruments :

- Early monitoring devices were bulky, heavy boxes. Data collected were recorded on strip-chart paper.
- The Earliest PQ monitoring instrument is a Lightning strike recorder developed by GE in 1920's Instrument makes an impulse-like mark on strip chart paper to record a lightning strike event.
- The data were most qualitative than quantitative. making the data interpretation rather difficult.
- significant development on PQ devices was not made until the 1960's, Martzloff developed a surge counter that could capture a voltage waveform of Lightning strikes. The improvement of this device over its predecessor was that recorded data were quantitative as opposed to qualitative.
- The First generation of PQ monitors began in 1970's.
  Power line disturbance analyzer is manufactured 1975.
  This is a µP based monitor analyzed, the output is
  text based, printed on paper tape. describes
  disturbance by type of event (sag, interruption etc)
  and voltage magnitude.

- Second generation PQ instruments developed in mid 1980s. These are featured full graphic display and digital memory to view and store captured PQ events including both transients and steady state events.
- By the mid 1990's the third generation PQ instruments emerged. These are more appropriate as a part of a complte PQ monitoring and software were developed. to collect and manage the data were developed.
- Basic categories of instruments are (i) wiring & grounding test devices (ii) Multimeters (iii) oscilloscopes (iv) Disturbance analyzers (v) Harmonic analyzer and spectrum analyzers (vi) Flicker meter (vii) Energy monitors. (viii) Combination disturbance and harmonic analyzers.

(a) Multi Meters :

- After initial tests of wiring, to make quick checks of V or I and overloading of circuits, under voltage and over voltage problems and unbalances between circuits can be detected with multimeter. signals used to check include.

(i) Phase to ground voltages (ii) Phase to neutral Voltages. (iii) Neutral to ground Voltages (iv) Phase to phase Voltages (v) Phase currents (vi) Neutral currents.

- The method of calculation used in meter is most important. All commonly used meters are calibrated to give an rms indication for the measured signal.
- No. of differerent methods are used to calculate the rms value. Most common methods are

(i) Peak method : Assuming the signal is sinusoid, the meter reads peak value and divides the signal by 1.414 to obtain rms value.

(ii) Averaging method: meter determines the average value of rectified signal. For a clean sinusoidal signal this average value related to rms value by a constant.

(iii) True rms: The rms value of a signal is the measure of heating, result the voltage is impressed across a resistive load.

- Different methods all give the same result for clean, sinusoidal signal, but give different answers for distorted signals.

Meter Type	True RMS	Peak method	Average
Circuit Type	Rms Converter	Peak/1.414	Avg × 1.11
Sine wave	100%	100%	100%
Square wave	100%	82%	110%
Triangle wave	100%	121%	96%
ASD current	100%	127%	86%
PC current	100%	184%	60%
Light Dimmer	100%	113%	84%

(b) Flicker meters:

- Many different methods for measuring flicker have been developed. These methods range from very simple rms meters with flicker curve to elaborate flicker meters. Use exactly tuned filters and statistical analysis to evaluate the level of voltage flicker.
- Rms strip charts: flicker normally measured with Rms meters, Load duty cycle and a flicker curve. If sudden Rms voltage deviations occured

with specified frequencies exceeding values found in flicker curves. The advantage is quite simple in nature and the rms data required are easy to acquire. But the disadvantage is lack of accuracy and inability to obtain exact frequency content.

Fast fourier Transform: Taking raw samples of actual voltage waveforms and implement a Fast fourier transform on the demoduated signal to extract the various frequencies and magnitudes found in data. This data will be compared with flicker curve.

Flickermeters: A flicker meter is a device demodulate the flicker signal, weights according to flicker curve and performs statistical analysis on the processed data.

- In the First section, the I/P waveform demodulated, thus removing the carrier signal. The second section removes these unwanted terms using filters, leaving only the modulating signal remaining. The last section usually consists of a statistical analysis of the measured flicker.

Problems caused by Power Quality:

1. Blinking of Incandescent Lamps
2. Failure of Pf correction capacitor
3. Tripping of circuit Breaker, for no visible reason.
4. computer malfunction or lock up or communication failure.
5. conductor failure or Heating
6. Electronic equipment shutting down.
7. Flickering of Fluorescent Lamps
8. Fuses blowing for no apparent reason.
9. Motor failures and over heating.
10. Neutral conductor and Terminal failures.
11. overheating of Metal Enclosures.
12. Power Interference on Voice communications added noise
13. Transformer failures and over heating

Good Power Qulity describes

(i) Power supply always available

(ii) Always within Voltage Tolerences

(iii) Always within frequency Tolerences

(iv) Pure Noise-free Sinusoidal Wave shape.

Electricity is unlike the other Products. Quality can not be assessed before delivery. It is used at the time of Production, but some distance away from the Point of Production having Passed through several Transformers, many Km's of Transmission lines and mixed with output of other generators. It is not Possible to withdraw Poor quality of electricity from the supply chain.

IEEE : concept of Powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment. (IEEE Standard 1100)

IEC(61000-1): Elecromagnetic compatibility is ability of equipment or a system to function satisfactorily in its electro-magnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

According to IEEE Std. 1100, PQ is defined as

The concept of Powering and Grounding sensitive equipment in a matter that is suitable to the operation of that equipment.

According to IEC 61000-1

Electromagnetic compatibility is ability of equipment or a system to function satisfactory in its electromagnetic environment with out introducing intolerable electromagnetic disturbance to anything in that environment.

Main Sources of PQ Problems

Problem	Source	Commercial	Public	Industrial
Harmonics	computers	71%	78%	34%
	Inductive load switching	5%	—	22%
	switched mode Power supplies	10%	17%	22%
	combination of factors	14%	5%	22%
Earth Leakage	Computers	100%	100%	41%
	Process control equipment	—	—	59%
Voltage disturbance	Lightning	—	—	—
Transients	Inductive load switching	12%	31%	43%
Dips	From the utility	88%	69%	57%
Ripple	Heavy Load switching	—	20%	40%
	From the ulility	100%	80%	30%
	Large cyclic loads	—	—	100%

Sector	Harmonics			Earth leakage			Voltage Disturbance		
Frequency of occurance	High	med	low	High	med	Low	High	med	Low
Commercial	71%	20%	9%	20%	31%	49%	51%	27%	22%
Public	60%	20%	20%	31%	31%	39%	31%	49%	20%
Industrial	60%	31%	9%	40%	31%	29%	40%	31%	29%

Frequency of occurance of PQ Problems.

Sector	Harmonics	Earth Leakage	Voltage Disturbance
Commercial	91%	51%	78%
Public	80%	62%	80%
Industrial	91%	71%	71%
Total	87%	61%	76%

Scale of occurance of PQ Problems