WHITEPAPER

POWER QUALITY REGULATIONS IN INDIA

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PRELUDE

Why Power Quality

Frequency distortion, voltage variation and harmonics distortion are the critical Power Quality issues that results in problems. Overloading conditions in distribution network cause voltage variations resulting in increased losses and faults in the network. In addition, increasing use of semiconductor based electronic equipment, non-linear loads and rapid integration of non-conventional energy sources into the grid network throws new challenges for the PQ environment.

In India, the issue of Power Quality has been typically looked at from the viewpoint of power factor, frequency, reliability of supply, i.e. duration of interruptions, restoration of supply (indices like SAIFI, SAIDI CAIDI etc. are buzzed about) and voltage regulations. While we have a strong system of frequency regulation, enforcement of the standards specified for reliability parameters are not really strictly monitored and implemented. Issues of voltage regulations, transients, and harmonics are hardly cared about.

An earlier study carried out by APQI shows that the direct costs of downtime in India are in the tune of Rs. 20,000 crore per annum. About 57% of these financial losses are due to voltage sags and short interruptions, while about 35% of the losses are due to transients and surges. However, the cost of prevention for these may be less than 10% of the cost of problems. Consumers suffer from poor quality of supply. Both the consumer and the distribution utilities suffer from equipment /process failure and high cost of operation and maintenance due to compromised equipment quality and poor monitoring of consumer establishments.

Regulations on Power Quality in India

In India we have various Regulations for quality of electricity supply which apply to the generation companies, transmission companies and distribution companies. There are standards specified for the consumers as well to help maintain the standards of the electricity grid. These Regulations have been specified by the Central Electricity Authority (CEA) and the Central Electricity Regulatory Commission (CERC) at central level and the State Electricity Regulatory Commissions (SERC) at state level as per the provisions of the Electricity Act, 2003.

State Regulatory Commissions have specified various Regulations in the respective States of their jurisdiction. However, electricity being a concurrent subject in the Indian Constitution, the State Commissions has come up with their own independent sets of Regulations. These Regulations, when dealing with the aspect of Power Quality, vary in approach, construct and applicability. Therefore, there is lack of consistency in the way Power Quality is dealt with in various States in India. This lack of consistency has inevitably fostered an ambience of misplaced understanding and subdued awareness of the economic importance of Power Quality in the entire eco system of electricity distribution, supply and utilisation / consumption.

A brief study commissioned by the International Copper association India under its flagship program **Asia Power Quality Initiative** indicates that the awareness and sensitivity towards the issues of Power Quality in India is moderate at best, which leaves a lot of scope for improvement.

CONSTRUCT OF PQ REGULATIONS IN INDIA

Since we have a fairly evolved and strict implementation regime of Frequency and Power Factor in the State distribution systems, other important Power Quality parameters i.e. voltage and harmonics were examined between different sets of Regulations in select States to identify the consistency of the approach to implement these aspects of Power Quality.

The table below summarises the salient features of Power Quality regulations applicable to DISCOMs. We find that voltage variation, harmonics distortion and voltage unbalance are commonly discussed in the regulations. However monitoring, management and control of these parameters are not widely covered with clearly defined framework in place.

State	Coverage of Voltage and Harmonics in Power Quality Regulations and Tariff Order					
	State Grid Code	State Supply Code	Standard of Performance	Distribution Open Access Regulation	Power System Management Standard Regulations	Tariff order
Gujarat	1.Voltage Monitoring and Management 2.Limits for THD and single harmonic content	-	1.Neutral Voltage 2.Voltage Variation 3.Harmonics	-	Voltage monitoring and control at 22/11kV substation	-
Maharashtra	Voltage variation limits up to 66kV	Harmonics with penalty and incentive provision	1.Voltage Variation 2.Compensation to consumers for voltage and Harmonics violation	Harmonics with penalty and incentive provision	-	-
Tamil Nadu	1.Considering Harmonics content in network planning stage 2.Voltage Monitoring 3.Special condition to install correction equipment for Harmonics	Consumer should provide harmonics suppression unit, failing to which compensation shall be paid	Voltage Variation	-	-	1. HT I and HT-III Consumer need to provide Harmonics filter. 2.Compensation at 15% of tariff
Madhya Pradesh	1.Limits of voltage variation up to 132 kV 2.Voltage unbalance limit up to 11 kV 3.Current unbalance 4.DISCOM shall not cause voltage unbalance and harmonics 5.Limit for THD	1.Voltage Variation 2.User need to install Harmonic filter if harmonic content detected by DISCOM 3.No penalty clause for Harmonics	1.Limit for voltage variation 2.Harmonic limit for EHT (220kV & 132kV) and HT (33kV& 11kV) consumers 3.DISCOM need to monitor harmonics regularly at strategic location and it can disconnect the supply to consumer in case of non-compliance	-	-	-

State	Coverage of Voltage and Harmonics in Power Quality Regulations and Tariff Order					
	State Grid Code	State Supply Code	Standard of Performance	Distribution Open Access Regulation	Power System Management Standard Regulations	Tariff order
			4.Compensation to consumer for violation of voltage variation and harmonic limit 5.Limit for voltage unbalance			
Andhra Pradesh	1.THD limit for Voltage and Current 2.Voltage variation limit up to 33kV	-	1.Voltage variation 2.No compensation to Industrial and agricultural consumer for voltage fluctuation who do not provide capacitor to prescribed extent 3.THD limits for 132kV,33kV and 11kV 4.Voltage unbalance limit 5.Compensation for voltage fluctuation	-	-	-
Delhi	Voltage variation limit up to 66kV	1.Voltage variation limits 2.Voltage unbalance limit 3.Compensation for voltage variation 4.Harmonics – Regulations says "Requirements will be specified separately at an appropriate time after conducting a detailed study.		-	-	-
Karnataka	1. Distribution licensee to monitor and control voltage, frequency, and power factor of 1 MW and above consumers. 2. Bulk consumers to control harmonics injection into grid. 3. Specification of voltage and harmonics limits.	1. Consumer to control harmonic injection. Failing which may lead to disconnection. 2. Consumer to raise complaint of voltage variation and licensee to rectify within specified time. However, no liability of licensee for consumer's loss.		1. Limit for voltage variation. 2. Compensation by licensee for voltage variation. 3. Reliability conditions.		

