POWER QUALITY – Developed countries improved & it's time for India

1 INTRODUCTION

The quality of electrical power is an important contributing factor to the development of any country and poor power quality of electrical power is hindering industrial growth in India. It is estimated that every year, a substantial revenue loss is suffered by the utility and the industry, due to poor power quality. Government's initiative of 'Make in India' has attracted global players to set up industries in India. At present, India doesn't pose a very good image when it comes to the quality of electricity supply. This is the major reason for the slow growth of manufacturing facilities / plants set up by foreign companies.

USA was the flag bearer in power quality domain and started journey way back in 1985. Journey started with understanding power quality issues, root causes, how to monitor it. Then they formed regulations & standards. Standard & regulations formed by involvement of experts from electricity companies, regulators & industries. European countries started with EN 50160 as a basis for regulation more than a decade ago. PQ monitoring helped in identifying weak areas, deploying mitigation techniques and their effectiveness. Later, they made criteria and compliance limits stricter, to further improve grid stability. Power quality issues and its impact on businesses and consumers are reduced significantly in due course of time. Monitoring is done mainly at permanent locations with the emphasis being placed on substations and industries (HV / MV) using power quality metering instrument, complying with IEC 61000- 4-30 Class A and compliance with EN 50160 or country-specific regulation is also ensured.

The entire Europe is interconnected with a single grid and supplies to over 400 million customers in 24 countries. India is no longer different from Europe as far as the electricity grid analogy is concerned. Europe comprises a single grid for different countries, while India comprises a single grid for different states. In 2014, India achieved a very ambitious goal of 'One nation-one grid-one frequency' by connecting all five regional grids together. 2019 must be a year for deploying harmonised regulation for power quality across all states in India.

This article begins with a simplified explanation of power quality and its relationship with power quality parameters defined in standards and regulations. Causes of poor quality and impacted parties are described in the subsequent section. Readers will get an insight into prevailing power quality regulations, monitoring practices and current status. Benefits of continuous power quality monitoring and integrated solution for revenue meter with power quality is emphasised.

Finally, the article concludes with recommendations to the regulatory bodies, utilities, commercial & industrial users and renewable energy generation companies.

2 POWER QUALITY FUNDAMENTALS

Electricity is a commodity and should be fit for consumer use. Good quality of electricity possess the following attributes:

- Continuity of supply
- Stability of rated magnitude
- Stability of rated frequency
- Purity of sinusoidal waveform
- Symmetry across phases

Any discrepancy in the above attributes results in poor power quality as depicted below.

Discrepancy in:		**Results in**:
Continuity of supply	⇨	Interruptions
Stability of rated magnitude	⇨	Sag, swell, flicker, under / over deviation
Stability of rated frequency	⇨	Under / over frequency
Purity of sinusoidal waveform	⇨	Harmonics and inter-harmonics
Symmetry across phases	⇨	Voltage and current imbalance

3 POWER QUALITY CAUSES & EFFECTS

Electricity supply characteristics are subject to variations during the normal operation in a supply system due to changes in load, disturbances generated by certain equipment and the occurrence of faults which are mainly caused by external events. Increasing use of semiconductor-based electronic equipment and non-linear loads (such as computers and its peripherals, data servers, adjustable speed drivers, arc furnaces etc.) along with rapid integration of non-conventional energy sources into the grid network throws new challenges to the PQ environment.

