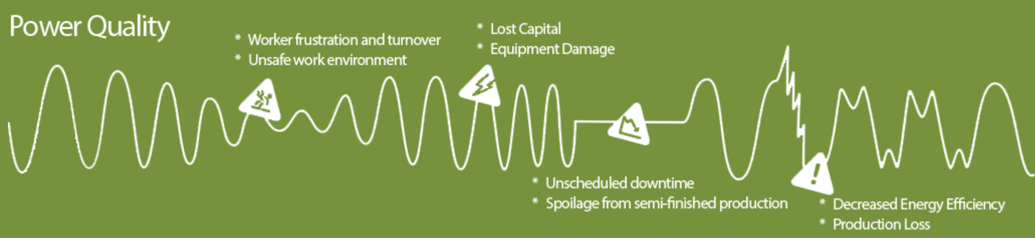
Report on Power Quality of Electricity Supply to the Consumers



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CENTRAL ELECTRICITY REGULATORY COMMISSION

सत्यमेव जयते

P. K. Pujari
Chairperson
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CERC

Dated – 5th September 2018

Forward

Starting its journey from commissioning first major electricity generation station in Karnataka in the year 1902 to being the 5th largest power generating country in the world, India has witnessed a tremendous growth of power sector. As the number of consumers rose, the electrical demand increased proportionately which further led to rise in complexity of the type of electrical loads. The widespread use of electronic equipment, such as information technology equipment, power electronics, programmable logic controllers (PLC), energy-efficient lighting, etc., led to a complete change of electric loads nature.

The Electricity Act 2003 has enshrined the basic need of consumers to be provided with continuous, reliable and quality supply by the Distribution Utilities. Meanwhile the accelerated growth of renewable energy along with meteoric rise of non-linear loads coupled with manifold increase in the intra-State, inter-State and inter-regional transaction of electrical energy, are posing serious challenges for quality of conventional unidirectional power flow from generation to consumption points. The quality of electricity has become an strategic issue for electricity regulator, electricity companies, the operating, maintenance and management personnel of service sector and industrial sites, as well as for equipment manufacturers, because of the economic necessity for businesses to increase their competitiveness, the widespread use of equipment which is sensitive to voltage disturbance and/or generates disturbance itself, reduction of costs linked to loss of supply continuity and problems of poor-quality; and the opening up of the electricity market.

Contd…..2/-

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Presently, all parameters of power quality are not covered under the Regulations framed by the Central Electricity Authority (CEA) and the State Electricity Regulatory Commissions (SERCs). Globally, in many countries, Power Quality (PQ) standards are implemented and enforced through Regulations for DISCOMs as well as for individual consumers. In India, various sectors are prone to both generation of higher PQ pollution as well as susceptible to PQ disturbances. Thus, the need to put emphasis on monitoring and introducing incentive/dis-incentive mechanism to ensure compliance to power quality within certain limits becomes more relevant.

The report on the "Power Quality of Electricity Supply to the Consumers" discusses all the above issues in great details. It is a matter of great satisfaction that the report was prepared under the guidance of the Working Group of the Forum of Regulators (FOR) after exhaustive consultation with SERCs, industry experts. The report lays emphasis on need for Regulations on Power Quality which define the power quality indices, roles and responsibilities of various entities, Standards/limits to be followed, incentive/ disincentive mechanism and procedure for monitoring, management and control of all aspects of power quality while exploring the present legal framework and the global regulatory scenario.

The Working Group on Power Quality was constituted under the Chairmanship of the Chairperson, FOR with Members as Chairpersons of Gujarat, Punjab, Assam, Arunachal Pradesh and Chhattisgarh Electricity Regulatory Commissions and Member (T) of Bihar Electricity Regulatory Commission. Subsequently, a Sub-Group on Power Quality was formed under Chairmanship of Shri A.S. Bakshi, Member (CERC) and Members as CEA, Chairpersons of few SERCs and industry experts to examine the issues in detail, make recommendations and to suggest model Regulations on Power Quality. The Sub-Group submitted its report on 11th July, 2018 to Chairperson, FOR. The Report of the Sub-Group was adopted by the Working Group in its 3rd meeting held on 23rd July, 2018 and accepted by the Forum of Regulators in its 64th meeting held on 24th August, 2018. Implementation of the recommendations of the this report in a time bound manner by all State Electricity Regulatory Commissions would go a long way in delivering quality power to consumers pan India. This framework would act as a foundation for several other regulatory interventions that are impending for strengthening power sector ecosystem and operation in India.

(P.K. Pujari)

Sub-group on Power Quality

Resolution

In view of the need of greater regulatory intervention in ensuring quality of power supply and the need for more effective compliance to Power Quality standards, a Working Group on Power Quality was constituted under the Chairmanship of the Chairperson, FOR. Subsequently, a Sub-Group on Power Quality consisting of the undersigned members was also constituted to examine the issues in detail, make recommendations and to suggest model Regulations on Power Quality.

The scope for work of Sub-Group was to study, examine issues involved and suggest measures to ensure reliable and quality power to the electricity consumers through appropriate regulatory interventions including drafting a model PQ Regulations.

The Sub-Group had six meetings at New Delhi to discuss the issues involved and the course of action to be adopted to frame Regulations on Power Quality to be presented to Forum of Regulators (FOR). In the sixth meeting held on 6th July, 2018, the report and draft Regulations on power quality was adopted by the members of the Sub-group.

The Sub-group hereby adopts the **Report on Power Quality of Electricity Supply to the Consumers and endorses it to the Working group of Forum of Regulators for acceptance.**

(S.C. Srivastava)
Chief (Engg.), CERC
Member Secretary

(Manas Kundu)
Representative, APQI

(P.S. Mhaske)
Member-Power System, CEA

(Sukumar Mishra)
IIT Delhi

(Anand Kumar)
Chairman, GERC

(R.N. Sen)
Chairman, WBERC

(M.K.Iyer)
Member, CERC

(R.N. Nayak)
Ex-Chairman-cum-MD, PGCIL
Co-Chair of the group

(A.S. Bakshi)
Member, CERC
Chair of the Sub-Group

Acknowledgement

It gives me immense pleasure in presenting this Report on "**Power Quality of Electricity Supply to the Consumers**" to the Forum of Regulators. The report documents the work of Sub-Group on Power Quality, consisting of Chairpersons of few SERCs and external experts including representatives from the public & private utilities as special invitees. The Sub-Group was constituted to examine the issues of power quality in detail, make recommendations and to suggest model Regulations on Power Quality. The Sub-Group deliberated on various issues related to quality of power supply to consumers and has come up with this report elaborating the various aspects of power quality in India.

Presently, all parameters of power quality are not covered under the CEA and SERCs Regulations. Globally, in many countries, PQ standards are implemented and enforced through Regulations for DISCOMs as well as for individual consumers. In India, various sectors are prone to both generation of higher PQ pollution as well as susceptible to PQ disturbances. Thus, the need to put emphasis on monitoring and introducing incentive/dis-incentive mechanism to ensure compliance to power quality within certain limits becomes more relevant.

The report lays emphasis on need for Regulations on Power Quality which define the power quality indices, roles and responsibilities of various entities, Standards/limits to be followed, incentive/disincentive mechanism and procedure for monitoring, management and control of all aspects of power quality while exploring the present legal framework and the global regulatory scenario. The draft model Regulation is enclosed is also a part of this Report. I am hopeful the report shall mark a golden beginning in improving the power quality in the Indian context.

I would like to express my gratitude to Shri P.K Pujari, Chairperson, FOR for his constant guidance, and all the members of the sub-group for their valuable inputs and participation and FOR secretariat for coordinating the meetings and driving the enthusiasm of the Sub-group.

I would like to thank Shri Akhil Kumar Gupta for providing valuable inputs in drafting the report and model Regulations. I would like to thank to Ms. Shilpa Agarwal, CERC for providing constructive insights. I would like to thank Ms. Anjuli Chandra, PSERC for her deep insights in the matter. I would also like to thank Shri Shahzad Alam, Solvina India Pvt. Ltd., Shri Praveer Sinha and Shri Lalit Wasan, TPDDL, Dr. Subir Sen, POWERGRID, Shri Venkatesh Dwivedi, EESL and Shri. Shyam Kumar, BIS for their valuable inputs. I would also like to place on record the Committee's special thanks to CPRI for conducting tests on LED bulbs & tube-lights. The Committee acknowledges the efforts made by Sh. Srinivas and Sh. Tanay, Research Associates of CERC for their help in organizing and managing the affairs of the Committee.

This could be taken up in FOR, once the report is adopted by the Working Group.

(A.S Bakshi)
Member, CERC &
Chairman of the Sub group on Power Quality

ACRONYMS AND ABBREVIATIONS

AC	Alternating Current or Air-Conditioners
ABT	Availability Based Tariff
APF	Active Power Filters
APFC	Automatic Power Factor Controller
APQI	Asia Power Quality Initiative
ARR	Annual Revenue Requirement
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
AT&C	Aggregate Technical & Commercial
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
BFSI	Banking, Finance & Service Industries
BS	British Standards
CAIDI	Customer Average Interruption Duration Index
CERC	Central Electricity Regulatory Commission
CEA	Central Electricity Authority
CEER	Council of European Energy Regulators
CFL	Compact Fluorescent Lamp
CML	Customer Minutes Lost
CPRI	Central Power Research Institute
CTAIDI	Customer Total Average Interruption Duration Index
CTU	Central Transmission Utility
CT/PT	Current Transformer/Potential Transformer
DC	Direct Current
DELP	Domestic Efficient Lighting Programme
DG	Diesel Generator
DISCOM	Distribution Company
DMS	Data Management System
DSM	Deviation Settlement Mechanism
DVR	Dynamic Voltage Restorer
DTRs	Distribution Transformers
EA	Electricity Act
EHT	Extra High Tension
EHV	Extra High Voltage
EN	European Norms
ENS	Energy Not Served
EPRI	Electric Power Research Institute
EE	Energy Efficiency
EESL	Energy Efficiency Services Limited
ESCO	Energy Service Company
EU	European Union
FACTS	Flexible AC Transmission System

FICCI	Federation of Indian Chambers of Commerce and Industry
FFT	Fast Fourier Transform
FOR	Forum of Regulators
HT	High Tension
HV	High Voltage
HVDC	High Voltage Direct Current
ICA	International Copper Alliance
IS	Inter-State Transmission System
ISTS	Indian Standards
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ITES	IT Enabled Services
LPQI	Leonardo Power Quality Initiative
LED	Light Emitting Diode
LT	Low Tension
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
MAIT	Manufacturer's Association of Information Technology
M&E	Measurement & Evaluation
MTTR	Mean Time to Repair
MV	Medium Voltage
NABL	National Accreditation Board for Testing and Calibration Laboratories
NEIPI	Number of Equivalent Interruptions Per Power Installed
PCC	Point of Common Coupling
PF	Power Factor
POC	Point of Connection
PQ	Power Quality
PSERC	Punjab State Electricity Regulatory Commission
RMS	Root Mean Square
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition System
SEB	State Electricity Board
SERC	State Electricity Regulatory Commission
SOP	Standard of Performance
STU	State Transmission Utility
TAT	Turn-Around Time
THD	Total Harmonic Distortion
TIEPI	Time of Equivalent Interruption Per Power Installed
ToD	Time of the Day
TPDDL	Tata Power Delhi Distribution Limited
UPS	Uninterrupted Power Supply

UI	Unscheduled Interchange
VCRs	Video Cassette Recorders
VOLL	Value of Lost Load
WBERC	West Bengal Electricity Regulatory Commission

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Executive Summary

Starting its journey from commissioning first major electricity generation station in Karnataka in the year 1902 to being the 5th largest power generating country in the world, India has witnessed a tremendous growth of power sector. As the number of consumers rose, the electrical demand increased proportionately which further led to rise in complexity of the type of electrical loads. At present India is the 4th largest consumer of electricity in the world but in spite of being one of the leaders both in electricity generation and consumption, it is facing major issues related to Power Quality (PQ).There are many reasons like huge gap between demand and supply just a decade back, lack of awareness and capacity to understand issues and challenges associated with quality of power, restricted availability of technology in detecting and overcoming such challenges.

The Electricity Act 2003 has enshrined the basic need of consumers to be provided with continuous, reliable and quality supply by the Distribution Utilities. Meanwhile the accelerated growth of renewable energy along with meteoric rise of non-linear loads, are posing serious challenges for quality of conventional unidirectional power flow from generation to consumption points. Poor quality of power lead to premature failure or reduced/degraded performance of equipment. It also caused increased system losses. Discerning consumers are looking for clean and quality power to drive their sensitive equipment at all levels. In this context, during thirty First Meeting of Forum of Regulators (FOR), issues pertaining to power quality were discussed and the need for greater regulatory intervention in ensuring quality of power supply was highlighted. The need for more effective compliance to power quality standards was also emphasised. In view of the same, a Working Group on Power Quality was constituted under the Chairmanship of the Chairperson, FOR. Subsequently, a Sub-Group on Power Quality consisting of Chairpersons of few SERCs and external experts including representatives from the public & private utilities as special invitees was also constituted to examine the issues in detail, make recommendations and to suggest model Regulations on Power Quality. The Sub-Group deliberated on various issues related to quality of power.

At present, a few parameters related to power quality are covered under the Central Electricity Authority (CEA) and SERCs Regulations. The State Regulations, when dealing with the aspect of Power Quality through Supply/Grid Code or Standards of Performance are not harmonious across different States and does not cover all aspects of power quality. .

There is a need to put emphasis on measurement and introducing incentive/dis-incentive mechanism to ensure compliance to power quality parameters within certain limits. Therefore a separate model Regulation on Power Quality is proposed. The report covers the following broad features:

1. Power Quality is drawing increasing attention due to the heavy penetration of Power Electronics based loads in every walk of our lives. PQ parameters like Frequency, Voltage Quality (interruptions, variations, unbalances, flicker, sags, and swells), Harmonics and Power Factor are key matrices/indicators for defining a good PQ environment.
2. The Grid Code, Supply Code and Standard of Performance (SOP) laid by various SERCs do mandate the quality of power to be maintained. But PQ parameters other than frequency and voltage interruptions are not given due attention. Even there are lot of variations in similar PQ parameters specified by different SERCs. Therefore there is a strong need to introduce a harmonized regulation on Power Quality across all States.
3. On a global level, PQ Standards and/or Regulations are specified by IEEE, IEC and EN which cover not only DISCOMs but individual consumers as well. In EU, a DISCOM's performance is measured by supply continuity, voltage monitoring (voltage variations, Flicker, unbalance, harmonics and mains signalling voltage) and Reliability indices (SAIDI, SAIFI, MAIFI etc.). EN 50160 is widely used as the standard for voltage quality.
4. Due to the complexity of the nature of loads connected to the electrical grid, measurement and evaluation of PQ parameters takes prime importance. From compliance monitoring to system performance monitoring and location based monitoring can be done using appropriate metering guidelines as laid down by IEC standards.
5. In India, various sectors are prone to both generation of higher PQ pollution as well as susceptible to PQ disturbances (such as Commercial Buildings, IT/ITeS, Automobiles, Steel, Cement, etc.)
6. The losses due to PQ issues are economic as well as technical. According to a study conducted by Manufacturer's Association of Information technology (MAIT) in 2009, Indian industries lost $9.6 billion due to PQ issues which could have been averted by spending less than 10% of the cost of losses. Both utilities as well as consumers are heavily impacted due to the techno-economic losses arising out of poor PQ.

7. Overall Recommendations:

- **a.** Model Regulations on Power Quality are needed which define the power quality indices, roles and responsibilities of various entities, Standards/limits to be followed, incentive/disincentive mechanism to be deployed and procedure for monitoring, management and control of all aspects of power quality.
- **b.** Since Reliability and Quality go hand in hand, the Reliability indices should be included in the Model Regulations.
- **c.** For power quality parameters at transmission and sub-transmission system level, Regulators should introduce appropriate reporting and incentive/dis-incentive mechanism in their Grid/Supply Code or in Standards of Performance Regulations for regular monitoring and implementation of the specified limits.
- **d.** Limits for some of power quality parameters like Harmonic Distortion, Voltage Variation & Flicker, Voltage Unbalance, Voltage Sags/Swells and Supply Interruptions have been specified in the Model Regulations on Power Quality keeping in view the international or national standards. The limits for other power quality parameters may be included in Power quality Regulations by the SERCs based on their experience and specific system requirements.
- **e.** The group recommends continuous monitoring and reporting of power quality parameters at identified locations by the Distribution Licensees.
- **f.** Incentive/dis-incentive mechanism may be structured and implemented in a phased manner.
- **g.** Power Quality measurements may be integrated with the smart grid applications for a reliable smart grid.
- **h.** SERCs may prescribe PQ reporting format and fix the responsibility to maintain the PQ database by the distribution licensees or bulk consumers, as the case may be, for a sufficiently long period.
- **i.** Regulatory framework may specify the training requirements for effective implementations of the PQ standards.
- **j.** Regulatory framework should introduce the compliance audit of PQ parameters by Independent agencies.

The draft model regulation in this regard is enclosed for exhaustive coverage with respect to all aspects of power quality and to ensure a harmonized framework.

Proceedings of the Sub-Group on Power Quality

1. The Forum of Regulators (FOR) was constituted by Notification dated February 16, 2005 in pursuance of the provision under section 166(2) of the Electricity Act, 2003. The FOR comprises the Chairperson of the Central Electricity Regulatory Commission (CERC), and Chairpersons of the SERCs. The Chairperson of the CERC is also the Chairperson of the FOR.

2. During Thirty First Meeting of FOR, issues pertaining to Power Quality were discussed and the need for greater regulatory intervention in ensuring quality of power supply was highlighted. The need for more effective compliance to Power Quality standards was also emphasised. In view of the same, a Working Group on Power Quality was constituted under the Chairmanship of the Chairperson, FOR. Subsequently, a Sub-Group on Power Quality consisting of Chairpersons of few SERCs and external experts including representatives from the public & private utilities as special invitees was also constituted to examine the issues in detail, make recommendations and to suggest model Regulations on Power Quality.

3. The Sub-Group on 'Power Quality' consists of:

1) Shri. A.S. Bakshi, Member, CERC – Chair of the Sub-Group
2) Shri. R. N. Nayak, Ex-Chairman-cum-Managing Director, Power Grid Corporation of India Ltd. – Co-Chair of the Sub-Group
3) Chairman, West Bengal Electricity Regulatory Commission – Member
4) Chairman, Meghalaya Electricity Regulatory Commission – Member
5) Member (Power System), Central Electricity Authority – Member
6) Representative of Asia Power Quality Initiative – Member
7) Shri. Akhil Kumar Gupta, Joint Chief (Engg.), CERC – Member Secy.

4. The Terms of Reference of the Sub-Group on Power Quality are:

a) To study Power Quality Regulations notified by different State Electricity Regulatory Commissions in India;
b) Review of Power Quality related national standards under CEA/BIS joint initiatives;
c) Review of actions initiated by various SERCs in line with the Act provisions for addressing power quality and suggests possible further improvements;

d) To study Power Quality Regulations in various other countries especially the ones followed by Council of European Energy Regulators (CEER);

e) Initiate comprehensive study to improve PQ performance. Study may include:

- Benchmarking of PQ performance parameters;
- Identification of polluting customers by providing monitoring equipment in distribution system ;
- Adequacy of PQ compliance by RE generators;
- PQ in Smart Grid / Green Energy Corridors;
- PQ performance indices linked to Annual Revenue Requirement (ARR) of distribution licensee;
- Cost of poor power quality affecting Indian Economy;

f) To find out various techniques available for monitoring and evaluation of PQ parameters;

g) To identify measures to mitigate the impact of power quality in the distribution system and introduce measures for top three PQ issues in the country;

h) To develop draft Regulations on Power Quality for the working group of FOR on Power Quality.

<u>Deliberations of the Sub-Group Meetings</u>

The Sub-Group deliberated on various issues related to quality of power. The summary of discussions held in these meeting is given below.

5. The Sub-Group had organized six meetings at New Delhi to begin the course of action on the Regulations on Power Quality to be presented to Forum of Regulators (FOR). The first meeting of the Sub-Group was convened on 2nd February 2016, second meeting was convened on 23rd May 2016, third meeting was convened on 13th July 2016, fourth meeting was convened on 9th October 2017, fifth meeting was convened on 2nd May, 2018 and sixth and last meeting was held on 6th July 2018. Ms. Anjuli Chandra, Member (PSERC) was invited as a special invitee post third meeting. During the meetings, various electrical codes and Regulations specified by statutory authorities (Supply Code, Grid Code and Standards of Performance Regulations), benefits of resolving PQ issues and Electrical Standards related to power quality practised globally were studied. The practical tests were conducted on LED bulbs by CPRI Bengaluru to analyse Power Factor, total Harmonic Distortion in current as well as voltage. In similar study conducted under the aegis of Chairman WBERC, similar

conclusions emerged where harmonic distortion is varying significantly. The results of these tests/studies were discussed during the meetings. Further, technical standards on power quality for distribution system were discussed by the sub-group with a view to specify the Model Regulations.

