

## POWER QUALITY OVERVIEW – PRACTICAL ASPECTS

Dr. K Rajamani  
Reliance Infrastructure Ltd., Mumbai

### 1.0 INTRODUCTION

Power quality has gained increased importance in power industry in the last two decades. The proliferation of sensitive electronic devices and sophisticated automation equipment in ICE (Information, Communication & Entertainment) driven modern economy calls for a “*Good Quality Power Supply*”. The question which immediately comes to our mind is what we mean by “*Quality Power Supply*”? From a utility point of view it may be defined as reliable and continuous power supply. From a user perspective quality power may be defined as *uninterrupted* power supply at specified voltage and frequency with minimum distortion from sinusoidal waveform that will ensure proper functioning of his equipment. Users are now more informed of power quality issues as the failure of highly sensitive process control / electronic devices has severe consequences in terms of time and cost. However an utility is a part of large integrated power system spread geographically over vast area and user has to be aware what the utilities can deliver *practically* considering external disturbances (mostly weather related) and internal failures(equipment forced outages). In brief, utility can't supply GWs of UPS quality of power and the user must factor this into account when he designs his internal system.

In the last two decades vast number of articles have appeared on Power Quality issues covering voltage variations like sags, swells and interruptions, transients, flicker, supply unbalance and of course the most dreaded word – Harmonics. IEEE Std 519 has become a Swiss Army Knife used by customers, regulators and utilities to enforce ‘Harmonics Discipline’ as per their interpretation. The focus of this article is not so much on stating the fundamentals which are well known but on knowledge and practical experience derived from data based on actual measurements done at site.

## 2.0 Voltage dips

This is one of the frequent problems faced by many users. The user complaint is that the voltage dip in utility supply results in tripping of critical equipment and stoppage of process. However dips caused due to faults in power system can't be avoided. In highly meshed integrated power network, faults in one part of system causes voltage dips in other neighbouring parts of system. The first step towards mitigation is to measure the dips. Reliance supplies power to Mumbai consumers through Mumbai Distribution Business (MDB). Distribution is done at 11kV and 0.415kV level. Bulk power is brought to Mumbai at 220kV by Mumbai Transmission Business (MTB) of Reliance and further stepped down to 33kV for supply to distribution system. Power Quality Cell was established in MDB in 2005. PQ meters (PQ-ID A-eberle) were installed at strategic stations feeding high end consumers to monitor 11kV voltage. Later PQ meter was installed at 220kV bus of one of the transmission stations of MTB to monitor grid voltage. Any dip exceeding 10% is instantly captured. The readings are downloaded every month, analysed and a report is generated every month. Sample report for 220kV monitoring is shown in Tables 1 & 2. Similar report is generated for dips in 11kV. If any customer complaints regarding dip in supply voltage, the PQ meter data is useful in identifying source of problem. Typically one dip per day can be expected in utility distribution system. The duration of dip depends on quality of protection system functioning in utility. In Reliance network, EHV faults are generally cleared within 80 msec and MV faults are cleared within 120 msec. This gives a clue to the customer that equipment in his premises should have the capability to ride over these transients which are unavoidable. In design stage, the customers should plan for a ride through of at least 300 msec. It may be emphasized that the customers should do a comprehensive audit of equipment and identify which part of equipment *really* needs ride through facility. In a sophisticated production process only the controllers may be vulnerable and may require ride through capability / UPS supply. Conventional auto-change over schemes (break before make) may suffice in majority of cases. In this way quality power is ensured at minimum cost.