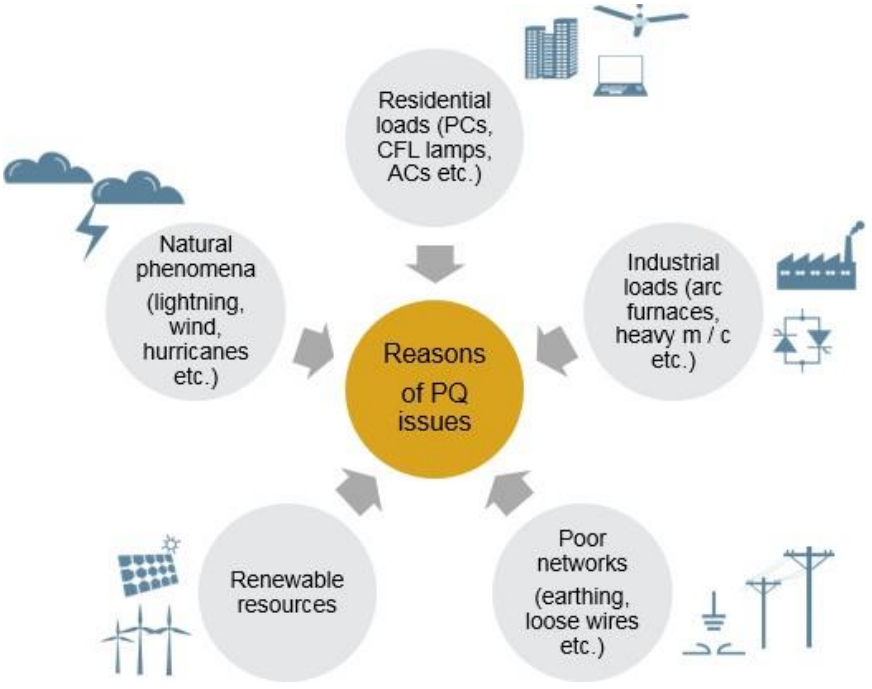


Figure 1: Causes of poor power quality

The supply characteristics randomly vary with time and with reference to any specific supply terminal, or any given instance of time.

Parties affected by power quality issues are:

- End users
- Equipment and system manufacturers
- Designers of plants and installations
- Electricity distributors
- Public authorities
- General public

4 LOSSES DUE TO POOR POWER QUALITY

Due to the poor quality of electricity supply, most large industries in India incur heavy cost. This is because of:

- investment in costly captive power generation unit(s)
- paying for feeder level above 22kV or an express feeder at additional costs

Industries without the capability of backup supply or provisions to work in poor power quality environment incur losses because of:

- lost productivity, idle people and equipment
- additional labour cost due to overtime (to meet targets)
- cost of scrap generated due to poor power quality
- costs to restart the plant
- equipment damage and repair
- lost orders, goodwill, customers and profits
- lost transactions and orders not being processed in time
- customer and / or management dissatisfaction

In reality, power quality issues in the distribution network are many more:

- supply voltage fluctuations
- harmonics and inter-harmonics
- sag, swell, interruption, flicker
- asymmetry of three-phase voltages
- rapid voltage change
- low true power factor due to harmonics
- higher failure and cable damage rate
- neutral overshoot
- mains frequency deviation / variation

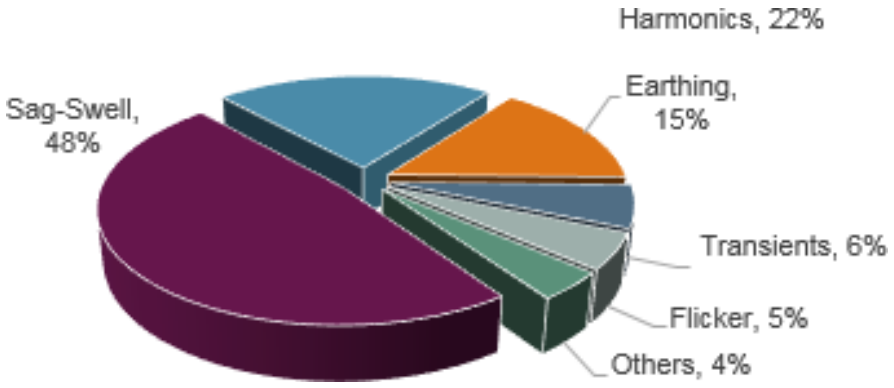


Figure 2: Loss due to different power quality events

5 COST OF POOR POWER QUALITY

The outcome of some surveys is given below, which reveals losses to industries due to poor power quality.

“A Voltage sag in a paper mill can waste a whole day of production - $250,000 loss”

Source: Business Week

A manufacturing company lost more than $3 million in one day last summer in Silicon Valley when the “lights went out.”

