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Power Quality Assessment and Harmonic Analysis of Saraswati Complex

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***Abstract*: A comprehensive energy study is being carried out in the Saraswati complex (Library) of DCRUST Murthal, a state government funded university for the power quality and harmonic analysis of the electrical network. This research paper aims at the power quality analysis & load balancing at the LT side of distribution transformer. Harmonic assessment at LT side of DT and calculation of THD%, TDD% and load unbalancing parameters, etc. is being proposed. Finally, recommendations are suggested for the improvement in usage of energy and reducing the energy losses.**

***Keywords*: Distribution transformer (DT), electrical infrastructure, harmonics, power quality, total harmonic distortion (THD), waveforms.**

1. Introduction

In addition to the Energy Accounting, the next important thing of concern is the Power Quality. Power Quality is a term that means different things to different domains. Institute of Electrical and Electronics (IEEE) standard IEEE 1100 defines power quality as ―the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment. All the electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, communication equipment, or a daily use house hold electrical appliance. The simpler version of the power quality states that Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern [4]. Deenbandhu Chhotu Ram University of Science & Technology, Murthal, an educational institute is located on the National Highway No. 1(G.T. Road) 48 Km. from ISBT, New Delhi towards Chandigarh &spread over 273 acres and has a fully residential campus. Deenbandhu Chhotu Ram University of Science & Technology have a 33 KV Power House, from this power house, there are five 11 KV outgoing feeders in the power house. Two 11 KV feeders that supply power to the University from this grid, namely, workshop feeder & colony feeder. These 11 KV feeders are used to feed the supply to the University campus. Being an educational institute major measure part of energy consumption is due to lighting. Survey of energy consumption electric load was done in the Saraswati complex of Deenbandhu Chhotu Ram University of Science & Technology.

From the survey, approximately 56% of the energy consumption in Saraswati complex is due to HVAC load, 30% is due to lighting, 4% is due to fan load, 10% motor load. Motor load analysis, harmonic analysis, lighting based energy audit for Saraswati complex has been proposed to find out KWH losses/year, and calculations thereon for TDD%, THD%, payback period, savings, etc. In this research paper, Harmonic assessment at LT side of DT and calculation of THD%, TDD% and load unbalancing parameters, etc. are done.

The paper provides a brief description of electrical infrastructure of Saraswati Complex in Section-2. We then give a theoretical approach to power quality assessment in Section-3. Section-4 includes the power quality assessment at LT side of distribution transformer, calculations of TDD% and relative load unbalancing of the Saraswati complex. Conclusion is put forth in Section-5.

2. Electrical Infrastructure of Saraswati Complex

Deenbandhu Chhotu Ram University of Science & Technology, Murthal is located on the National Highway No. 1(G.T. Road) 48 Km. from ISBT, New Delhi towards Chandigarh &spread over 273 acres and has a fully residential campus. This section provides a brief description of the electrical layout of D.C.R.U.S.T murthal that includes the key diagram, substations and the load distribution of Saraswati complex (University library).

1) 33/11KV Electrical Substation

A UHBVN 33/11 KV substation is located inside the premises of D.C.R.U.S.T Murthal is being fed from 132KV HVPNL grid .There are five 11KV outgoing feeders namely colony feeder, workshop feeder, nangal feeder, Raveli feeder & Anand diary feeder. The details of workshop feeder that supply power to saraswati complex is as:

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2) Work shop feeder

This feeder gives the power supply to university teaching Departments, administration block, library, workshop, CIPET & boys hostels. This feeder further divide in to two parts first part is for the university campus & second part is for boys hostels. The substation which is used for university campus is situated in the work shop of the university. This substation contains three transformers one is 350 KVA another two is of 500 KVA rating. The two transformer 350 KVA & 500 KVA are used for giving power supply to the university campus & another one 500 KVA is spare. This feeder also gives the supply to the separate transformer of 990 KVA rating which is used for giving the supply to the library complex. The second part of the feeder which is used for boys hostels is situated in the between hostel 1& 2.