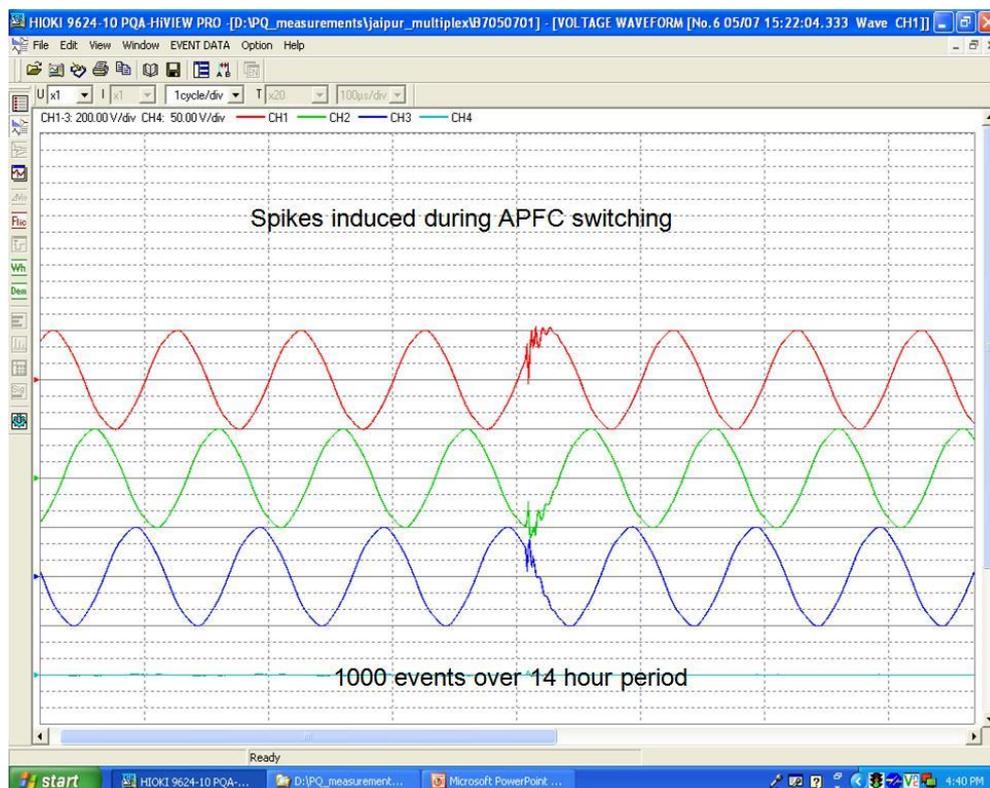
Sr No	Dec-2015	Numbers	Remarks
1	No of dips > 10%	13	0.42 dips per day
2	No of dips > 20%	9	69% of total
3	No of dips due to external faults	10	77% of total
4	No of dips due to internal faults	3	23% of total

**Table 1**

Sr No	Date	Time	Phase	Prefault Vol in kV	Postfault Vol in kV	% Vol Dip	Duration msec	Location	Remarks
1	08-12-15	00:17:29	R-N	130.96	25.9	80.22	90	Internal	220kV Aarey-Borvili line fault
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	10-12-15	19:52:22	Y-N	130.55	82.84	36.55	70	External	Bus fault at Padge
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	31-12-15	18:10:12	B-N	132.49	91.61	30.86	90	External	400kV Kalwa1 – Padge line fault

**Table 2**

In some customer installations, it is found that voltage spikes are induced by internal equipment. For example, at a particular location voltage spikes due to APFC switching is shown in Fig 1. Almost 1000 incidents were recorded by PQ meter (Hioki) in 14 hour period, i.e. almost one incident every minute. It is desirable in these cases to increase the 'dead band' and reduce APFC switching incidents.



**Fig 1**

### 3.0 Harmonics

Pre 1980s, ‘Ferro-resonance’ was used as scapegoat to apportion blame on unexplained electrical disturbances. Now this is replaced with ‘Harmonics’. From inadvertent tripping to increase in losses is attributed to harmonics. To really understand what is happening in the field is to deploy the PQ analyser and capture the data. Some of the case studies from field data are presented here.