SALIENT FEATURES OF PQ REGULATIONS IN INDIA

A study of the Regulations of various SERCs in India indicates that the implementation of Power Quality of electricity distribution, supply and utilisation / consumption are not very structured, nor they are strictly enforced by the Regulators. The Regulators, so far, have largely focused only on the **Frequency** and **Power Factor (mostly classical definition oriented i.e. average PF and not true RMS PF suitable for non-linear load environment)** of the electricity supply. These are monitored and mechanisms have been put in place for implementing the standards of these parameters. Frequency regime is implemented through CERC Regulations and consistently followed across the country. Power factor is also largely maintained at similar levels and implemented through incentives and penalties in tariff determined by the SERCs. Reliability indices like SAIFI, SAIDI, CAIDI, and MAIFI are almost invariably specified by the SERCs but there is no evidence to demonstrate that these reliability indices are strictly monitored and implemented by the SERCs.

Highlights of key Regulations in selected states

Gujarat

- *No clarity in monitoring and implementation methodology* for Harmonics and Voltage regulation. *No compensation on account of failure to maintain voltage and harmonics within prescribed limits.*
- DISCOMs need to monitor the voltage, frequency and power factor at peak and off peak hours and take reasonable measures for improvement of same in co-ordination with users.
- Consumer is responsible for taking corrective action for harmonics injection.
- Provision for voltage monitoring in 11 kV feeder and 22/11 kV sub-station. However there is no clarity about other voltage levels feeder and sub-station.
- It is DISCOM's prime responsibility to comply with voltage and harmonics regulation by providing sample compliance tests to the Commission in a format and manner specified by the Commission.
- DISCOMs need to monitor the harmonics at regular interval at strategic points where it is prone to harmonics voltage generation.

Maharashtra

- Consumer is responsible for taking corrective action for preventing harmonics injection.
- Provision for penalty and incentive for harmonics in accordance with relevant orders of the Commission. However, no such penalty or incentive is ever specified so far.

Tamil Nadu

- DISCOMs need to monitor the voltage, frequency and power factor at peak and off peak hours and take reasonable measures for improvement of the same in co-ordination with users. No monitoring provision for other Power Quality parameters.

- *No clarity in monitoring methodology and implementation for Harmonics and Voltage regulations. No compensation on account of failure to maintain voltage within prescribed limits.*

- Consumer is liable to pay compensation at 15% of the respective tariff when it exceeds harmonics injections limits specified by CEA. *However the compensation is not levied with respect to the intensity of harmonics injected to the grid.* Penalty of 15% of respective tariff is applied flatly irrespective of the amount of harmonics injected by consumer in the distribution grid.

- Existence of special condition to install corrective equipment to control harmonics by consumers.

Madhya Pradesh

- *No clarity in monitoring and implementation methodology* for Harmonics and Voltage.

- User need to install harmonic filters *if DISCOM detects* and proves to the consumer that the consumer's system is generating harmonics.

- User should not cause voltage unbalance and harmonics.

- Provision for current unbalance in addition to voltage unbalance.

- Specification of accuracy level for instrument with 1% limit to measure voltage unbalance at sub-stations.

- DISCOM need to monitor the harmonics at regular interval at strategic points where it is prone to harmonics voltage generation.

Andhra Pradesh

- DISCOMs need to monitor voltage and harmonics as per prescribed limits. But *no clarity on method of recording harmonics*.

- *No compensation* on account of failure to maintain voltage variation and harmonics within prescribed limits.

- kVAh based billing charges customers for harmonic distortion but that is not keeping customer informed about rights and responsibility towards harmonic control.

- DISCOMs need to monitor voltage and harmonics as per prescribed limits.

- Compensation to consumers applies in case of default in voltage regulations. However, No compensation on account of voltage fluctuation payable to industrial and agricultural consumers who do not provide capacitors to prescribed extent.

Delhi

- *No clarity in monitoring and implementation methodology* for Voltage and Harmonics.
- *No compensation* on account of failure to maintain Voltage and Harmonics within prescribed limits.
- No clarity on harmonics as the regulations mention that the harmonics limits will be specified separately at an appropriate time after conducting a detailed study.

Karnataka

- *No clarity in monitoring methodology and implementation for Harmonics and Voltage regulation. No compensation on account of failure to maintain voltage and Harmonics within prescribed limits.*
- Distribution Licensee needs to monitor harmonics at the point of common coupling (PCC)
- The Consumer needs to limit 'current distortion' levels within the acceptable limits stipulated by the Distribution Licensee from time to time.
- Consumer complaints for voltage and frequency variations shall be attended to by Distribution Licensee within the time frame specified under K.E.R.C. (Consumer Complaints Handling Procedure) Regulations, 2004.
- Consumer to rectify any defect in the Consumer's system on the advice of Distribution Licensee.
- Distribution Licensee will not be liable for any claims for loss or damage arising out of failure or variation in supply.

The table below provides a summary of the limits prescribed in the Power Quality regulations applicable to DISCOMs and consumers. It is noted that the minimum voltage variation limit for Extra High Tension (EHT) is 10% in Madhya Pradesh and Tamil Nadu whereas it is maintained at 12.5% in other select states. Also, prescribed limits for harmonics in 11 kV and 33 kV feeders are not consistent across the States.

Power Quality standards prescribed in SERC Regulations

Power Quality Parameters	Limit prescribed in the regulations					
	Gujarat	Maharashtra	Tamil Nadu	Madhya Pradesh	Andhra Pradesh	Delhi
Reliability Indices	SAIFI,SAIDI and MAIFI	SAIFI,SAIDI and CAIDI	SAIFI and SAIDI	SAIFI,SAIDI and MAIFI	SAIFI,SAIDI and MAIFI	SAIFI,SAIDI and MAIFI
LT voltage variation	+6% and -6%	+6% and -6%	+6% and -10% (for 240 V)	+6% and -6%	+6% and -6%	+6% and -6%

Power Quality Parameters	Limit prescribed in the regulations					
	Gujarat	Maharashtra	Tamil Nadu	Madhya Pradesh	Andhra Pradesh	Delhi
HT voltage variation	+6% and -9%	+6% and -9%	+6% and -10 % (for 415 volts)	+6% and -9%	+6% and -9%	+6% and -9%
EHT voltage variation	+10% and -12.5%	+10% and -12.5%	+6% and -10% (for 11/22kV)	+10% and -10% +5% and -10% (for 400kV line)	+10% and -12.5%	+10% and -12.5%
Harmonics	THD – 5% with single harmonic content not exceeding 3 %	HT &LT (Industrial only) need to control harmonics at the levels prescribed by IEEE STD 519-1992	As specified by CEA regulation	THDv shall not exceed 1% at the interconnection point of EHV system	Cumulative THDv – 3% (for 132kV) Cumulative THDv- 8% (for 11 & 33kV)	No limit prescribed
Voltage Unbalance	No limit prescribed	No limit prescribed	No limit prescribed	2% for 220kV and above 3% for 132 kV 3% for 33kV and 11kV buses in EHV sub-station	3%	3%

