CHAPTER 3

ECONOMIC ASPECTS OF POWER QUALITY

3.1 INTRODUCTION

The poor PQ hurts industrial competitiveness drastically and thereby impedes our efforts to turn into an global supplier. In this IT era, there is a rapid increase on the usage of computers in almost all the sectors of industry, i.e. commerce, business, trade, finance, healthcare, etc. The latest electronic gadgets and equipments are sensitive to various aberrations, prompting the need for regular and reliable power, and the India’s State Electricity Boards simply find it difficult to deliver. The users are eventually accountable for the protection and proper function of their equipments. The awful power quality and the need to have clean power for the informatics infrastructure are the two regrettable realities of today’s electronic age in India. The six vital adversaries, who prompt this, are:

- Voltage sags
- Total failure of power or blackouts
- Voltage spikes
- Voltage surges
- Electrical noise
- Waveform distortion

In India, even in metropolitan cities like Hyderabad, there could be unpleasant blackouts each day, several of them lasting even hours. Sags, spikes, surges, noise, and distortion are everyday realities.
Besides damaging computers and other electronic equipments, poor power quality costs consumers a lot due to the substantial damage caused to the everyday electrical appliances i.e. bulbs fuse, motor windings burn, synchronous clocks fails to show the accurate time, air compressors burst, and pump sets need high-priced repairs all the time. In computers, keyboards lock, motherboards burn, at times even hard disk fails to read, loss of previously written files or loss of complete data. Unfortunately, in India, things are unlikely to improve for the next decade or so, even with large scale privatization. There is a necessity to address this grave situation at the earliest [36].

Fortunately, with the latest technological advancements, majority of these issues, have been successfully resolved. Power electronics in combination with microcontrollers and switching logic have facilitated us to get rid the opponents of the regular and reliable power. PQ related issues also appear from the augmented fine tuning of the contemporary commercial industrial equipment. The variable speed drives, automated CNC machine tools, programmable logic controllers, computers, are far more susceptible to turbulence on the commercial line voltage than the earlier generation of the electromechanical equipment. The power sensitive equipment is often so susceptible that even aberrations for a fraction of a second can put the whole industry into dismay.

The poor PQ might initiate a chain of technical troubles thus aggravating a great monetary loss. Here, an outline of diverse PQ issues as faced by the various consumers in different parts of the
world is presented. Few technological and financial implications on account of poor PQ are discussed in brief. The obligation for PQ regulation at the POC is highlighted, to characterize the accountability of the associated parties: i.e. the network operator, the equipment manufacturer and the consumers [37].

3.2 SURVEY ON POWER QUALITY PROBLEMS

Power quality is generally viewed as a blend of voltage and current quality. It is usually opined that the network operator holds the responsibility for voltage quality (VQ) at the point of connection (POC) but the current quality (CQ) at the POC is mostly influenced by the consumer’s loads. These two qualities of VQ and CQ manipulate each other by joint interface and this might distort the power supply at the POC. PQ disturbances can be classified into two types [37]: 1) ‘continuous’ or ‘variation type’ and 2) ‘discrete’ or ‘event type’. Continuous type disturbances are present in every cycle and typically include voltage variations, unbalance flicker and harmonics, while the discrete type disturbances appear as isolated and independent events and mainly include voltage sags, swells and oscillatory or impulsive transients [37].
3.2.1 Power Quality Complaints

The distinctive PQ grievances occur from the consumer side when the operation of the consumer’s susceptible devices (for example data processing equipments, computers, electronic ballasts, variable speed drives) is affected, resulting in the partial loss of data, corruption or complete loss of data, physical damage of sensitive devices, flickering of computer screens, or complete loss of the power supply [38]. Analyzing the nationwide and local surveys in India and other countries like USA, Netherlands it was found that nearly 69% of PQ issues at the POC are generally caused by the consumers themselves or their neighbours by the operation of the appliances at their location, while the other 31% of PQ issues are created from the network side due to natural events or other reasons, as shown in Fig 3.1

![Power Quality Disturbances](image)

Fig 3.1 Power Quality disturbances
(a) Initiated by consumers (69% of total)
(b) Initiated by utilities (31% of total)
The Voltage flicker and under-voltage issues are the two vital PQ problems as shown in Fig 3.2. It is observed that the major chunk of the power quality complaints are recorded from the domestic consumers (56%) followed by commercial (12%), agricultural (11%), industrial (10%) and other consumers (11%) [38]. It is found that the main PQ complaints in a distribution network with overhead lines are due to voltage sags and voltage transients because the network is more prone to natural disturbances. The distribution networks with underground cables have issues like harmonics and resonances. The capacitive impedance of the cables interacts with the inductive impedance of the network components and their by causing the resonance problem [38].
### 3.2.2 Possible Causes of Power Quality Problems

