The Journal of CPRI,
Vol. 12, No. 3, September 2016 pp. 473-480

Performance evaluation of distribution network - power quality approach

Surendra Kalambe*

In the modern era power quality has become a serious issue due to ever increase in use of Non linear loads i.e. variable speed drives, power electronics gadgets etc. The IEEE 519 guidelines deliberates the concept of powering equipment in a manner that is suitable to the operation of that equipment. This paper explains details of quality of power supplied and handled by the equipments at the distribution substation, to know the status of the substation equipment; which are mainly responsible for the power quality, The reality check of substation losses and the compatibility of distribution network with standard of performance for reliability improvement of electrical system and network. Means adopted for loss reduction, Overview of various power quality parameters. The best possible solutions to the power quality problems are discussed and their practicable functioning is discussed. The solutions present in the field are explained and field results are presented. Emphasis has been given to explain that by using proper technology a various power quality problems can be addressed.

Keywords: *APDRP (Accelerated Power Development and Reforms program), OLTC (On load tap changer), PQ (Power Quality), IRT (Infrared thermography). IEC (International Electrotechnical Committee), RTCC (Remote Tap Changer Control cubical), HVDS (High Voltage Distribution System).*

1.0 INTRODUCTION

The equipment manufacturers, utility, generating stations, system designers, installation engineers and end users; all are the stake holders in power quality. Ensuring high power quality is every professional's responsibility. The power quality of a system expresses to which degree practical supply system resembles the ideal supply system. Power sector is reforming day by day to give us the uninterrupted and continuous supply upto our homes.

Regulatory standard of performance & electricity Act-2003 need to be followed by all concerned for the Economic development of country. If the power quality of network is good then any load connected to it will run satisfactorily and efficiently. Thus, Installation running cost and carbon foot prints will be lowest possible.

In order to characterize the power quality various parameters explaining the criteria are laid down by IEEE 519 they will be discussed with the field data in this paper.

2.0 ENERGY FLOW – DISTRIBUTION SYSTEM

After APDRP the Distribution System is placed as shown in Figure 1 below. Generally in India from the generating station; the power is Transmitted by 400 kV, 765 kV etc voltage grade EHV transmission lines with 1 to 1.5 % losses. The power is then step down to 400 kV,

* Engineering Officer, Central Power Research Institute, Switchgear Testing & Development Station, Bhopal.
E-mail: spkalambe@cpri.in, 09421777340

220 kV grade Transmission lines having 1-3 % losses. Subsequently it is further reduced to 132 kV Grade transmission lines and lastly to 33 kV grade Distribution voltage level having 2.25% to 4.5% loses. The low voltage distribution lines and Service connections account for 4 to 7% losses. Generally losses in the system range from 8 to 15%. There are approximately 450 distribution circles in our country.

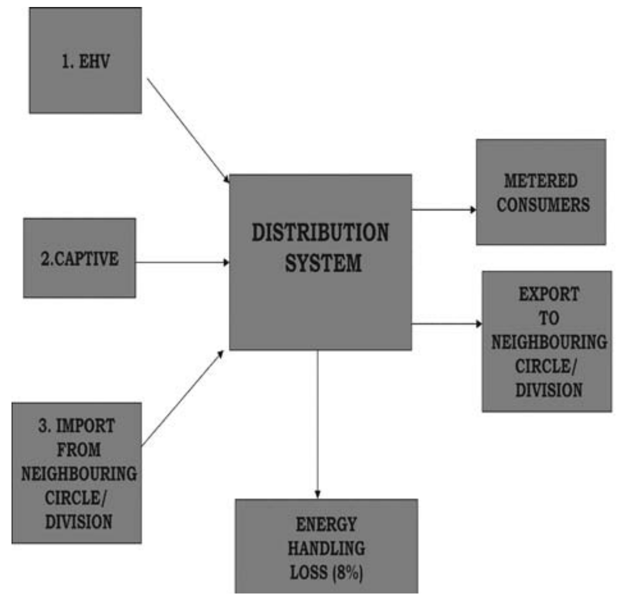

FIG. 1 ELECTRICAL DISTRIBUTION SYSTEM

The power supply is feed from 33 kV substations to the consumers by 11 kV feeders. 33 KV substations are feed by the Radial ring main feeders from 132 kV Receiving station.

3.0 OBJECTIVE OF THE STUDY

Maintaining quality of power supply depends upon utilities as well as consumers. The voltage sensitive and frequency sensitive loads need quality power supply**.**

The brief objective of the study includes: To acquire the details of quality of power Supplied at user end. To study the energy accounting and data logging process. To know the status of the substation equipment such as power transformer, OLTC, capacitor banks etc. To know the substation losses and means adopted for the loss reduction.

