

## Real Time Power Quality Phenomenon for Various Distribution Feeders

C. Bharatiraja\*, Harish Chowdary V

Department of Electrical Engineering, E&T, SRM University

\*Corresponding author, email:bharatiraja@gmail.com

### Abstract

Power Quality (PQ) brings more challenges to the large- scale and medium scale industries because in the recent years most of them use high efficiency and low energy devices which cause vulnerable PQ disturbances at Point of Common Coupling (PCC). In this paper, the measurement at different times during load condition and analysis of all types of disturbances occurred has been done. When large rated equipments run, the disturbance (harmonics, RMS variations, and switching transients) levels are very high and poor power factor (PF) has also appeared. Due to this poor PF, reactive power consumption in load increases and accordingly total power increases. An electronic device such as LED lights, fluorescent lamps, computers, copy machines, and laser printers also disturb the supply voltage. We are very well known that every PQ problem directly or indirectly must affect economically. Many researchers have investigated PQ audit for over three decades. However these studies and analysis have been done only at simulation level. Hence, the PQ analyzer based study is required to find out the PQ issues at distribution feeders. It will be a valuable guide for researchers, who are interested in the domain of PQ and wish to explore the opportunities offered by these techniques for further improvement in the field of PQ. This paper gives a brief Real Time PQ measurement using PQ analyzer HIOKI PW3198 at Distribution Feeders and it gives an idea to the researcher to optimize problems-related to PQ with respect to the high rated and low rated electric machinery of different feeders at PCC level. This study further extends to analyze the grid disturbances and looks forward to the optimization methods for each individual PQ disturbance.

**Keywords:** power quality, monitoring, disturbances, and results

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### 1. Introduction

Power Quality (PQ) is a small term but this phenomenon includes various disturbances & various situations in which the sinusoidal voltage and current waveforms deviates from its quality at rated frequency [1]. Our human life collaborates with electrical equipment and electronic gadgets by the boon of technology. In the earlier days the power quality (PQ) disturbances were not that much of an issue but over the past decades, the use of electronic devices, the converter based drive system & variable frequency drives which are controlled by semiconductor switches has dominantly increased PQ disturbances. So, the non-linear characteristics of this kind of load creates enormous PQ issues to the consumer. The major PQ issues cover sudden and short duration variations such as harmonics, flicker, voltage sags, short interruptions, oscillatory and impulsive transients as well as steady-state deviations [2]. The subject of PQ is raised quite often due to increase of size and capacity of the power system, which becomes intricate and heads towards reducing reliability. Voltage interruptions and voltage sags most commonly are originated from faults in the power system network, which causes tripping of sensitive loads (relay, PLC) in industries where the equipment brings about stoppage of production accompanied by high budget [3]. These disturbances have direct economic impact on industrial consumers. To avoid the economic losses and to protect the plant, industrial consumers install mitigation equipment. Some loads (like converter load) draw commutated current that disturbs the source. The diode bridge rectifiers are a major source of producing harmonics into the power system network and the concerns vary from electrical components overheating (like winding heating leading to failure/breakdown of the machine) to communication interference in communication lines [4]. The demand goes on increasing

because the consumer installs new capacity into the network. This imposes deep research and study on 'Power Quality'. Many industrial consumer has concerns regarding Power Quality [5].

In the current scenario, the utilization and consumption of power is comparatively very high. Meanwhile, the significance of PQ is playing a dynamic role for an uninterruptable and effective power supply. According to central electricity authority govt. of India (CEA), the total installed capacity has reached 278733.62 MW in India as on 30th September 2015. This intends that a massive number of electrical installations are being newly deployed in the power system network, which challenges the reliability and quality of power in the power system network. Unfortunately, some non-linear characteristic equipment which creates the distorted voltage at the supply side and leads to poor power quality [6]. PQ determines the health of electrical power to the consumer equipment and the overall concept of PQ depends on the consumer. The voltage which is free from all sort of disturbances is a good one.

Different consumers have faced distinct disturbances that pollute the voltage waveform away from its purity. PQ issues are causing continually increasing load which disturbs the supply [7]. PQ is a blend of current quality and voltage quality but we cannot control the currents because current depends on the load. So, we can only control the voltage. If we succeed to maintain the voltage within the tolerable limits, then we get a good quality of power. In brief, power quality disturbances may cause equipment malfunction, memory malfunction of sensitive loads such as a computer, programmable logic controller controls; protection and relay equipment; and erratic operation of electronic controls [8]. So, it is obligatory to monitor because the demand goes on increasing as suggested in [9-11] and monitoring standards are available from Ref [12]. Figure 1 representing the single line diagram of the distribution network having the ratio 33/11kV and 11/0.433kV to the load. This distribution network is connected to the various Feeders of different loads.