#### 3.1 Derating of Transformer capacity for harmonic loading at IDC

Two major effects of harmonics are:

- (i) Increased RMS current and hence increased copper loss.

$$I_{RMS} = \sqrt{\sum_{H=1}^N I_H^2 H^2}$$

The effective current is significantly higher than only fundamental current.

- (ii) Increased eddy current loss due to flow of induced currents in winding, core and other conducting bodies subjected to magnetic flux. This loss is proportional to  $I^2 f^2$ .

The procedure outlined below is based on “IEEE Std C 57.110 - IEEE recommended practice for establishing transformer capability when supplying non-linear load”. The first step is to establish ‘K factor’. It is defined as follows:

$$K_F = \frac{\sum I_H^2 H^2}{\sum I_H^2}$$

For pure sinusoidal waveform,  $K_F = 1$ . Higher the value of  $K_F$ , higher is the harmonic content. Most of the PQ meters directly display  $K_F$  phase wise. From  $K_F$ , Eddy current loss factor ( $P_{EC}$ ) is obtained using standard graphs. The average values of  $P_{EC}$  for different values of  $K_F$  are given in Table 3. Derating Factor ( $D_F$ ) is given by:

$$D_F = \sqrt{\frac{1 + P_{EC}}{1 + P_{EC} K_F}} \dots\dots(1)$$

<b>K<sub>F</sub></b>	1	2	3	4	5	6	7	8	9	10
<b>P<sub>EC</sub></b>	1.0	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.7	0.68

**Table 3**

To verify the adequacy of transformer capacity to supply non-linear loads, PQ meter was deployed in an IDC (International Data Centre) at Mumbai which has large population of non-linear loads. Readings were taken on a 11/0.415kV, 2000KVA transformer feeder. The measured K factor is 10. From Table 3,  $P_{EC} = 0.68$ . From Eqn (1),

$$D_F = 0.46$$

The permitted loading on transformer =  $2000 \times 0.46 = 920\text{KVA}$ .

With the existing harmonic loads, the transformer loading is restricted to less than 50% of name plate rating. At site, the readings of WTIs embedded in dry type transformer windings were very high even though the transformer was not fully loaded. Extra fans were installed to augment the cooling.

The lesson is that if equipment gets overheated (transformer, busbar, etc) even though operating within name plate rating, the immediate step to rule out harmonic effects is to deploy PQ meter and measure K Factor. If it is below 2, it is not of immediate concern; otherwise further studies are required. When taking the measurements, the loading should be at least 25% to get meaningful results.

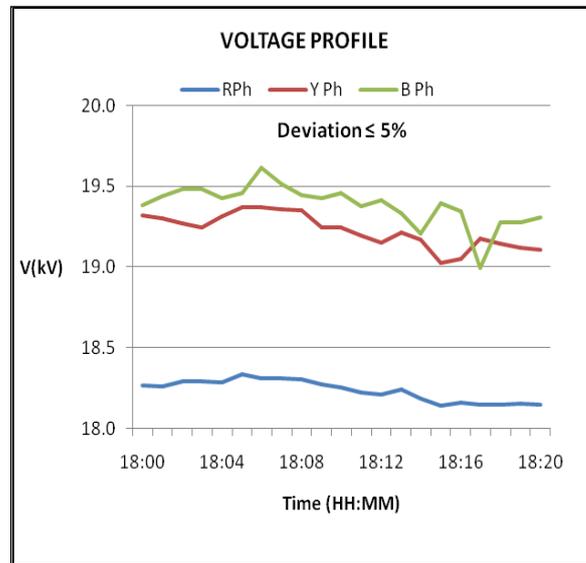
### **3.2 Effect of traction load on power quality**

Supply to traction for Mumbai Metro is given at 33kV. PQ meter is installed on feeder supplying to traction substation of Mumbai Metro. Single phase traction load is connected between YB phases. Some snap shots of data collected during evening peak load on traction supply are given in Figs 2 to 7 and Table 4.