4.0 PQ PARAMETERS

4.1 Voltage Criteria

Voltage across each pair of phases shall be equal in magnitude and 120º apart in phase angle. Deviations cause decrease in efficiency, Negative torque, vibrations and Over heating. Under voltages are the result of long term problems that create sags. Under voltages can create overheating of motors and can lead to failure of non-linear loads.

Over voltages can be due to long term problems that create swells. These are common in areas where transformer tap settings are set incorrectly and loads have been reduced.

TABLE 1

PERMISSIBLE VOLTAGE LIMITS

Sl. No.	**System Voltage**	**Max RMS**	**Min RMS**
1	400 kV	420 kV	360 kV
2	220 kV	245 kV	200 kV
3	132 kV	145 kV	120 kV

The variation of voltages beyond the limits is corrected by operating OLTC.

TABLE 2

PERMISSIBLE VOLTAGE LIMITS

Sl. No.	**System of supply**	**Voltage Levels**	**Variations**
1	Low or Medium voltage	250 V, 650 V	+6% to -6%
2	High voltage	11 kV, 33 kV	+6% to -9%
3	Extra high voltage	132 kV	+10% to -12.5%

Thus, for 11 kV

Upper limit 11.66 kV

Lower limit 10.01 kV

4.2 Frequency and Power Factor Quality Criteria

The power plants in India generates Electric power, the voltage is in the form of 50 hertz AC sine wave. The sensitive Electronic equipments require a constant 50 Hz supply to operate correctly. These digital electronics gadgets process information by operating simple on/off switches. These electronics gadgets have power supplies which changes power from AC to DC of much smaller values usually 5 V or less. They switch this small voltage on and OFF at speeds in excess of 100 MHz. The electronic devices are designed to be operated from a uniform sine wave. If the AC wave becomes distorted electronics may send false signals and this conversion process becomes disoriented. If frequency increases the turbine speed will increase and may cause tripping of unit.

The power factor is a measure to know how efficiently electrical power is consumed The ideal power factor is unity. Less than unity means extra power is required for the same load. The leading power factor will draw maximum power from Genertor thus release of system capacity from same source.

Statuary limits	48.5 to 51.5 Hz.
CERC standards	49.5 to 50.5 Hz

The minimum power factor allowed is 0.9

4.3 Voltage Flicker

According to IEC, flicker is defined as Impression of Unsteadiness of visual sensation induced by light stimulus whose luminance or special distribution fluctuates with time. In short it can be explained as voltage fluctuation on the supply network cause change of the luminance of lamps, which in turn can create visual phenomenon called flicker.

Some customers draw intermittent current or create a steep increase in current. If it happens frequently and magnitude is significant the resulting voltage fluctuations will be sufficient to cause a flicker. Thus, flickers are usually produced by customer loads

Flicker is expressed as

$$F_v = 100(V_{max} - V_{min}) + V_{nom} \qquad ...(1)$$

Where,

F_v = Flicker voltage in V
V_{max} = maximum voltage
V_{min} = minimum voltage
V_{nom} = nominal voltage

4.4 Reliabilty Indices Monitoring System

The parameters required for evaluating reliability indices i.e. number of interruptions, duration of interruptions, number of customer interruptions and total number of customer connected with the system.

A. System Average Interruption Frequency Index (SAIFI)

This index shows the average number of interruptions per customer served per year and is given as

$$SAIFI = \sum \left(\frac{Ni}{Nt}\right)$$

Where, i = interruption event
Ri =restoration time
Ni =No. of consumers.
Nt = Total no. of consumers

B. System Average Interruption Duration Index (SAIDI)

This index shows average interruption duration for customers during the year

$$SAIDI = \sum (RiNi / Nt)$$

C. Customer Avearge Interuption Duration Index (CAIDI)

This index shows average time required to restore service to the average customer per sustained interruption during a year.

$$CAIDI = \frac{SAIDI}{SAIFI}$$

D. Benchmark values

The indices are needed to be monitored as per "Standard of performance for Distribution Licenses"

SAIFI=3 per month.

SAIDI=90 per month.

CAIDI=30 min per occurrence.