3) Details of Substation

The 11kV line coming to the substation and voltage here is step down to 415 V. As the transformer rating at the substation of Library is 990kVA, 11/0.4 kV, star connected. The cable size for power distribution is 3 core, 300mm2 copper unarmored PVC cable, the cable is DUCT installed, 3 cores means 3 cables for three phases of dimension 300 mm2 and wire indicates neutral wire of 150mm2.Two DG's sets (kirloskar make) of capacity 620 KVA & 300 KVA are also installed for backup supply. APFC is also installed for power factor improvement. Figure no 4.1 shown the transformer used in substation.

4) Load Distribution for Saraswati Complex

Following are the details of the load distribution of Saraswati complex that is fed from 990 KVA DT:

- Two nos. three-phase, 4 pole standard induction type motors of capacity 40 hp are used for Fire system.
- One 7.5 hp motor is used as water pump.
- Chiller plant is installed for cooling purposes in which three units are installed each of capacity 150TR. So, total capacity of chiller plant is 450TR.
- 3 AHU are used for air flow in chiller plant in which 10 hp motors are used.
- 6 Air suction units are used to suck air from land & that air than goes to AHU in each suction unit 5 hp motor is used.
- The lightening used in the hostel is mostly T5 of 28W with 2W loses.

The above load is presented in fig 1 in the form of pie chart.

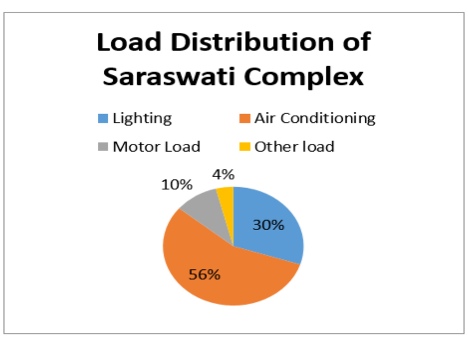

Fig. 1. Load distribution of Saraswati complex

In Saraswati complex of DCRUST murthal 3 units each of 150 TR is installed having 3 AHU, 6 Air Suction units

3. Power Quality Assessment

In this section, power quality assessment, harmonic content & relative phase imbalance has been done at LT side of Distribution transformer. The power quality of Saraswati complex is assessed by measuring the harmonic content at the LT side of the distribution transformers as well as calculating the Total Harmonic Distortion (THD%) and Total Demand Distortion (TDD%) at LT side of Transformer. Lastly, load imbalance of three phases of LT feeders is done.

1) Terminology

IEEE Recommendation Practices and Requirements for Harmonic Control in Electrical Power Systems, this recommended practice intends to establish goals for the design of electrical systems that include both linear and non-linear loads.

2) Total Harmonic Distortion (THD)

THD is the most commonly used harmonic index and is given by:

$$THD_V=\frac{\sqrt{\sum_{k=2}^{\infty} V_k^2}}{V_1} \quad (1)$$

$$THD_I=\frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \quad (2)$$

Total Harmonic Distortion is defined as the ratio of the rms value of the harmonic components to the Rms value of fundamental component and is generally expressed in percent. This index is used to measure the deviation of a periodic non-sinusoidal waveform from a perfect sine wave. THD for a perfect sine wave (containing only the fundamental frequency) is zero [2-3]. Similarly, the measure of individual harmonic distortion for voltage and current at hth order are defined as Vh/V1 and Ih/I1 respectively.