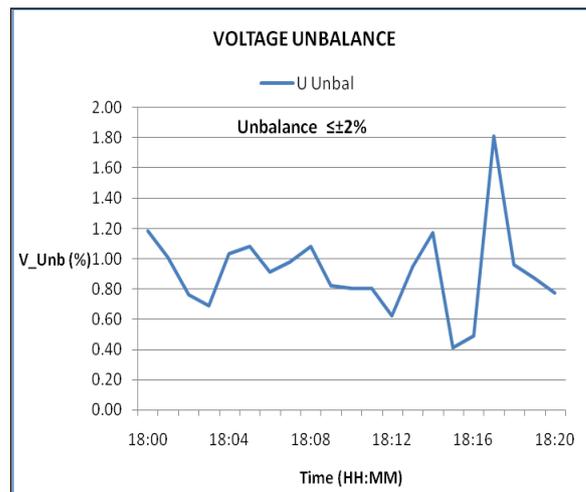
The peak load drawn during monitoring period is 12MW (Fig 5). The fault level of 33kV supply bus is about 833MVA. The expected unbalance in supply voltage is given by the following formula (as per IEC 61000-2-12, CI 4.6):

$$\Delta V = (12 / 833) \times 100 = 1.44\%$$

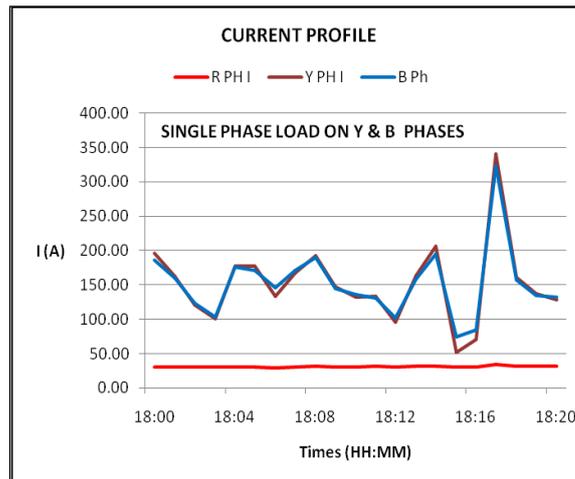
The maximum unbalance recorded by meter is 1.8% and is in close agreement with the calculated value (Fig 3). Since reactive power (Fig 5) is fed into the system by traction load (leading power factor), voltage of Y & B phases are higher than R phase (Fig 2). Voltage THD recorded is less than 3% (Fig 6).