The field data collected from one of the 33 kV substation is tabulated below

TABLE 3
RELIABILITY INDICES OF FEEDERS

Name of feeder	No. of consumer	No. of Inturuptions	Duration of Interuption	SAIFI	SAIDI	CAIDI
11 kV -1	525	1	29	525	15225	
11 kV -2	640	0	0	0	0	
Total	1165	1	29	525	15225	
				0.45	13.07	29.00

5.0 CASE STUDY OF 33 KV SUBSTATION

FIG. 2. 33 KV SUBSTATION

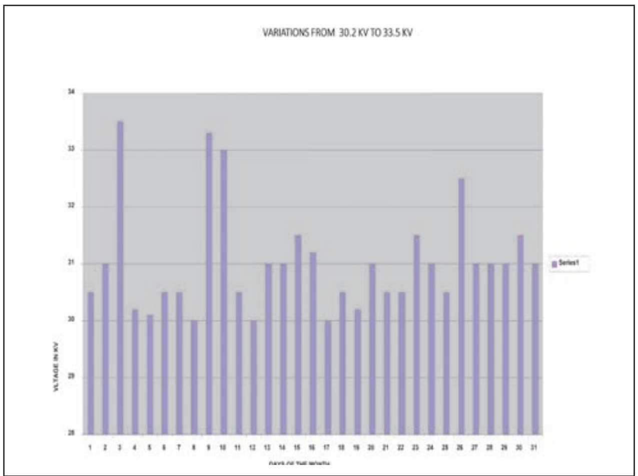

FIG. 3. VOLTAGE PROFILE OF 33 KV INCOMER

Data measured at one of the 33 kV Substation for 24 hours:

Unit consumption, the load on feeder in amperes, Bus voltage and feeder voltage, details of the capacitor bank in service, transformer tap position, station battery parameters, Interruption on the feeders, parameters derived from the above collected field data: Import export of energy, OLTC operation details, Power factor profile of the feeder, voltage profile of the feeder, Peak load of the substation, substation losses, Maximum and minimum load of the substation.

5.1 Voltage profile of the 33 kV incomer

Poor voltage profile means poor quality of power. The voltage profile of 33 kV incomer feeder to the substation is shown below:

Remark: Voltage variation from 30.2 kV to 33.5 kV

5.2 Voltage profile of the 11 kV incomer

Over voltage's can cause stress on the insulation and substantially reduce its life.

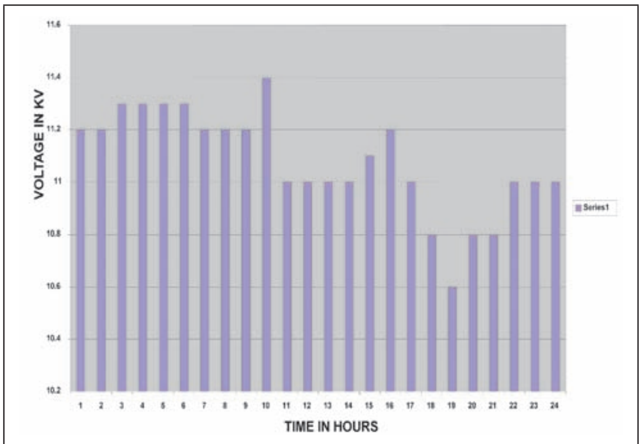

FIG. 4. VOLTAGE PROFILE OF 11 KV INCOMER

5.3 Power Factor profile of 11 kV feeder

Shows PF varies from 0.78 to 0.86. There exists margin for improvement.

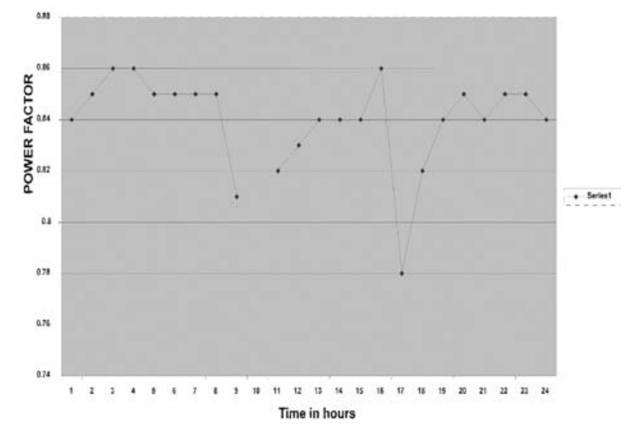

FIG. 5. PF PROFILE OF 11 KV INCOMER

5.4 Load Curve of the substation

Peak demand 33 kV 200 A, Ideally DISCOM should always try for flattening of load curve. This can be achieved by Shifting of agricultural load during night hours. It a normal practice adopted by DISCOM to exercise load shedding on agricultural feeder.