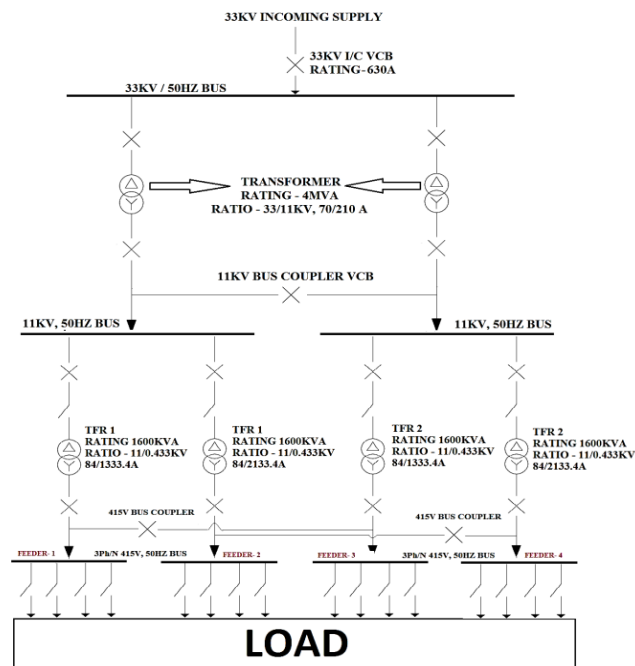


Figure 1. Single Line Diagram of a Distribution Network

In this, the complete measurement is done by HIOKI PW 3198 power quality analyzer and the software used is HIOKI PQA-HIVIEW PRO 9624-50 for the analysis which is very helpful and makes the process of finding the disturbance very simple. Some of the disturbances which play a key role in the quality of power are frequency, harmonics, voltage sags/swells, interruption, transients, and flicker. Harmonics are caused by non-linear loads which may cause

damage to the electrical devices. Many standards are available for the classification of harmonic levels in the distribution system as specified by different standards such as IEC 61000-3-2, IEEE-519 and IEC 61000-4-30 [13]. These power quality standards are verified and referred while analyzing and monitoring the system.

## 2. Different Power Quality Disturbances & Issues

Here the PQ monitoring and study deals with three different types of distribution feeders which are CVD-Chemical vapour deposition (feeder-1), SIC-Silicon carbide (feeder-2) and LDB-Lighting distribution board (feeder-3). These feeders are connected to the non-linear characteristics of the load which are primarily the cause of different power quality problems. Figure 1 represents feeder connections to the load and also the distribution structure. The disturbances are monitored and analyzed over the weeks with the help of a PQ analyzer HIOKI PW 3198. These disturbances create some issues within the network. Some disturbances play a key role which is clearly mentioned in results and discussions. All the PQ disturbances and problems caused are mentioned as follows.

- a. Frequency fluctuations: these are due to line disconnection caused by changes in supply stability or some circuit issues and these fluctuations change the speed of a motor.
- b. Voltage sag (Dip): system faults, loose connections, switching ON large loads and switching ON/OFF power factor correction capacitor bank causes voltage dip.
- c. Voltage swell: Turning OFF heavy loads, switching ON/OFF power factor correction capacitor bank causes voltage swell.
- d. Transient overvoltage (surge or impulse): transients can originate internally within the building or externally by utility power lines. They represent about 12 to 15% of all power line problems [14]. Due to this, power is exceptionally damaged and loses the wiring.
- e. Flicker: it consists of voltage fluctuations from sources such as thyristors control loads, arc welding, and blast furnace. It causes the light bulb to flicker.
- f. Interruption: interruptions and power outages can originate from electrical short circuits in building wiring or utility power lines [14]. It results in circuit breakers being tripped.
- g. Harmonics: these are originated by non-linear loads. It causes overheating of transformers, motors, and cables. It overloads the power factor correction capacitors and it is a source of the fuse gets blown, relay trip and meter misoperation.
- h. Unbalance: improperly connected single phase loads in the three-phase network causes unbalance.
- i. Inrush current: when a large electric equipment is turned on, inrush current that flows momentarily.