3) Total Demand Distortion (TDD)

Total Demand Distortion (TDD) is defined as:

$$TDD=\frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{Il} \quad (3)$$

Where, IL is the maximum demand load current at the Point of Common Coupling (PCC), calculated as the average current of the maximum demands for the previous twelve months. Current distortion levels can be characterized by a THD value, but it can be misleading in some situations. A small current may have a high THD value but may not be a significant problem for the system. For example, many adjustable-speed drives exhibit high THD values for the input current when they are operating at very light load. This may not be a major concern because the magnitude of harmonic current is low, even though its relative current distortion is high. This difficulty can be addressed by referring THD to the fundamental of the peak demand load current rather than to the fundamental of the present sample. The term TDD is particularly relevant while applying IEEE 519-1992 Standard

4. Harmonic Analysis at LT Side of Distribution Transformer

With the help of Power and harmonic analyzer, total harmonic distortions (THD) are recorded at LT side of distribution transformer that supplies power to Saraswati Complex. Also, total demand distortion (TDD %) is manually calculated. Lastly, TDD% at LT side of distribution transformer for three phases is compared with current distortion limit of IEEE-519-1992 Std. If TDD% goes beyond the limit then it is recommended to install filters to mitigate the harmonics and maintain TDD% and THD% within limits.

For TDD% calculation, some important data of the Distribution Transformer capacity: 11KV/415Volts, 1MVA, % impedance 5.75 %. Short circuit ratio is required to be calculated by

Short circuit current = $\frac{ShortcircuitMVA \times 1000}{Totalsystemimpedence}$.............................. .(4),

Short circuit ratio = $\frac{I_{SC}}{I_L}$.......................... (5)

For the power quality assessment of LT side of transformer, current harmonic spectrums and waveforms are recorded with the help of power and harmonic analyzer at the LT side of the distribution transformer. The waveforms and harmonic spectrums having information about the total harmonic distortion, magnitude of current value, etc. are shown in figures (4.1- 4.4). The following waveforms also give an idea for the crest factor, as for pure sine wave the crest factor is equal to 1.414.

1) Details of harmonics at LT side of Saraswati Complex distribution transformer, 1000/0.4 kVA

This section of the dissertation shows the current waveforms and harmonic spectrum of LT feeder for three phases and the neutral as shown in figures (2 to 5).