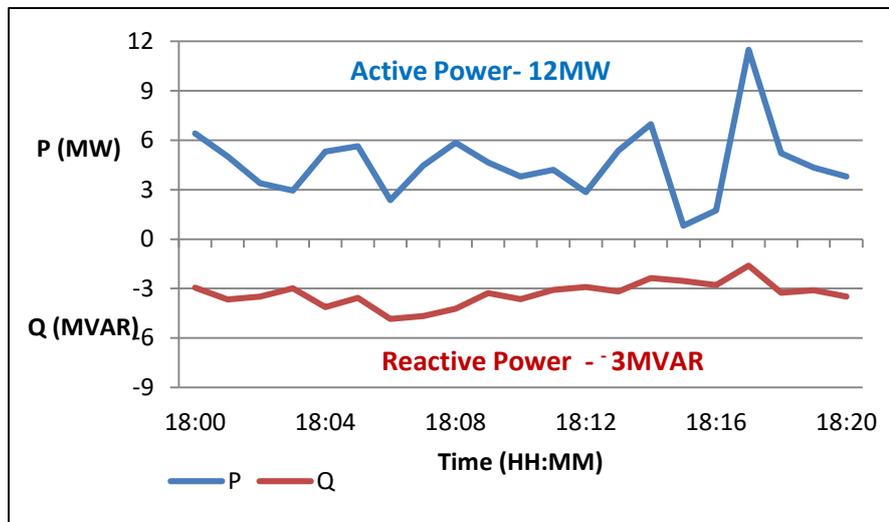
**Fig 2**



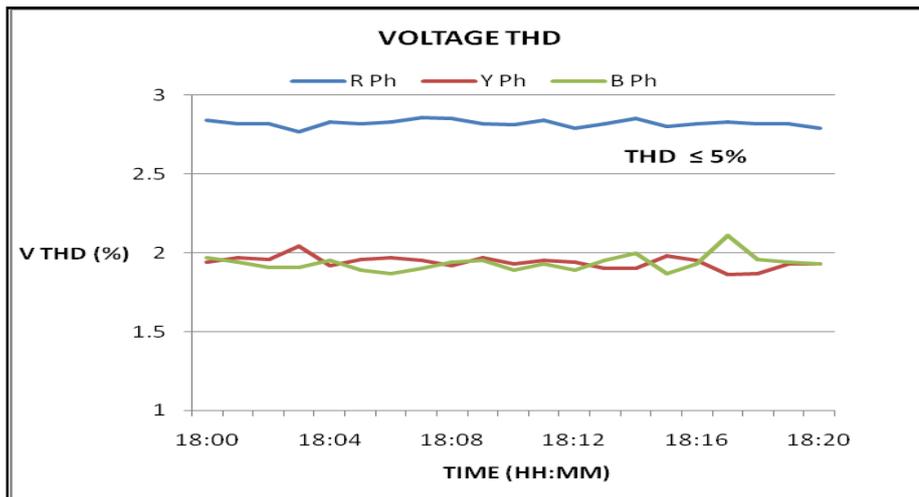
**Fig 3**



**Fig 4**



**Fig 5**



**Fig 6**

In case of voltage harmonics, measured THD is of direct use as the voltage is near rated value irrespective of load current.

However, measured THD of current harmonics is not directly interpretable as the current at the time of measurement may vary from small value (almost unloaded feeder) to a maximum (rated current of connected equipment). Hence IEEE Std 519 has introduced a term TDD (Total Demand Distortion) which is a normalized value based on rated current of equipment and fault level of source. If THD of no load current of transformer is measured, it could be even 100% but the fundamental current itself is very low (less than 1% of rated current).

The point is clarified with following example.

Rated Current of equipment  $I_{RAT} = 200A$ .

Allowable TDD as per standard, say = 20%

$$= 0.2 \times 200 = 40A$$

On the day of spot measurement,

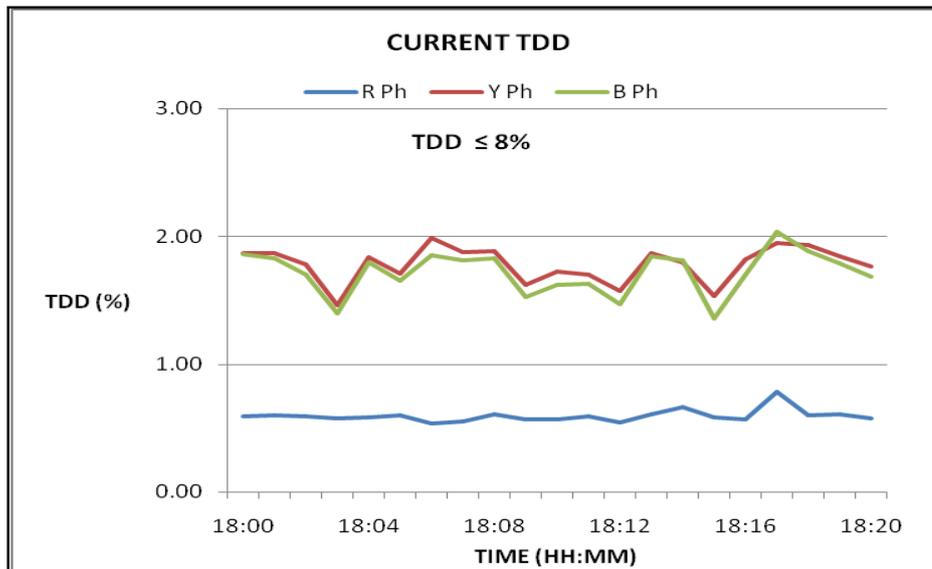
Current drawn by load,  $I_L = 50A$

Measured THD = 50%. Even though THD appears alarmingly high, it is still within limits.