6. During the first meeting, to facilitate a focused discussion, Chair of the Sub-Group requested Shri. Manas Kundu, Representative of Asia Power Quality Initiative (APQI) to make a presentation on the subject. Mr. Kundu emphasized on the issues due to poor PQ and its impact, various electrical codes specified by statutory authorities (Supply Code, Standards of Performance and Grid Codes) and benefits of resolving PQ issues. He also referred to various Electrical Standards related to power quality practised globally. After the discussion, the following consensus emerged among the members:

- The components of power quality need to be identified. Apart from quality with respect to harmonics, quality with regard to voltage, supply and frequency should be considered.
- Accelerated effort to bring in harmonic control regulations supported by respective States ARR/Tariff order directive on incentive /penalty may be undertaken.
- As regards electrical parameters, there should be two distinct analyses: one related to reliability and the other related to quality.
- Current practices of reliability reporting by various DISCOMs to be looked into for identifying the gaps, lessons learnt and improvement for future robust national information database to facilitate national plan.
- A detailed study may be conducted on present provisions being followed in India with regard to power quality and international practices in force.

During the first meeting it was decided to co-opt Shri Sukumar Mishra, IIT Delhi as member of the Sub-group. Further approval was taken to nominate Shri Anand Kumar, Chairman, Gujarat SERC, who was earlier Chairman of Meghalaya SERC to continue as member of the Sub-group in place of Chairman of Meghalaya SERC.

7. During the second meeting, Chairman (WBERC) and Member of the Sub-Group raised an alarm about the performance parameters of LED bulbs. In view of the same, the tests were conducted by CPRI Bengaluru to analyse Power Factor, Total Harmonic Distortion in current as well as voltage. Shri Akhil Kumar Gupta, Member Secretary of the Sub-Group, made a presentation on these studies conducted on LED bulbs and tubes. The Sub-Group noted the

study and discussed key points like: inclusion of harmonics in measuring True RMS Power Factor and increasing incidences of failures due to harmonics.

In another study conducted under the aegis of Chairman WBERC, similar conclusions emerged where harmonic distortion is varying significantly. The members further suggested to formulate technical standards on PQ and harmonic control in CEA. Shri.Shahzad Alam, Representative of Solvina India Pvt Ltd emphasized on the importance of power quality monitoring and recommended that Regulations should be brought-in to help network operators, encourage them to go for PQ monitoring and help strengthen the grid. Shri. Lalit Wasan TPDDL elaborated on the emerging PQ challenges in India and concluded all stakeholders must give their inputs in framing long term policies. Dr.Subir Sen, GM, POWERGRID suggested the need of capacity building and training program, establishment of National & State level organization for PQ certification, R&D, etc. for improving PQ environment. After the discussion, the following consensus emerged among the members:

- Attention needs to be drawn about quality of products entering the market, which is polluting the power system. Corrective action needs to be taken in this regard by strengthening the applicable standards.
- A detailed technical study may be conducted on current provisions being followed and benchmark it with International practices. Technical standards on power quality and harmonic control may be developed for transmission as well as distribution.
- Tata Power was requested to carry out studies on PQ characteristics with regard to inverter based air-conditioners (AC) and solar inverter.
- With reference to the Terms of Reference of the Sub-Group, it was considered necessary that product standards and supply system standards are to be formulated by Bureau of Indian Standards.

8. During the third meeting, Shri. Venkatesh Dwivedi, Representative of EESL in response to tests conducted by CPRI, informed the Sub-Group that there is a mandatory IS specification: IS 16102-Part 1, wherein any entity marketing LED bulbs in the country needs to register them and pass the requisite tests. He also informed the Sub-Group that EESL has multi-stage quality assurance for DELP scheme and street lights. NABL certified labs carry out three tests like electrical parameters, electronic parameters and photometric parameters such as Colour Temperature and Colour Rendering Index etc. He also drew the attention of the Sub-Group to various issues on power quality (e.g. lightning surge, switching surge) that impacts the LED bulb, street light or tube light. Shri Shyam Kumar, Representative of BIS informed

the Sub-Group that Draft standards on LED tube lights have been promulgated by BIS, which has been circulated for comments by stakeholders. He also informed about the prevailing 'Driver' testing specifications in LED systems, i.e., IS 15885 Part 2 Section 13. Shri Akhil Kumar Gupta presented the draft Structure of the Regulatory Report on Power Quality. After the discussion, members came to a consensus on following points:

- The prevailing 'Driver' testing specification, i.e., IS 15885 Part 2 Section 13 may be strengthened and made mandatory for all LED systems as driver specification would result in control of power factor and current harmonics.
- Need to initiate measures to make IS 16102- Part 2 standards mandatory, which is voluntary at present.

9. Shri M.K. Iyer, Member (CERC) was co-opted as a Member of the Sub-group.

10. Chief (Engg.) was co-opted as Member Convenor of the sub-group by competent authority on 23.12.2016, on completion of tenure of deputation of Shri Akhil Gupta at CERC.

11. During the fourth meeting, Professor Math Bollen, Lulea University of Technology, Sweden was invited to deliberate on international experience and best practices in area of power quality. Representatives of DISCOMs and other State Regulatory Commissions were invited for the meeting.

12. During the fifth meeting, the preliminary report and draft Regulations on power quality were deliberated amongst the members of the Sub-group. The members suggested following salient points which need to be covered in the Report:

- Definition of power quality to be included in the report
- Identify the responsibility of utility or consumer for specific parameter.
- Interruptions at 11kV/33kV/400kV carry different values and appropriate weightage may be given accordingly.
- To start with Make installation of PQ meters mandatory at strategic locations.

13. The work of Sub-Group is to study, examine issues involved and suggest measures to ensure reliable and quality power to the electricity consumers through appropriate regulatory interventions including drafting a model PQ Regulations.

Chapter 1: Introduction and Context

Business and the economy in digital era depend upon reliable and quality power supply. So far, the focus of the sector was limited to providing uninterrupted power supply to consumers. This was understandable at the time of deficit when the limited supply of power was available to meet peak demand and the expectation of end consumers was availability of power supply. The issue of power quality remained largely ignored in the Electricity Supply Industry of India.

1.1 What is Power quality?

The Reliability and Quality are two important aspects of any electrical power supply system. Power Reliability means availability of power supply 24 x 7 basis which constitutes adequacy of electrical system at all levels from generation, transmission to distribution. However, power quality refers to both the extent of deviation or distortion in pure supply waveform and the continuity of supply. Any significant deviation in the magnitude, frequency, waveform or symmetry of line voltages is a potential power quality problem. Ideally, a wave form should be smooth and free from disturbances. But even the best power systems are subject to fluctuations and all electrical equipment are susceptible to damages caused by these fluctuations. When quality of the power supplied is deficient, it results in performance degradation and reduced life expectancy of an equipment. Therefore, we may understand poor power quality as any power problem manifested in voltage, current, or frequency deviations that result in failure, increased energy loss or malfunctioning of an equipment, thus causing economic loss. Poor power quality can also result in problems with electromagnetic compatibility and noise. For example, it can affect sophisticated protection systems and/or malfunctioning/failure of vital control and signal systems.

Typical electrical loads, such as lighting, heating, and motor, are less sensitive to variations in the supply voltage, and more sensitive to availability (free from interruptions) of supply. However, electronic/digital equipment are more sensitive to variations in supply voltages. As per Standard Handbook of Electrical Engineers, 14th edition (2000):

"Good power quality, however, is not easy to define because what is good power quality to a refrigerator motor may not be good enough for today's personal computers and other sensitive loads. For example, a short (momentary) outage would not noticeably affect motors,

lights, etc. but could cause a major nuisance to digital clocks, videocassette recorders (VCRs) etc."

The IEC/IEEE defines power quality as under:

IEEE Std.1159: *"Power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment."*

IEC 61000 – 4 – 30: *"The characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters."*

Characteristics that affect power quality are voltage fluctuation, Harmonic distortion, voltage unbalance, flicker, supply interruptions, voltage sags, voltage swells and transients etc.

1.2 Why is there a need to improve Power Quality?

In the emerging surplus power scenario, the characteristics of loads and the requirements of electrical systems have changed significantly. The devices and equipment used presently in industrial, commercial and domestic facilities are more sensitive to supply variations than equipment used in the past. It is due to increased use of power electronics and microprocessor-based technologies in equipment and appliances. The increasing penetration of Renewable sources of energy, semiconductor based electronic equipment, non-linear loads, data centres, industries running on adjustable speed drives and arc furnaces, etc. distort voltage/current waveforms in non-conformity to their desired form. This brings challenges to maintain the quality of power to ideal one and ensuring efficacy.

Poor power quality not only causes performance degradation and premature failure of electrical equipment but also results in increased system losses, financial loss etc. Therefore, apart from the reliability i.e. continuous supply, the preference of the electricity consumers is now shifting towards quality power supply from the distribution licensees. Optimum power quality can enhance productivity and reduce losses.

1.3 What are different Power Quality Parameters?

Distribution Utilities can largely control the voltage since the customer will be controlling the loads and thereby the current drawn. Regulations and Standards are mostly focused on voltage. The standards for voltage and other technical criteria are there which can be used to measure power quality.

Important parameters affecting power quality can be divided into two categories, i.e. Steady-state (or continuous) and Disturbances. Steady-state power quality parameters include Harmonics (waveform distortion), frequency deviation, voltage unbalance, voltage fluctuations and flicker. Disturbances include outages, momentary interruptions, momentary or transient overvoltage or surges, voltage dips and voltage swell. Long duration variations encompass root mean square (rms) deviations at power frequencies longer than 1 min. The important parameters are defined below with their probable causes and effects on the electrical equipment or supply system:

a. **Frequency** – Any variation of the power system fundamental frequency from its specified nominal value (e.g. 50 Hz in India) is defined as a frequency deviation. Frequency variations that go outside of the accepted limits for a normal steady-state operation of the power system can be caused by faults on the bulk power transmission system, a large block of load being disconnected, or a large source of generation going offline. Large frequency variations results in long-term damage to both generator and end use rotating electrical equipment whose rated output may suffer in low frequency regime. It may affect system stability and also leads to blackout of the grid. In interconnected power systems, significant frequency variations are rare.

b. **Voltage**

   i. **Supply Voltage Interruptions** - It is a condition in which the voltage at the supply terminals is lower than 10% of the nominal voltage. It may be long or sustained interruption if duration is longer than 1 min. and short interruption if duration is up to and including 1 min. However, different countries have specified different durations based on system conditions in their standards. Voltage interruptions longer than 1 min. are often permanent and require human intervention to repair the system for restoration. For poly-phase systems, an interruption occurs when the voltage falls below 10% of the nominal voltage on all the phases otherwise, it is considered to be a voltage dip. Reasons behind interruptions could be power system faults (short-circuits), equipment failures and/or failure of the control equipment. Long power interruptions are a problem for all users, but many operations e.g. continuous process operations, multi-stage batch operations, digital data processing semiconductor fabrication etc. are very sensitive to even very short interruptions. These kind of interruptions are popularly known as **'Black Outs'** or **'Load Shedding'**.

ii. **Voltage Variations or Voltage Fluctuations** - It is defined as a cyclic variation of the voltage envelope or series of random voltage changes, the magnitude of which does not normally exceed the specified voltage ranges. They are relatively small (less than $\pm$5 or $\pm$10 percent) variations in the rms line-voltage. These variations can be caused by static frequency converters, cyclo-converters, arc furnaces, rolling mill drives, main winders and large motors during starting, etc. Voltage fluctuations may cause nuisance tripping due to mal-operation of relays and contactors and unwanted triggering of UPS units to switch to battery mode. It may stress electrical and electronic equipment toward detrimental effects that may disrupt production processes with considerable financial loss. These kind of fluctuations are popularly known as '**Brown Outs'**.

iii. **Voltage Unbalance** – It is a condition in a poly-phase system in which the root mean square (rms) values of the line-to-line voltages (fundamental component), or the phase angles between consecutive line voltages, are not equal. The sources of unbalanced voltages are due to malfunctioning of equipment, mismatched transformer taps and impedances, blown capacitor fuses, open-delta regulators, or open-delta transformers. It can also be caused by uneven single-phase load distribution among the three phases. Unbalanced systems indicate the existence of a negative sequence component of supply voltage, which is harmful to all poly-phase loads, especially three-phase induction machines. It can cause an over-load on induction machines and malfunctioning of frequency converters. Voltage unbalance can create a current unbalance which can be 6 to 10 times the magnitude of voltage unbalance. In turn, current unbalance produces heat in the motor windings which degrades motor insulation causing progressive performance deterioration and permanent damage to the motor.

iv. **Voltage Sag (dip)** – It is a condition in which the voltage at the supply terminals ranges within10% to 90% of the nominal voltage for a duration of about half a cycle to several seconds. Common sources of sag are the starting of large induction motors and system faults. Sags can happen due to an overloaded circuit, malfunction of a transformer's tap changer, breakers connecting a large inductive load to the grid or a disconnected capacitor bank. Also, arc furnaces initially take large amperes to produce high temperatures causing voltage sag. Voltage sag result in malfunction of equipment/ relays and contactors, under voltage tripping, loss of efficiency of motors and intermittent reduction of light illumination etc. In case voltage is too low (<90% of nominal voltage), accelerated aging may take place in components and eventually causing faults in the network.

v. **Voltage Swell (rise)** –It is a condition in which the voltage at the supply terminals ranges within 110% to 180% of the nominal voltage for a duration of about half a cycle to several seconds. Over-voltage could be the result of connecting a capacitor bank or disconnecting a large inductive load. Other sources of voltage swells are line faults and incorrect transformer tap changer settings in the sub-stations. It also occurs due to transfer of loads from one source to another. Voltage swell results in malfunction of an equipment, insulation failure, intermittent increase in light illumination, tripping of relays and contactors etc. In case of very high voltage (>110% of nominal voltage), damage to electrical appliances may occur.

vi. **Flicker** –It is the impression of uncomfortable visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates rapidly with time. It is caused under certain conditions by voltage fluctuations resulting in change of the luminance of lamps. Quantitatively, it may be expressed as the change in voltage over nominal voltage expressed as a percent. The main cause of these effects is fast switching operations of industrial processes and electrical appliances connected to the supply system. Flicker is considered the most significant effect of rapid voltage fluctuations because it can affect the production environment by causing personnel fatigue and lower work concentration levels.

vii. **Voltage Transients** – Transients are momentary changes in voltage or current which occur over a short period of time usually for microseconds. It is divided into two categories. Impulse transient, which is a brief, unidirectional variation in voltage, current, or both on a power line and Oscillatory transient, which is a brief, bidirectional variation in voltage, current, or both on a power line. The most common causes of impulsive transients are lightning strikes, switching of inductive loads, opening and closing of energized lines and tap changing on transformers. Oscillatory transient can occur due to the switching of power factor correction capacitors, or transformer Ferro-resonance. Poor or loose connections in the distribution system can also generate transients. Due to transients, electronic devices may operate erratically. Motor winding insulation is degraded and resulting in eventual failure. The electrical distribution system is also affected by transient activity. Voltage Transients degrade the contacting surfaces of switches, isolators, and circuit breakers. Intense transient activity can produce "nuisance tripping" of breakers. Transformers may get saturated if exposed to high voltage transients. In such cases hysteresis losses will increase thus causing transformers to run hotter than normal.

viii. **Voltage Harmonics -** It is a sinusoidal component of a periodic voltage waveform having a frequency that is an integral multiple of the fundamental frequency. It is the deviation from the original or pure voltage sine waveform. Generally at the source point, the Voltage harmonics is absent. As the power flow progresses towards load end, voltage harmonic creeps in due to the effect of current characteristics of non-linear loads reflecting on network impedances. Voltage harmonics is generally expected to be managed by the Utility service provider.

c. Reactive Power & Current Harmonics

i. **Current Harmonics** –It is sinusoidal component of a periodic current waveform having a frequency that is an integral multiple of the fundamental frequency. It is the deviation from the original or pure current sine wave. Voltage and Current Harmonic pollution can be quantified by Total Harmonic Distortion or THD. Current harmonics in the system are produced by non-linear loads and causes power pollution akin to air pollution caused by automobile emission. Examples of such non-linear loads are power electronic equipment including variable speed drives, fan regulators, CFLs, LEDs, Televisions, Switched Mode Power Supplies, Data Processing equipment, high efficiency lighting, electrical machines working under magnetic saturation, arc furnaces, welding machines, rectifiers, DC brush motors, etc. These harmonics have serious effects on various electrical equipment such as overheating of cables and equipment. Further Harmonic causes increased system losses, interference with communication lines, errors while indicating electrical parameters, probability to produce resonant conditions, etc.

ii. **Power factor –** Power factor is a key indicator for an efficient energy delivery in AC electrical system. It is a measure of how effectively a specific load consumes electricity to produce work. Power factor may be categorized into Displacement power factor and True power factor. Displacement power factor is the cosine of the angle between the fundamental voltage and current waveforms. However, presence of harmonics introduces additional phase shift between voltage and the current. True power factor is calculated as the ratio between the total active power used in a circuit (including harmonics) and the total apparent power (including harmonics) supplied from the source. True power factor is always less than displacement power factor if harmonics are present in the system. Poor power factor results into requirement of higher apparent power and thus higher current flow at nominal voltage to do the same work against a higher power factor. To cope with these higher currents due to a poor power factor one has to increase conductor sizes or capacities of electrical equipment like generators or transformers thus resulting in blocked capital expenditure (capex) and increased operating cost of the system. The large current at low lagging power factor causes greater voltage drops in alternators, motors, transformers and transmission cum distribution lines. This leads to decrease in voltage at the driving end and forces the use of extra equipment like voltage stabilizers to counteract the voltage drop, or FACTS devices. Improving the power factor can maximize current-carrying capacity, improve voltage to equipment, reduce power losses, and lower electric bills. The simplest way to improve power factor is to add power factor correction capacitors preferably at load ends of the electrical system but ensuring network resonance due to harmonics is not magnified.

Chapter 2 : Legal and Policy Framework

2.1 Provision in Electricity Act, 2003

- The Electricity Act, 2003 in clause (h) and (i) of sub-section (1) of section 79 read with clause (g) of sub-section (2) of section 178 conferred the powers to the CERC for specifying Grid Code & specify and enforce the standards with respect to quality, continuity and reliability of service by licensees. The relevant provision is extracted as under:

> ***Section 79. (Functions of Central Commission): ---*** *(1) The Central Commission shall discharge the following functions, namely:-*
>
> *(a)…*
>
> *(h) to specify Grid Code having regard to Grid Standards;*
>
> *(i) to specify and enforce the standards with respect to quality, continuity and reliability of service by licensees;*

Similarly, clause (h) and (i) of sub-section (1) of Section of the Electricity Act, 2003 conferred the powers to the SERC for specifying the Grid Code and Standards. The relevant provision is extracted as under:

> ***Section 86. (Functions of State Commission): ---*** *(1) The State Commission shall discharge the following functions, namely:-*
>
> *(a)…*
>
> ….
>
> *(h) specify State Grid Code consistent with the Grid Code specified under clause (h) of sub-section (1) of section 79;*
>
> *(i) specify or enforce standards with respect to* ***quality, continuity and reliability*** *of service by licensees;*

- The Electricity Act, 2003 in section 50 and in sub-section (1) of section 57 read with clause (x) and (za) of sub-section (2) of section 181 conferred the powers to the SERC for specifying the Electricity Supply Code and the Standards of Performance for the Distribution licensees. The relevant provision is extracted as under:

> ***Section 50. (The Electricity Supply Code):*** *The State Commission shall specify an Electricity Supply Code to provide for recovery of electricity charges, interval for*

billing of electricity charges, disconnection of supply of electricity for non-payment thereof, restoration of supply of electricity, tampering, distress or damage to electrical plant, electric lines or meter, entry of distribution licensee or any person acting on his behalf for disconnecting supply and removing the meter, entry for replacing, altering or maintaining electric lines or electrical plant or meter.

….

Section 57. (Consumer Protection: Standards of performance of licensee): *(1) The Appropriate Commission may, after consultation with the licensees and persons likely to be affected, specify standards of performance of a licensee or a class of licensees.*

….

- The Electricity Act, 2003[1] provides in clause (b) of the section 73 empowering CEA as

"Section73. (Functions and duties of Authority): *The Authority shall perform such functions and duties as the Central Government may prescribe or direct, and in particular to -*

(a) advise the Central Government on the matters relating to the national electricity policy, formulate short-term and perspective plans for development of the electricity system and co-ordinate the activities of the planning agencies for the optimal utilisation of resources to subserve the interests of the national economy and to provide reliable and affordable electricity for all consumers;

(b) specify the technical standards for construction of electrical plants, electric lines and connectivity to the grid;

…."