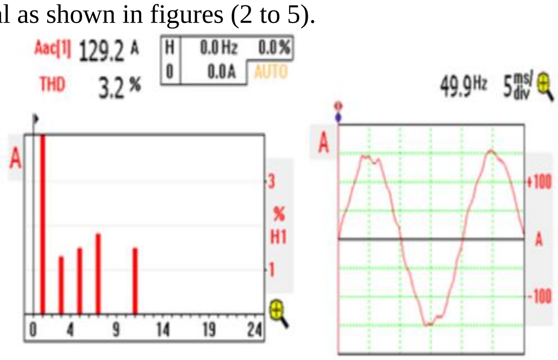

Fig. 2. Harmonic Spectrum and Current waveforms at RED Phase

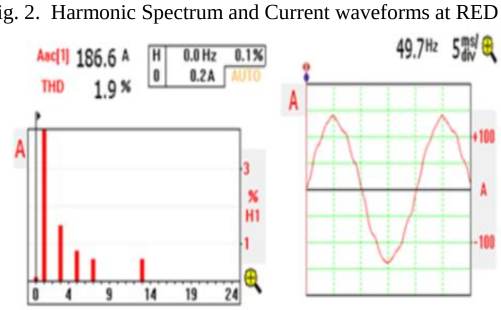

Fig. 3. Harmonic Spectrum and current waveforms at YELLOW Phase

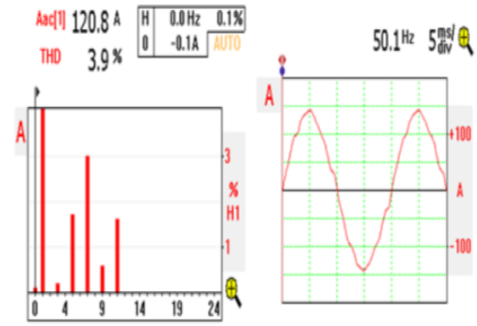

Fig. 4. Harmonic Spectrum and Current waveform at BLUE Phase

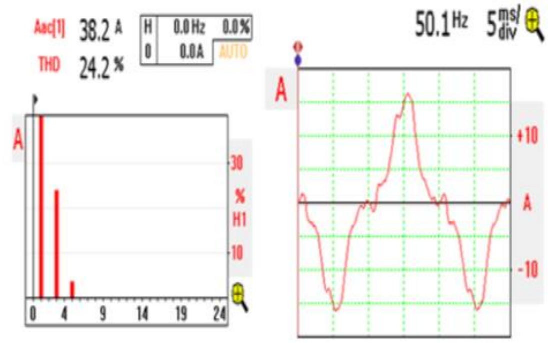

Fig. 5. Harmonic Spectrum and current waveform at Neutral

Based on the harmonic analysis shown in figures (2 to 5), table 4.1 shows the summary of current & (THD %) of each phase and neutral.

With the help of above recorded THD% using harmonic analyzer, total demand distortion (TDD) % is calculated as per the formulae given in equation (6).

Table 4.1
THD% phase wise of LT feeder

	LT Cable1	LT Cable2	LT Cable3	Neutral
	Phase Red	**Phase Yellow**	**Phase Blue**	
Current	129.2	186.6	120.8	38.2
THD%	3.2%	1.9%	3.9%	24.2%

Table 4.2
Current Distortion Limit of IEEE-519-1992 Standard

I_{sc}/I_L	<11	11 □ h<17	17 □ h<23	23 □ h<35	35 □ h	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

TDD%=$\frac{THD}{\sqrt{1+THD^2}} \times \frac{I_{rms}}{I_l}$ ....(6)

Where, TDD is Total Demand Distortion and THD is Total Harmonic Distortion. Table 4.2 shows the current distortion limits of IEEE-519-1992 standard [5-6].

2) Calculation of Short Circuit Current

The data collected from the Distribution transformer of saraswati complex to compute various electrical values like short circuit current & short circuit ratio are given below:

Short circuit calculation:

Grid Transformer: 11kV/415volts MVA, % impedance 5.75 %

Impedance of transformer= $\frac{(\text{base kV}^2)}{(\text{base MVA})} \times$ pu impedence =

$\frac{.415^2}{1} \times .057 = .0106\,\Omega$

Rated Full load current $=\frac{1000\ kVA}{\sqrt{3}\times 415} = 1391 amps$

Short Circuit current= $1391\times \frac{100}{5.75\%} = 24191\ amps$

Short Circuit ratio $= \frac{I_{SC}}{I_L} = \frac{24191}{1391} = 17$

3) 8.51 TDD% Calculation

Total Harmonic Distortion (THD) for R Phase = 3.2%

TDD $=\frac{\text{THD}}{\sqrt{1+\text{THD}^2}}\times\frac{\text{I}_{\text{rms}}}{\text{I}_l}$

$= \frac{.03}{\sqrt{(1+.03^2)}} \times \frac{129.2}{1391} = .0027 \text{ or } .3\%$

Total Harmonic Distortion (THD) for Y Phase = 1.9%

TDD$=\frac{THD}{\sqrt{1+THD^2}}\times\frac{I_{rms}}{I_l}$

$= \frac{.019}{\sqrt{(1+.019^2)}} \times \frac{186.6}{1391} = .0025 \text{or } .25\%$

Total Harmonic Distortion (THD) for R Phase = 3.9%

TDD$=\frac{THD}{\sqrt{1+THD^2}}\times\frac{I_{rms}}{I_l}$

$= \frac{.039}{\sqrt{(1+.039^2)}} \times \frac{120.8}{1391} = .0033 \text{or } .33\%$

Table 4.3 gives the brief summary of THD% and TDD% of three phases.

