Power Quality of Electricity Supply to consumers

Base Paper

(Based on FOR report on Power Quality)

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Abstract

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 Report and Model Regulations on power quality as submitted by the Sub-Group was adopted at 64th meeting of Forum of Regulators held on 24.8.2018 The paper is based on the Report of FOR on Power Quality.

1. Introduction

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.

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.

2. Power Quality - current state of affairs

a. 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.

b. 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.

c. 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.

d. 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.

e. 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.)

f. 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.

3. Recommendations as per FOR Report on Power Quality

The recommendations are aimed to provide the solutions which can be used to develop appropriate regulatory framework in India.

a. Need for Power Quality Regulations

The prevailing legal and policy framework with respect to power quality 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, 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.

It has been recommended that there is a 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.

b. 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.

It has been recommended 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.

c. 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.

It has been recommended 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 the 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.

d. 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. During the deliberations sub-group observed that Top three PQ parameters to be monitored are Harmonics, Voltage Variations and Voltage Unbalance.

It has been recommended 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 the Report 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.

e. 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.

It has been recommended that 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.

f. 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. 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.

It has been recommended 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.

g. 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.

It has been recommended 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.

h. 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.

It has been recommended 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.

i. 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.

It has been recommended 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.

j. 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.

It has been recommended 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.

4. Model Power Quality Regulations-Salient features

a. 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.

b. The characteristics of power quality of electrical supply considered in these Regulations to be controlled by distribution licensee are:

- Supply voltage variations
- Supply voltage flicker
- Supply voltage unbalance
- Supply voltage dips and swells
- Supply voltage harmonics
- Supply Interruptions

c. The characteristic of power quality of electrical supply considered in these Regulations to be controlled by designated customers is Current harmonics

d. 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.

e. The compensation is payable or receivable by distribution licensee depending on cause of deterioration of power quality. Such compensation 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.;

5. Conclusions

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.Since Reliability and Quality go hand in hand, the Reliability indices should be included in the Model Regulations.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. 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. Incentive/dis-incentive mechanism may be structured and implemented in a phased manner. Power Quality measurements may be integrated with the smart grid applications for a reliable smart grid. 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. Regulatory framework may specify the training requirements for effective implementations of the PQ standards. Regulatory framework should introduce the compliance audit of PQ parameters by Independent agencies.