Power Quality standards prescribed in CEA and CERC Regulations

Power Quality Parameters	Limits prescribed in the regulations		
	CEA-Grid Standard Regulation	CEA- Technical Standard for Grid Connectivity	CERC – Indian Electricity Grid Code
Voltage Variation			
765 kV	+5% and-5%	Maximum 3% and Minimum 1.5% for step changes	+5% and-5%
400 kV	+5% and-5%		+5% and-5%
220 kV	+11% and -10%		+11% and -10%
132 kV	+10% and -8%		+10% and -8%
110 kV	+10% and -10%		+10% and -10%
66 kV	+9% and -9%		+9% and -9%
33 kV	+9% and -9%		+9% and -9%
Harmonics	THD – 5% with single harmonic content not exceeding 3 % for 33 to 132 kV THD – 1.5% with single harmonic content not exceeding 1 % for 765 kV THD – 2% with single harmonic content not exceeding 1.5 % for 400 kV THD – 2.5% with single harmonic content not exceeding 2 % for 220 kV	THD – 5% with single harmonic content not exceeding 3 %	-
Voltage Unbalance	1.5% for 765 and 400 kV 2% for 400kV 3% for 33 to 132 kV	3% for 33 kV and above	-

INTERNATIONAL STANDARD FOR POWER QUALITY

IEEE 519-1992 standard i.e. Harmonic Control in Electrical Power Systems specifies the international standard for Power Quality with emphasis on Voltage and Current Harmonics for consumers and utilities. The standard specified for various users are presented in this section. These are:

1. Harmonics voltage limits for individual consumers
2. Harmonics current distortion limits for distribution systems
3. Voltage distortion limits for utilities

Recommended Practice for Individual Consumers and Distribution Systems by IEEE 519-1992

Maximum Individual Frequency Voltage Harmonics

SCR at PCC	Maximum Individual Frequency Voltage Harmonics (%)	Related Assumption
10	2.5% - 3.0%	Dedicated System
20	2.0%-2.5%	1-2 Large Customers
50	1.0-1.5%	A few relative large customers
100	0.5%-1.0%	5-20 medium size customers
1000	0.05%-0.10%	Many small customers

SCR: Short circuit ratio

PCC: Point of common coupling

Maximum Harmonic Current Distortion in Percent of IL for General Distribution Systems

Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above.

Current distortions that results in a dc offset, e.g., half wave converters, are not allowed

*All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L

Where

I_{sc} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at PCC

Recommended Practices for Utilities by IEEE 519-1992

Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

Note: For shorter periods, during start-ups or unusual conditions, the limits may exceeded by 50%.

Performance assessment of distribution utilities in India

In India, distribution loss and aggregated technical & commercial (AT&C) loss are generally monitored by regulators to determine DISCOM performance. In addition, reliability indices such as SAIFI, SAIDI, CAIDI and MAIFI are also considered. However, Power Quality is not a parameter generally considered in India when assessing the DISCOM health and their obligation to provide quality supply.

A few states such as Gujarat and Madhya Pradesh have voltage monitoring and management program as a part of electricity distribution regulations. However the method of monitoring the voltage, frequency of such monitoring and time period of monitoring the voltage are not clearly mentioned in any of the existing voltage monitoring and management programmes. As far as the monitoring is concerned, Gujarat goes beyond conventional voltage monitoring and management program regulations and it asks the Distribution Licensee to monitor the voltage at the LT side of transformer at least at the beginning of 11 kV feeder and at the tail end of 11kV feeder. Nevertheless, monitoring methods at other distribution voltage levels are not clear.

Most of the SERC regulations ask DISCOMs to monitor the voltage in the distribution system at different points, only during the peak and off peak hours. Also, the Distribution Licensees are obliged to verify the voltage fluctuation only on receipt of voltage fluctuation complaint. Also, the DISCOMs are generally vested with the responsibility of monitoring harmonics injected by consumers. But there is hardly any guideline or enforcement mechanism except in the case of Tamil Nadu. It is clear that there is no continuous monitoring and reporting of voltage and harmonics in the Indian distribution system which is primarily due to the absence of clear regulatory framework and guidance.

Performance assessment of distribution utilities and benchmarking of Power Quality in European Countries (CEER benchmarking)

In European countries continuity of supply (transient interruption, short interruption and long interruption) and voltage monitoring are considered as evaluating factor when assessing the DISCOM performance. In addition indices such as SAIDI, SAIFI, MAIFI, ASIDI, ASIFI, CAIDI, CML, ENS, IEEE 1366-2003 indicators, CTAIDI,TIEPI and NEIPI are used to quantify long interruptions.

Most of the Europeans countries have adopted EN50160 standard as voltage quality legislation, regulations and standardization.

Standard EN 50160 Summary

Voltage Disturbance	Voltage Level	Voltage Quality Index (Limit)
Supply Voltage variation	LV	95% of the 10 minute mean r.m.s values for 1 week (±10% of nominal voltage). 100% of the 10 minute mean r.m.s values for 1 week (+10% / -15% of nominal voltage).
	MV	99% of the 10 minute mean r.m.s values for 1 week below +10% of reference voltage and 99% of the 10 minute mean r.m.s values for 1 week above -10% of reference voltage. 100% of the 10 minute mean r.m.s values for 1 week (±15% of reference voltage).
Flicker	LV,MV,HV	95% of the Plt values for 1 week.
Unbalance	LV,MV,HV	95% of the 10 minute mean r.m.s values of the negative phase sequence component divided by the values of the positive sequence component for 1 week (0% - 2%).
Harmonic Voltage	LV,MV	95% of the 10 minute mean r.m.s values for 1 week lower than limits provided by means of a table. 100 % of the THD values for 1 week (≤8%).
	HV	95% of the 10 minute mean r.m.s values for 1 week lower than limits provided by means of a table.
Mains signaling voltage	LV,MV	99% of a day, the 3 second mean value of signal voltages less than limits presented in graphical format.

Obligations for monitoring voltage quality

An important aspect of overall regulation is the monitoring of voltage quality parameters in such a way that it provides a system-wide evaluation of the voltage quality and its evolution in time.

In a number of European countries, the distribution system operators (DSOs) are obligated to perform voltage quality measurements, either on a continuous basis (the Czech Republic, Hungary, Norway, Slovenia and - starting from January 2012 - Italy) and/or during shorter but predefined periods of time, e.g. one or more weeks at each location (Austria, Lithuania, The Netherlands and Portugal).