Table 1. IEEE Harmonic Standards 519-1992

Bus Voltage	Individual $V_b$ (%)	THD V (%)
V < 69 kV	3.0	5.0
69 ≤ V < 161 kV	1.5	2.5
V ≥ 161 kV	1.0	1.5

Table 2. IEEE Harmonic Standards 519-1992

	Special Applications	General system	Dedicated system
Notch depth	10%	20%	50%
THD (Voltage)	3%	5%	10%

Table 3. IEC Flicker Standards IEC 61000-2-2

Value	Observation Interval	Limiting Value
$P_{st}$	10 min	1.0
$P_{lt}$	2 hr	0.8

IEEE 519-1992 provides guidelines for an allowable limit of voltage Harmonic distortion on the utility system. Table 1 shows the maximum individual harmonic component and the Total Harmonic Distortion (THD). Many industrial consumers are following these IEEE standards which is the allowable level. The compatibility level of voltage distortion on MV and LV systems is specified in IEC 61000-2-2 is 8%. These standards permit the same procedure by the customers at different locations but the current limit values vary in these cases. Table 2 shows the notch depth and THD (Voltage) limits at different applications according to the IEEE 519-1992. The Flicker intervals and the limiting values for Pst and Plt are specified according to the IEC 61000-2-2 standard is shown in Table 3. These standards provide several guidelines to all kind of industrial consumers.

### 3. Problem Identifications for Different Distribution Feeders

The three feeders Feeder-1 (chemical vapor deposition-CVD), Feeder-2 (silicon carbide-SIC) and Feeder-3 (lighting distribution board-LDB) have a different type of load. The Feeder-1 is connected to the CVD (chemical vapor deposition) furnace which is operated and controlled by micro-processor based programmable controller. Feeder-2 is connected to large rated equipment like induction furnaces, hot press, chillers and hanging cranes. And Feeder-3 is connected to the total lighting load. The feeder's structure is shown in Figure 1. The Figure 2 Shows the PQ monitoring and measurement at Feeder-1. The PQ analyzer helps in finding all kinds of disturbances.



Figure 2. Power Quality Monitoring at CVD

Figure 3 and Figure 4 shows the voltage and current waveforms at Feeder-1 during no-load and load condition respectively. At no-load condition, the voltage waveform is perfect without any disturbance. When the load is turned on, the voltage waveform is disturbed due to load behavior. Since the load draws distorted current, the notching is formed in the voltage waveform as shown in Figure 4. This load disturbs the supply voltage by drawing the distorted current and the voltage waveform loses its purity.

Figure 5 shows the harmonic bar graph at Feeder-2. The harmonic distortion appears when 50Hz is shown in the bar graph. Part of this noise is due to light flicker. According to the IEC standard, measurement of harmonic distortion (IEC-61000-4-30) should be below 5% but the THD value crosses the 5% limit. The individual harmonics second, third and fifth crosses the individual harmonic limit 3% according to the IEEE standards [13]. These harmonics are mitigated by using the Harmonic Filters (passive filter or active filter) [15].

Figure 6 shows the RMS variations in the total measurement period. The load creating large voltage fluctuations (sag and momentary interruptions), which causes flickering is shown in Figure 8. Due to large fluctuations, the flicker (Pst and Plt) values exceeded the IEC flicker standard. When the interruption happens the voltage goes to zero and after the interruption the load draws momentary inrush current as shown in Figure 7. The voltage dips are mitigated by using static series compensator or static transfer switch [15] and the flicker is mitigated by static var compensator (SVC) or D-STATCOM [15].

Figure 9 shows the frequency variations at Feeder-3 which is connected to a lighting load which create the large frequency variations in the supply. The oscillatory transients (momentary transients) are caused by power factor correction capacitor switching ON/OFF which is shown in Figure 10. These disturbances are monitored by using the HIOKI PQA PW-3198 and the analysis has been done by HIOKI PQA-HIVIEW PRO 9624-50. For harmonic limits, IEC and IEEE use two different approaches.