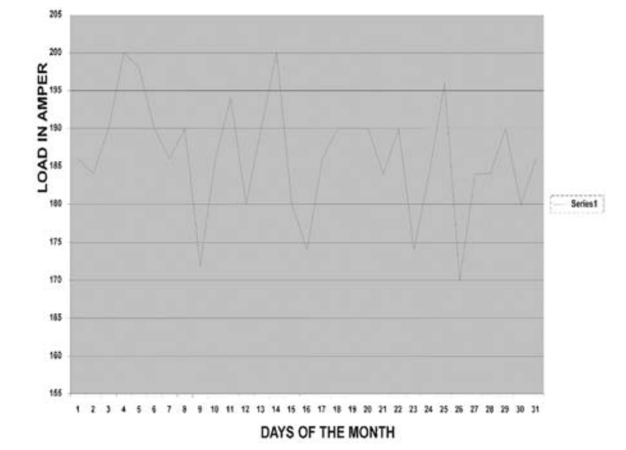

FIG. 6. LOAD CURVE OF 11 KV SUBSTATION

5.5 OLTC Functioning Detail

The tap should be changed depending upon the voltage level. It should be done by RTCC. On inspection most of the RTCC panels found not functioning.

Transformer Details : 33/11 kV, 10 MVA
OLTC make : M/s On Load Gears, Chennai.
Number of Taps : 17
Type of Operation of OLTC: Local / Manual

TABLE 4

OLTC FUNCTIONING DETAILS

Date	Time of Operation	Tap position		Counter Reading	Type of operation			Reasons
		Existing	Changed to		Manual	Remote	Automatic	
28.10. 2015	Data not available	05	-	11190	Manual	-	-	Tap Changed to maintain bus voltage.

5.6 Performance of the Capacitor Bank

Capacitor banks provided on the 11 kV feeders are combination of switched capacitors and automatic voltage regulators. They should be installed near to load centers. The capacitor banks found functioning properly.

The capacitors observed were of two type's i.e. Line type and Station type

TABLE 5

CAPACITOR BANK CHECHING

System Parameters	Capacitor Banknot in service	With capacitor Bank/s - KVA_R in Service		
		1x 660	2x 660	3x 660
Voltage-kV	11.4	11.28	11.33	11.44
PF	0.86	0.89	0.94	0.98
Load- A	192	181	175	170

5.7 Calculation of substation losses

The substation losses were worked out and found to be less than 3% which is within acceptable limits.

TABLE 6	
a. ENERGY RECEIVED	
Incomer I	2105472 KWH
Incomer II	1746396 KWH
Other 33 kV substation	187440 KWH
Total	4039308 KWH
b. ENERGY SENT	4149600 KWH
c. Substation Losses	(A-B) / A
Substation losses	2.65 %

5.8 Methodology adopted for calculating losses

The HT units billed are subtracted from Monthly net units received.

Net import excluding HT loss of 3 %

The LT Billed units are subtracted from the Net import excluding HT component gives LT loss.

LT losses are considered on 12 monthly sliding basis i.e. sum of the sliding losses of 12 months divided by the number of months.

Note: 12 month including the month of interest.

FIG. 7 11 KV DTC DURING INSPECTION

6.0 DSM METHODS ADOPTED

Feeder Energy Management System (FEMS) found in place. The objective is "To prepare an energy account so as to establish the energy input and quantum consumed by/billed to various categories of consumers". DTC Mapping on feeder, Consumer Mapping on DTC, Reduction in DT failure by carrying out periodic maintenance, DTC Energy Accounting, Installation of capacitor banks etc.

6.1 Other Methods which are under implementation

Theft detection drive, Meter replacement with high accuracy one, Detection of unauthorized load, regularization of DLF, Relocating energy meters from inside of houses to entrance, Introduction of transparent enclosures for the energy meters.

Removing of LT lines from the premises of HT, IP consumers, Photo meter reading Replace old DP structure with Load break switch: It comes with HRC fuse hence accurate control is possible, less fire chances, Elimination of single phasing problem.

7.0 HVDS DISTRIBUTION

TABLE 7

LOCATION	End Voltage		% Losses	
	LVDS	HVDS	LVDS	HVDS
A	350	420	18.63	5.47
B	385	430	13.76	5.44
C	340	420	16.82	5.30
D	320	430	16.30	3.77

By implementing HVDS over LVDS: There will be improvement in voltage profile at user end thus better quality power will be delivered. The registered customer will feel ownership and take responsibility and not allow others to meddle with the LT network. Prevention of unauthorized loads by the consumers themselves since the distribution transformer may fail if loaded beyond its capacity. Accidents chances will be reduced since breaker will trip at substation because the line is at 11kV potential.