The frequency of PQ disturbances and their associated issues depend on many factors such as[38]: the type of customer and the equipment under use, the topology and length of the electric lines supplying the customers and the geographical area[38]. The reasons and severity of PQ problems varies with climate conditions, operating practices and the behaviours of the load. The various circumstances by which the PQ problems occur are as follows [39]:

a) Natural phenomena that leads to system disturbances. It can be due to the weather (e.g. storm, lightning etc.) and animal activity.

b) Normal utility operations that include capacitor and load switching which cause transients in the power system operation.

c) Neighbouring customers who are connected to the same or adjacent feeder of the network might cause PQ problems by to the operation of large or periodic high demand loads.

d) The operation of customer’s sensitive loads which have nonlinear behaviour and produce current harmonics during their operations. The current harmonics in addition to the network disturbances generate different distortions in the power supply voltage waveform at the consumer’s POC and their by cause poor PQ of the electric supply.

The domestic consumers use diverse susceptible electronic devices i.e. personal computer (PC), digital video recorder (DVD), micro-oven, digital LCDs, LEDs etc. These devices are susceptible and responsive to various PQ disturbances. All these domestic appliances have nonlinear current features that generate current harmonics in
the network and distort the supply voltage waveform in addition to the network disturbances [39]. The wide use of energy efficient lamps, such as compact fluorescent lamp (CFL) with electronic ballast, is generally promoted as it promotes usage of lesser active power when compared to the conventional incandescent lamps. The drawback with the CFL is that they tend to produce the reactive power and harmonic distortions much more than the incandescent lamps [39].

3.3 EFFECTS OF POOR POWER QUALITY

The effects of poor PQ on the electrical equipment differ from equipment to equipment. The equipment differs from another by the kind of susceptibility of electronic equipment; it differs in terms of magnitude and intensities of electrical stress that it can bear before failing. The critical factors that determine the tolerances of the equipment are as follows [40]:

- the nature, magnitude and duration of the PQ event
- the frequency of the event
- the sensitivity of the component to the event
- the location of the equipment within the customer’s installations
- the age of the component

The loss of the power supply causes operational hassle to the consumer and monetary losses for the consumer and the utility. In the industrial production unit, the cost of unsupplied energy due to an outage is much higher than the cost of the supplied energy [40] that is supplied when needed. An outage or a disruption event even
for a few seconds can lead to the loss of production from few minutes to even hours depending on the regeneration time of the whole process.

3.3.1 Technical Consequences

The diverse PQ issues have varying effects on different kind of consumers. The power supply disturbance is often incorporated in the reliability analysis of the power system. Voltage sag is one of the most significant PQ issues as it has often a direct impact on the consumer’s services and its finances. The Industries such as semiconductor industry, paper plants, glass and steel industries etc. suffer technically and financially on account of voltage sags. At times the entire plant operation gets interrupted and it takes time to resume its operation. So, the voltage sag is considered as a critical problem for continuous process operation. Sudden voltage sags can also cause inconveniences to the commercial consumers as they might damage the equipment and get low on business by down time, data loss etc [40].

For household customers, voltage sag might cause regular disturbances and hamper the tempo of completing the normal work. The Voltage sag is measured by the magnitude of voltage drop and its duration. Different devices have different sensitivity towards voltage sags and are described by their individual voltage tolerance curves. When voltage sag occurs, the voltage available at the equipment terminal is lower than the nominal voltage. If the available voltage at
the equipment terminal is less than its minimum voltage limit for duration longer than the maximum tolerance time, the equipment will shutdown [41]. Many modern power electronic devices experience operational problems when the voltages at the terminals drop below 85% of the nominal voltage for duration longer than 40 ms [41].

The PQ problems originated from natural events or due to the switching of large loads. High frequency noise is also a PQ problem that causes equipment failure and data error. It is noticed from statistical records that in the electricity network voltage sags occur more frequently than transient surges. A current surge that accompanies a voltage sag recovery is mainly the cause of equipment damage [17], [41].

Many 1-Φ loads generate hefty of 3rd order (or its multiple number) harmonic currents that overload the neutral conductor and cause excessive heating. The apparatus, with nonlinear current characteristics, cause a distortion in the supply voltage waveform. This will change the power factor of the system to a lower value and the reactive power demand will be augmented. Thus, various network components might be overloaded as the demand of total apparent power, which is a combination of active and reactive power, will be increased. In Figure 3.3, the technical consequences of PQ problems are shown from the survey of the Copper institute at 1400 sites in 8 countries[41].
Short duration voltage changes resulting from switching, short circuits and load changes can cause flicker. It is an irritating problem for human eye’s perception. The residential customers have inconveniences due to light flicker, flickering of computer screen or television screens etc. This problem generally does not have direct financial impacts. Flicker does not cause harmful equipment damage. Nevertheless, excessive flicker can cause physical sickness for people (for example: migraine and ‘sick building syndrome’) [41].
3.3.2 Financial Implications

Electric power quality issues can have considerable financial implications for different types of facilities. The direct and indirect cost rises heavily due to poor power quality. It is very difficult to calculate the precise amount of loss when a PQ event or a voltage disturbance occurs. Field surveys, client’s interaction and studies are done to calculate approximately the cost of poor PQ of the electric supply.