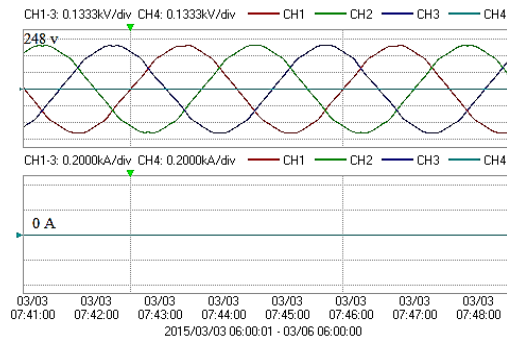


Figure 3. Voltage Waveform During No-load Condition at CVD

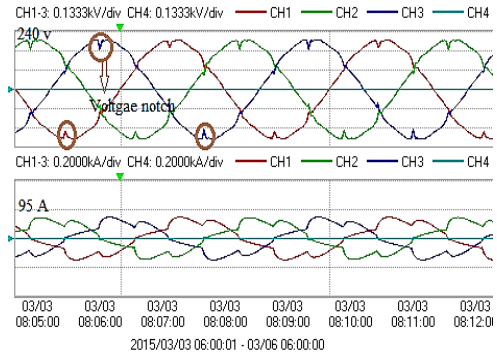


Figure 4. Voltage & Current Waveforms During Load Condition at CVD

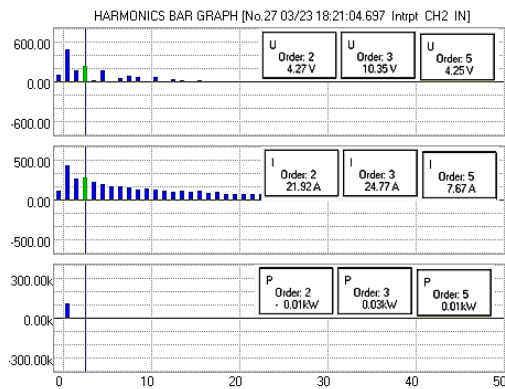


Figure 5. Harmonic Bar Graph at SIC

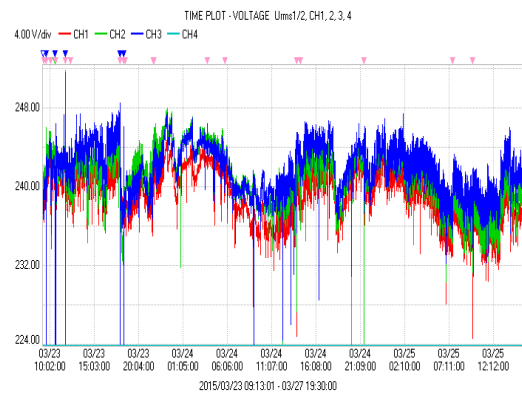


Figure 6. RMS Variations at SIC

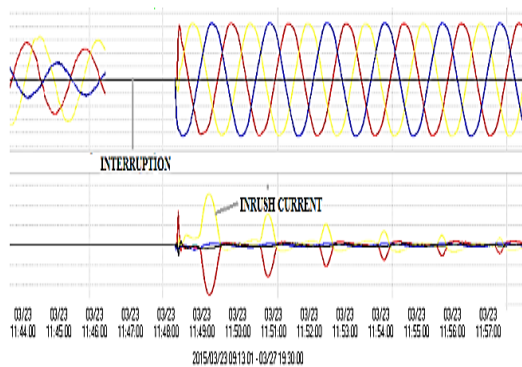


Figure 7. Interruption Period (Inrush Current) at SIC

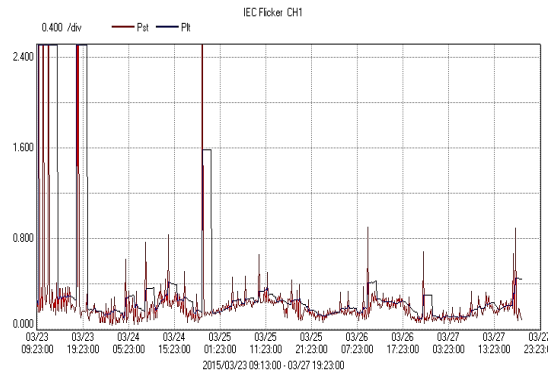


Figure 8. Flicker (Voltage Fluctuations) at SIC

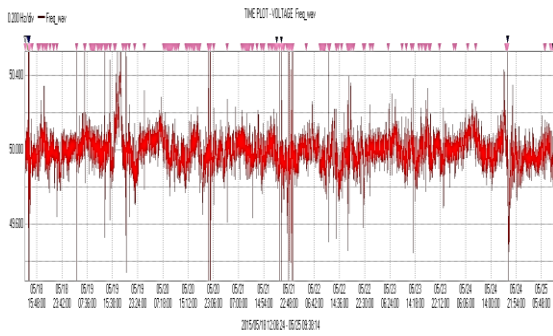


Figure 9. Frequency Variations at LDB

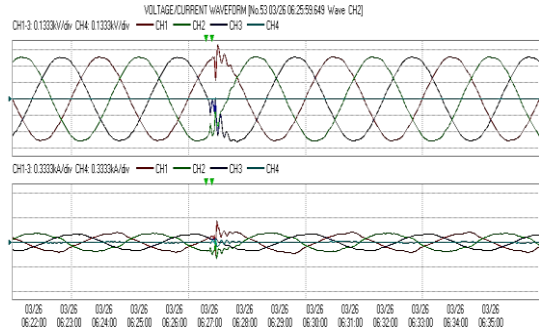


Figure 10. Oscillatory Transient Event at LDB

A very high THD value appears at SIC (Feeder-2), which doesn't obey the IEC 61000-4-30 standard. The Total Demand Distortion (TDD) depends completely on load pattern. The harmonic currents thus generated get fed back to the source and cause voltage harmonics at the point of common coupling (PCC). Voltage harmonics generated by loads at PCC will depend on system impedance as well as TDD. Total Harmonic Distortion (THD) It depends on TDD as well as system impedance. Eventually, a very bad PF value appears at CVD and SIC feeders during the running load period, it increases the total RMS current. The measurement results of THD for some applications are presented in Reference number [16]. The individual harmonics 5 and 11 at CVD and SIC feeders shown in Figure 10. are exceeding the individual harmonic limit according to IEEE harmonic standard.

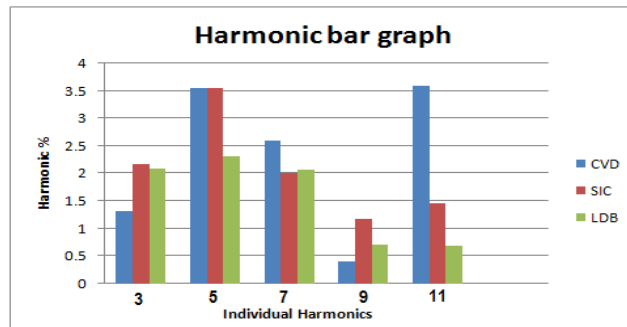


Figure 10. Individual Harmonic Bar Graph at all Feeders

**4. Results & Discussion**

We have discussed about the PQ issues, problems, related PQ standards & the corresponding consequences of PQ problems. As a result, we can rectify the problem and afterward judge it by making certain results within International standard limits. The comparison of disturbance events at different feeders is shown in the Table 4.