Source: New York Times

Unplanned data centre outages cost companies nearly $9,000 per minute.

Source: Emerson network power study

Half of all computer problems and one-third of all data loss can be traced back to the power line. This data is commercially very sensitive and could be priceless. The ill- effects of poor PQ on data centres can be drastic.

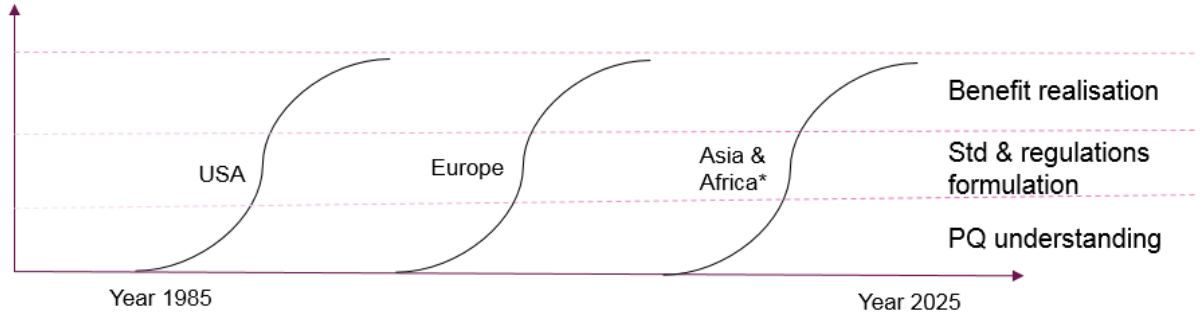
Source: Contingency Planning Research, LAN Times

Main conclusions of surveys on costs due to poor voltage quality (source: CEER 4th benchmarking report)

Country / year	**Estimated annual costs**
Norway by NVE and stakeholders (2002)	Estimated annual costs due to dips for end-users between 120 and 440 million Norwegian kroner.
Sweden by Elforsk (2003)	Estimated annual costs for industrial customers due to dips and interruptions at about €157 million.
Italy by AEEG and Politecnico di Milano (2006)	Estimated annual costs due to dips and interruptions (< 1 s) for the whole production system between €465-780 million
Pan European survey by Leonardo Power Quality Initiative (2005-2007)	Costs of PQ wastage EU- 25 exceeds € 150 billion annually.

According to the study carried out by Asia Power Quality Initiative (APQI), the direct costs of downtime in India are nearly ₹ 20,000 crores per annum. Voltage sags & short interruptions are the major contributors for these losses. However, the cost of prevention for these may be less than 10 per cent of the cost of the problems they cause.

6 POWER QUALITY MONITORING PRACTICES IN DEVELOPED COUNTRIES



USA was the Flag bearer in power quality domain and started journey way back in 1985. Journey started with understanding power quality issues, root causes, how to monitor it.

Then they formed regulations & standards. Standard & regulations formed by involvement of experts from electricity companies, experts, regulators & industries. European and developed countries started with EN 50160 as a basis for regulation more than a decade ago. PQ monitoring helped in identifying weak areas, deploying mitigation techniques and their effectiveness. Later, they made criteria and compliance limits stricter, to further improve grid stability. Power quality issues and its impact on businesses and consumers are reduced significantly in due course of time. Monitoring is done mainly at permanent locations with the emphasis being placed on substations and industries (HV / MV) using power quality metering instrument, complying with IEC 61000- 4-30 Class A and compliance with EN 50160 or country-specific regulation is also ensured.
Electrical Industry in the developed world does not wait for regulations and frame-work around measurement, management and control of power quality as these impact their day-to-day business and well-being. India is no exception. In India, big industries install power quality meters to identify, solve and manage their own problem. They seldom come out in public to challenge causes beyond their network boundaries, like poor regulation of network, or harmonics generated by the neighbouring industry. This also means that the PQ knowledge is not pooled and leveraged at the industry level.