The term "electrical line' and "grid" is further defined under the Act as under:

(20) "electric line" means any line which is used for carrying electricity for any purpose and includes

(a) any support for any such line, that is to say, any structure, tower, pole or other thing in, on, by or from which any such line is, or may be, supported, carried or suspended; and

[1]The Electricity Act 2003

(b) any apparatus connected to any such line for the purpose of carrying electricity;

(32) "grid" means the high voltage backbone system of inter-connected transmission lines, sub-stations and generating plants;

It is observed that section 73(b) of the Electricity Act, 2003 empowered CEA to specify the technical standards for construction of electrical lines connected with grid which inter-alia refers the high voltage backbone system of inter-connected transmission lines, sub-stations and generating plants.

2.2 Provision in Tariff Policy

- The Tariff Policy of Ministry of Power notified on 28th January, 2016 provides as

"8.0 DISTRIBUTION

Supply of reliable and ***quality power*** *of specified standards in an efficient manner and at reasonable rates is one of the main objectives of the National Electricity Policy. The State Commission should determine and notify the standards of performance of licensees with respect to quality, continuity and reliability of service for all consumers. It is desirable that the Forum of Regulators determines the basic framework on service standards. A suitable transition framework could be provided for the licensees to reach the desired levels of service as quickly as possible. Penalties may be imposed on licensees in accordance with section 57 of the Act for failure to meet the standards."*

From the above discussion, it may be concluded that there is a need for ensuring quality power as mandated by the Act and Tariff Policy through Regulations. As per the Act it is the responsibility of Regulatory Commission to specify and enforce the standards with respect to quality, continuity and reliability of service by licensees. Therefore responsibility for specifying & enforcing standards on power quality with respect to distribution system and intra-state transmission system may come under functions of State Regulatory Commissions and that of ISTS shall be the responsibility of Central Regulatory Commission through Regulations such as Grid Code, Supply Code and Standards of Performance etc..

Chapter 3 : Existing Standards and Regulations

The existing Regulations cover the power factor, frequency, reliability of supply and voltage regulations as Power Quality parameters. While there is a strong system of frequency regulation, enforcement of the Standards specified for reliability parameters are required to be strictly monitored and implemented. Issues of voltage regulations, transients, and harmonics are not given the attention they deserve. Presently, there is no comprehensive national Power Quality Standard issued by Bureau of Indian Standards, however, the Regulations such as Supply Code, Grid Code or Standards of Performance etc. are notified by CERC at central level and SERCs at state level which specify limits for some Power Quality parameters as per International standards/guidelines.

3.1 Central Electricity Authority (Grid Standards) Regulations, 2010

These Regulations specify the applicable standards for various power quality parameters for the Indian grid. These standards apply to Entities, Appropriate Load Despatch Centres, and, Regional Power Committees. The Entities is defined in clause (h) of section 2(1) of the Regulations as *'Entity'* means a Generating Company including captive generating plant or a transmission licensee including Central Transmission Utility (CTU) and State Transmission Utility (STU) or a distribution licensee or a Bulk Consumer whose electrical plant is connected to the Grid at voltage level 33 kV and above.

Section 3 of the Regulations specifies the various standards for operation and maintenance of transmission lines. These standards are extracted as below:

> *"3. Standards for Operation and Maintenance of Transmission Lines.- (1) All Entities, Appropriate Load Despatch Centres and Regional Power Committees, for the purpose of maintaining the Grid Standards for operation and maintenance of transmission lines, shall,-*
>
> *(a) make all efforts to operate at a frequency close to 50 Hz and shall not allow it to go beyond the range 49.2 to 50.3 Hz or a narrower frequency band specified in the Grid Code, except during the transient period following tripping.*
>
> *(b) maintain the steady state voltage within the limits specified below in Table1:*

Table 1. Steady state voltage within the limits

Sr. No.	***Nominal System Voltage (kV rms)***	***Maximum (kV rms)***	***Minimum (kV rms)***
1	*765*	*800*	*728*
2	*400*	*420*	*380*
3	*220*	*245*	*198*
4	*132*	*145*	*122*
5	*110*	*121*	*99*
6	*66*	*72*	*60*
7	*33*	*36*	*30*

(c) ensure that the temporary over voltage due to sudden load rejection remains within the limits specified in Table 2:

*Table 2.*Temporary over voltage limit due to sudden load rejection

Sr. No.	***Nominal System Voltage (kV rms)***	***Phase to Neutral Voltage (kV peak)***
1	*765*	*914*
2	*400*	*514*
3	*220*	*283*
4	*132*	*170*

Provided that for the voltage level below 132 kV, the temporary over voltage limits as given in Table 2 shall be decided by the State Commission in the respective State Grid Code.

(d) ensure that the maximum permissible values of voltage unbalance shall be as specified in Table 3 below:

Table 3. Maximum permissible values of voltage unbalance

Sr.No.	***Nominal System Voltage (kV rms)***	***Voltage Unbalance (%)***
1	*765 and 400*	*1.5*
2	*220*	*2*
3	*33 to 132*	*3*

Provided that Bulk consumers shall avoid unbalanced load during operation,

Provided further that the distribution licensees shall ensure that their loads are not unbalanced.

Further, Regulation 3(1)(h) specifies the limits for voltage fluctuation. The relevant extract is reproduced below:

"...

(h) observe the following permissible limits of voltage fluctuation:

(i) the permissible limit of voltage fluctuation for step changes which may occur repetitively is 1.5 percent:

(ii) for occasional fluctuations other than step changes the maximum permissible limit is 3 percent:

Provided that the standard on voltage fluctuations shall come into force concurrently with clause 4 of Part IV of the Schedule to the Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007."

Regulation 3 (2) provides the harmonic limits to be maintained, as reproduced below:

"...

(2) The transmission licensee shall ensure that the voltage wave-form quality is maintained at all points in the Grid by observing the limits given in Table 4 below,-

Table 4. Voltage wave-form quality

Sr. No.	***Nominal System Voltage (kV rms)***	***Total Harmonic distortion (%)***	***Individual Harmonic of any Particular Frequency***
1	*765*	*1.5*	*1.0*
2	*400*	*2.0*	*1.5*
3	*220*	*2.5*	*2.0*
4	*132*	*5.0*	*3.0*

Provided that the standard on Harmonic Distortion shall come into force concurrently with clause 3 of Part IV of the Schedule to the Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007."

3.2 Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007

Part IV of the CEA (Technical Standards for Connectivity to the Grid) Regulations, 2007 specifies the Grid Connectivity Standards applicable to the Distribution Systems and Bulk Consumers. The applicable standards for voltage and current harmonics, voltage unbalance and voltage fluctuation are specified, extract of which is reproduced below:

"3. Voltage and Current Harmonics

(1) The total harmonic distortion for voltage at the connection point shall not exceed 5% with no individual harmonic higher than 3%.

(2) The total harmonic distortion for current drawn from the transmission system at the connection point shall not exceed 8%.

(3) The limits prescribed in (1) and (2) shall be implemented in a phased manner so as to achieve complete compliance not later than five years from the date of publication of these regulations in the official Gazette.

4. Voltage unbalance

The voltage unbalance at 33 kV and above shall not exceed 3.0%.

5. Voltage Fluctuations

(1) The permissible limit of voltage fluctuation for step changes which may occur repetitively is 1.5%.

(2) For occasional fluctuations other than step changes the maximum permissible limit is 3%.

(3) The limits prescribed in (1) and (2) shall be implemented in a phased manner so as to achieve complete compliance not later than five years from the date of publication of these regulations in the official Gazette."

It may be observed that the limits specified in CEA Grid Connectivity Regulations are similar to standards prescribed in various IEEE specifications, especially IEEE 519-1992.

3.3 Draft Second Amendment to Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007

In view of the revised IEEE 519-2014 standards, CEA has proposed the draft second amendment to the Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007 in November, 2016. The amendment proposes to revise the limits for voltage and current harmonics in accordance with IEEE 519-2014 standards. It proposes that measurement of harmonics shall be done at PCC which is defined as the point on the Power supply system which is electrically nearest to a particular load, at which other loads are, or could be connected. Utility shall install Power Quality meters in a phased manner within next three years of publication of the Regulation covering at least 33% of the identified measuring points each year. Measuring and metering of harmonics shall be a continuous process with permanent meters complying to IEC 61000-4-30 Class A and capable of detecting direction of Harmonics (whether it is upstream or downstream). Measured data in regard to harmonics shall be available with utility and will be made available in public. This is to ensure continuous compliance as distortion limits are to be calculated based on daily and weekly percentile values. In addition to harmonics, periodic measurement of other power quality parameters like voltage sag, swell and disruptions shall be done on monthly basis and reports made public. It also proposes that the provision with regard to continuous measurement of quality parameters shall also be applicable for consumers having load more than threshold limit as decided by appropriate Commission. These consumers shall install meters at their own expenses and share data as and when required by the utility.

However, these proposed Regulations are yet to be notified.

3.4 Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013

These Regulations specify, inter-alia, power quality parameters for the connectivity of distribution generation resources. The relevant extract of these Regulations is reproduced below:

> *"5 (11).Standards for distributed generation resources. - Harmonic current injections from a generating station shall not exceed the limits specified in IEEE 519.*
>
> *(2) The distributed generating resource shall not inject Direct Current greater than 0.5% of the full rated output at the interconnection point.*
>
> *(3) The distributed generating resource shall not introduce flicker beyond the limits specified in IEC 61000:*
>
> ………
>
> ………
>
> *(8) Every time the generating station is synchronised to the electricity system, it shall not cause voltage fluctuation greater than ± 5% at the point of connection."*

These Regulations are applicable only for the generating stations feeding electricity into the electricity system at voltage level of below 33 kV.

CEA has proposed the **draft first amendment** to the Central Electricity Authority (Technical Standards for Connectivity of the Distributed generation Resources) Regulations, 2013 in

April, 2018. The draft amendment proposes to rename these Regulations as Central Electricity Authority (Technical Standards for Connectivity below 33 kV) (First amendment) Regulations, 2018. These draft Regulations proposes to substitute the definition of the Applicant as:

> *"(b) "Applicant" means a generating company, charging station, prosumer or a person seeking connectivity to the electricity system at voltage level below 33 kV."*

These Regulations are yet to be notified.

The CEA Regulations are applicable to consumers drawing power at 33kV or above voltage level which may cover either sub-transmission or transmission systems. The standards of power quality parameters at distribution level of voltages below 33kV have been covered by a few SERCs through their Supply Code or Standards of Performance Regulations.

3.5 Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2010

In exercise of various powers conferred under clause (h) of sub-section (1) of Section 79 read with clause (g) of sub-section (2) of Section 178 of the Electricity Act, 2003, and all other powers enabling it in this behalf, the CERC notified the Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2010. These Regulations were subsequently amended on dated 06.03.2010, 06.01.2014, 07.08.2015 and 06.04.2016.

Power Quality standards prescribed by CERC are given in Table-5 below:

*Table 5.*Voltage Variations

Power Quality Parameters	Limits prescribed in the regulations CERC – Indian Electricity Grid Code
Voltage Variation	
765 kV	+5% and-5%
400 kV	+5% and-5%
220 kV	+11% and -10%
132 kV	+10% and -8%
110 kV	+10% and -10%
66 kV	+9% and -9%
33 kV	+9% and -9%

3.6 Standards notified by BIS

A comprehensive coverage of Power Quality in the form of National Standards is yet to emerge in India. During 3rd meeting of the Sub-group, Representative of Bureau of Indian Standards (BIS) informed that BIS through its Electro Technical Division Council has given approval for the creation of a separate technical committee ET-45 for standardization in the field of power quality. Standards covering terminology, various power quality indices, assessment methods of Power Quality, measuring equipment and other related subjects are expected to be formulated by this technical committee.

He further informed that currently the committee ET-45 is merged under the committee ET-1 and a draft Voltage Quality Standard is under circulation for comments.

3.7 Regulations issued by State Electricity Regulatory Commissions

SERCs have notified various Regulations in the respective States of their jurisdiction covering a few Power Quality parameters. These Regulations, when dealing with the aspect of Power Quality, vary in approach, construct and applicability. In Indian State distribution systems, Power Factor requirement has evolved over a period of time. Therefore, other important Power Quality parameters i.e. voltage and harmonics were examined between different sets of SERC Regulations for a few States to identify the consistency of the approach to implement these aspects of Power Quality. The Table-6 overleaf summarises the salient features of Power Quality Regulations applicable in selected Distribution Utilities.

Table 6. Salient features of PQ Regulations applicable in selected Distribution Utilities

State	State Grid Code	State Supply Code	Standard of Performance	Distribution Open Access Regulation	Power System Management Standard Regulations
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 with penalty and incentive provision	-

			Harmonics violation		
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	-	-
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 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	-	1. Voltage variation 2. No compensation to Industrial and	-	-

	variation limit up to 33kV		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	-

It is found from the above table that voltage variation, harmonics distortion and voltage unbalance are commonly specified in the Regulations. The below Table-7 provides a summary of the limits prescribed in the State Regulations applicable to DISCOMs and consumers.

Table 7. Summary of the limits prescribed in the State Regulations

Power Quality Parameters	Limit prescribed in the regulations					
	Gujarat	Maha-rashtra	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%
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	--	--	--	2% for 220kV and above 3% for 132 kV 3% for 33kV and 11kV buses in EHV sub-station	3%	3%

It is noted that the minimum voltage variation limit for Extra High Tension (EHT) and prescribed limits for harmonics in 11 kV and 33 kV feeders are not same across the States.

The above Regulations by SERCs are not uniform and require review. Therefore being part of the single national grid a strong need arises to introduce a harmonized Regulation or Standard on Power Quality in India with exhaustive coverage of PQ parameters. It is recommended that a model Regulations on Power Quality is prescribed by Forum of Regulator to facilitate respective SERCs in formulating their Power Quality Regulations with exhaustive coverage of PQ parameters along with well-defined incentive and disincentive mechanism to ensure effective monitoring and compliance of PQ parameters.

Chapter 4: Global Overview of Power Quality Standards

Globally, there are various Regulations for quality of electricity supply which apply to distribution companies. There are Codes and Standards of Institute of Electrical and Electronics Engineers (IEEE) and International Electrotechnical Commission (IEC) specified for the consumers as well to help maintain the standards of the electricity grid.

4.1 Institute of Electricals and Electronics Engineers (IEEE) 519-2014

The IEEE has specified the 'Recommended Practice and Requirements for Harmonic Control in Electric Power Systems' through IEEE 519-2014, approved on March 27, 2014 by the IEEE-SA Standards Board. The recommended practice seeks to establish goals for the design of electrical systems that include linear and non-linear loads. Paragraph 1.2 of the standards defines the purpose of the standards, extract of which is reproduced below:

"1.2 Purpose

This recommended practice is to be used for guidance in the design of power systems with nonlinear loads. The limits set are for steady-state operation and are recommended for "worst case" conditions. Transient conditions exceeding these limits may be encountered

…

The limits in this recommended practice represent a shared responsibility for harmonic control between system owners or operators and users. Users produce harmonic currents that flow through the system owner's or operator's system which lead to voltage harmonics in the voltages supplied to other users. The amount of harmonic voltage distortion supplied to other users is a function of the aggregate effects of the harmonic current producing loads of all users and the impedance characteristics of the supply system. Harmonic voltage distortion limits are provided to reduce the potential negative effects on user and system equipment. Maintaining harmonic voltages below these levels necessitates that

– *All users limit their harmonic current emissions to reasonable values determined in an equitable manner based on the inherent ownership stake each user has in the supply system and*

–Each system owner or operator takes action to decrease voltage distortion levels by modifying the supply system impedance characteristics as necessary.

In order to allow the system owner or operator to control the system impedance characteristics to reduce voltage distortion when necessary, users should not add passive equipment that affects the impedance characteristic in a way such that voltage distortions are increased. In effect, such actions by a user could amount to producing excessive voltage harmonic distortion. Such passive equipment additions (that lead to undesirable system impedance characteristics) should be controlled by the user in the same manner as current harmonic-producing devices operated by the user."

4.1.1 The standards have recommended the harmonic limits at Point of Common Coupling (PCC). The standards have specified the limits for the following:

a) Recommended harmonic voltage limits;
b) Recommended current distortion limits for systems nominally rated 120V through 69 kV;
c) Recommended current distortion limits for systems nominally rated above 69kV through 161 kV; and
d) Recommended current distortion limits for systems nominally rated above 161 kV

Recommended Standards

4.1.2 The standards recommended for various users are reproduced below:

4.1.2.1 Recommended Practice for Individual Consumers and Distribution Systems:

Users should limit their harmonic currents as follows:

- Daily 99th percentile very short time (3s) harmonic currents should be less than 2.0 times the values given in Tables below.
- Weekly 99th percentile short time (10 min.) harmonic currents should be less than 1.5 times the values given in Tables below.
- Weekly 95th percentile short time (10 min.) harmonic currents should be less than the values given in Tables below.

a) Current Distortion limits for systems rated 120 V through 69 kV

Table 8. Current Distortion limits as specified by IEEE 519-2014 (120V – 69 kV)

Individual harmonic order (odd harmonics)						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	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

It can be observed from above table that the current distortion limit decreases at higher harmonic values and increases with larger ratios.

b) Current Distortion limits for systems rated 69 kV through 161 kV

Table 9. Current Distortion limits as specified by IEEE 519-2014 (69kV-161kV)

Individual harmonic order (odd harmonics)						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
<20	2.0	1.0	0.75	0.3	0.15	2.5
20<50	3.5	1.75	1.25	0.5	0.25	4.0
50<100	5.0	2.25	2.0	0.75	0.35	6.0
100<1000	6.0	2.75	2.5	1.0	0.5	7.5
>1000	7.5	3.5	3.0	1.25	0.7	10.0

c) Current Distortion limits for systems rated >161 kV

Table 10. Current Distortion limits as specified by IEEE 519-2014 (>161kV)

Individual harmonic order (odd harmonics)						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
<25	1.0	0.5	0.38	0.15	0.1	1.5
25<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75

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 are limited to these values of current distortion, regardless of actual Isc/I_L, where*

Isc = maximum short-circuit current at PCC

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

TDD = total demand distortion, harmonic current distortion in % of maximum demand load current (15 or 30 min. demand)

4.1.3 Recommended Practices for Utilities by IEEE 519 - 2014:

Voltage Harmonic Distortion Limits

Table 11. Voltage harmonic distortion limits for Utilities by IEEE 519-2014

Bus Voltage at PCC	**Individual harmonic (%)**	**Total Harmonic Distortion THD (%)**
V ≤1.0 kV	5.0	8.0
1kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161 kV	1.5	2.5
161 kV < V	1.0	1.5*

**Note: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.*

4.2 International Electrotechnical Commission (IEC) Standards (For Equipment)

This section reviews the various standards on harmonics and voltage dip recommended by International Electro-technical Commission (IEC) for equipment.

a) Maximum Permissible limits based as per IEC standards

Table 12. Maximum Harmonic Limits for Class A & B as per IEC 61000-3-2

Harmonic Order (n)	**Class A**	**Class B**
Odd Harmonics		
3	2.30	3.45
5	1.14	1.71
7	0.77	1.155

9	0.40	0.60
11	0.33	0.495
13	0.21	0.315
15≤n≤39	2.25/n	3.375/n
Even Harmonics		
2	1.08	1.62
4	0.43	0.645
6	0.30	0.45
8≤n≤40	1.84/n	2.76/n

Table 13. Maximum Harmonic limits for Class C as per IEC 61000-3-2

Harmonic Order (n)	Class C (Maximum value expressed as a percentage of the fundamental input current)
2	2
3	30λ*
5	10
7	7
9	5
11≤n≤39	3

**λ is power factor*

Table 14. Maximum Harmonic Limits for Class D as per IEC 61000-3-2

Class D (Rated Load Condition)		
Harmonic Order (n)	**75 W<P<600 W**	**P> 600 W**
3	3.4	2.30
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.22
13	0.296	0.21
15≤n≤39	3.85/n	2.25/n

Where,

Class A: Balanced 3-phase equipment, household appliances excluding equipment identified as class D, tools, excluding portable tools, dimmers for incandescent lamps, audio equipment, and all other equipment, except that stated in one of the following classes.

Class B: Portable tools, arc welding equipment which is not professional equipment.

Class C: Lighting equipment.