Different voltage quality disturbances are monitored in the different countries. However, the requirements and test methods from standard EN 50160 are used as a reference in most of the countries. Monitoring is performed mainly in permanent locations with the emphasis being placed on substations (HV/MV and MV/LV).

In a number of European countries, if a customer wants to monitor voltage quality at his/her own connection point; the DSO or the TSO is compelled to provide a voltage quality monitor. For the rest of the countries, it appears that voltage quality monitoring is performed even if the TSO or the DSO is not legally obliged to do so. In Slovenia, a predefined payment is set (the predefined charges vary per utility and on average are around 400€ per week according to the tariff for supplementary services). However, in practice, the DSO will charge the customer only after a series of unjustified complaints – the customer is notified that any new measurement will be charged. In some countries, the customer pays only if the

measurements are found to be within the limits (Bulgaria, the Czech Republic, Hungary, Latvia, Poland and Slovenia). It is important to highlight that the customer, in order to take advantage of the monitoring service, must be informed about all the relevant aspects, including the cost of the service.

Customer compensation in Hungary for supply voltage variation

The regulation prescribes that the voltage variation should be within 230 V ± 7.5% (95% of the 10 minute r.m.s. voltage value for 1 week) and ±10% (100% of the 10 minute r.m.s. voltage value for 1 week), and further within +15% and -20% for all 1 minute r.m.s. voltage values. According to the regulation, if the requirements above are not met, the DSO compensates the consumer according to the following scheme: once in the first year, quarterly in the first half of the second year, and monthly from the second half of the second year, until the problem is resolved. Compensation is set considering the European experience as described in the 4th Benchmarking Report. 3 different groups of customers are considered in the compensation scheme:

A. Household customers: approx. 18€.

B. LV non-household customers: approx. 36€.

C. MV non-household customers: approx. 109€.

Until 2009, compensation was paid to consumers upon request. Since 2010, the DSO is obliged to compensate consumers automatically within 30 days from the date that the consumer complaint was verified. In 2009, the DSO paid a total of approx. 16,000€ and in 2010, a total of approx. 43,000€ in compensations to customers. For 2010, 96.7% of the compensation was for LV customers and the rest (3.3%) for MV customers.

Majority of the European countries have developed voltage quality monitoring systems using measuring units installed at EHV/HV, MV an LV level. In some cases, number of measurement periods with a duration of one week being performed with several measuring instruments per year. Also, some fixed measuring instruments are used by the DSOs in the HV and MV networks for continuous monitoring. Many countries have initiatives for Voltage Quality monitoring for the purpose of statistics, regulations, research and development, monitoring and network development. The cost of voltage quality monitoring is the responsibility of DSOs, TSOs, covered via tariffs to all connected customers and wind power station above 10 MW.

(Source: CEER benchmark Report, 2011)

GAPS IN THE INDIAN STANDARDS

When analysing the Power Quality regulation and its prescribed limits, it is observed that the regulatory requirements are not consistent among the States in India, and the central regulations framed by CEA and CERC. Some observations in this regard are listed below.

Inconsistency in standards for voltage variation

Several inconsistencies are observed amongst these regulations in the identified States. These are listed below

- Tamil Nadu does not specify the voltage variation limits for 33 kV and 66 kV.
- For voltage level 11 kV Tamil Nadu specifies limit as (+6% and -10%) whereas other states specify limits as (+6% and -9%).
- For voltage level 22 kV Tamil Nadu specifies limit as (+6% and -10%), Maharashtra specifies limit as (+10% and -12.5%), whereas other states specify limits as (+6% and -9%).
- For low voltage levels Tamil Nadu specifies limit as (+6% and -10%) whereas other states specify limits as (+6% and -6%).
- For EHT voltage levels, some states have voltage variation limits different from the central regulations as indicated below.

The above inconsistency in regulations results in a situation of different compliance requirement by utilities/consumers connected at 33 kV, 22 kV and 11 kV interconnection points. When looking at the voltage variation limits at interconnection points, regulations specified by few of the states are different compared to the CEA technical standards and Indian Electricity Grid Code which is summarized in the table below.

Limits for voltage variation at interconnection point				
Nominal Voltage(kV)	Maximum Limits (kV/%)		Minimum Limits (kV/%)	
	SERC Regulation	Central Regulation	SERC Regulation	Central Regulation
Madhya Pradesh				
400	+5%	+5%	-10%	-5%
220	+10%	+11%	-10%	-10%
132	+10%	+10%	-10%	-8%
Maharashtra				
66	73kV	72kV	60kV	60kV
Delhi				
66	73kV	72kV	60kV	60kV
Highlighted cells contains limits higher the central regulations prescribed value				

Inconsistency in standards for voltage unbalance

CEA has defined **voltage unbalance** as the deviation between the highest and lowest line voltage divided by average line voltage of the three phases of supply. Certain differences are observed in approach towards the standards for voltage unbalance amongst the identified states. These are listed below. Some States do not specify any standard for voltage unbalance. Also, there are differences amongst the States which specify the standards for voltage unbalance.

State	Standard for Voltage Unbalance
Tamil Nadu, Maharashtra, Gujarat	• No standard specified for voltage unbalance
Andhra Pradesh, Madhya Pradesh, Delhi	• Voltage unbalance shall not exceed 3% at the point of supply to the consumer.
Karnataka	• Voltage unbalance shall not exceed 3% at 33 kV and 3.5% at 11 kV.
CEA	• Voltage unbalance shall not exceed 3% at 33 kV and above. • Does not specify any standard below 33 kV.

Inconsistency in standards for harmonics

Differences were observed in the standards for harmonics specified by the identified States. These are listed below.

(1) At 11 kV level

- For voltage level 11 kV, Tamil Nadu, Gujarat and Maharashtra specifies THDv as 5% with individual harmonics content not exceeding 3% whereas Karnataka specifies THDv as 3.5% with individual harmonics content not exceeding 2.5%. Andhra Pradesh and Madhya Pradesh specify the cumulative THDv as 8% for 11 kV.

(2) At 33 kV level

- For voltage level 33 kV, Karnataka specifies THDv limit as 3% with no individual harmonic content higher than 2.5% whereas Tamil Nadu, Gujarat and Maharashtra specifies THDV as 5% with individual harmonics content not exceeding 3% for 33 kV level. Andhra Pradesh and Madhya Pradesh specify the cumulative THDv as 8% for 33 kV.

(3) Karnataka has inconsistency in its own Regulations

- Karnataka specifies THDv limit as 5% for 11kV and 33 kV in one regulation and 9% in another regulation. There are three different limits for single state.