The three main factors which are often considered for accurate assessment of PQ cost are disturbance report at the bus bars involved, customer load susceptibility and the calculation of losses induced by damage or malfunction of equipment or process interruption. It may happen that a PQ problem that is initiated from a manufacturing plant may affect the operation of the nearby neighbouring industry. The actual financial losses are customer specific and that depend a lot on other factors including customer category, type and nature of the activities interrupted and the customer size. The various costs of poor PQ can be broadly categorized as follows:

Direct Costs: This cost is associated with production loss, product damage, equipment damage, loss of raw material, salary costs during non-productive hours, extra maintenance etc.

Indirect / Hidden Costs: Costs of lost sales, cost of premature equipment damage, costs of out-of specification products delivered or services rendered, costs associated with poor reputation for non-delivery etc.
Non-material Inconveniences: Some inconveniences due to PQ disturbances cannot be expressed in terms of money (for example: loss of entertainment).

Two distinct methods of measuring the economic impact of poor PQ have been identified. The first method is the direct method which is an analytical approach to consider the probabilities and impacts of the events. This method leads to a precise answer about the cost of a PQ event but it is often difficult to obtain correct input values. The second method is an indirect method, which considers historical data for analysis and also takes the customer’s willingness to pay for solving PQ problem [42].

Fig 3.4 Percentage cost of PQ aspect

It is shown in Fig 3.4 that 57% of the total financial loss is by voltage sags and short interruptions, while 35.2% of the losses are
due to transients and surges; other 7.8% financial losses are by harmonics, long interruptions, flicker, earthing and EMC problems.

Actually estimating the costs of poor power quality in different sectors (and customers) is a very tough task. The reference of representation of the cost data is distinct, which makes it difficult to compare the financial loss figures among various customers. Hence, a proper classification method for the analysis of data is required.

3.4 Economic Aspects of PQ in INDIA

The Electricity Supply Monitoring Initiative (ESMI), Prayas is an Indian non-governmental, non-profit public charitable trust actively working in the areas of health, energy, learning, and parenthood initiatives. The concept of ESMI is to execute basic monitoring system to know about the supply continuity and voltage levels at ordinary consumer locations, in order to get an understanding of actual picture in practice and to increase the accountability of electricity utilities. A data logger records the supply voltage at one minute intervals, as well as makes a note of the timing and duration of supply interruptions.

The results might look startling for PQ experts who are used to IEEE standards. In the first monitoring week:

- The rated voltage was supplied only for 23% of the time
- The low voltage was supplied for the majority 69% of the time
- The voltage was very low 7% of the time
- There was no supply at all 1% of the time
The last figure means that there were outages for one hour and forty minutes during that week. The study was undertaken by a research firm, Feedback Consultancy, covering 325 firms across six centres—Mumbai, Delhi, Bengaluru, Chennai, Kolkata and Hyderabad. This, in turn, was divided across eight major industry segments, namely telecom, IT services, IT-enabled services, ISPs, banking & finance, services and manufacturing. The findings of the study have turned out to be a real eye-opener for Indian industry. For instance, as power outages are not as exciting as compared to other disasters, the common perception has been to treat power disruptions as minor irritants. And while the problem of power outages cannot be solved overnight, it is important for the organisations to take the next best step—invest in solutions that can help in overcoming from power disruptions.

Even in Bengaluru, the silicon capital of India, only 2 percent of companies says that they have never encountered power disruptions. Obviously, if Bengaluru needs to continuously attract new investment, it needs a higher figure than the meagre 2 percent. This number is insignificant when compared to other cities, i.e. 4.1 percent of firms in Chennai, 4 percent in Delhi, 21.5 percent in Hyderabad and 18.4 percent in Mumbai say they have never experienced power disruptions.

Most of us don’t bother to do much beyond cursing power utilities whenever a power disruption takes place. And while a power disruption at home may not cost much—the same, if it takes place in
a commercial and industrial sector can run into crores of rupees. That is exactly what a study commissioned by the Manufacturers Association of Information Technology (MAIT) and Emerson Network Power (India) reveals. The cost of downtime for India Inc. is a staggering Rs 20,000 crores in direct losses due to poor power quality and downtime impact. This accounts for roughly 2 percent of the gross output of the industrial and service sectors.

There is a need to identify the origin of power quality disturbances by the scientific methodology, so that the features of disturbance can be recognized for further classification.