7 REGULATIONS ON POWER QUALITY IN VARIOUS PARTS OF WORLD

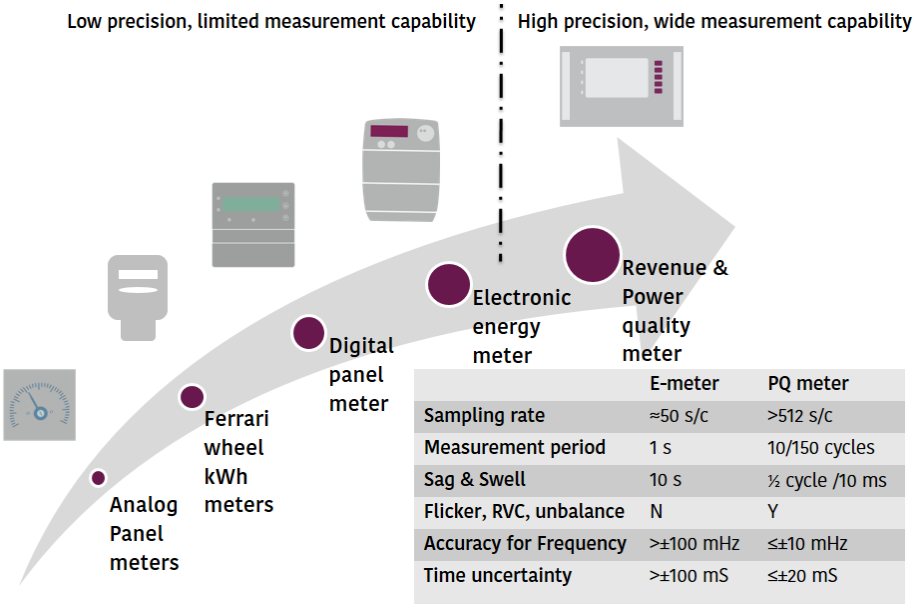
All the European countries have adopted the standard EN 50160 as the basis for voltage quality legislation, regulations & standardization more than a decade ago.
EN 50160 defines voltage characteristics of electricity supplied by public electricity networks covering LV, MV and HV. It describes the limits or values within which the voltage characteristics must be. For example, during each period within a week, 95 per cent of THD values shall be less than or equal to 8 per cent. Similarly, limits are defined for mains frequency, supply voltage variations, rapid voltage changes, flicker, supply voltage unbalance, individual harmonic voltages, inter-harmonic voltages, mains signalling voltages. This standard also specifies a framework for statistical evaluation of voltage sag and swells by classification based on the duration of an event and residual / swell voltage.

In India, there are electricity supply quality regulations applicable for generation, transmission and distribution companies. The objective of these regulations is to help in maintaining the standards of the electricity grid and to protect the interest of consumers. These regulations have been specified by the Central Electricity Authority (CEA) and the Central Electricity Regulatory Commission (CERC) at a Centre and the State Electricity Regulatory commissions (SERC) at the state level, as per the provisions of the Electricity Act, 2003.
At present, State level regulations cover harmonic distortion (mostly THD), voltage variation and voltage unbalance. But it does not focus on other important parameters of power quality (e.g. voltage sag, swell, interruption, flicker, voltage inter-harmonics, current harmonics etc.) Also, all the states do not have power quality regulations, and where they do, they don't always regulate the same parameters. This creates disparity and gives certain geographical advantage / disadvantage.
CEA regulations, Technical standards for connectivity to the grid & Technical standards for connectivity of the distributed generation resources are amended and come into force after publication in official Gazette in Feb-2019.
Amendment have following inclusions/modifications for power quality monitoring:

- Continuous Power quality monitoring using power quality meter complying to IEC 61000-4-30 Class A by a distribution licensee and consumers (11 kV & above)
- Harmonic measurements at point of common coupling and limits as per IEEE 519-2014
- Distribution licensee shall install power quality meters in phased manner within three years from the date of commencement of this regulation
- Data measured & metered shall be available with distribution licensee and shall be shared with the consumers periodically

8 ADVANCEMENTS IN METERING TECHNOLOGIES

The world has witnessed much technological advancement in each and every area; metering domain has also grown leaps and bounds. Journey from analogue panel meter to electronic energy meter was long.