(4) Difference from Central Regulations

- For EHT voltage levels, some states (such as Karnataka and Maharashtra) have harmonics limits different from the central regulations as presented in next slide.
- Madhya Pradesh regulation recommends following IEC Std 1000-4-7 or IEEE limit and Delhi doesn't specify any harmonics limits so far.

These are presented in a tabular form below.

State	SERC Limits	CEA Regulation
Tamil Nadu	• CEA grid connectivity standards.	• THD – 5% with single harmonic content not exceeding 3 % for 33 to 132 kV. • THD – 2.5% with single harmonic content not exceeding 2 % for 220 kV. • THD – 2% with single harmonic content not exceeding 1.5 % for 400 kV. • THD – 1.5% with single harmonic content not exceeding 1 % for 765 kV.
Gujarat	• THD – 5% with single harmonic content not exceeding 3 %.	
Maharashtra	• HT &LT (Industrial only) need to control harmonics at the levels prescribed by IEEE STD 519-1992 .	
Delhi	• Not specified.	
Madhya Pradesh	• IEC Std 1000-4-7 or IEEE Std. • THD not exceed 1% at the interconnection point of EHV system in accordance with IEC Std. 1000-4-7. • Cumulative THD_V – 3% (for 220 kV and 132 kV). • Cumulative THD_V- 8% (for 11 & 33 kV).	
Andhra Pradesh	• Cumulative THD_V – 3% (for 132 kV and above). • Cumulative THD_V- 8% (for 11 & 33 kV). • THD_V – 5% with single harmonic content not exceeding 3 %, THD_I – not exceeding 1% at drawl from transmission.	
Karnataka	• THD 3% at 33 kV and 3.5% at 11 KV with no individual harmonic higher than 2.5%. • THDV – 9% (for 400 V and 45 kV), 4% (for 400 V and 45 V), 3% (for 220V and above). • THDV – 5% (69 kV and below), 2.5% (69 kV up to 161 kV), 1.5% (161KV and above), 2% (HVDC terminals).	

Deviation in harmonics with IEEE-519 standard

In comparison with IEEE-519 standard, it is observed that harmonics limits prescribed by CEA Grid Standard Regulations are slightly on the higher side at 220 and 400kV voltage level. CEA Grid Standard Regulations recommends 5% THD with single harmonic content not exceeding 3 % for 33 to 132 kV, however IEEE recommends the CEA advised limits only up to 69 kV level and it suggests having 2.5% THD with individual harmonic content not exceeding 1.5% for 132 kV. This indicates the scope to narrow down the harmonics limits advised in Indian regulations. Also, most of the states which specified voltage harmonics limits have not specified the limits for current harmonics.

The majority of the states are referring to IEEE519 -1992 standards for harmonics limits. In contrast, the cumulative THDv of 11 kV, 33 kV and 132 kV level in Andhra Pradesh and Madhya Pradesh are higher than IEEE standards and CEA regulations.

STATUS OF IMPLEMENTATION AND SCOPE FOR IMPROVEMENT IN POWER QUALITY REGULATIONS IN INDIA

Though the Power Quality regulations are specified by the electricity regulatory commissions in various forms, many consumers are facing voltage variation beyond the prescribed limits form upstream supply and many consumers are dumping harmonics in the licensee's network. The brief study conducted by APQI indicates that due to poor voltage regulation, many continuous process consumers have been forced to invest in costly captive power generation units, pay for dedicated feeder that loses sanctity over time and also connected at feeder level above 22 kV or express feeders at additional costs.

Several regulations specify the Power Quality norms like voltage variation at point of supply and inter connection points; and norms for harmonics and voltage unbalance. However the States do not have framework to monitor and implement these standards on consumers and utilities for maintaining grid Power Quality right at distribution level where it is vital to avoid economic loss.

A point in case is the penalty to distribution licensee for not maintaining the voltage level at the point of supply. Most of the states have regulations which impose a penalty of INR 100 per week or part thereof for which voltage varies beyond the specified range. This may not be a sufficient compensation to the production loss or equipment failure due to voltage variation from upstream. Only Tamil Nadu has specified provisions and mechanisms for penalizing the consumers defaulting on harmonics injection limits specified by CEA. This is done through the tariff order for the DISCOM. Maharashtra has similar regulatory provisions however there is no specific order from the Commission as in Tamil Nadu. Majority of the States have harmonics limit provisions, however there is no clarity on the consequence of non-compliance to that.

Tamil Nadu is the only state in India, as of now, which has provisions (through tariff order) to penalise the High Tension consumers for dumping harmonics in to the Licensees network. The HT-I & HT-III category consumer is liable to pay compensation at 15% of the respective tariff, but the set compensation is not with respect to the intensity of dumped harmonics. Moreover, other HT consumers such as Irrigation, Agriculture, Townships and Residential colonies and Green Power are not covered under the ambit of these rulings.

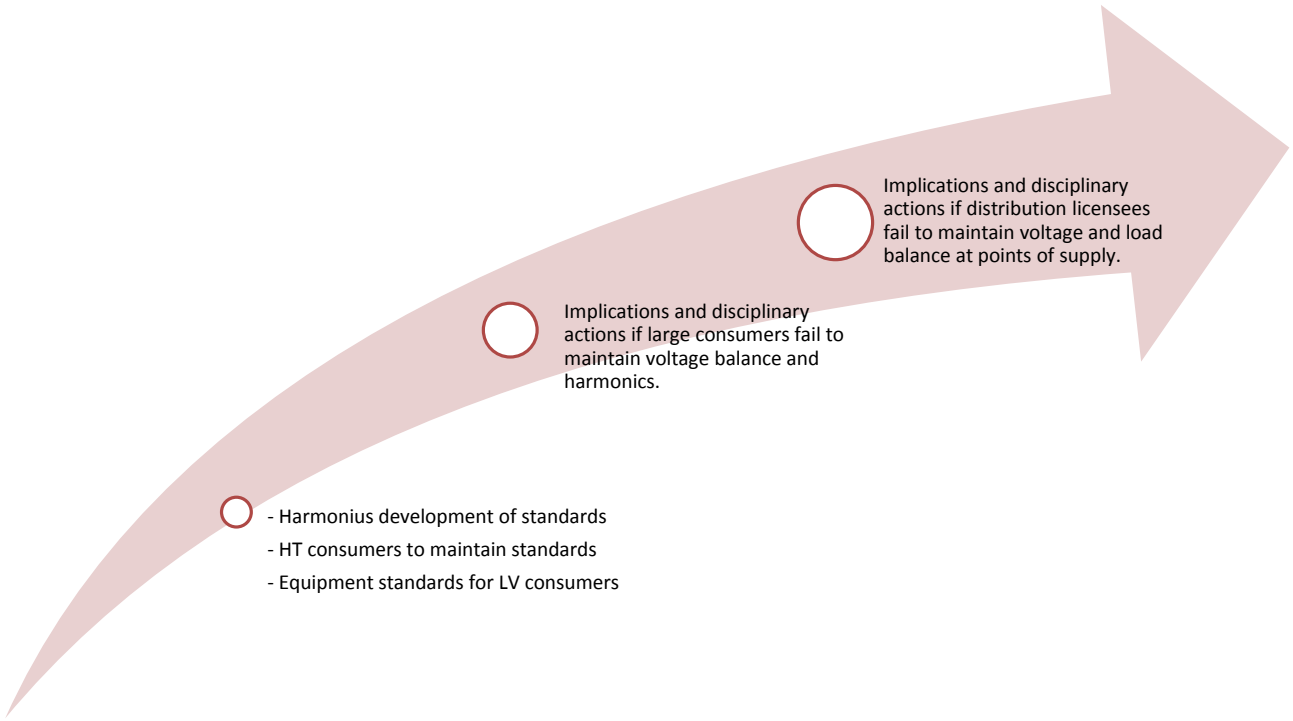
Various issues that arise from deficiency in Power Quality can be summarised as below.