Measured harmonic current =  $0.5 \times 50 = 25A$  which is less than allowable limit of 40A. In this case, even THD of 80% permissible.

TDD calculation for traction load is shown in Table 4 and time series plot is given in Fig 7.

Measured TDD is well within allowable limits.



**Fig 7**

Rating of traction transformer = 20MVA

Rated voltage = 33kV

Maximum demand Load Current =  $I_L = 20/33 = 0.6\text{kA}$

Short Circuit Level at 33kV =  $I_{SC} = 15\text{kA}$

$I_{SC} / I_L = 15 / 0.6 = 25$

As per IEEE Std- 519, acceptable limit of TDD for  $20 < I_{SC} / I_L < 50 = 8\%$

Time HR:MT	Measurands by PQ Meter						TDD (%)		
	Current THD (%)			Current (A)			R	Y	B
	R	Y	B	R	Y	B			
18:00	11.8	5.8	6.1	30.7	195.6	186.2	0.6	1.89 (*1)	1.86
18:01	11.8	7.0	6.9	30.9	162.8	159.9	0.6	1.87	1.83
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
18:20	10.9	8.3	7.7	31.9	128.8	132.3	0.57	1.76	1.68

(\*1) →  $5.8 \times 195.6 / 600 = 1.89$

**Table 4**

### 3.3 LED lights and harmonics

In the last few years LED lighting is introduced in mass scale as part of loss reduction and energy efficiency drive. This is actively supported by both central and state governments. But LED lights without proper inbuilt filters are great harmonic polluters and load power factor is also low. LEDs with large difference in Power Quality are available in market. For sample study, LEDs of different make and rating were selected for testing using a PQ meter. For illustrating the contrast, current waveforms are shown in Fig 8 & 9, one a series of spikes and the other near sinusoidal. The results of test (input power, THD and PF) are summarized in Table 5. There is a wide variation in power quality. It is desirable that statutory bodies assign star ratings to LEDs of different makes and types based on output

lumen per Amp, THD and PF. The star ratings can be used for quantum of subsidy if contemplated.