Class D: PC, PC monitors, radio, or TV receivers. Input power $P \leq 600$ W.

b) Voltage sag (dip) limits specified in various international standards are listed below:

Table 15. International Standards for Voltage Dip limits

Standards	Amplitude	Min. Duration	Max. Duration
IEC 1000-2-1	10–100% of Un	0.5 cycle	Several seconds
IEC 1000-2-5	10–99% of Un	10 ms	Several seconds
EN 61000-4-11	10–95% of Un	0.5 cycle	Several seconds
EN 50160	10–99% of Un	10 ms	1 min
GOST 13109-97 (Russian Standard)	More than 10% of Un	10 ms	Several tens of seconds
IEEE Std. 1159-1995	10–90%	0.5 cycle	1 min
Brazilian classification	10–90%	1 cycle	1 min
EPRI	<95%	1 cycle	1 min
UIE (International Union for Electricity Applications)	10–99% of Un	10 ms	1 min

where, U_n = Nominal System Voltage

4.3 Practice in European Countries

4.3.1 The Council of European Energy Regulators (CEER) periodically surveys and analyses the quality of electricity supply in its member countries (27-member states of the European Union, Iceland and Norway). These surveys and analyses take the form of CEER Bench-marking Reports on Quality of Electricity Supply.

4.3.2 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, CTAIDI, TIEPI and NEIPI are used to quantify long interruptions. Most of the European countries have adopted EN-50160 standard as voltage quality legislation, regulation and standardization as listed below:

Table 16. Standard EN 50160 summary[2]

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 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 (mean ≤8%)
		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 (mean ≤8%)
Mains Signalling Voltage	LV, MV	99% of a day, the 3 second mean value of signal voltages less than limits.

[2] 5th CEER benchmarking report on the quality of electricity supply, 2011

Chapter 5: Need for Model Power Quality Regulations

Electricity is a concurrent subject which means that both the Central Govt. and the State Govt. are empowered to enact laws related to electricity. Accordingly, States may specify different set of Standards for reliability and quality of power based on the legal and field condition. The objective of the power quality Standards is to ensure reliable and quality power to the electricity consumers. It is observed that the Regulatory Standards specified by the State Commissions are not uniform which indicates that the Standards exhibit different level of benchmarks. First, only few power quality parameters are specified in the Regulations notified by the State Commissions. Secondly, even the prescribed limits for the parameters which are specified are not harmonious across different States. Further monitoring, management and control of these parameters are not widely covered with clearly defined framework in place by the State Commissions.

The Act and the Tariff Policy emphasizes the need for supply of reliable and quality power of specified standards at reasonable rates. It is desired that the harmonious and uniform Standards should be specified by the State Regulatory Commissions to serve the best interest of the Utilities and consumers connected to the national grid.

5.1 Prescribed Limits for Harmonics

Differences were observed in the prescribed limits for harmonics specified by the select States. These are listed below:

a) For voltage level of 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%.

b) 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%.

c) Karnataka specifies THDv limit as 5% for 11kV and 33 kV in one of the Regulations and 9% in other Regulations. There are three different limits for single State.

5.2 Prescribed Limits for Voltage Variation

The Standards for voltage variation or fluctuation specified by the different selected States have been compared. Tamil Nadu does not specify the voltage variation limits for 33 kV and 66 kV. For voltage level of 11 kV, Tamil Nadu specifies limit as (+6% and -10%) whereas other States specify limits as (+6% and -9%).For voltage level of 22 kV, Tamil Nadu specifies limit as (+6% and -10%), Maharashtra specifies the 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 different voltage variation limits from the CEA/CERC Regulations.

5.3 Prescribed Limits for Voltage Unbalance

CEA has defined voltage unbalance as the deviation between highest and lowest line voltage divided by average line voltage of the three phases of supply. Certain differences are observed in approach towards the prescribed limits for voltage unbalance amongst the identified states. These are listed below:

Table 17: Approach for voltage unbalances

Central Standards	Standard for Voltage Unbalance
CEA	• Voltage unbalance shall not exceed 3% at 33 kV and above. • Does not specify any standard below 33 kV.
State Standards	
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.

As given in the above Table, some States have not specified any limits for the voltage unbalance. Also, there are differences amongst the States which specify the standards for voltage unbalance.

The above differences in prescribed limits for the harmonics, voltage variation and voltage unbalance in different State Regulations results in a situation of different compliance requirement by utilities/consumers connected at 33 kV, 22 kV and 11 kV interconnection points. The Sub-Group is of the view that difference in the prescribed limits indicates that the measures of power quality received by the users of one State is different from the other. The Sub-Group noted that Distribution & Sub-Transmission voltage levels followed by the different States are same therefore, the limits should be consistent and in line with the notified BIS Standards or CEA technical Standards. In case BIS Standards/ CEA technical Standards are yet to be notified for distribution system supply voltage quality then the benchmark may be in line with the applicable IEEE/IEC Standards.

5.4 What are different PQ Parameters which should be considered for Model Regulations on Power Quality?

PQ parameters required to be measured are specified in various Standards. Some of the International Standards on PQ are listed as below:

- ***IEEE Standard 519-2014:*** IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
- ***BS EN 50160:2010:*** Voltage characteristics of electricity supplied by public electricity networks
- ***IEC 61000-4-30:*** Testing and measurement techniques – Power quality measurement methods
- ***IEC 61000- 4-15:*** For Flicker
- ***IEEE Standard 1159:*** IEEE Recommended Practice for Monitoring Electric Power Quality
- ***IEEE Standard 1250:*** IEEE Guide for Identifying and Improving Voltage Quality in Power Systems
- ***CIGRE Report 596 - Joint Working Group CIGRE/CIRED C4. 112:*** Guidelines for Power Quality Monitoring – Measurement Location, Processing and Presentation of Data
- ***IEC61000-3-6:1998*** – Assessment of emission limits for distorting loads in MV and HV power systems
- ***IEC 61000-3-3:2001*** – Limitation of voltage changes, voltage fluctuations and flicker in public low voltage power systems, for equipment with rated current ≤ 16A per phase
- ***IEC 61000-3-11:2001*** –Limitation of voltage changes, voltage fluctuations and flicker in public low voltage power systems, for equipment with rated current ≤ 75A per phase

- ***IEC 61000-3-12:2005*** **–** Limits of harmonic currents produced by equipment connected to public low voltage power systems, with input current >16A and <75A per phase

Various PQ parameters are measured based on the different objectives. However for compliance monitoring, the following PQ parameters are recommended for measurements:

Frequency deviations

The main cause of frequency variations is unbalance between generation and the demand. There were wide variations in system frequency prior to introduction of Availability Based Tariff (ABT) in India. Due to grid indiscipline by State entities in Indian transmission system, the frequency was not stable. CERC in exercising its power under the Act has taken number of steps to improve frequency profile in the grid over the time. The frequency band has been tightened from 0.5 Hz (49.7-50.2) to 0.15 Hz (49.9-50.05) by amending the Grid Code by CERC. However, the statutory limit for frequency of supply is49.2 to 50.3 Hz[3]as per CEA Grid Standards Regulations. Deviation Settlement Mechanism (DSM) in place of UI mechanism under ABT has also been introduced by CERC to curb indiscipline by some of the grid connected participants. CERC has also introduced Ancillary Services Operations Regulations in 2015 and presently the Un-Requisitioned Surplus of ISGS is being utilized as Ancillary Services to support grid operation and thus stabilizing the frequency profile.

The system frequency of the grid is controlled by System Operators through Load Despatch Centres. Distribution Utilities and the consumers have practically no control over the system frequency variations. Therefore, the Sub-group is of the view that in the first draft of Model Regulations on PQ, frequency variations limits may not be included and it remains the part of Supply or Grid Code notified by the SERCs.

Harmonics

Another important aspect of power quality is Harmonics. Voltage or current waveforms are normally sinusoidal in shape of fundamental frequency (50 Hz) but get distorted due to non-linear loads connected at user end. An important result of the increase of harmonic distortion is the increase of losses in the network. Harmonics also cause overheating of electrical equipment and cause interference with communication system. The amount of voltage harmonics often depends upon the amount of harmonics current drawn by the load, and the

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[3]CEA Grid Standards Regulation

source impedance. If the source harmonic impedance is very low then the harmonic current will result in lower harmonic voltages than if the source impedance were high.

There are differences in the prescribed limit for harmonics specified by different State Regulators. The Sub-Group observed that BIS has circulated draft Voltage Quality Standards, which is yet to be notified. Therefore the Sub-Group is of the view that the limits for voltage & current harmonics may be implemented by State Regulators in accordance with IEEE 519-2014 standards till the time BIS notifies their Distribution system supply voltage quality standards. Thereafter the BIS standards may be implemented for monitoring and control of the voltage quality standards.

The Sub-Group is also of the view that there should be a continuous measurement of harmonics with permanent Power Quality meters complying with the IEC 61000-4-30 Class-A for all new installations/connections. For existing installations/connections where CTs/PTs are of lower accuracy class than mandated by IEC 61000-4-30 Class-A, the meters complying with the IEC 61000-4-30 Class-B may be installed. The harmonic components up to 50th order excluding inter-harmonics may be used for calculating harmonic distortions. For the initial phase, Utility may install Power Quality meters for all strategic locations and for bulk consumers

Voltage variations and Flicker

Equipment or devices that exhibit continuous, rapid load current variations (mainly in the reactive component) can cause voltage fluctuations and light flicker. Overloading conditions in distribution network cause voltage variations resulting in increased losses and faults in the network. Voltage variations may also cause nuisance tripping and stress electrical and electronic equipment which leads to their reduced performance. Flicker affects the production environment by causing personnel fatigue and lower work concentration levels.

Voltage variation limits are prescribed by many State Regulators as discussed above. However limits for Flicker are not prescribed by State Regulators. Further, the calculation parameters for assessment of the continuous voltage quality parameters i.e. aggregation interval, aggregation method, assessment quantile and assessment interval are not defined. International Standards on voltage variation requires for most continuous parameters the 95% quantile of the 10 minute mean values of the declared or nominal supply voltage for one week. The use of 10 minute mean values addresses long-term effects (thermal). The studies for effect of the aggregation interval have shown that shorter intervals than 10 minutes in LV & MV networks provide virtual no additional information.

The Sub-Group is of the view that for prescribing the limits, the voltage deviation may be assessed from mean rms value of the supply voltage measured over 10 min. from declared or nominal voltage. Flicker may be assessed in two severity level, the 'short term severity' measured over a period of 10 min. and the 'long term severity' calculated from a sequence of twelve short term values over a 2 hour time interval as per IEC-61000 Standards. Further, the reference time frame for voltage variations and flicker may be taken as either 95% or 100% of each period of one week. The limits for voltage variations may be taken as ±10% of the declared or nominal voltage. The limits for short term voltage flicker and long term voltage flicker may be taken as less than 1.0 and 0.8 respectively.

Above limits are implemented by State Regulators till the time BIS notifies their Distribution system supply voltage quality standards. Thereafter the BIS standards may be implemented for monitoring and control of the voltage quality standards.

Voltage unbalance

Voltage unbalance is caused by faulty operation of power factor correction equipment, unevenly distributed single-phase loads, unidentified single-phase to ground faults, an open circuit on the system primary, large single-phase loads (induction furnaces, traction loads), etc. The main effect of voltage unbalance is motor damage from excessive heat.

In CEA Regulations, the limit for voltage unbalance is specified for voltage levels of 33 kV and above only. Some State Regulators have not specified any limits for the voltage unbalance and also, there are differences amongst the States which specify the standards for voltage unbalance.

The Sub-Group is of the view that the prescribed limit of voltage unbalance may be assessed from the ratio of rms value of negative phase sequence component (fundamental) to the rms value of positive phase sequence component (fundamental) of the supply voltage for 95% of each period of one week and it should be less than or equal to 2% till the time BIS/CEA notifies their Distribution system supply voltage quality standards. Thereafter the BIS standards/CEA technical standards may be implemented for monitoring and control of the voltage quality standards.

Voltage dips and swells

Voltage sags are caused by system faults, faults in consumer's installation, abrupt switching-in of heavy loads, start-up of large motors, etc. It may result into malfunction of microprocessor-based control systems that may lead to a process stoppage, tripping of contactors and electromechanical relays etc. On the other hand, voltage swells are caused by the disconnection of a very large load, switching of large capacitor banks and switching of long transmission lines etc. The increased energy from a voltage swell often overheats equipment and reduces its life. It can cause control problems and hardware failure in the equipment due to overheating that could eventually result into shut down. Electronics and other sensitive equipment are prone to damage due to voltage swell. It also results in flickering of lighting and visualization screens.

There are no limits specified by State Regulators for voltage dips and swells. The Sub-Group is of the view that for prescribing the limits for voltage dips/swells, the voltage dip/swell event duration, voltage dip/swell start/end threshold and number of events per year values are needed to be defined. For the model Regulations, the voltage dip/swell duration may be taken from 10 ms up to and including 1 min. till the time BIS/CEA notifies their Distribution system supply voltage quality standards. Thereafter the BIS standards/CEA technical standards may be implemented for monitoring and control of the voltage quality standards.

Voltage Transient

Transient voltages are short duration oscillatory or impulse over voltages usually highly damped and with duration of few ms or in microseconds. These are caused by lightning, arcing, switching or blowing of fuses. Capacitor switching is the most common cause of an oscillatory transient and Lightning is the most common cause of impulsive transients. Transients affect equipment in transmission/distribution system badly. At present there is no limits prescribed for voltage transients in any Standards in India. The International standards prescribe the limits for Mains Signalling voltage.

The Sub-Group is of the view that in the Model Regulations on PQ, voltage transient limit and Mains signalling voltage limit may not be included and user should apply surge suppression devices or equipment at the service entrance and at sensitive equipment to protect against damage and mal operation due to lightning and other high frequency transients based on appropriate application engineering and analysis.

Supply voltage interruptions

A voltage interruption is the complete loss of electric voltage or a drop to less than 10% of nominal voltage. Voltage interruptions may be further defined as instantaneous, momentary, temporary & sustained. Short duration interruption for a time period less than 0.5 cycle is termed as instantaneous interruption whereas interruption between 0.5 cycles and 3 seconds is called momentary interruption and between 3 seconds and 1 min is known as temporary interruption. Long duration or sustained interruption is complete loss of voltage for a time greater than 1 min. In European countries, continuity of supply (transient interruption, short interruption and long interruption) is 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.

IEEE Standards defines the short interruption as supply voltage drop to less than 10% of nominal voltage for duration from 20 ms to 1 min and the long interruption as supply voltage drop to less than 10% of nominal voltage for duration of more than 1 min. European Standards define the short interruption as supply voltage drop to less than 10% of nominal voltage for duration from 20 ms to 3 min and the long interruption as supply voltage drop to less than 10% of nominal voltage for duration of more than 3 min.

In India, reliability indices like SAIFI, SAIDI, CAIDI, and MAIFI are almost invariably specified by the State Regulators but it is required to demonstrate that these reliability indices are strictly monitored and implemented by the SERCs.

The Sub-Group is of the view that short voltage interruptions limit and the reliability indices for sustained interruptions (SAIFI, SAIDI) may be included in the Model Regulations on PQ. The short voltage interruption as supply voltage drop to less than 10% of nominal voltage for duration from 20 ms to 1 min and long interruption as supply voltage drop to less than 10% of nominal voltage for duration of more than 3 min may be considered in model Regulations. The long interruptions due to scheduled or planned outages should be taken into account while calculating values of reliability indices.

Considering the criticality of the reliability indices & voltage interruptions and their impact on consumers' productivity and uptime it is recommended to use SCADA or equivalent systems to capture and generate these indices on a regular basis and make public disclosure as recommended by respective SERCs.The monthly reliability data should be maintained by the licensees. The reliability indices data must be captured directly from the feeder and there should not be any manual interventions as far as possible.

The limits of SAIDI and SAIFI may have not been defined by the State Regulators in their notified Regulations. However for determining the limits for SAIDI/SAIFI, the SAIDI/SAIFI data of last one year for urban feeders of all the Distribution Utilities have been captured from URJA app and analysed. It is found that the monthly average values of SAIDI and SAIFI are 8 hours and 12 interruptions respectively. Therefore for the start and considering the effect of agriculture feeders also, the limits of 600 min per customer and 15 interruptions per customer for SAIDI and SAIFI respectively may be specified in the model Regulations.

Power Factor

Power factor is a measure of how effectively a specified load is using electricity. True power factor consists of two terms: displacement power factor (cosine of the angle between the current and the voltage) and total harmonic distortion. It is frequently simplified to just displacement power factor, but that is relevant only for loads that are linear and the waveforms are purely sinusoidal. With the increase in non-linear loads, measuring the displacement power factor is not adequate. The presence of harmonics introduces additional phase shift between the voltage and the current. If harmonics are present in the supply system, then true power factor will always be less than the displacement power factor. The lower the power factor, the higher the current drawn. Higher current requires thicker wires and a more robust infrastructure in order to minimize power dissipation. The large current at low lagging power factor causes greater voltage drops.

The conventional method of installing power factor correction capacitors however, is not an effective way of increasing power factor under these conditions with harmonics. In fact, power factor correction capacitors can often make the situation worse if they happen to resonate with the power system inductance. What is required is removal of the harmonic currents to lower distortion reactive power. Passive harmonic filters can be effective in this regard but they must not introduce too much capacitive reactive power.

The Regulators, so far, have largely focused only on the Displacement 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.

There are either kWh plus Maximum Demand (MD) based billing or kVAh based billing in different States.

It is observed that although kVAh billing to subsumes or includes the effect of power factor and for the current harmonics to some extent, it may be difficult to assess the full and separate impact of Current harmonics. A customer in such a situation may not become aware that it is due to harmonic content that its bill is high and will not be able to take corrective action of installing filters rather it may install more capacitors. This may lead to high voltage condition. Therefore, the extent of current harmonics should be measured at consumers end and mitigation measures to be taken for keeping the level of harmonics within prescribed limits. It is recommended that the Regulators may continue for time being with the incentives or penalties for reactive power and for power factor as notified in their Tariff orders, Grid/Supply Code or in Standards of Performance Regulations which later to be included as part of PQ Regulations. Moreover, they should also introduce compensation for injecting current harmonics as suggested in PQ Regulations for encouraging the designated customers with non-limner loads to take mitigation measures to improve power quality.

Chapter 6: Measurement and Evaluation of Power Quality

6.1 Measurement & Evaluation Techniques of PQ parameters

6.1.1 While the global digital/electronic economy is redefining business operations, it is also setting new standards for electric power reliability and quality requirements. Downtime is undesirable for any business and even the smallest interruption or power quality event can cause equipment failure, data loss or lost revenue. Therefore, there is a need to verify if real PQ improvements have been made, for which effective measurement of the supply quality is crucial. It also helps track the sources of interruptions and enable comparisons of PQ at various locations.

6.1.2 Mal-operation of end-use equipment caused by poor PQ are a common problem. However, it is not easy to identify whether the cause of poor power quality is at the utilities end or at the users end. In a typical electrical power grid, various measurement equipment are placed however, regular PQ monitoring is not given due attention. It is extremely important to consider Measurement & Evaluation (M&E) at all levels of the system to identify and minimize PQ issues before they occur. Systematic procedures for power quality M&E at each end is necessary to understand the actual causes of power quality problems and to design effective countermeasures.

6.1.3 Installing measurement equipment can help managers/supervisors determine if disturbances are coming from the supply side or are being generated at the consumer end. Several measurement tools/equipment are available for PQ measurement which includes:

- **Multi-meters** –these are the basic equipment to measure voltage and/or current. It measures overloading of circuits, under and over voltage issues, and unbalances between circuits, etc.
- **PQ Data Loggers -** A PQ data logger (or data recorder) is an electronic device that records data over time or in relation to location either with a built in current/voltage sensor or via external CT/PT. Increasingly, but not entirely, they are based on a digital processor (or computer). They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors.

- **Oscilloscopes** – these are valuable when performing real time measurements. By looking at the voltage and current waveforms, an observer can look for distortions and detect any major variations in the signals.
- **Disturbance Analysers** – they can typically measure a wide variety of system disturbances from very short duration transient voltages to long duration outages or under-voltages.
- **Spectrum Analysers and Harmonic Analysers** – these are online monitoring equipment with the capability to sample waveforms and perform FFT* calculations. They characterize the statistical nature of harmonic distortion levels with changing load conditions.
- **PQ Analysers**– they are used to continuously monitor and analyse power supply lines for disturbance which can disrupt the reliable delivery of power or cause damage to equipment plugged into the grid supply. Power quality disturbances include events such as voltage sags and swells, transients, harmonic distortion, and voltage/current imbalance, etc.

* Note: Fast Fourier Transform (FFT) is a software tool for harmonic calculations.[4]

As technology is developing, better and faster monitoring systems, large data storage, fast communication enabled Power quality monitoring solutions are becoming available for implementation.