8.0 OTHER DISTRIBUTION LOSS REDUCTION & PQ IMPROVEMENT TECHNIQUES

The distribution loss reduction techniques i.e. ABC (Aerial Bunch Cabling), static energy meters, prepaid meters, Implementation of SCADA, inspection of feeder by IRT, Introduction of AVR etc.

Harmonic study of the network- The flow of harmonic current in the network increases the distribution network IR losses and increases the voltage drop at the farthest end by increasing distribution circuit impedance. Some of the methods are discussed below with field results.

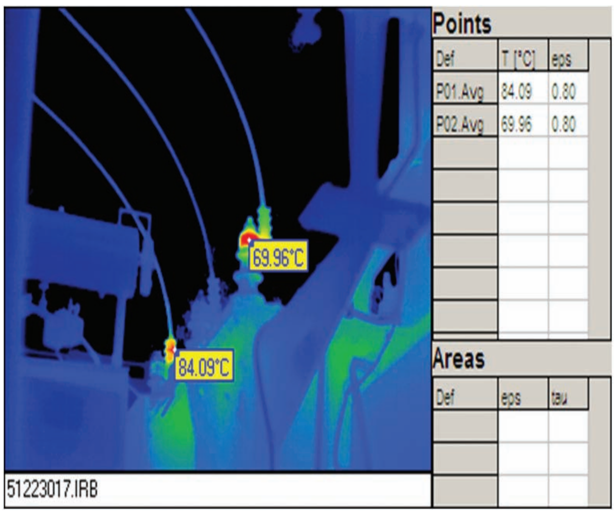

FIG. 8. IR THERMOGRAM OF TRANSFORMER SHOWING HOT SPOT ON HT BUSHING

IR losses can be detected by identifying hot spots if any; hence preventive action can be planned and system losses can be minimised. The faults can be pinpointed before severity hence advance maintenance planning can be done. Reduced unscheduled power shutdown. Improvement of system efficiency, The problems can be found out before they reach to severity. Equipment reliability is enhanced.

8.1 Causes of Hot spots

Electrically induced heating, loose connection, corroded contacts, loss of insulating property by the materials, electrical and or thermal Oxidation of contacts, incipient fault in the equipment

9.0 CONCLUSION AND RECOMMENDATION

a. The substation losses normally varies from 3 to 5 % but in case of one 33 kV substation the losses computed are found more than 7 %

b. The quality of power supplied reviewed in terms variation in 11 kV bus voltage. It indicates that there is a tendency for the variation to be marginally exceeding and lowering the permissible level on the higher and lower side at a couple of hours of the day.

c. The operation from RTCC need to be implemented and training to the substation staff found required for the operation of OLTC from remote. So as to take preventive action in case of sudden increase or decrease in bus voltage.

d. The capacitor banks found working satisfactorily in the substations and are confirmed to be effective also but found inadequate in some substation.

e. In case of substation covered under study the average power factor is 0.86 by incorporating small capacity capacitor banks the effective control of power factor is possible. The power factor can be maintained above 0.9.

f. All the substation transformers are provided with OLTCs and RTCC panels. The OLTCs are in satisfactory working condition. However, the OLTCs are operated only on local- manual and never from remote.

By incorporating suggested PQ improvement measures and program the losses can be brought down below 15% and power quality can be improved.

REFERENCES

[1] K Schipman, F Delince; The importance of Good power quality, ABB power quality products Belgium.

[2] A Bendre, D Divan, W Kranz, and W Brumsickle, Equipment failures caused by power quality disturbances

[3] S P Kalambe, T M Rao, Condition Monitoring of Substation Equipments, National seminar on NDT for power plants conducted by CPRI TRC Nagpur during October- 2010

[4] W E Brumsickle, D M Divan, G A Luckjiff, J W Freeborg and R L Hayes, Operational Experiances with Nationwide Power Quality and reliability monitoring system, IEEE-IAS Annual meeting conference record, October 2003, Vol 2, pp 1063-1067.

[5] Manual on transformers (Revised), CBIP, Golchamarg New Delhi December, 1987.

[6] Harmonics, Transformers & K factors – Copper development *Association* – Publication 144

[7] J Seymour - The Seven types or power problems - White paper 18, rev1, Schneider electric – data center Science Center