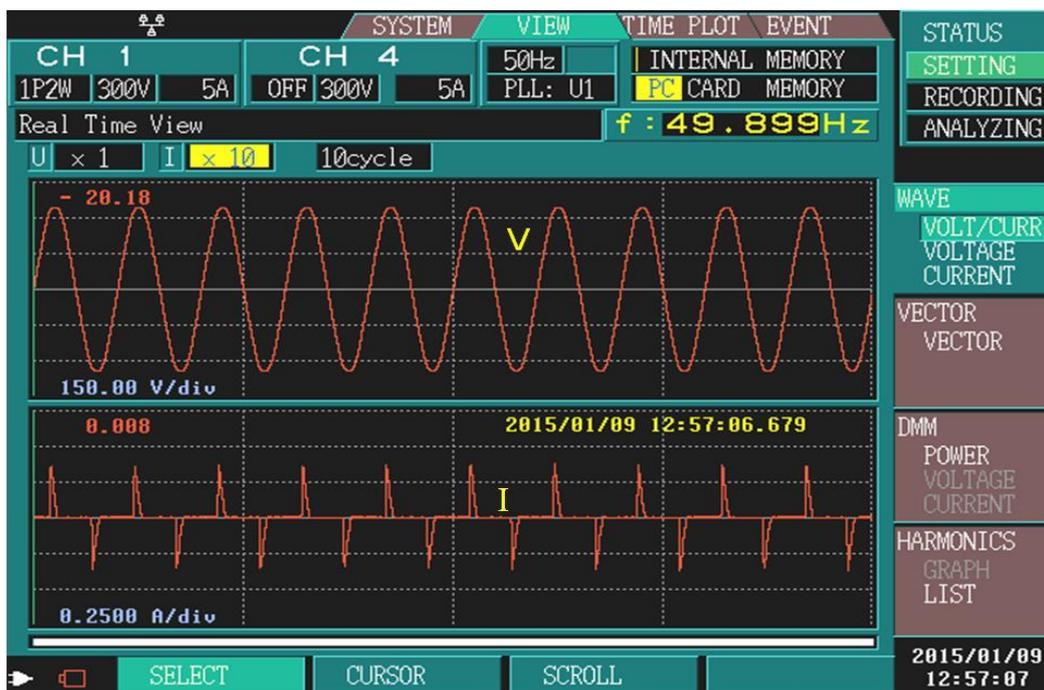
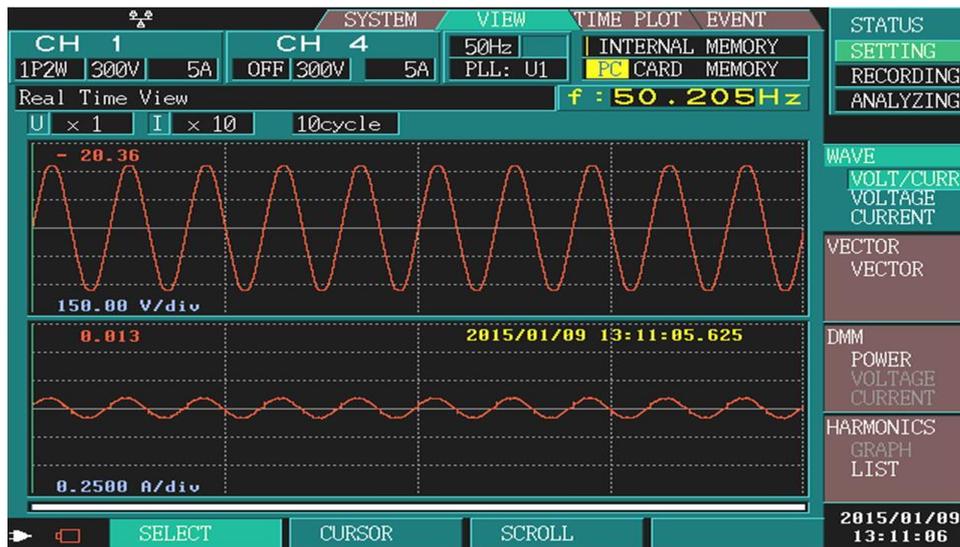


Fig 8



**Fig 9**

Make	Watt	THD Ct(%)	PF
1	3.7	183	0.45
2	9.4	154	0.50
3	10.7	166	0.50
4	29.7	35	0.94
5	22.4	35	0.93
6	14.8	6	0.96