6.1.4 Further, the evaluation of PQ issues is another important aspect for ensuring power quality. PQ evaluation techniques can be classified into 2 sections:

1) **Evaluation of PQ issues affecting utilities**: Analysing PQ disturbance signatures and correlating them with equipment abnormalities/failures such as transformer/cable overheating, protection equipment malfunctioning, cable joint arcing; tree contact with overhead lines; restrike of capacitor switch, lightning arrestor operation, etc. This involves use of data analytics and advanced image processing algorithms to identify and zero in on such failures in real time allowing much shorter Mean Time to Repair (MTTR) and Turn-Around Time (TAT) metrics for utilities allowing them multiple

[4]http://dranetz.com/wp-content/uploads/2014/02/powerquality-measurements-interpretation-analysis-1.pdf

benefits of increase in customer revenue, better customer satisfaction and reduced operation & maintenance costs.

2) **Evaluation of PQ issues affecting the end users**: Poor Power quality environment & Power Quality disturbances needs evaluation to overcome the challenges of economic loss and safety breaches amongst others. It includes identifying and locating the equipment subject to disturbance, determining the time and date when the problem occurred, any correlation with particular meteorological conditions (strong winds, rain, storm), or applying corrective measures by data collection (such as type of load, age of network components etc.).Some other evaluation techniques such as analysing the installation especially the wiring, grounding, circuit breakers & fuses and monitoring of installation to detect and record the event where the problem originated can be used.

These evaluation techniques will eventually help in optimising the operation of electrical installations through complementary actions such as saving energy & reducing energy bills, making users aware of costs and ensuring good power quality environment. Therefore, with continuous power quality measurement, it is very important to be able to evaluate variations with time trends and statistics, in addition to characterizing individual events and capturing their impacts on installation.

6.1.5 The objectives of PQ Monitoring may vary depending upon system requirements, the CIGRE Report 596, JWG CIGRE/CIRED lists different monitoring requirements as following:

Types of PQ Monitoring

- **Compliance Monitoring –**it is for the purpose of Verification of the Regulatory requirement based on the parameters measured as per a given standard for a specific site.
- **System Performance Monitoring**– it is for the purpose of assessment usually done across several sites with monitoring units scattered throughout the network. The main purpose is assessment of average power quality for a specified region for internal use such as asset management, strategic planning and determining long term trends for the system operator.

- **Site Characterization**– it is specific monitoring of a site for purpose like pre-connection PQ levels for a specific customer, specifying constraints on new customers and verification of performance by existing customers.
- **Troubleshooting Monitoring**- it is mostly for an existing PQ issue based on customer complaint, for analysis of network phenomena and investigation of equipment damage. It may be followed by compliance monitoring if PQ limits are breached.
- Monitoring for Advanced application and studies are also carried out by system operator who use transient and fault data for their studies.

Active PQ Management also requires PQ monitoring where measured PQ values trigger system operation control such as control of harmonic level in LV grids by use of active infeed converters such as FACT devices or active filters.

6.1.6 Few requirements for PQ Measurement are given below:

- **Class of Meter -** IEC 61000-4-30 specifies the class of PQ monitoring equipment and their utility. For overall performance of the system where continuous monitoring is required, Class-A monitors are used for better and precise measurements. Class-A monitors are used for Compliance Monitoring and for System Performance monitoring where a dispute between two stakeholders is required to be settled. The processing requirements are low for Class-B monitors and they are used for power quality assessment where lower precision can be accepted.
- **Accuracy** – The accuracy needed to measure the continuous power quality phenomena for Class-A instruments is 0.1% of the nominal voltage and for Class-B is 0.5% of the nominal voltage.
- **Time Interval** – The time interval, measuring the continuous power quality phenomena is an interval of 10-cycle time period i.e. 0.2 second. Using this measuring data, a 3s (150-cycle) and a 10 min. time interval average value can be calculated. The Time-stamp is attached to the data of the last ten minutes. The average value indicates the average of the last ten minutes of measurement. The accuracy of the timestamp should be within 20ms.
- **Flagging** - Concept of Flagging is incorporated in IEC61000-4-30. During a dip, swell, or interruption, the measurement algorithm for other parameters (for example,

frequency measurement) might produce an unreliable value. The flagging concept therefore avoids counting a single event more than once in different parameters.

6.1.7 **Locations for PQ monitoring**

PQ Monitoring Location is another important criterion to be defined by the Regulators. It is normally chosen based on the following:

- Based on Voltage Level –596 CIGRE/CIRED document mentions that all EHV points to be covered for statistical studies.
- Based on Power System elements like substations, important feeders (mainly MV) or at the customer end Point of Connection (POC).
- Based on identified or reported customers complaints.
- Based on selections of sites where important/sensitive users are connected or will be connected.
- Based on selection of sites for monitoring of expected high level of PQ disturbances or expectation of future problems.
- Based on selection of sites which are important for the operation of the power system like Transmission–distribution interface (connection point); Customer connection points or points of common coupling; substations supplying many or significant system users (large industrial users, HVDC substations), etc.

Though in India a detailed Power Quality heat map on the end user side hasn't been attempted, yet the study of "Economic Impact of Poor Power Quality in Various Industrial Sectors in India"[5] indicates various sectors are prone to both generation of higher PQ pollution as well as susceptible to PQ disturbances. The same are

a. Commercial buildings (Healthcare, Hotels, Airports, malls etc.)
b. IT/ITES and Banking, Finance & Service Industries (BFSI)
c. Automobiles
d. Iron &Steel, Aluminium
e. Textile
f. Paper & Pulp
g. Chlor-Alkali, Petro-Chemical

[5]Economic Impact of Poor Power Quality in Various Industrial Sectors in India – A report by IIT Delhi 2015

h. Cement
i. Pharmaceuticals
j. Fertiliser
k. Food Processing
l. Plastic & Rubber
m. Railways/Metros
n. Grid connected distributed generating resources
o. Electric vehicle charging infrastructure

6.2 Quantification of Power Quality at Grid Level

(“Swacch Power - A Glimpse of Power Quality in India” A Report by POWERGRID)

- In an effort to establish base line data about Power Quality parameters in the Indian Power System, POWERGRID had conducted field measurements at different voltage levels i.e. EHV level (765 kV, 400 kV, 220 kV, etc.), sub-transmission level (132 kV, 33kV), LT level (415 V) and at end consumer level on various appliances, e.g., fan, light, laptop, UPS etc. These measurements were taken to measure power quality at grid level across all the five regions in the country covering all the States and Union Territories. The measurements were carried out in 175 cities/towns at various voltage levels covering more than 500 feeders/points. Power quality parameters were collected from all the feeders and buses of the selected substation and measurements were carried out for about 6 to 24 hours on different feeders of the substation. Simultaneous measurements of various power quality parameters were carried out using portable 3-phase Power Quality Analyser.
- It was found that there is presence of high content of voltage harmonics at 65 cities/towns, for a duration ranging up to 4% of time. Transmission system voltages and current were found to be rich in 5th& 7th harmonics. Whereas LT level was found to have high content of 3rd harmonics. Voltage unbalance exceeding permissible limit (for short durations) were observed at 79 cities/towns during the field measurements. Many instances of voltage sag/dip were also observed in the transmission network. Higher value of flicker that gives an impression of instability in the visual sensation were observed mainly in the LT supply in almost all the cities/town across the country.

- On the other hand, at end consumers' level, Power quality parameters measured on commonly used appliances used in the offices and homes show their non-linear nature, which in turn reflects in the form of high content of current harmonics. It has been observed that these appliances draw current rich in odd harmonics such as 3rd, 5th, 7th, and so on in the diminishing order of magnitude. Further, high content of harmonics were also observed in the current/voltage of the supply feeder of offices and apartments (at 415V) along with large values of neutral current.

6.3 Measurement & Evaluation by the Distribution Utility

- Recently Tata Power Delhi Distribution (TPDDL) initiated an intelligent power quality monitoring project in association with Metrum, a Swedish product development and solutions manufacturing company focusing on power monitoring solutions, under the India-Sweden Innovations' Accelerator programme. The intelligent power quality management solution is facilitating TPDDL in monitoring power quality issues at the network voltage level of 66KV/11KV/415V. Also, installation of necessary software at server systems is deployed for checking of power quality parameters such as power factor, harmonics, etc. and monitor them through web based systems while integrating with other systems. Overall, the monitoring solution can help to improve reliability of the grid, improve quality of power, increase asset life, reduce power outages and provide better grid management. TPDDL is using the PQ monitoring system to fix technical problems in real time, aid in preventive maintenance, prevent energy losses and plan the integration of solar into the grid in a better way.
- Further, today most DISCOMs have high-end SCADA/DMS systems, ABT meters, ToD Meters, etc. in place for consumers with some threshold Contract Demand; however still in existing revenue metering protocol, real time PQ monitoring aspect is not recognized. Also, as per the report on reliability index by CEA, most utilities / DISCOMs are not furnishing the machine level reliability data which should be possible by automated advanced SCADA or DMS facility.
- In addition, lack or absence of clearly defined specific PQ parameters and its data makes it even more difficult for the user to take a decision. Intelligent and efficient PQ monitoring will provide the utilities and end users information needed to validate

compliance, improve system stability, and eliminate unplanned downtime thereby contributing to the overall turnaround of utilities and their services for end users.

Chapter 7: Impact of Poor PQ and Estimated Investment

7.1 Techno-Economic Impact due to PQ Issues

7.1.1 Power Quality issue is also an economic problem, rather than a technical problem alone. Developed economies like that of USA and Europe, who have stable & robust power supply system, have recognized the PQ risk, and are working for its mitigation for more than last two decades. The developing economies, because of their continuing struggle with lack of robust utility infrastructure and 24x7 power supply are lagging in terms of their preparedness for a good PQ environment, and continue to absorb 'techno-economic losses' caused due to poor PQ. Some of the individual case studies are dealt in Chapter-8 to bring out the economic impact of poor quality relevant to Indian context and pertaining to individual industry.

7.1.2 It is a challenging task to calculate the actual amount of loss due to a PQ event (say voltage disturbance, harmonic related etc.) especially in absence of better understanding of PQ issues amongst Indian industries. Some of the studies comprising of field surveys, industry's interaction indicate approximately the economic loss incurred due to poor PQ. Some of the key surveys and its findings are mentioned below:

Table 18. Economic impact on different countries due to PQ issues

Country	Survey done by	Survey Coverage	Economic loss incurred	Key Findings
Europe	Leonardo Power Quality Initiative (LPQI) in 2007	Study was carried out in 8 EU countries across 16 sectors, 62 face-to-face surveys	$186 billion (€150 billion)	'Industry' sectors accounted for over 90% of this loss. Dips and short interruptions account for almost 60% of the overall loss. The survey brings out that in 30% cases PQ issues are caused due to external causes, but in 70% cases the problem lies within the business facility/user premises.
USA	Electric Power Research Institute	Study covered 1000 samples across 3 broad categories (Digital Economy,	$119 to $188 billion	PQ losses are average 12% of overall Power Disturbance losses. 4% of surveyed companies

	(EPRI) in 2000	Continuous Process Manufacturing and Fabrication & Essential Services)		reported annual PQ costs representing 10% or more of their annual revenue.
China	International Copper Alliance (ICA) in 2011	Study was carried out in Shanghai in 7 industry sectors	$0.472 billion	PQ loss was carried out in 7 industry sectors, which is about 0.1% of total annual output of these sectors.
Southeast Asia	International Copper Alliance (ICA) in 2012	Study was carried out in 3 countries (Indonesia, Thailand & Vietnam) covering 124 surveys across 13 sectors	$1 billion per annum	Voltage dips and long interruptions contribute over 90% of overall economic costs. No facility has a dedicated PQ monitoring system for the PQ parameters, which prevents any thorough diagnosis.

7.1.3 It can be seen from above table that the PQ issues are creating huge economic losses, posing threat to end-user productivity as well as equipment and therefore has become a global concern.

7.1.4 In the past, power system was defined as one-way traffic however the present situation is more two-way traffic with new power systems integrated with distributed power generating resources including renewable. The unpredictable behaviour of wind speed and solar radiation can cause significant voltage and frequency variations. These variations can become critical if at any particular location where there are high proportions of decentralized generation. With Renewable energy integration many of conventional consumers are today turned into 'Prosumers' i.e. both producer and consumer of energy, while remaining connected to the grid.

The network of the future will probably look more or less the same as today's grid with the same components, transmission lines, cables, transformers, switchgear etc. and some (relatively) new components based on power electronics and DC. But the main difference will be the power flow steering, control & protection and consequently the need for more sensors and metering that will help in curbing PQ issues. Hence, if a network is well prepared for handling PQ issues right from its conception stage, it will cut down on its huge techno-economic losses as well as unpredictable network behaviour.

7.2 Cost of poor PQ impacting Indian Economy

In the present scenario, power quality is not just about uninterrupted power but more importantly about supply of voltage and frequency at a defined standard levels. Poor Power Quality causes performance degradation or/and premature failure of the consumer equipment and also results in increased system losses, etc.

7.2.1 A study by Manufacturers Association of Information Technology (MAIT) and Emerson Network Power (India) in 2009[6] shows that that Indian industries lost $9.60 billion in direct costs due to poor power quality and operating environment related downtime. When further enumerated in terms of network events, it was noticed that 57% of the total financial loss was due to voltage sags and short interruptions, while 35% of the losses were due to transients and surges. However, the cost of prevention for these events may be less than 10% of the cost of problems.

7.2.2 Another study performed by Wartsila India in 2009 estimated that India suffers a staggering loss of INR 1000 Billion, because of power disturbances, primarily because of outages. It also estimated that the industries are spending close to INR 300 Billion annually to operate inefficient power back-ups, Gen-sets and Inverters. The cost of back-up power in order to avoid outages is much higher than the electricity tariff of the network operator. This can go up to 15 times the tariff per kWh by the utilities.

7.2.3 In a recent report by FICCI, it was concluded that due to poor power factor, transmission capacity gets reduced and it is estimated a loss worth Rs.5400 Cr. is incurred due to unserved energy. This much energy could otherwise be served to the users, if the average power factor would have been 0.9. In today's heavy non-linear load environment especially industry and commercial buildings, the power factor is no more conventional but should be True RMS power factor that takes care of both reactive power demand due to fundamental waveform and distorted waveform too. The computational example of the FICCI report is provided below:

[6]http://shodhganga.inflibnet.ac.in/bitstream/10603/16056/10/10_chapter%203.pdf

Example

A case study "Lack of Affordable & Quality Power: Shackling India's Growth Story (2012)" by FICCI was carried out at all-India level, spreading across major industrial 25 cities, to understand the frequent power cuts being faced by Indian Industries. Below is an example of cost of poor power quality incurred due to low power factor.

Assuming network is designed to operate at PF = 0.9

Actual operating PF = 0.8

Total Technical losses = 10% of power flow

Generation Tariff = 2.5 Rs. /unit

*Energy Consumption in fiscal year (2014-15) = 1030 BU (**Source**: CEA Report)*

<u>Unserved Energy due to lower quality of PF:</u>

Unserved energy = [1- [operating PF/designed PF]^2] x (% technical losses) x total energy consumption

Unserved Energy (using above formulae) = 21.6 BU

Value of unserved energy due to poor power factor = INR 5400 Crore

7.2.4 In the recent past, the industrial sector in India is witnessing weekly interruptions ranging from less than one hour to more than 40 hours. Assuming an average interruption of say 30 minutes per week to the Industrial load (connected load is approx. 170 GW) in India, the average cost escalation accounts to be around Rs.2.65 Lakh Cr. per year (assuming a very conservative cost escalation of Rs.10 per minute per kW of connected industrial load). Hence, it is required in India, that a nation-wide survey is conducted to evaluate the various economic impacts of Poor Power Quality & bring awareness about the same.

7.2.5 Also, a joint study on 'Impact of PQ in Indian Industries' in 2012 undertaken by IIT Delhi with Asia Power Quality Initiative (APQI) concluded as follows:

"Almost all the industries suffer due to various power quality problems. In fact, many of the industries are not even aware of various PQ problems like harmonics, flickers, etc. They do not even possess equipment to measure this irregularity in power quality. It is a must to educate and create awareness among industries regarding power quality. This calls for Bureau of Indian Standards (BIS) taking a firm and bold step to introduce power quality standards that are suited for our country. For this, academicians, industrialists, consumers, utilities and regulatory bodies should come together and

have several thorough brainstorming sessions. This will create a healthy and reliable power grid and utility in our country enhancing productivity and GDP growth."

7.3 Importance of PQ Mitigation Equipment

7.3.1 POWERGRID, in its 'Swachh Power' report has estimated deployment of different power quality interface devices at the load ends. The cost of these PQ mitigating devices like Dynamic Voltage Restorer (DVR), Voltage Sag Corrector, Active Power Filters (APF), Automatic Power Factor Controller (APFC), D-STATCOM, etc. depends on load requirement in terms of kW or MW. It may vary from Rs.4,000/Amp to Rs.17,000/Amp. Market survey also reveals that there are very limited domestic manufacturers of Power Quality mitigating/monitoring devices. Even if some types of mitigating/monitoring devices are available, its size (rating) and features are limited. However, there are several international manufacturers in this field.

7.3.2 The estimated expenditure has been worked out assuming that the PQ Conditioning device would cost around Rs.10,000/Amp. It has been assumed that the 'Power-Conditioning' device would improve the power-factor from 0.8 to 0.9 and also mitigate the current harmonics of the order of 20 Amps at LT level (It has been observed that the net harmonic current is of the order of few tens of Amp in LT supply at 415V). The investment required for PQ conditioning per kW of connected load would be around Rs.2,100/- as calculated in below table.

Table 19. Cost of Power Conditioning Device for a typical DT of 500kVA

Cost of Installing Power Conditioning device at LT Level (415V)	
Power Factor Improvement	
Reference DT Rating (kVA)	500
Average Loading	70.00%
Power Factor Improvement	0.8 to 0.9
kVAr requirement	46.0
PF Correction Amps	63.9
Harmonic Mitigation	
Harmonic Current Amps	20.0
Total Amp Rating of PQ Conditioning Device	83.9 A
Considering Rs. 10,000 per Amp	
Net Investment (Rs. Lac) per 500 kVA DT	8.4
Connected Load is assumed to be 400kW with 0.8 pf	
Investment per kW of Connected Load	Rs.2098/kW Say Rs.2100/ kW

7.13 The total estimated investment required in initial phase for Power Quality improvement for the industrial, domestic and commercial loads is about Rs.24,840Cr. A breakup of this estimation is given in below table considering installation of Power Conditioning devices and PQ monitoring devices at the LT level.

Table 20. Initial Investments for PQ Improvement

Sr. No.	**Load Category**	**Load Considered for PQ Improvement (GW)**	**Rate Rs. per kW**	**Estimated Investment (Rs. Cr.)**
A. Power Conditioning Device (Such as DSTATCOM, SVG, APF, DVR, Active Harmonic Filter, etc.)				
1	Industrial	45	2100	9,450
2	Domestic	53		11,130
3	Commercial	20		4,200
			Sub-Total	**24,780**
Sr. No.	**Number of Power Quality Monitoring devices required**		**Rate Rs. per Device**	**Estimated Investment (Rs. Cr.)**
B. Power Quality Monitoring Device (Such as power Quality Analyzer, Power Quality Logger, etc.)				
1	1180		5,00,000	59
			Sub-Total	**59**
			Total Investment	**Rs.24,840 Cr.**

It is observed that there is a necessity to generate more authentic data on Power Quality before making investment decisions to mitigate and address Power Quality challenges. Some of the solutions may be very basic and easy to implement based on data on PQ. Hence the Sub-group recommends that at the initial phase substantive PQ monitoring infrastructure be put in place so as to generate sufficient data and facilitate meaningful decision making based on such validated data.

Chapter 8: Case Studies and Observations

Successful Business Case Studies

Understanding the significance of Power Quality issues, some industry and service sectors undertook power quality studies. Based on its findings, appropriate mitigation measures were taken resulting into various savings with less payback. Below given are four case studies from industry & service sector that have been successful in mitigating PQ issues with reduced downtime and reduction in failure rate of electrical equipment.

8.1 Case study 1 – India’s largest steel wire rope industry (Industry Sector)

The effect of reducing harmonics on breakdown and specific energy consumption of Steel wire rope industry is discussed as under:

Problem Statement

8.1.1 The unit is India's largest and world's second largest steel wire rope manufacturer. Steel wire manufacturing involves number of DC motors and AC to DC convertors. Various manufacturing processes like surface treatment, galvanizing, etc. are adopted during the making of wire rope. In the process, numbers of motors (equipped with drives) with different capacities are used. The unit noticed presence of harmonics in the system, which caused problems like additional heat generation in cables, increased failure rate of equipment, increased consumption due to higher losses and nuisance tripping of circuit breaker. A detailed study of the plant revealed that the transformers associated with rope and wire mill processes were generating high harmonics.