	E-meter	PQ meter
Sampling rate	≈50 s/c	>512 s/c
Measurement period	1 s	10/150 cycles
Sag & Swell	10 s	½ cycle /10 ms
Flicker, RVC, unbalance	N	Y
Accuracy for Frequency	>±100 mHz	≤±10 mHz
Time uncertainty	>±100 mS	≤±20 mS

Figure 3: Advancements in measurement technologies

Advancements in semiconductor and high speed processing technologies made it possible to accurately measure harmonics, very short term sag, swell, flicker and other PQ parameters. Power quality meters sample at 512 samples / cycle and are capable of recording sags and swells as small as 10mS (1/2 cycle) with an accurate time stamp.

9 CONTINUOUS POWER QUALITY MONITORING

Continuous monitoring of power quality can be achieved using a fixed installed power quality meter complying with IEC 61000-4-30 Class A.

It conducts a continuous health check of the electricity network connected to it, by:

- monitoring harmonics flow between load and supply, and its direction
- monitoring power quality events like sag, swell, interruption and their severity
- monitoring other important parameters like mains, frequency, flicker, supply unbalances, k-factor etc.

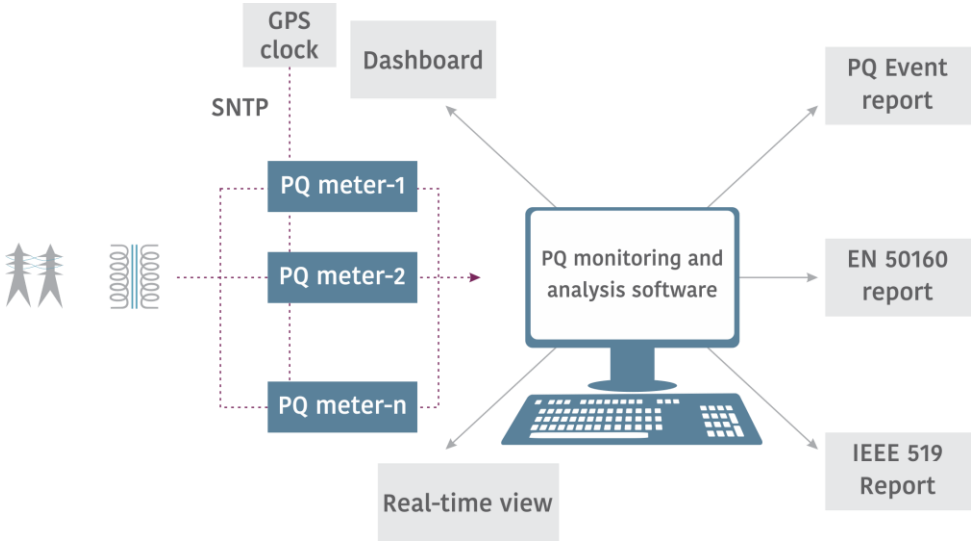


Figure 4: Typical system for continuous power quality monitoring

Power quality meters are used to view, monitor and analyse data to initiate a plant/equipment maintenance programme. These meters also act like the black box of an air plane, providing information on what went wrong and when a poor power quality event occured. In nutshell, continuous power quality monitoring detects, records and leads to the correction and prevention of all power quality problems. Improving power quality is a journey, which starts with the first step of measurement.