Voltage and harmonics pollution in upstream distribution system.	Many consumers are facing voltage variation and injecting Harmonics in to grid though regulations may specify limits. Lack of implementation and monitoring framework fosters non-compliance.
High cost alternate source – losing market competitiveness in business.	Due to voltage variation, many continuous process consumers are opting for captive generation or higher voltage level i.e. above 22 kV or express feeders at additional cost. MV and LV consumers are forced to opt for UPS/ Inverter kind of power conditioning device, another source of non-linearity.

Measurement, verification and implementation framework.	Several regulations specify Power Quality norms but few states have framework to monitor the consumers and utilities for implementing and maintaining Power Quality in distribution.
Economic loss.	Increasing non-linear loads in the system is causing higher harmonic distortion resulting into failure of equipment, system, unexplained tripping, blockage of equipment capacity, loss of energy efficiency, safety hazard like fire etc.

In the current circumstances, the following aspects are not governed by existing regulations where we perceive a scope to improve the Power Quality discipline in future. The observations are listed below:

- Implications and disciplinary actions if bulk consumers fail to maintain voltage balance;
- Implications and disciplinary actions if distribution licensees fail to maintain voltage and load balance at points of supply; and
- Action plan including tariff incentive/ penalty mechanisms for entities which cause distortion of voltage-wave form quality.



FIELD SURVEY AND FINDINGS

In the survey conducted by APQI, industrial and commercial consumers were selected and invited to participate. These consumers represented sectors like manufacturing, fertilizer, chemical, commercial, etc., who are vulnerable to poor PQ. Most of them have operations in the state of Maharashtra and one from Gujarat. The population of entities surveyed were as below.

Sector	Sub-Sector	No. of Respondents
Manufacturing	Steel	1
	Automobile	1
Chemical	Alkali and Chemicals	1
	Petrochemical Handling and Transportation	1
Commercial	Retail Mall	2
Fertilizer	Fertilizer and Petrochemical	1
Precision Engineering Process	Precision Tool	1

Participants in the survey are mostly High Tension consumers with large contract demand and most of them are connected at 22 kV and above with the distribution licensee.

Respondent Segment	Product Line	Upstream Voltage Level	Contract Demand
Steel	Steel Sheets 24x7 process	220 kV/33kV Power use at 33kV	More than 2 MVA
Automobile	Cars 24x7 process	22 kV MSEDCL	More than 2 MVA
Alkali and Chemicals	Alkalis 24x7 process	33 kV	More than 2 MVA
Petrochemical Handling and Transportation	Petrochemical 24x7 process	22 kV	More than 2 MVA
Fertilizer and Petrochemical	Nitrite and Methanol 24x7 process	22kV	More than 2 MVA
Precision Tool	Process control instruments – not a continuous process	430 volt, 3Phase MSEDCL	Less than 1 MVA
Retail Mall-1	Commercial Mall – not a continuous process	22 kV MSEDCL	More than 1 MVA
Retail Mall-2	Commercial Mall-not a continuous process	33 kV MSEDCL	More than 1 MVA

Pre survey was conducted among FT consumers across various sectors to know the willingness of industries to carry out Power Quality field survey at their premises. About 65% of approached HT consumers were not interested in the subject matter out of which 27% expressed statutory concern as a main reason for not participating in the survey.

Approached consumers

About 23 HT consumers across Textile, Cement, Copper, Steel, Fertilizer, Petrochemical, Paper & Pulp, and Chemical and Industrial gas sector were covered in the pre survey to assess the willingness for Power Quality field survey. It is noted that, only 35% of the HT consumers are interested in participating in the survey.

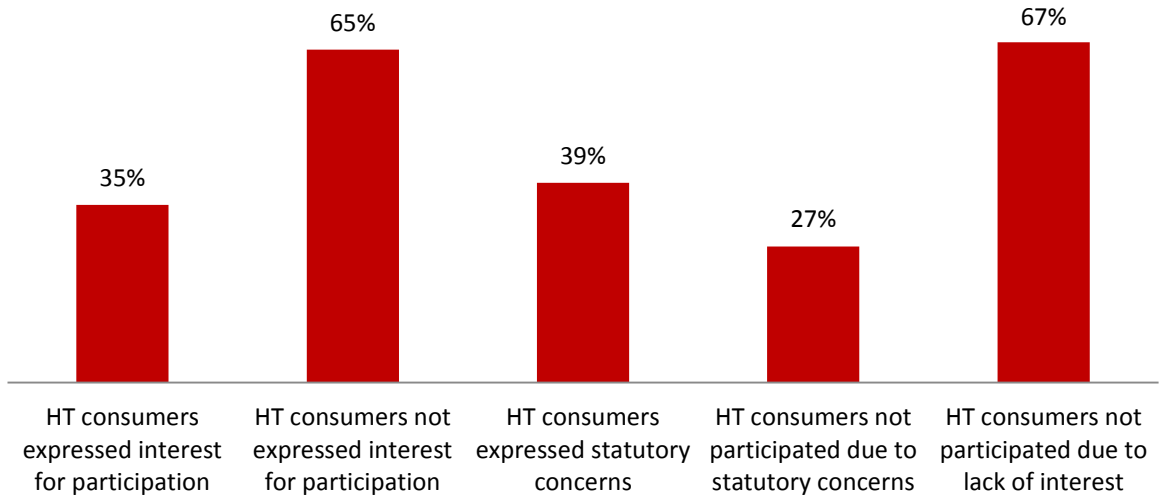
Only 35% of industrial consumers are interested about Power Quality

Response related to PQ

Non-participation is observed due to statutory concern and lack of interest on the Power Quality matters. Statutory concern is one of the inhibiting factors which is not providing transparent platform for the industries to discuss about the Power Quality issues and problems among peers and other stakeholders. In fact, it was a prime concern for 60% of participants who were not open for the Power Quality survey.