Solution and Benefits

After carrying out the detailed study, the unit management came to a decision of mitigating harmonics by installing passive harmonic filter in the system. Passive harmonic filters were designed as per load current and order of harmonics. This resulted in significant reduction in energy consumption (thereby resulting in monetary benefit due to reduction in energy cost), improved productivity due to reduced downtime and reduction in failure rate of electrical equipment. Post implementation, the readings were recorded and compared to see the improvement achieved by eliminating harmonics in the feeder line.

8.1.2 The table below gives voltage and current THD comparison findings:

Table 21. Voltage and current THD comparison findings

Location	Without harmonic filter		With harmonic filter		Difference (%)	
	V (THD)	I (THD)	V (THD)	I (THD)	V (THD)	I (THD)
Transformer – 4	12%	21%	2.10%	11.20%	↓9.9%	↓9.8%
Transformer – 5	15%	60%	1.20%	7.20%	↓13.8%	↓52.8

8.1.3 The table below indicates change in annual failure rate before and after installation of harmonic filter:

Table 22. Change in annual failure rate before & after harmonic filter

Component	Annual failure rate before Harmonic filter	Extrapolated Annual failure rate after harmonic filter	Change in Failure rate
Motors	43	8	↓81%
Drives	52	8	↓85%
PLC's	22	8	↓64%

8.1.4 The table below shows the reduction in energy consumption & maximum demand before and after installation of harmonic filter:

Table 23.Change in energy consumption & energy demand before & after harmonic filter

ACTUAL ELECTRICITY BILLS (in 2013)			
	Before Harmonic Filter (per month)	**After Harmonic Filter (per month)**	**Change (%)**
Energy Consumption (kWh)	18,91,130.00	17,78,352.00	↓6%
Maximum Demand (kVA)	9,236.00	7,872.00	↓14.77%

Conclusion

The main aim of unit was to reduce the production cost. In order to reduce the production cost, reliable operation and efficient use of manufacturing process forms an integral part for any unit. The company made investment close to Rs.1 Cr. by installing PQ equipment to mitigate the harmonics. Subsequently, with the reduction in energy consumption and maintenance cost, the plant saved around Rs.1.75 Cr. per year. The savings incorporated had the simple payback period of 7 months on the investments.

8.2 Case study 2 – Hospital (Service Sector)

8.2.1 The mitigation of Harmonics in a hospital and its benefits has been examined as discussed in following paragraph:

8.2.2 One of the biggest hospitals in Southern India specializes in treatments of heart diseases, neurology, neuro-surgery, cancer and other life-threatening diseases. The hospital has installed best available technology in terms of sophisticated medical equipment and electrical distribution system. The hospital was facing problems in their distribution system like higher temperature in the transformer, noise in the capacitor bank, disturbance on monitor screens of machines, higher energy charges, etc. It noticed the presence of high harmonics at point of common coupling (PCC), higher than 30% as per the limits set by standards.

8.2.3 After a detailed power quality study, the hospital management decided to mitigate these harmonics by installing 120 Amp Active Harmonic Filter. This has resulted in significant reduction in energy consumption (thereby resulting in monetary benefit due to reduction in energy cost), improved services and diagnosis capabilities due to reduction in harmonics. Post installation, study was carried out to analyse the benefits achieved by installing active harmonic filter. The table below shows the results of study before and after installation of harmonic filter:

Table 24. Results of the study before & after installation of harmonic filter

Component	Before Harmonic Filter	After Harmonic Filter	Change
Total Harmonic Distortion (THD)	25%	5%	↓ 80%
Power Factor	0.97	0.995	↑ 2.5%
Avg. kVA	216 kVA	204 kVA	↓ 5.55%
Transformer Temperature	80-850C	450C	↓ 47%

Conclusion

By investing Rs.7,50,000/- and installing PQ mitigation equipment, hospital management gained substantial monetary benefit in terms of reduced electricity charges and improved services to its patients. The strategy worked out well and hospital had simple payback period of less than 1 year. There is indirect benefit accrued to the concerned utility too in terms of lesser demand on their distribution system making its infrastructural capability to cater to higher number of customers.

8.3 Case Study 3 – Food & Beverage Industry

The impact of interruptions on Food and Beverage Industry is discussed as under:

8.3.1 One of the largest food & beverage industry with bottling facilities with 2400 bottles per minute capacity across different service lines has been experiencing poor quality of incoming power from State Electricity Board (SEB). Also, all major industries (including food & beverage industry) in this estate have been impacted badly due to this issue. The plant was facing problem of stoppage of production line thereby causing loss of productivity. The problems were mainly due to interruptions in power supply and under voltage events. After each power supply interruption, there was some time required to resume productivity.

Table 25. Shows monetary loss plant was facing due to each event of supply interruption

Sr. No.	Line	Line running time after power resume (in mins)	Production Capacity per hour (No of cases per hour)	Load factor	Actual Cases Lost	Monetary Loss (in Rs per event)
1	Krones	15	1500	80%	300	3168
2	Maaza	12	1500	80%	240	2534
3	RGB	10	1500	80%	200	2112
4	Kinley	10	300	80%	40	422
5	PET- 140	15	933	80%	187	1970
					Total Loss	**10207**

Table 26. Power Supply Interruptions in each month

Month	Unscheduled Power cut	Unbalanced Voltage	Total No. of Occurrences
	No. of Occurrences	No. of Occurrences	
January'14	10	9	19
February'14	17	8	25
March'14	45	42	87
April'14	68	51	119

8.3.2 From above table it can be seen that from January to April 2014, number of under voltage and unscheduled power supply interruptions were 250. With cost of each event estimated to Rs.10,207/- the plant had a loss of about Rs.25,51,750/- during this period. Combining PQ, other losses due to higher energy cost and loss in productivity, the plant had economic loss of around Rs.62 million per year.

Solutions Adopted

8.3.3 The plant took various measures like automatic switch over system for DG sets during power failure, forward and reverse synchronization system, and SCADA system. The SCADA system helped to monitor the voltage profile more closely and the team could identify cause of malfunctioning of various sensitive equipment. Further, in order to find more reliable solution during the un-scheduled power interruptions and voltage variations, the plant team carried out a detailed power quality audit to discover reasons of voltage variations. Measurements were carried out at all critical locations and logged for longer duration of time to record number of events and duration of each such event. In order to protect its failures and loss of productivity, based on the power quality study and its finding, the plant team decided to install two UPS each of 600 kVA at critical locations to avoid breakdown arising due to voltage variations and unscheduled power interruptions.

Benefits Achieved

By implementing above solutions, the plant carried out regular measurement and analysis of voltage profile, current and total harmonic distortions and its deviations were brought down close to standard limit as per the standards. The plant ensures regular power quality monitoring and thereby avoids production and economic loss. Besides steps for voltage quality improvement was undertaken further by concerned utility to keep high revenue customer satisfied.

8.4 Case Study 4 – Utility Sector

The harmonics generated from the industry impacts the electricity supply to the electricity consumers. The effect of harmonics on the electricity consumers of the distribution system is discussed as under:

8.4.1 A small town at South Tamil Nadu called Rajapalayam is fully inhabited with spinning mills and the people are dedicated to textile business. Due to usage of equipment like spindles, electrical motors, energy efficient lighting, etc., 80 to 90% load at spinning mills are non-linear that generates harmonics. Generation of harmonics through all spinning mills collectively distorted voltage waveform and created high voltage harmonic distortion in the utility distribution system. If the entire grid's voltage is distorted, then other loads, even if they are linear will be fed through a distorted voltage waveform that will have an impact on operation of such loads.

8.4.2 Detailed harmonic measurements were carried out at various spinning mills and compared with IEEE-519 standards. The results were alarming indicating that the voltage distortion anywhere within the town can be seen from 6 to 9% THDv. These voltage harmonic distortions of 9% are very high. When few of the spinning mills were advised to shut down, it was found that the distortion of voltage had drastically come down to less than 4.5% at one of the nearby substation. Also, it was discussed that installation of passive filters will be an appropriate solution in this kind of pollution.

8.4.3 It can be concluded from the case study that harmonics generated by plants were so high that it polluted the entire utility network. Apart from technical aspect, higher order harmonics will cause great financial loss to both domestic consumers or industries and Distribution Company. In order to meet today's load requirement, grid has to be designed in a way that the Utility concerned has to deploy mitigating equipment simultaneously while making customers to observe discipline in power utilisation. Apart from that, individual consumer should take the responsibility to ensure that harmonics in the system should not go beyond a certain limit.

Chapter 9: Recommendations

The Sub-Group deliberated on various issues related to quality of power supply to the consumers. The discussions were held keeping in view the impact of power quality on present and future electrical system and the existing regulatory framework in India. The recommendations of the Sub-Group are aimed to provide the solutions which can be used to develop appropriate regulatory framework in India.

9.1 Recommendation 1: Need for Power Quality Regulations

The prevailing legal and policy framework with respect to power quality, as detailed in Chapter-2, provides that State Regulators are entrusted with the responsibility to specify or enforce standards with respect to quality, continuity and reliability of services by licensees to the consumers through Regulations. At present, Aggregate Technical & Commercial (AT&C) losses along with few reliability indices are generally monitored by the Regulators to determine performance of DISCOMs. It was observed that main focus of the State Regulators is on management of power factor, frequency and reliability indices of power supply to the consumers. The other important power quality parameters such as voltage sags/swells, voltage fluctuations, voltage unbalance, harmonic distortion and voltage transients etc. are not covered comprehensively in the Regulations. These power quality parameters are not considered for assessing the health of DISCOMs and their obligation to provide quality supply as of now.

Further from the discussion in Chapter-4, it was observed that PQ problems in distribution system are not yet studied extensively by the Utilities. There is either none or only few power quality parameters specified in the Regulations of State Commissions. Further the prescribed limits for the parameters which are specified are varying across different States. Also the standards specified by different State Regulators exhibits different level of efficiency. Moreover monitoring, management and control of power quality parameters, incentive/disincentive mechanism are not widely covered with clearly defined framework in place by the State Regulators. Few of the power quality parameters are covered by some States in different Regulations such as Supply Code or Standards of performance. With increasing penetration of renewable energy, electronic equipment, non-linear loads, data centres and industries running on adjustable speed drives etc. there is a need of emphasizing separate Regulations covering exhaustively all parameters of power quality with a clear incentive/disincentive mechanism to ensure compliance of specified parameters. The separate Regulations on power quality - shall ensure the effective monitoring and compliance.

Sub-Group recommends the need for Model Regulations on Power Quality which define the power quality indices, roles and responsibilities of various entities, Standards/limits to be followed, incentive/disincentive mechanism and procedure for monitoring, management and control of all aspects of power quality. Model Regulations on Power Quality may be adopted by the SERCs to implement the uniform and consistent Standards on power quality across the country having single national grid.

9.2 Recommendation 2: Should Reliability Indices be Part of the PQ Regulations?

The Act and Tariff Policy emphasize for supply of reliable and quality power to the consumers. The reliable power means interruption free power supply, whereas power quality refers to both the extent of deviations or distortions in supply wave form and the continuity of supply. The reliability of the power supply is more tangible than power quality therefore over the many years, power quality was perceived as a function of the reliability and the electrical consumers were not averse to the poor power quality by the distribution licensee. State Regulators have specified reliability indices such as SAIFI, SAIDI, CAIDI & MAIFI etc. in Grid/Supply Code or in Standards of Performance Regulations for reporting. However, there is a need that these reliability indices be also strictly monitored and implemented.

The Sub-Group recommends that reliability indices like SAIFI & SAIDI, at the minimum, along with other power quality parameters may be specified in the Model Regulations on Power Quality.

9.3 Recommendation 3: Monitoring of Power Quality parameters at Transmission and Sub-Transmission System Level.

There is a need to monitor power quality parameters at Transmission and Sub-Transmission System also to ensure that quality power is supplied to the Distribution Utilities. Further power quality monitoring in total supply chain from generation to consumption is required to find out the entity due to which quality is being deteriorating to ensure remedial measures are taken by the entity deteriorating the power quality. CERC and SERCs have notified limits on only few power quality parameters such as frequency, voltage variations etc. in their Supply/Grid code for the transmission & sub-transmission systems. CEA standards which are applicable only to the consumers connected at 33kV or above voltage level also specify limits for a few power quality parameters and these limits are applicable only either for sub-transmission or transmission systems. However strict monitoring and control of all the power quality parameters are required to be implemented for reliable and secure grid operations. It is the prime responsibility of different STUs and the CTU to maintain the quality of power at sub-transmission or transmission level as per the limits specified in CERC & SERCs Regulations. However, the experience shows that there is no strict monitoring and implementation of these quality parameters by the Regulators.

The Sub-Group recommends that Regulators at Centre and State level should introduce appropriate reporting and incentive/dis-incentive mechanism in their Grid/Supply Code for regular monitoring and control of the limits for various power quality parameters at transmission and sub-transmission system level. However the Model Regulations on power Quality recommended in this report covers power quality parameters, their limits and incentive /disincentive mechanism for the DISCOMs and the consumers connected at voltage level of 33kV and below in the distribution system.

9.4 Recommendation 4: Which Power Quality Parameters need to be specified in PQ Regulations?

Power quality is about compatibility between the quality of the power supply from the grid and the proper operation of equipment at consumer end. There is economic cost associated with poor quality of power in the form of degraded performance or premature failure of equipment.

There are a number of power quality parameters in IEEE/IEC and other International Standards which can be categorized in Steady State power quality and Disturbances. Large investments may be needed to maintain the quality of power from the existing level to the level of limits specified in these Standards for all power quality parameters. Therefore, it is a challenge to find out optimum balance between investments to improve power quality (or prevent disturbances) and investments in equipment and facility protection. The limits for power quality characteristics may be implemented phase wise based on recommendations of economic analysis of poor power quality on distribution system. Various power quality parameters are discussed in Chapter-5. During the deliberations sub-group observed that Top three PQ parameters to be monitored are Harmonics, Voltage Variations and Voltage Unbalance.

The Sub-Group recommends that limits for Harmonic Distortion, Voltage Variation & Flicker, Voltage Unbalance, Voltage Sags/Swells and Short & Long Supply Interruptions may be specified in the Model Regulations on Power Quality. The limits for other power quality parameters could be included in Power quality Regulations by the SERCs based on their experience and specific system requirements.

The specified limits for various power quality parameters should be consistent and in line with the notified BIS Standards and/or applicable IEEE/IEC Standards or CEA Standards. The limits recommended in Chapter-5 for various power quality parameters may be specified in Model Regulations on Power Quality till the time BIS/CEA notifies their Distribution system supply voltage quality standards. Thereafter the BIS/CEA standards limit may be implemented by SERCs.

9.5 Recommendation 5: Locations for Power Quality Monitoring.

The most important aspect in the roadmap towards ensuring better power quality to the consumers is to implement PQ monitoring by installing PQ analysers/meters and thereby compliance monitoring of PQ parameters by the Regulators. PQ measurements at all locations will incur huge investment which may not be advisable in present scenario. PQ measurement may be implemented phase-wise and during first phase, PQ meters may be installed at selective representative locations based on voltage level, type of consumers and significance of the power quality. The measurements undertaken to determine compliance shall be carried out in accordance with the requirements as specified in IEC 61000-4-7 and IEC 61000-4-30. There should be a continuous metering of harmonics with permanent Class-A Power Quality meters complying with the IEC 61000-4-30 and capable of detecting direction of Harmonics (whether it is upstream or downstream) for all new installations/connections of identified locations. For existing installations / connections at identified locations where CTs/PTs are of lower accuracy class than mandated by IEC 61000-4-30 Class-A meters, the meters complying with the IEC 61000-4-30 Class-B may be installed.

The information on various PQ parameters extracted from power quality meters should be reported in a standard formats at regular intervals to the Regulators. These compliance standards can be framed referring to various available International standards and guidelines.

As per available data, there are about 1.5 Lakh 11kV feeders (about 90,000 rural and 60,000 urban feeders) and about 90 Lakh Distribution Transformers (DTRs) for feeding power to about 25 Crore households across different States in the country. For compliance monitoring, the State Regulators may take pre-defined percentage of 11kV feeders and of DTRs to start PQ measurement and verification during initial phases. In the first phase, the distribution licensee may install Power Quality meters for 50% of total 33kV/11kV feeders, 25% of total DTRs. In the second phase, Distribution Licensee should cover 100% of 33kV/11kV feeders and at least 60% of total DTRs. In the third phase, 100% DTRs may be covered.

Further, the PQ meters may be installed at all consumers' end prone to PQ disturbances or harmonic generation such as arc furnace, data centres, large industries, malls etc. There should be a provision in Regulations for verification of PQ parameters by DISCOM on sample basis based on the consumer's complaints.

Further power quality should be monitored at other grid connected entities such as generating company whose distributed generation resource are connected at voltage level of 33kV or below, electric vehicle charging stations and prosumers which may be a source of current harmonics. In case of solar and wind generation, the power quality may also be monitored at input of transformer.

The Sub-Group recommends continuous monitoring and reporting of power quality parameters as specified in the Model regulations by the Distribution Licensees at all the identified locations. The compliance may be reported in standard formats at regular intervals. For the initial phase, Regulators may direct Distribution Licensee to install Power Quality meters for all strategic locations and for bulk consumers with threshold Contract Demand of 1 MVA and above.

9.6 Recommendation 6: Incentive/ Dis-incentive Mechanism for Power Quality.

To ensure quality supply in the entire Power System, all stakeholders (DISCOMs, Regulators, Consumers, Service Providers, etc.) in the power system chain are expected to contribute in a collaborative manner to ensure high quality of power to end-consumers. After notifying the model Regulations on Power quality with consistent and uniform limits for various power quality parameters by different SERCs, it will become important for compliance to introduce tariff based incentive/dis-incentive mechanism for entities which cause distortion in power supply to the consumers. Additional tariff component based on extent of violation of PQ limits may be imposed to the power quality polluters.

Ideally the level of incentive (being the penalty or reward) should be based on the costs that customers incur as a result of quality not being perfect as per the standards. But it is very challenging to calculate actual amount of loss when a PQ event occurs as discussed in Chapter-7. Some State Regulations provide incentive/penalty to maintain power-factor. However there is no such provision of incentive or penalty for power quality limits in any State Regulations except in few such as Tamil Nadu. In Tamil Nadu State, consumer is liable to pay compensation at 15% of the respective energy 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.

During the first year of implementation, the distribution licensee may monitor and report the power quality parameters in standard formats at regular intervals. From second year, the compensation payable by distribution licensee to consumers for voltage variations, voltage unbalance and voltage harmonics may be kept as nominal as Rs.100/- per week for the deviations beyond limits. The compensation for voltage dips/swells, short voltage interruptions and for long voltage interruption (SAIFI) may be kept as nominal as Rs.50/- per event.

In case of long or sustained voltage interruptions (SAIDI), the distribution licensee is required to pay Value of Lost Load (VOLL) to the consumers. On sustained supply interruptions, consumers are dependent upon alternative supply such as DG set etc. to meet its load requirements. On considering conservative level of supply security, Rs.3/- per kWh may be taken as marginal cost for ensuring uninterrupted supply. Therefore 5.0 paisa/minute/kW of contract demand may be taken as compensation for SAIDI violations. There may be situations, where it may be difficult to provide 24x7 power supplies. For example in few a States in India especially North Eastern States and in Hilly States such as Uttarakhand & Himachal Pradesh, the distribution system is being upgraded and strengthened to provide 24x7 power supply to the consumers. In such cases for the time being State Regulators may set different SAIFI/SAIDI limits based on system conditions in particular areas.

Further, for current harmonics injection by the designated customers, there is no benchmark available for level of compensation. Therefore we may consider the available benchmark of reactive energy charges and designated customers may be liable to pay compensation equivalent to the multiples of the reactive energy charges applicable at that time. The reactive energy charges vary from approximately 14 to 25 paisa per unit in different States across the country. The average rate works out to 20 paisa per unit. For the start, 50 paisa per unit (which is 2.5 times of average charge) may be levied on for the duration for which current harmonics was beyond the specified limits. In case of repetitive offenders who are not taking measures to reduce the level of current harmonics (which is measured in terms of total demand distortion) may be made liable to pay higher compensation progressively on each continued violation. When there is no improvement in power quality for 6 months such consumers may be served notice of dis-connection from the supply network and may be disconnected after approval of Commission. State Regulators may incorporate suitable provisions in the Regulations. From third year the State Regulators may implement an incentive or dis-incentive scheme based on its experience and specific system requirements.

It is noted that above discussed level of compensation is very nominal and for kick start of incentive/dis-incentive mechanism in model Regulations on Power Quality. And also compensations will be levied based on the violation of limits only and not on the intensity of the violations except for SAIDI index. It is recommended that the different SERCs may initiate a study in the first year of implementation to estimate the costs that customers incur as a result of poor power quality as per the standards and decide the compensations based on recommendations of the study.