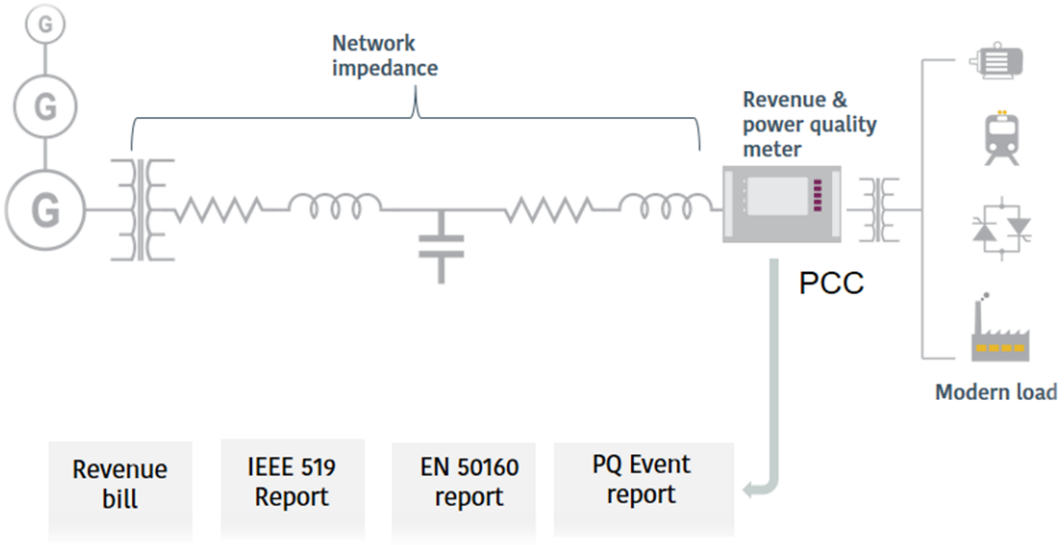


Figure 5: Integrated solution for revenue metering and power quality monitoring

As world is moving towards more and more integration, the above state-of-the-art solution combines both revenue metering and power quality in one box. Hence provides vital piece of information for revenue metering along with power quality monitoring to user.
This solution gives:

- comprehensive report on voltage quality compliance (EN 50160 or equivalent nation standard)
- report card of harmonic emission measurement (according to IEEE 519)
- log of power quality events and power quality parameters (according to IEC 61000-4-30) recorded during predefined period with indications for whether cause of event or harmonics is supply side or load

10 CONCLUSION

The quality of electrical power is an important contributing factor to the development of any country. Developed countries do not wait for regulations and frame-work around measurement, management and control of power quality as these impact their day-to-day business and well-being. They use power quality monitoring as a tool to identify weakness
Poor power quality of electrical power is hindering industrial growth in India. It is estimated that every year, a substantial revenue loss is suffered by the utility and the industry, due to the supply of poor power quality.
If these problems are not handled effectively, and in time, then utilities and their customers may be adversely affected in the next few years. It may even result in a slower pace of growth for India.

Here are a few recommendations to improve power quality:

- Increase power quality awareness among transmission and distribution companies and bulk electricity consumers
- Regional & state electricity regulatory commission should implement CEA regulation amended recently for power quality monitoring

- Regulatory bodies should build and implement a regulatory framework with incentive and penalisation mechanism for power quality
- Electricity metering for revenue should be done along with power quality monitoring. Quality and quantity of electricity should be considered together for billing purpose
- Distribution companies should monitor power quality at the point of interface between Transco to understand what PQ they receive and what collective actions are needed to improve it, with the objective of managing it
- Monitor power quality generated by non- conventional energy sources at a grid network level
- Power quality performance should be displayed in the public domain
- Utilities should monitor power quality to identify 'polluting' consumers and facilitate efforts to reduce the amount of harmonics injected into the network by such consumers

References:

[1] IEC 61000-4-30:2015 Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods

[2] EN 50160:2010 European standard for Voltage characteristics of electricity supplied by public electricity networks

[3] IS17036:2018 Indian standard for Distribution system supply voltage quality

[4] IEEE 519:2014 IEEE recommended practice and requirement for harmonic control in Electric power systems

[5] CEER bench marking report on quality of electricity supply

Author's Introduction:

Devendra Vyas is working at Secure Meters Limited as a Senior Manager, leading development of high-end metering products & solutions. He has worked in various diversified areas throughout his career like project management, embedded software development, design & development of energy meters (residential, industrial, smart meters, pre-payment meters & grid meters), simulation & modeling of current & voltage transducers, development & maintenance of calibration & testing laboratory. He has been participating for power quality initiatives in India and interacting with utilities, test laboratories & power quality experts of developed countries for last many years.

Devendra is graduate in electronics & communication engineering and MBA in operations management. He is based at Udaipur (INDIA) and having 23 years of experience of research & development in energy metering domain.