Most of the research has been done here on finding the disturbances at distribution feeder level with the help of power quality monitoring. Further measurements are required to test various networks and loads. Various types of load creates various disturbances. So, the further study requires more monitoring results. The PQ monitoring and management methods has been discussed in Reference [17]. The obtainability of increasing amount of monitoring equipment makes study more easy. Eventually we are forward to looking to mitigate disturbances whatever discussed in this paper. The Mitigation of voltage flicker and reduction in THD by using STATCOM compensators are given in [18]. The harmonics can also be reduced by harmonic filters. The discussions regarding the disturbance level which can cause serious problems have been going on. So, we are trying to mitigate these disturbances as early as possible. As mentioned before, we are trying to find out all the disturbances level at each load point and we try to mitigate these disturbances in near future.

Table 4. Power Quality Disturbance Events and Corresponding Values

Feeder	CVD Feeder	SIC Feeder	LDB Feeder
THD	2.81%	6.2%	1.72%
PF	0.6	0.5	0.9
Interruptions (momentarily)	✓	✓	✓
Sag/Swell	✓	✓	✓
Transient (oscillatory)		✓	✓
Voltage Notch	✓		

## 5. Conclusion

In this paper, an overview of power quality along with the real-time monitoring results have been given and various power quality issues have been discussed at the medium voltage level. Unfortunately, the load disturbs the supply system enormously and the power demand keep increasing. More importantly, the physical effect on the equipment is a loss of productivity, misoperation of sensitive equipment and downtime. Consequently, with the wide range of technology and software's which are available now, monitoring is highly effective to find problems and solutions. However, without monitoring, finding the solutions is very difficult. Hence, the power quality monitoring is essential before finding out the solutions.

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