The above compensation payable by distribution utilities should not be included in their ARR. The expenses incurred towards implementation and monitoring of power quality parameters by the distribution licensee may be considered in the ARR. Further distribution licensee should make efforts to improve power quality in their supply area by deploying devices such as filters or controllers etc. to mitigate power quality issues. The expenses incurred towards deploying these devices by the distribution licensee may be considered in the ARR.

The Sub-Group recommends that incentive/dis-incentive mechanism may be implemented in a phased manner. In the first year after notification of model Regulations on Power Quality, the compliance of all specified power quality parameters are reported in prescribed formats at regular intervals to the Regulators and put in public domain by posting on the website of the distribution licensees. From the second

year after notification of model Regulations, an incentive or penalty may be levied on the defaulters. SERCs may also implement the incentive/dis-incentive mechanism for identified industries earlier than start of second year (e.g. within 6 months) based on the system requirements. From the third year, based on the experience and specific system requirements, the SERCs may implement their incentive/dis-incentive mechanism.

9.7 Recommendation 7: Integration of Power Quality with Smart Grid Applications in Distribution.

Smart Grid with two-way energy flows, connecting large and small, centralised and dispersed power sources poses a challenge in measuring & monitoring Power Quality. The incorporation of many decentralised electricity sources into the grid can cause deterioration of the power quality, and degradation of the grid's supply. The interactions between the many sources, and the multiple loads that draw power from the grid are highly complex and take place over an intricate network of distribution links. Together these have a high risk to the stability of the grid, with the potential to degrade the power quality of the supply from the grid, cause higher losses in the grid and may cause malfunctioning of equipment connected to the grid.

The Smart Grid is essential for successful uptake of renewable electricity generation and to support a low carbon future. However, it needs substantially good measurements related to power quality and network stability to ensure the quality and reliability of the electricity supply.

The Sub-Group recommends that power quality may also be integrated with the smart grid application for a more reliable smart grid and promote adoption of technologies such as advanced power quality meters, wide-area power quality measurement, power quality enhancement devices for system component and sensitive loads that can provide fast diagnosis and correction of PQ disturbances. The power quality measurement for smart grid may be further extended for grid intelligence as part of the Power Quality Regulations.

9.8 Recommendation 8: Power Quality Database.

A more elaborative power quality database is essential, as the demand for electricity and electronic devices has increased. PQ databases and Characterisation of loads can be used to provide the equipment specifications and guidelines, identifying which are most susceptible to PQ variations and informing manufacturers accordingly. Moreover, the database can also be used for accurately analysing the causes of recorded disturbance and finding appropriate solutions based on set PQ standards.

The Sub-Group recommends that SERCs may fix the responsibility to maintain the PQ database by the distribution licensee or bulk consumers, as the case may be, for a sufficiently long period. The distribution companies must ensure the data security and the data should only be used for identified purpose and should not be transferred to any other person without the consent of the specific consumer.

9.9 Recommendation 9: Trainings in the area of Power Quality and customer awareness

For effective implementation of PQ regulation, target DISCOM engineers should be trained in PQ area regularly. Further, in order to strengthen the employees, end-users should run technical training programs continuously to give enough training and knowledge to its employees. Training will encourage employees to find specific techniques for resolving PQ issues across the power systems. Educating the staff and engineers through workshops and seminars is crucial; such activities should promote familiarity with PQ definitions and disturbances. During the meeting, representative of BIS informed the Sub-Group that in IS 16102- Part 2, specific norms of electrical parameters for LED lamps have been specified. However, the same is a voluntary standard. It was requested that BIS may consider making the standard mandatory. It is suggested that distribution licensee should make the customer aware for using only BIS compliant electrical appliances/equipment.

The Sub-Group suggests that regulatory framework may specify the training requirements for effective implementations of the PQ standards and Regulations. The distribution companies should carry out customer awareness programmes and explain the customers about effects of poor power quality.

9.10 Recommendation 10: Power Quality Audits.

While Energy Efficiency (EE) has already caught industry attention, it will be appropriate to build improved PQ awareness and services together with EE audits and ESCO services. A PQ audit identifies possible threats that may impact PQ. It will be worthwhile to review and further specify PQ parameters, together with EE rating for standard industrial equipment and energy management solutions.

To start with, accredited agency may be entrusted to do third party auditing. The existing Energy Auditor can also add PQ audits and further strengthen performance guarantees in their services portfolio. Further, a pool of nationally accredited PQ auditor merged under Energy Auditor scheme of BEE can be created, which in turn, may give accreditations. Auditing fee may be fixed by respective SERCs.

The Sub-Group suggests that the regulatory framework should introduce the compliance audit of PQ parameters by Independent agency. The power quality parameters should be published for awareness of the public and also ensures the stakeholders engagement through feedback system. The distribution company shall carry out 100% audit by itself once a year and 5% random audit by the independent agency and shall file the audit report along with ARR truing up petition.

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Annexure –I: MODEL REGULATION ON POWER QUALITY FOR STATE – APPLICABLE FOR DISTRIBUTION SYSTEM

MODEL REGULATION ON POWER QUALITY FOR STATE – APPLICABLE FOR DISTRIBUTION SYSTEM

(STATE) ELECTRICITY REGULATORY COMMISSION

NEW DELHI

Dated ________________

DRAFT NOTIFICATION

In exercise of powers conferred under section 181 of the Electricity Act, 2003 (36 of 2003) read with section 61, section 57 and section 59 thereof and all other powers enabling it in this behalf, and after previous publication, the [State] Electricity Regulatory Commission hereby makes the following regulations, namely:

CHAPTER - 1

PRELIMINARY

1. Short Title, Extent and Commencement

(1) These regulations may be called the [State] Electricity Regulatory Commission (Power Quality) Regulations, 2018;

(2) These Regulations shall extend to the whole of the [State].

(3) These Regulations shall come into force from the date of their publication in the Official Gazette.

2. **Definitions and Interpretations.**–In these regulations, unless the context otherwise requires -

(1) **'Act'** means the Electricity Act, 2003 (36 of 2003);

(2) '**Authority'** means the Central Electricity Authority;

(3) **'Consumer'** means any person who is supplied with electricity for his own use by a licensee or the Government or by any other person engaged in the business of supplying electricity to the public under the Act or any other law for the time being in force and includes any person whose premises are for the time being

connected for the purpose of receiving electricity with the works of a licensee, the Government or such other person, as the case may be;

(4) **'Central Commission'** means the Central Electricity Regulatory Commission;

(5) **'Commission'** means the [State] Electricity Regulatory Commission;

(6) **'Continuous Phenomenon'** means deviations from the nominal value that occur continuously over time;

(7) **'Contract Demand'** means demand in kilowatt (kW)/kilovolt ampere (kVA)/Horse Power (HP) as mutually agreed between Distribution Licensee and the Consumer and as entered into in the agreement for which Distribution Licensee makes specific commitment to supply from time to time in accordance with the governing terms and conditions contained therein or equal to the sanctioned load, where the contract demand has not been provided through /in the agreement;

(8) **'Declared Supply Voltage (Uc)'** means the voltage at the consumers supply terminals declared by the supplier of electrical energy. Declared supply voltage is usually equal to the nominal voltage;

(9) **'Designated Customers'** means the customers identified as major power quality polluters due to their installed non-linear loads or generation or otherwise under these Regulations and shall interalia include commercial buildings (Healthcare, Hotels, Airports, malls etc.), IT/ITES and Banking, Finance & Service Industries (BFSI), Automobiles, Iron & Steel, Aluminium, Textile, Paper & Pulp, Chlor-Alkali, Petro-Chemical, Cement, Pharmaceuticals, Fertiliser, Food Processing, Plastic & Rubber and Railways/Metros, grid connected distributed generating resource and Electric Vehicle Charging infrastructure etc.;

(10) **'Flicker'** means the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time. It is caused under certain conditions by voltage fluctuation changing the luminance of lamps;

(11) **'Flicker Severity'** means intensity of flicker annoyance evaluated by the following quantities:

a) Short term severity (P_{st}) measured over a period of 10 min;

b) Long term severity (P_{lt}) calculated from a sequence of twelve P_{st}-values over a 2 hour time interval;

(12) **'Forum'** means as defined under [State] Electricity Regulatory Commission (Consumer Grievance Redressal Forum & Electricity Ombudsman) Regulations including any amendment thereto in force from time to time ;

(13) **'Frequency'** means the number of alternating cycles per second [expressed in Hertz (Hz)];

(14) **'Grid Code'** means the Grid/Distribution Code as specified by the [State] Electricity Regulatory Commission;

(15) **'Grid Standards'** means the Grid Standards specified by the Authority;

(16) **'Harmonics'** means the sinusoidal component of a periodic wave, either Voltage or Current waveform, having a frequency that is an integral multiple of the fundamental frequency of 50 Hz;

(17) **'High Voltage'** means the voltage whose nominal r.m.s. value is more than 33000 volts but less than or equal to 150000 volts as per IS 12360:1988 standard;

(18) **'Indian Standards (IS)'** means standards specified by Bureau of Indian Standards;

(19) **'IEC Standard'** means a standard approved by the International Electrotechnical Commission;

(20) **'Interconnection Point (Distribution System)'** a point on the electricity system, including a sub-station or switchyard, where the interconnection is established between the customer and the electricity system of the distribution licensee and where electricity injected into or drawn from the electricity system can be measured unambiguously for the customer;

(21) **'licensee'** means the distribution licensee;

(22) **'Low Voltage (LV)'** means the voltage whose nominal r.m.s. value is less than or equal to 1000 Volts as per IS 12360:1988 standard;

(23) **'Medium Voltage (MV)'** means the voltage whose nominal r.m.s. value is more than 1000 volts but less than or equal to 33000 volts as per IS 12360:1988 standard;

(24) **'Maximum demand load current'** means the current value at the point of common coupling calculated as the sum of the currents corresponding to the maximum 15 minute demand during each of the twelve previous months divided by 12;

(25) **'Nominal voltage (of the Distribution System) (Un)'** means the value of voltage by which the electrical installation or part of the electrical installation is designated and identified;

(26) **'Normal Operating Condition' means o**perating condition for an electricity network, where generation and load demands meet, system switching operations are concluded, faults are cleared by automatic protection systems and in the absence of:

i. temporary supply arrangement;
ii. exceptional situations such as:
   a. exceptional weather conditions and other natural disasters;
   b. force majeure;
   c. third party interference;
   d. acts by public authorities;
   e. industrial actions (subject to legal requirements);
   f. power shortages resulting from external events

(27) **'Nominal Frequency'** means the frequency of 50.00 Hz of the supply voltage.

(28) **'Point of Common Coupling (PCC)'** means the point of metering, or any other point on supply system of distribution licensee, electrically nearest to the particular load at which other loads are, or could be, connected. For service to industrial users (i.e., manufacturing plants) via a dedicated service transformer, the PCC is usually at the HV side of the transformer. For commercial users (office parks, shopping malls, etc.) supplied through a common service transformer, the PCC is commonly at the LV side of the service transformer.

(29) **'Power Factor' or 'Displacement Power Factor'** means the cosine of the electrical angle between the voltage and current vectors in an AC electric circuit;

(30) **'Power Quality Meter'** means a device suitable for monitoring and recording of

power quality. It shall be capable of accurate measurement, monitoring and recording of harmonics, sags, swells, flickers and other power quality parameters;

(31) **'Rural areas'** mean the areas covered by Gram Panchayats, including major and minor Panchayats;

(32) **'r.m.s. (root-mean-square) value'** means square root of the arithmetic mean of the squares of the instantaneous values of a quantity taken over a specified time interval and a specified bandwidth;

(33) **'Sanctioned load'** means load in kilowatt (kW)/kilovolt ampere (kVA)/Horse Power (HP) for which the Distribution Licensee had agreed to supply from time to time subject to governing terms and conditions;

(34) **'Supply Area'** means the area within which a Distribution Licensee is authorised by his License to supply electricity;

(35) **'Supply Terminals'** means point in a distribution system designated as such and contractually fixed, at which electrical energy is exchanged between the Customer and distribution licensee. This point can differ from the electricity metering point or the point of common coupling.

(36) **'Supply Voltage'** means the r.m.s. value of the voltage at a given time at the supply terminal, measured over a given interval;

(37) **'Supply Voltage Interruption'** is a condition in which the voltage at the supply terminals is completely lost or lower than 10% of the nominal voltage condition. It can be classified as:

a) **Planned or Prearranged Supply Interruptions** means a supply interruption when network users are informed in advance;

b) **Forced or Accidental Supply Interruptions**, caused by permanent or transient faults, mostly related to external events, equipment failures or interference.

c) A Planned or forced supply interruption is classified as:

1) **Sustained or long interruption** means supply interruption is longer than 3 min;

2) **Short interruption** means supply interruption is from 20ms to 3 min;

d) For poly-phase systems, a supply interruption occurs when the voltage falls below 10% of the nominal voltage on all phases (otherwise, it is considered to be a dip).

(38) **'Supply voltage dip'** means a temporary reduction of the r.m.s. supply voltage at a given point in the electrical supply system of 10 to 90% of the declared voltage for a duration from 10 ms up to and including 1 min. Typically a dip is associated with the occurrence and termination of a short-circuit or other extreme current increase on the system or installation connected to it;

(39) **'Supply voltage dip duration'** means time between the instant at which the r.m.s. voltage falls below the start threshold and the instant at which it rises to the end threshold. For poly-phase events, a dip begins when one voltage falls below the dip start threshold and ends when all voltages are equal to or above the dip end threshold.

(40) **'Supply voltage dip end threshold'** means r.m.s. value of the supply voltage specified for the purpose of defining the end of a supply voltage dip;

(41) **'Supply voltage dip start threshold'** means r.m.s. value of the supply voltage specified for the purpose of defining the start of a supply voltage dip;

(42) **'Supply voltage dip Residual Voltage'** means minimum value of r.m.s. voltage recorded during a voltage dip;

(43) **'Supply voltage swells (temporary Power Frequency Overvoltage)'** means temporary increase in the r.m.s. supply voltage at a given point in the electrical supply system above 110 of the declared voltage for a duration from 10 ms up to and including 1 min;

(44) **'Supply voltage swell duration'** means time between the instant at which the r.m.s. voltage exceed the start threshold and the instant at which it falls below the end threshold;

(45) **'Supply voltage swell end threshold'** means r.m.s. value of the supply voltage specified for the purpose of defining the end of a supply voltage swell;

(46) **'Supply voltage swell start threshold'** means r.m.s. value of the supply voltage specified for the purpose of defining the start of a supply voltage swell;

(47) **'System Average Interruption Duration Index' (SAIDI)** means the average

duration of sustained interruptions per consumer occurring during the reporting period, determined by dividing the sum of all sustained consumer interruptions durations, in minutes, by the total number of consumers;

(48) **'System Average Interruption Frequency Index' (SAIFI)** means the average frequency of sustained interruptions per consumer occurring during the reporting period, determined by dividing the total number of all sustained consumer interruption by the total number of consumers;

(49) **'True Power Factor'** means the ratio between total active power used in a circuit (including harmonics) and the total apparent power (including harmonics) supplied from the source. True power factor is always less than displacement power factor if harmonics are present in the system;

(50) **'Transient over voltages'** means short duration oscillatory or non-oscillatory over voltages usually highly damped and with duration of few ms or in microseconds;

(51) **'Total Demand Distortion (TDD)'** means the ratio of the root mean square of the harmonic content, considering harmonic components up to the 50^{th} order, expressed as a percent of the maximum demand current;

(52) **'Total Harmonic Distortion' or 'THD'** means the ratio of the root mean square of the current harmonic content, considering harmonic components up to the 50^{th} order, expressed as a percent of the fundamental;

(53) **'Voltage Events'** means sudden and significant deviations from normal or desired wave shape. Voltage events typically occur due to unpredictable events (e.g. faults) or due to external causes (e.g. weather conditions);

(54) **'Voltage Fluctuation' or 'Voltage Variations'** means series of voltage changes or a cyclic variation of the voltage envelope, the magnitude of which does not normally exceed the specified voltage ranges;

(55) **'Voltage unbalance'** means a condition in a poly-phase system in which the r.m.s. values of the line-to-line voltages (fundamental component), or the phase angles between consecutive line voltages, are not all equal. The degree of inequality is usually expressed as the ratios of negative and zero sequence components to the positive sequence component;

(56) **'Urban Areas'** means the areas covered by all Municipal Corporations and other Municipalities including the areas falling under the various Urban Development Authorities, Cantonment Authorities and Industrial Estate and Townships including those specified by the[State] Government;

The words and expressions used in these regulations and not defined herein but defined in the Act or any other regulation of the Commission shall have the meaning assigned to them under the Act or any other regulation of the Commission respectively.

CHAPTER – 2

GENERAL

3. Objectives

(1) The Power Quality of the electrical system refers to both the extent of deviation or distortion in pure supply waveform and the continuity of supply. An ideal power supply is never interrupted, always within voltage and frequency tolerances and has a noise free sinusoidal waveform. Poor power quality causes performance degradation and premature failures of electrical equipment. It also results in increased system losses.

(2) Different type of disturbances that affects the power quality include Harmonics (waveform distortion), frequency deviations, voltage unbalance, voltage fluctuations, flicker, supply interruptions, transient overvoltage or surges, voltage dips and voltage swell etc. Each of these disturbances has different causes and effects.

(3) Power quality disturbances can propagate upstream or downstream and could affect other customers connected in the same supply network. Power quality monitors are available to measure all aspects of power quality.

(4) The objective of standards specified in these Regulations is to ensure the quality and reliability of electricity supplied by the distribution licensee to the end consumers and by the designated customers.

(5) Any failure by the Distribution Licensee or Designated Customer to achieve and maintain the power quality parameters specified in these Regulations shall render the Distribution Licensee or Designated Customer liable to payment of compensation under the EA 2003 to an affected entity.

4. Assessment of Power Quality

(1) The assessment of Power Quality shall consist of measuring the various parameters of the power quality and comparing them with the standards specified in these regulations.

(2) Measurement methods for assessment of Power Quality under these Regulations shall be as per applicable notified IS and in absence of IS, it shall be as per IEC 61000-

4-30:2015 namely 'Testing and measurement techniques – Power quality measurement methods' and as amended from time to time.

(3) For three phase four-wire connections, the line to neutral voltages shall be considered. For three phase three-wire connections the line to line voltages shall be considered. For single phase connections, the supply voltage (line to line or line to neutral, according to the network user connection) shall be considered

5. **Scope and extent of application**

(1) These Regulations shall apply to Distribution Licensee(s) including Deemed Distribution Licensee(s), distribution franchisees and all Designated Customer(s) of electricity connected at or below 33kV voltage level.

(2) The scope of these Regulations is to specify the main characteristics of power quality of electrical supply at point of common coupling (PCC) or at supply terminals of Customers in distribution system. The characteristics of power quality of electrical supply considered in these Regulations to be controlled by distribution licensee are:

i. Supply voltage variations
ii. Supply voltage flicker
iii. Supply voltage unbalance
iv. Supply voltage dips and swells
v. Supply voltage harmonics
vi. Supply Interruptions

The characteristic of power quality of electrical supply considered in these Regulations to be controlled by designated customers is:

vii. Current harmonics

(3) These regulations unless reviewed earlier, shall remain in force from the date of notification in official gazette.

(5) The limits specified in these Regulations for power quality parameters shall apply only under normal operating conditions.

6. Roles and Responsibilities

(1) Distribution licensee shall be responsible to their consumers for supplying electricity with adequate power quality levels as defined in these Regulations.

(2) Distribution licensee shall identify strategic locations in their electrical network and install the power quality meters at all such locations to maintain power quality in their supply area.

(3) Distribution licensee to identify the designated customers which are major power quality polluters and inject harmonics into the distribution system beyond the limits specified in these Regulations.

(4) The designated customers shall be responsible to control the harmonic injection into the distribution system within the limits specified in these Regulations.

7. Redressal of Consumer Complaints with regard to Power Quality: The consumer complaints in relation to the Power Quality shall be redressed in the following manner in accordance with these Regulations as under:

(1) On receipt of a power quality complaint, the distribution licensee shall demonstrate and satisfy that it meets the requirement of Power Quality standards specified in these Regulations.

(2) In case of complaint on voltage variations, unbalance and voltage harmonics, distribution licensee shall –

i. ensure that the power quality parameters are brought within the specified limits within 2 days of the receipt of a complaint, provided that the fault is identified to a local problem.

ii. ensure that the power quality parameters are brought within the specified limits, within 10 days of the receipt of a complaint, provided that no expansion/enhancement of the network is involved; and

iii. resolve the complaint within 180 days, provided that if up-gradation of the distribution system is required.

(3) Where, the designated customer is required to demonstrate that he meets the requirement of Power Quality standards, a reasonable period may be given to the

designated customer on case to case basis.