Pre Survey Statistics

Pre Survey Details	Count
Number of HT consumers approached	23
HT consumers expressed interest for participation	8
HT consumers not expressed interest for participation	15
HT consumers expressed statutory concerns	9
HT consumers not participated due to statutory concerns	4
HT consumers not participated due to lack of interest	10



Outcome of field survey

The survey revealed that the majority of the respondents are having current harmonics far beyond the prescribed limit of IEE-519. However, the overall impact of same on the network is dependent on the source and its capacity. The table below reports the summary of Power Quality status for the surveyed entities.

Summary of Power Quality field survey

Sub-Sector	Voltage Level (kV)	Voltage Variation	Presence of Harmonics beyond limit	Harmonics injection	Flicker Events	Dips	Swell	Unbalance
Steel	33	Minimal	Current Harmonics	Yes	Very High	Few	Very High	No
Automobile	22	Minimal	Current Harmonics	Yes	No	No	High	No
Alkali and Chemicals	33	Minimal	No	No	No	No	Low	No
Petrochemical Handling Unit	22	Beyond norms	Current Harmonics	Yes	High	High	High	No
Retail Mall-I	22	Minimal	Current Harmonics	No	No	No	No	No
Retail Mall-II	33	Minimal	Current Harmonics	No	No	No	No	No
Fertilizer and Petrochemical	22	Beyond norms	Current Harmonics	No	No	No	No	No
Precision Tool	0.43	Minimal	No	No	Yes	Few	High	No

Harmonics injection

- Three out of the eight entities surveyed (37%) are injecting harmonics in to the distribution network from their operations.
- Six out of the eight entities surveyed (75%) are generating current harmonics from their operations beyond the permissible limits.
- However, not all of them are injecting these harmonics in to the distribution network. Some of these entities are not injecting any harmonic dumps in to the grid as the intensity of the harmonic loads is not enough to disturb the grid network.
- Out of the surveyed sectors, evidence is found that the automobile, steel and the petrochemical sector are the segments that generate larger harmonics and tend to dump into the distribution network.

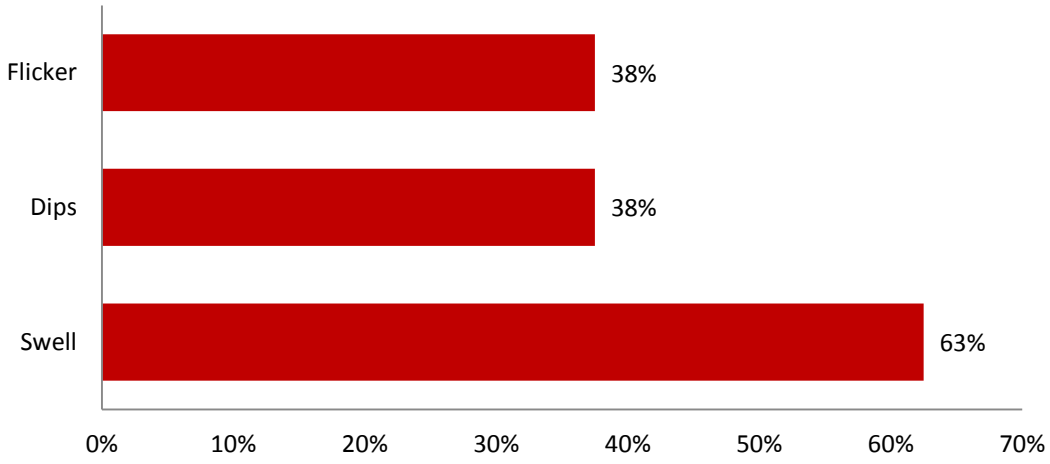
Voltage variation is predominant at 22 kV level

- Voltage variation is a common issue in distribution network at the points of supply.
- Majority of the respondents, who are taking supply at 33 kV and 22 kV voltage level from distribution utilities are observed to suffer voltage variations in supply ranging from 1 to 3%.

- Two out of eight (25%) respondents are observed with the voltage variation of 9 to 10% which is beyond the SERC recommended limit of +6%. Importantly, this high variation is observed only at the entities connected at 22 kV voltage level.
- Two out of the four (50%) respondents taking supply at 22 kV are having the voltage variation problem beyond the limit advised by the SERC regulations.

Flicker, Swell and Dips

When looking at other Power Quality issues, 63% of respondent are facing the swells issue in which 50% respondent are having higher events of swells. The highest events are faced by steel segment followed by automobile, petrochemical transportation and precision equipment sector.



About 38% of the respondents are experiencing flicker and dips which are seen in steel, petrochemical handling and precision equipment segment.

Inference of field survey

The survey has highlighted two major issues existing in upstream and downstream of the network. It is noted that a DISCOM in the surveyed state has supplied power to the HT consumer with the voltage variation beyond the prescribed limit. On the other side, some of the respondents particularly energy intensive industries such as steel and automobile manufacturing are injecting harmonics in to the grid.

Respondents are not observed to be well aware of the prevailing Power Quality regulations and norms as there is no control or concern over Power Quality parameters in the operations except for few indicators such as power factor, voltage balance and voltage variation. The hidden impact of other Power Quality parameters and its issues are yet to gain the attention of distribution companies and consumers.

Overall outcome of Power Quality surveys are reported below in the table.