**Table 5**

### 3.4 Power Quality Standard for Utility Supply

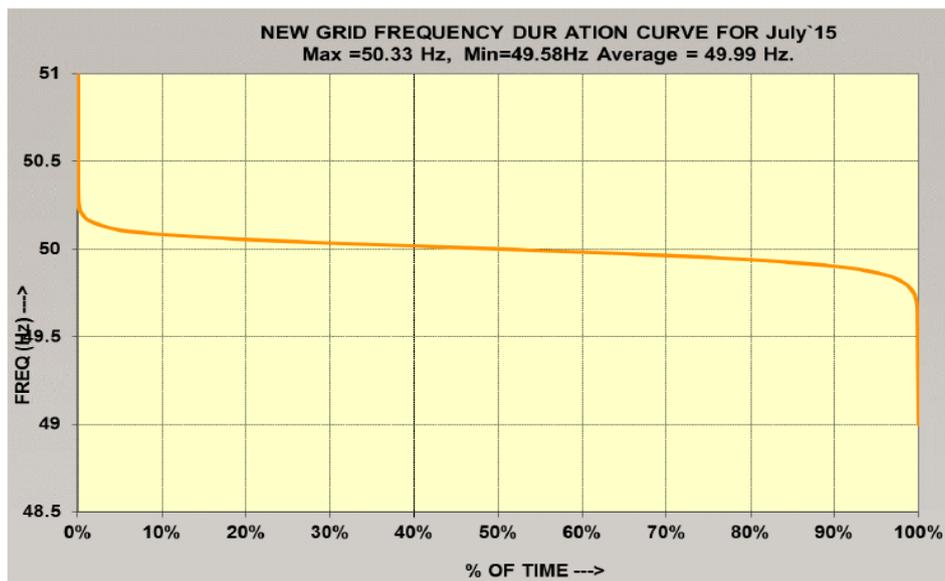
A very useful standard for practical applications is “BS - EN 50160:2000 Voltage characteristics of electricity supplied by public distribution systems”. The limits and tolerances of important phenomena that can occur from supply side are summarized in Table 6.

Supply voltage phenomenon	Acceptable limits	Measurement Interval	Monitoring Period	Acceptance Percentage
Grid Frequency	49.5Hz to 50.5Hz 47Hz to 52Hz	10 S	1 Week	95% 100%
Slow voltage changes	230V ± 10%	10 min	1 Week	95%
Voltage Sags or Dips (≤ 1 min)	10 to 1000 times per year (under 85% of nominal)	10 ms	1 Year	100%
Short Interruptions (≤ 3 min)	10 to 100 times per year (under 1% of nominal)	10 ms	1 Year	100%
Voltage unbalance	Mostly 2% but occasionally 3%	10 min	1 Week	95%
Harmonic Voltages	8% Total Harmonic Distortion (THD)	10 min	1 Week	95%

**Table 6**

Observations based on values given in Table 6 are given below:

- (a) Regarding grid frequency, implementation of ABT and penal cost for non-compliance has dramatically improved the grid frequency profile in India. Sample frequency profile for Western Region is shown in Fig 10. The frequency is between 49.5 and 50.5 for almost 100% of time.



**Fig 10**

- (b) The acceptable limits for voltage limits for slow changes as well as permissible number of dips are wide.
- (c) Customer equipments shall be designed with adequate capability to ride over voltage dips.
- (d) The measurement interval and monitoring period for voltage unbalance and harmonic measurement are substantial. For example, violation over the permissible limits for 5% of time (8.4 hours in a week) is permitted. This is based on the important fact that harmonics is not a transient phenomena but a steady state one and ultimately results in increased heating. Value judgment regarding harmonics should *not* be based on measurements taken over a few hours but based on performance over a longer period like a week.

#### **4.0 CONCLUSIONS**

The deleterious effects of poor power quality have necessitated study and investigation of power quality issues. The main tenet of this article is to bring out the actual facts by making measurements at site. Results of few case studies are presented. Critical remarks are made on the obligations by utility and consumer. If many utilities, railways, large industrial plants (like steel plants) and variety of consumers (like IT parks, Malls, etc) publish data on actual site measurements, these results could be the basis for future course of action either for curative solutions or for forming new regulations. Also availability of actual site measurements from a variety of sources can spur researchers to come out with solutions for 'real life problems'.

#### **5.0 ACKNOWLEDGEMENTS**

Bina Mitra was one of the core members when Power Quality cell was established in Reliance. She had done extensive work at various customer sites resolving PQ issues. Mohan Waingankar and his team contributed for voltage dip monitoring at EHV level. Vini Vazhappully's help in analyzing the data pertaining to Metro supply is acknowledged. Methil Menon furnished data on performance of LED lamps.