(4) The consumer, who is aggrieved by non-redressal of his grievances of Power Quality, may make a representation for the redressal of his grievance to Grievance Redressal Forum and Ombudsman.

(5) The cost of the verification shall be borne by the distribution licensee.

CHAPTER – 3

STANDARDS OF POWER QUALITY

8. Supply Voltage Variations

(1) The supply voltage variations in LV and MV networks from declared voltage shall comply with Table given below and specified with reference to mean r.m.s. values of supply voltage measured over 10 min.

Table 1 – Supply Voltage Variation Limits for LV Systems Interconnected with Transmission System.

Supply Voltage Characteristic	**Reference Time Frame**	**Limits**
Mean r.m.s. value of the supply voltage over 10 min	95% of each period of one week	*Un ± 10 %*
	100% of time	*Un + 10 % / - 15%*

Table 2 – Supply Voltage Variation Limits for MV Systems Interconnected with Transmission System.

Supply Voltage Characteristic	**Reference Time Frame**	**Limits**
Mean r.m.s. value of the supply voltage over 10 min	99% of each period of one week	*Un ± 10 %*
	100% of time	*Un ± 15%*

Table 3 – Supply Voltage Variation Limits for LV and MV Systems not interconnected with Transmission System

Supply Voltage Characteristic	**Reference Time Frame**	**Limits**
Mean r.m.s. value of the supply voltage over 10 min	100% of time	*Un* +10 % / -15 %

Provided that:

The measurements shall be undertaken in accordance with applicable notified IS and in absence of IS, IEC 61000-4-30:2015 as amended from time to time;

For statistical evaluation, voltage variations shall be assessed for the period not less than 7 continuous days. The short time 10 min values (measured as per IEC) are accumulated over periods of one week and the 95th and 99th percentile values (i.e., those values that are exceeded for 5% and 1% of the measurement period) are calculated for each 7-day period for comparison with the recommended limits. The values are measured in normal operating condition.

For poly-phase systems, the voltage variations shall be measured in all phases of supply.

9. Supply Voltage Flicker (P_t)

(1) The voltage flicker shall be assessed in two different severity level: Long-Term severity (P_{lt}) and Short-Term severity (P_{st}). Short term severity shall be measured over a period of 10 min and long term severity shall be calculated from a sequence of twelve P_{st}-values over a 2 hour time interval, according to the following expression:

$$P_{lt} = \sqrt[3]{\sum_{i=1}^{12} \frac{P_{st}^3}{12}}$$

The permissible limits of short-term voltage flicker and long-term voltage flicker severity for distribution licensee shall be 1.0 and 0.8 at all supply terminals 100% of the time respectively.

Provided that:

The measurements shall be undertaken in accordance with IEC 61000-4-30;

For statistical evaluation, voltage flicker shall be assessed for the period not less than 7 continuous days. The short time 10 min values are accumulated over periods of one week and the 95th percentile values (i.e., those values that are exceeded for 5% of the measurement period) are calculated for each 7-day period for comparison with the recommended limits. The values are measured in normal operating condition excluding the time period of a voltage dip.

For poly-phase systems, the voltage flicker shall be measured in all phases of supply.

10. Supply Voltage Unbalance (UB)

(1) The supply voltage unbalance in respect of three phase supply shall be assessed from the ratio of rms value of negative phase sequence component (fundamental) to the rms value of positive phase sequence component (fundamental) of the supply voltage. The supply voltage unbalance shall be maintained less than or equal to 2% by the distribution licensee.

Provided that:

For statistical evaluation, voltage unbalance shall be assessed for the period not less than 7 continuous days. The short time 10 min values are accumulated over periods of one week and the 95th percentile values (i.e., those values that are exceeded for 5% of the measurement period) are calculated for each 7-day period for comparison with the recommended limits. The values are measured in normal operating condition.

11. Voltage Dip or Sag

(1) The Supply voltage dips shall comply with Table given below and are specified with reference to:

i. Number of events per year
ii. Event duration (t)
iii. Residual Voltage (u)
iv. Declared voltage (Uc)

Table 4: Supply Voltage Dip Limits for LV and MV Networks in Terms of Number of Events per Year

Residual Voltage (%)	**Duration t (ms)**				
	10 ≤ t ≤ 200	**200 < t ≤ 500**	**500 < t ≤ 1000**	**1000 < t ≤ 5000**	**5000 < t ≤ 60000**
90 > u ≥ 80	30	40	10	5	5
80 > u ≥ 70	30	40	5	5	5
70 > u ≥ 40	10	40	5	5	5
40 > u ≥ 5	5	20	5	5	5

Provided that:

The voltage dips shall be measured in accordance with IEC 61000-4-30 and shall not fall outside the duration from 10 ms up to and including 1 min;

The voltage dips shall be measured in all phases of supply.

12. Voltage Swells

(1) The Supply voltage swell shall comply with Table given below and are specified with reference to:

i. Number of events per year
ii. Event duration (t)
iii. Swell Voltage (u)
iv. Declared voltage (Uc)

Table 5: Supply Voltage swell Limits for LV and MV Networks in Terms of Number of Events per Year

Swell Voltage u (%)	**Duration t (ms)**		
	10 ≤ t ≤ 500	**500 < t ≤ 5000**	**5000 < t ≤ 60000**
u ≥ 120	--	--	--
120 > u ≥ 110	--	--	--

Values may be as per relevant IEC/IEEE Standard

Provided that:

The voltage swell shall be measured in accordance with IEC 61000-4-30 and shall not fall outside the duration from 10 ms up to and including 1 min;

The voltage swell shall be measured in all phases of supply.

13. Voltage Harmonics

(1) The voltage harmonic distortion of the supply voltage shall be assessed in terms of the Total Harmonic Distortion (THD_V) considering harmonic components up to the 50th order. THD_V shall be taken as square root of the sum of squares of all voltage harmonics expressed as a percentage of the magnitude of the fundamental measured with following formula:-

$$THD_V = \sqrt{\sum_{h=2}^{N} V_h^2}$$

Where,

V_h represents the percent rms value of the h[th] harmonic voltage component, and N represents the highest harmonic order considered in the calculation.

The distribution licensee shall control the value of THD_V measured at Point of Common Coupling (PCC) for LV and MV network to less than or equal to 8% and 5% respectively for 100% of time.

(2) The distribution licensee shall also control the mean rms values of each individual harmonic voltage measured over 10 minutes period up to the 25[th] harmonic order component to the values as given in table below:

Table 6: Values of Individual Harmonic Voltages of the Supply Voltage in Percent of the Fundamental Voltage

Odd Harmonics (%)						**Even Harmonics (%)**		
Not Multiple of 3			**Multiple of 3**					
harmonic	**LV**	**MV**	**harmonic**	**LV**	**MV**	**harmonic**	**LV**	**MV**
5	6	6	3	5	5	2	2	1.9
7	5	5	9	1.5	1.5	4	1	1
11	3.5	3.5	15	0.5	0.5	6 to 24	0.5	0.5
13	3	3	21	0.5	0.5			
17	2	2						
19	1.5	1.5						
23	1.5	1.5						
25	1.5	1.5						

(3) For statistical evaluation, voltage harmonics shall be assessed for the period not less than 7 continuous days. The short time 10 min values are accumulated over periods of one week and the 95[th] percentile values (i.e., those values that are exceeded for 5% of the measurement period) are calculated for each 7-day period for comparison with the recommended limits. The values are measured at PCC in normal operating condition.

Provided that:

The limits of each individual voltage harmonics by the distribution licensee in its electricity system, point of harmonic measurement i.e. Point of Common Coupling (PCC), method of harmonic measurement and other matters shall be in accordance with per applicable notified IS and in absence of IS, the IEEE 519-2014 namely 'IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems', as modified from time to time.

14. Current Harmonics

(1) The designated customers shall limit the value of harmonic currents measured at Point of Common Coupling (PCC) measured over 10 minutes period to the values as given in table below:

Table 7: Values of Current distortion limits (TDD)

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	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

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

[a]Even harmonics are limited to 25% of the odd harmonic limits above;

[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed;

where

I_{SC} = maximum short-circuit current at PCC;

I_L = maximum demand load current (fundamental frequency component);

(2) For statistical evaluation, current harmonics shall be assessed for the period not less than 7 continuous days. The short time 10 min values are accumulated over periods of one week and the 95th and 99th percentile values (i.e., those values that are exceeded for 5% and 1% of the measurement period) are calculated for each 7-

day period for comparison with the recommended limits. The values of TDD are measured at PCC in normal operating condition.

Provided that:

The weekly 95th percentile short time 10 min harmonic current values should be less than the value given in above Table-7. However, the weekly 99th percentile short time 10 min harmonic current values should be less than 1.5 times the value given in above Table-7.

The limits of current harmonics injected by the designated customer, point of harmonic measurement i.e. Point of Common Coupling (PCC), method of harmonic measurement and other matters shall be in accordance with per applicable notified IS and in absence of IS, the IEEE 519-2014 namely 'IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems', as modified from time to time.

The measurements undertaken to determine compliance shall be carried out in accordance with the requirements as specified in IEC 61000-4-7 and IEC 61000-4-30.

15. Short Supply Voltage Interruptions

(1) Short voltage interruptions shall comply with Table given below and are specified with reference to:

i. Number of events per year
ii. Event duration (t)
iii. Declared voltage (Uc)

Table 8: Short Voltage Interruptions Limits (number of events per year) for LV and MV Networks.

Residual Voltage (%)	**Duration t (ms)**				
	10 ≤ t ≤ 200	**200 < t ≤ 500**	**500 < t ≤ 1000**	**1000 < t ≤ 5000**	**5000 < t ≤ 60000**
5 > u	5	20	30	10	10

Provided that:

The short voltage interruptions shall be measured in accordance with IEC 61000-4-30 and shall not fall outside the duration from 10 ms up to and including 1 min;

The voltage swell shall be measured in all phases of supply.

16. Long or Sustained Supply Voltage Interruptions

(1) The Distribution Licensee shall calculate the reliability of its distribution system on the basis of number and duration of sustained or long supply voltage interruptions (longer than 3 min) in a reporting period, using the following indices:

i. System Average Interruption Frequency Index (SAIFI);
ii. System Average Interruption Duration Index (SAIDI);

(2) The Indices shall be computed for the distribution licensees for each month for all the 11kV and 33kV feeders in the supply area, and then aggregating the number and duration of all interruptions in that month for each feeder. The Indices shall be computed using the following formulae:

$$SAIFI = \frac{\sum_{i=1}^{N} A_i * N_i}{N_t}$$

$$\mathrm{SAIDI} = \frac{\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{B_i} * \mathrm{N_i}}{\mathrm{N_t}}$$

Where,

A_i = Total number of sustained interruptions (each longer than 3 min) on i^{th} feeder for the month;

Bi = Total duration in minutes of all sustained interruptions (longer than 3 min) on i^{th} feeder for the month;

N_i = Number of Customers on i^{th} feeder affected due to each sustained interruption;

N_t = Total number of customers served by the Distribution Licensee in the supply area;

n = number of 11kV and 33kV feeders in the licensed area of supply;

(3) The distribution licensee shall maintain the reliability on monthly basis within the limits specified in table below:

Table 9: Limits for Reliability indices

Reliability Indices	Limits *
SAIDI	600 Minutes per customer
SAIFI	15 interruptions per customer

*Limits may be decided based on area on supply and local conditions by SERC.

Provided that:

The feeders must be segregated into rural and urban and the value of the indices must be reported separately for each month.

While calculating the given reliability indices, the following types of interruptions shall not be taken into account:

i. Momentary outages of duration less than three minutes.
ii. Outages due to Force Majeure events such as cyclone, floods, storms , war, mutiny, civil commotion, riots, lightning, earthquake, lockout, grid failure, fire affecting licensee's installations and activities;
iii. Outages that are initiated by the National Load Despatch Centre/ Regional Load Despatch Centre/State Load Despatch Centre during the occurrence of failure of their facilities;

While calculating the given reliability indices, the interruptions due to scheduled or planned outages shall be taken into account.

The distribution licensee shall capture reliability indices data directly from the feeder monitoring system and there should not be any manual interventions as far as possible.

The Distribution Licensee shall maintain data on the reliability indices specified above for each zone/circle/division/sub-division on a monthly basis.

The Distribution Licensee shall put up, at the end of each month, such monthly information on reliability indices, on website of the Distribution Licensee and shall submit such report quarterly to the Commission.

CHAPTER – 4

MONITORING AND REPORTING OF THE POWER QUALITY

17. Monitoring of Power Quality

(1) PQ measurement shall be implemented in phased manner and during first phase, PQ meters shall be installed at selective representative locations based on voltage level, type of consumers and significance of the power quality in such a way that such measurements should adequately represent the Power Quality and Reliability in the area of supply.

(2) The distribution licensee for the purpose of requirements for the quality of electricity supplied shall identify the locations of 33kV/11kV feeders, Distribution Transformers (DTRs) and designated customers to ensure the measurement of the power quality parameters at sufficient locations in their electrical networks to adequately characterize and report performance in terms of these Regulations. The feeders and DTRs should be identified for PQ monitoring based on type of load connected.

(3) The distribution licensee shall enforce the continuous monitoring of power quality standards at the inter-connection point of identified locations at or below 33kV voltage level for development of profile of power quality measurement in the area of supply;

(4) In the first phase, the distribution licensee shall install Power Quality meters for 50% of total 33kV/11kV feeders, 25% of total DTRs and at all designated customers supply terminals or at point of common coupling (PCC). In the second phase, Distribution Licensee shall cover 100% of 33kV/11kV feeders and at least 60% DTRs. In the third phase 100% DTRs shall be covered.

(5) The measurements undertaken to determine compliance shall be carried out in accordance with the requirements as specified in IEC 61000-4-7 and IEC 61000-4-30. There shall be continuous metering of harmonics with permanent Power Quality meters complying with the IEC 61000-4-30 Class-A meters for all new installations/connections of identified locations. For existing installations/

connections at identified locations where CTs/PTs are of lower accuracy class than mandated by IEC 61000-4-30 Class-A meters, the meters complying with the IEC 61000-4-30 Class-B may be installed. These meters should be capable of detecting direction of Harmonics (whether it is upstream or downstream) for all new installations at identified locations.

(6) In the event when the distribution licensee receives a customer complaint concerning Power Quality, the distribution licensee shall deploy power quality meter for a particular period for the purpose of verification. Distribution licensee can also measure the level of harmonics generation at PCC of any consumer(s) on receipt of complaint(s) from other affected consumer(s).

(7) These Regulations specifies the minimum requirements for Power Quality meters for measurement at sites directly affecting the quality of the power supplied to the consumer(s). The distribution licensee may require the additional PQ meters to establish the power quality at other bulk supply points and at other major network nodes and to investigate consumer(s) complaints, for which these additional PQ meters may be installed temporarily.

(8) The distribution licensee may opt to integrate the smart grid meters compatible for measurement of the PQ parameters for economic and operational optimization.

18. Compliance of the Power Quality and Reliability Standards

(1) The distribution licensee shall submit the monthly and quarterly report of information collected on PQ parameters extracted from power quality meters and machine based reliability data in standard formats (as specified separately) to the Commission.

(2) It shall be the prime responsibility of the distribution licensee to comply with these Regulations and submit the compliance report every 6 months in standard formats (as specified separately), including transparent data disclosure regarding electrical system, to the Commission. Commission may direct designated agencies to be notified separately, to carry out PQ audit on the basis of compliance reports filed by distribution licensee for verification. The distribution company shall carry out

100% audit by itself once a year and 5% random audit by the independent agency and shall file the audit report along with ARR truing up petition.

(3) The distribution licensee shall publish the reports indicating the compliance with the standards under these Regulations and post all the reports on its website. The distribution licensee shall also seek comments, if any, on the same from the customers availing supply from the distribution licensee.

(4) The Commission from time to time may seek reports on PQ improvements from distribution licensee.

(5) The distribution licensee shall make efforts to improve power quality in their supply area by deploying devices to mitigate power quality issues such as filters or controllers etc. The expenses incurred towards deploying these devices by the distribution licensee shall be considered in the ARR.

(6) The distribution companies shall ensure the data security and the data should only be used for identified purpose and should not be transferred to any other person without the consent of the specific consumer.

CHAPTER – 5

INCENTIVE / DIS-INCENTIVE MECHANISM FOR POWER QUALITY

19. Incentive/dis-incentive mechanism for Power Quality

(1) During the first year after notification of Power Quality Regulations, there shall be monitoring and reporting of power quality parameters by distribution licensee in prescribed standard formats at regular intervals. Therefore, there shall not be any incentive/dis-incentive for the stakeholders during the first year after notification or as may be specified by SERCs.

(2) The expenses incurred towards implementation and monitoring of power quality parameters by the distribution licensee shall be considered in the ARR.

(3) From the second year after notification of PQ Regulations, an incentive/dis-incentive mechanism shall be implemented for distribution licensees and for designated customers. The distribution licensees or designated customers shall be liable to pay compensation.

Provided that the Distribution Licensee shall compensate the affected person(s) in second-next billing cycle. In case the Distribution Licensee fails to pay the compensation or if the affected person is aggrieved by non-redressal of his grievances, he may make a representation for the redressal of his grievance to the concerned Consumer Grievance Redressal Forum.

Provided further that such compensation shall be based on the classification of such failure as determined by the Commission and the payment of such compensation shall be paid or adjusted in the consumer's future bills (issued subsequent to the award of compensation) within thirty (30) days of a direction issued by the Forum or by the Ombudsman, as the case may be.

(3) The Distribution Licensee shall not be excused from failure to maintain the power quality parameters under these Regulations, where such failure can be attributed to negligence or deficiency or lack of preventive maintenance of the distribution system or failure to take reasonable precaution on the part of the Distribution Licensee.

(4) The designated customers shall be liable to pay compensation for injecting current harmonics in to the supply system beyond the specified limits as given in Table below. In case the designated customer does not take measures to reduce the level of current harmonics (which is measured in terms of total demand distortion), he shall be made liable to pay higher compensation progressively on each continued violation as decided by the Commission separately. When there is no improvement in power quality even after 6 months, such consumers shall be served notice of dis-connection from the supply network and shall be disconnected after approval of the Commission.

(5) Level of compensation payable for failure to meet power quality standards are given in table below:

Table 10: Level of compensation

<table>
<tr><th>PQ Parameter</th><th>Standard</th><th>Compensation Payable</th><th>Compensation Payable by</th></tr>
<tr><td>Voltage Variation</td><td>As per Table-1, 2 and 3</td><td>Rs.100/- per week or part thereof for which voltage variation was beyond the specified limits</td><td rowspan="4">Distribution Licensee to each consumer connected on the feeder/ designated DTR. These compensations shall be cumulative for each violation.</td></tr>
<tr><td>Voltage unbalance</td><td>$V_{unbalance} \leq 2\%$</td><td>Rs.100/- per week or part thereof for which voltage unbalance was beyond the specified limits</td></tr>
<tr><td>Voltage dips or swells</td><td>Number of events per year as per Table- 4 and 5</td><td>Rs.50/- per event for which voltage dips or swell was beyond the specified limits</td></tr>
<tr><td>Voltage Harmonics</td><td>$THD_V < 8\%$ for LV
$THD_V < 5\%$ for MV and as per Table - 6</td><td>Rs.100/- per week or part thereof for which voltage harmonics was beyond the specified limits</td></tr>
</table>

Current Harmonics	As per Table-7	Compensation shall be 50 paisa per unit for the duration for which current harmonics was beyond the specified limits.	Designated Customer to distribution licensee
Short Voltage Interruptions	Number of events per year as per Table- 8	Rs.50/- per instance for which voltage dips or swell was beyond the specified limits	Distribution Licensee to each consumer connected on the feeder/ designated DTR. These compensations shall be cumulative for each violation.
Long Supply Voltage Interruptions	SAIDI in Minutes per Customer as per Table- 9	5 paisa/min/kW of contract demand for which SAIDI was beyond the specified limits	
Long Supply Voltage Interruptions	SAIFI in interruption per customer as per Table- 9	Rs.50/- per interruption for which SAIFI was beyond the specified limits	

Provided that such compensation as given in above Table-10 shall not be claimed in ARR by distribution licensee and further the compensation received by the distribution licensee from the designated customers shall be utilized only on the measures taken to improve power quality such as installation of filters, controllers etc.;

CHAPTER – 6

MISCELLANEOUS PROVISIONS

20. Power to Relax. The Commission, for reasons to be recorded in writing, may relax any of the provisions of these regulations on its own motion or on an application made before it by an interested person.

20. Power to Remove Difficulty: If any difficulty arises in giving effect to the provisions of these regulations, the Commission may, by order, make such provision not inconsistent with the provisions of the Act or provisions of other regulations specified by the Commission, as may appear to be necessary for removing the difficulty in giving effect to the objectives of these regulations.

Secretary