Fertilizers & Petrochemical Sector
P.Q. Issues: Poor Voltage regulation and cause of voltage dips with large rating of motors
Probable Reasons: The source must have large number of industrial consumers and residential area loads. The source strength being inadequate to handle load variations during day. Hence voltage vary over wider range.
Remark: Up gradation of transmission, distribution might not have taken place over longer period of time. It is issue at utility end.
Steel Sector
P.Q. Issues: Harmonics, Swells in voltages, Flickers in voltages
Harmonics are injected by the client into the power distribution network. The Flickers and Swells have origins due to large load changes.
Probable Reasons: Nature of process and operations in the plant
Precision Process Sector
P.Q. Issues: RMS level voltage variation, dips & swells and transients in voltages
Probable Reasons Low voltage power sources in areas with mixed residential and industrial loads show disturbances in the network. The consumers and utility power companies are having their contributions.
Automobile Sector
P.Q. Issues: Harmonics in Body Shop and Media Shop
Probable Reasons: The process has non-linear loads which do inject harmonics to upstream.
Petroleum Handling and Transportation
P.Q. Issues: Harmonics, Voltage Fluctuation
Probable Reasons: The 22 kV line as remarked above (Fertilizers & Petrochemical) in the same area will show same P.Q. symptoms. Harmonics are injected by loads in the facility.
Commercial Mall-1
P.Q. Issues: No major issues except minor transient activity due to internal loads switching
Probable Reasons: The transient activity recorded was minor and was due to capacitor switching.
Commercial Mall-2
P.Q. Issues: Transients in voltages & Harmonics
Probable Reasons: The power from Utility supply company is known for good stability. As such reason for transients could not be ascertained but it is guessed as chiller switchover. Harmonics are due to presence of non- linear loads within the facility.
Chlor Alkali and Chemicals
P.Q. Issues: No P.Q. issues observed.

CONCLUSION AND RECOMMENDATIONS

The brief field survey conducted and described in the previous parts indicates that there are real issues on ground related to Power Quality, be it from the supply side or from the demand side. Through interactions with the participating consumer establishments it became evident that there is a general high level awareness about the issues on Power Quality. However, it is not a common practice of the industrial or commercial organisations to create broader awareness within the people of the organisation. Therefore, no evidence was found of a structured approach to understand, estimate and evaluate the impact these organisations may be suffering due to compromised Power Quality. The brief survey provided only a dip-stick assessment of the Power Quality issues surrounding the electricity supply and consumption. Wider and more in-depth studies are required to understand deeply the issues and their impacts on the overall system.

It is a possibility that the consumers are unnecessarily subjected to huge cost to deal with the Power Quality issues they face. For example, the automobile manufacturer reported to suffer downtimes and loss of production due to poor voltage regulations at the supply end. The fertiliser manufacturer had to make permanent arrangement of captive supply as the voltage regulation of the utility supply was beyond acceptable limits that cause process downtimes and huge production losses in the 24X7 continuous process operations. Unfortunately, no response was received from the participating organisations on the structured questionnaire that was provided them to understand the issues of Power Quality in a little more detail. This questionnaire sought inputs from the organisations like process downtime in a given period, damage and loss of equipment due to Power Quality issues, estimate of costs due to such events etc. This again indicates the lack of interest and awareness around the Power Quality theme.

Under such a scenario, we believe that the following steps may set the track for increase in awareness and sensitivity towards Power Quality issues and may lead to improve the overall scenario.

Regulatory interventions

Regulations are subordinate legislations that compel utilities and consumers to abide by the rules framed in the regulations. Therefore, we believe it will be extremely beneficial to start with regulatory interventions for improving the Power Quality issues. From the review of existing Power Quality regulations and results of the field survey, we suggest the following key aspects to be brought under regulatory compliances. Some of the requirements are submitted below for the consideration of regulators to maintain and supply quality power.

- Power quality indices/ KPI need to be additionally considered while evaluating the standards of performance of DISCOMs. PQ KPI shall include voltage variation, neutral voltage variation, voltage unbalance, dips, swells, transient, interruption at point of supply and harmonics.

- Making the norms consistent among central and state regulations by considering all relevant Power Quality parameters and aligning the same to widely acceptable international norms.
- Expanding the applicability of existing frameworks beyond HT consumers.
- Establishing procedures for monitoring and management of all aspects of Power Quality, i.e. continuity of supply, voltage regulation, and harmonics for all voltage levels in the regulations. Monitoring cum reporting methodology, monitoring frequency and responsibilities needs to be additionally incorporated in existing frameworks. Some of the existing regulations already specify the voltage monitoring and management provisions, but only at select voltage levels. Also, penalties and incentives need to be provided for both non-compliance and compliances.
- Mandating installation of Power Quality monitoring instruments at transmission and distribution sub-station and provision for phase wise installation of PQ monitoring systems at sub stations.
- Mandating smart systems for network which communicates the real time information and Power Quality deviations existing in upstream and downstream to all stakeholders.
- Measurement and monitoring of harmonics is a largely ignored area. Therefore, specific provisions need to be created by the Regulators to limit harmonics injection by consumers and utilities.
- Introducing penalties and disciplinary actions in regulations if utilities and consumers fail to comply with regulatory requirements. Introduction of incentive and penalty mechanism for consumers to maintain and comply with Power Quality norms.
- Increasing the existing penalty applicable for DISCOMs for not complying with voltage and harmonics limit at the points of supply. Penalties shall be such that it creates sufficient deterrent for the offenders of Regulations.

Utility action plans

The voltage variation and interruptions are major Power Quality issues faced by the end users at the points of supply. Distribution companies need to adopt Power Quality monitoring systems at sub-station as well as across the network to monitor and control the quality of power supply. Distribution companies must supply continuous, quality and reliable power to consumers. Distribution companies need to create institutional mechanisms for monitoring and assessing the impact of poor quality of power that cause equipment failures, and system downtime leading to higher operation and maintenance cost.

Consumer awareness programmes

Though there is provision for penalizing the utilities for not adhering to the voltage variation and harmonics limit, majority of the consumers are not using the provisions for following reasons:

- Absence of awareness among end users;
- Insufficient penalty or compensation by utilities to consumers; and
- Absence of measurement and monitoring system at user end to track deviations and abnormal events.

Distribution utilities need to design and implement awareness programmes for the consumers by engaging with them periodically through structured awareness programmes. This will also help create a forum for exchanging views with consumers and vice versa.

Equipment standard and control interventions

Equipment quality plays a large role in the quality of supply of electricity. The quality of the equipment decides its response to varying situations in Power Quality. Equipment are used by distribution utilities to supply power and consumers use equipment for their own individual purpose of manufacturing, production or otherwise. It is the quality of such equipment that influences the behaviour of Power Quality. Therefore, it is very important to specify the standards of the equipment that are used at different points of the value chain of electricity distribution and utilisation / consumption.

From the viewpoint of electricity distribution it is imperative that the distribution systems procure and use equipment of the desired quality. Equipment standards shall comply with the requirements specified by the bodies like BIS, or IEC or international equivalent. The electricity regulators need to consider this aspect of the equipment and devise mechanisms for monitoring and approval of equipment and system maintenance cost accordingly.

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