Table 4.3
THD% and TDD% phase-wise

Phases	**Current (I) in Ampere**	**THD%**	**TDD%**
Red phase	129.2 amperes	3.2%	.3%
Yellow phase	186.6 amperes	1.9%	.25%
Blue phase	120.8 amperes	3.9%	.33%

4) Load Balancing

Load Balancing is the process of achieving and maintaining equal load on each phase of a distribution transformer (DT). The loadings on primary and secondary side of a distribution transformer are shown in Fig 6

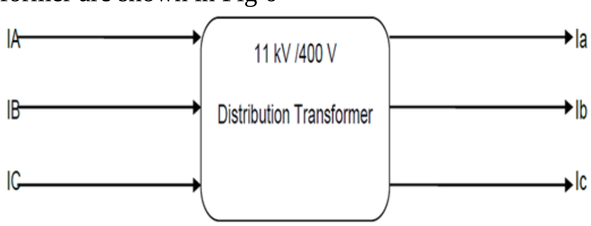

Fig. 6. Representation of distribution transformer

HT Side Current = IA, IB, IC LT Side Current = Ia, Ib, Ic For Balanced Load, Ia = Ib = Ic and IA = IB= IC. If load on each phase of the distribution transformer (DT) is not equal, it is called as unbalanced loading of the distribution transformer. Practically speaking, balanced load cannot be maintained on the transformer due to variable nature of the load. Each transformer supplies power to resistive loads in the form of lighting system, heaters, etc. and inductive loads in terms of motors. These loads can be either single phase, distributed separately on the three phases, or three- phase in nature. If the distribution transformer is supplying power to only three phase loads, then achieving and maintaining the balanced load on distribution transformer could be an easier affair [1]. However, in actual practice, this doesnot happen, because each installation possesses either three phase or single phase or both the loads, which keep on changing at different aspects of time. Due to this unbalanced load, some current will flow through the neutral wire and increase the losses.

Thus, it is a difficult task for a distribution utility to maintain balanced load on the distribution transformer. However, it is important for many reasons like extended life of the transformer, which remains in service for longer period of time. Improved power quality of supply and lesser maintenance cost on distribution transformer leading to increase in utility‘s reliability and finally leads to consumer satisfaction.

5) Load Unbalancing at LT side of distribution transformer

Up to 5% load unbalancing is tolerable but above 5% it is required to balance the load on the three phases. The unbalanced load, current will flow through the neutral wire, which is represents energy loss & in turn revenue loss to the university in the form of monthly energy bill. The measured current for three phase and the neutral at transformer is given below in the table 4.4.

Table 4.4
Current at Each Phase

Phases	Red Phase	Yellow Phase	Blue Phase	Neutral
Current	129 Amp	186.6 Amp	120.8Amp	38 Amp

Load analysis was done at LT feeder and relative unbalances are calculated among three phases:

6) % Unbalance b/w Red Phase and Yellow Phase

% Unbalance = $\frac{\text{Max Deviation}}{\text{Average}} \times 10$

Average= (129+186.6)/2 = 157.8

Max deviation= 157.8-129 = 28.8

% Unbalance = 18.1%

7) % Unbalance b/w Yellow Phase and Blue Phase

Average= (186.6+120.8)/2 = 153.7

Max deviation= 153.7-120.8 = 32.9

% Unbalance = 21.4%

8) % Unbalance b/w Blue Phase and Red Phase

Average= (120.8+129)/2 = 124.9

Max deviation= 124.9-120.8 = 4.1

% Unbalance = 3.36%

Table 4.5 shows the relative unbalance in current for three phases expressed in percentage

Table 4.5
% Relative Unbalance Phase wise

Red and Yellow Phases	Yellow and Blue Phases	Blue and Red Phases
3.76%	19.85%	23.44%

9) Recommendations for load balancing

So, load balancing must be done in order to reduce the neutral current and losses in the electrical network. Few points are recommended in context to the load balancing which are as following:

- Distribute the single phase load (lighting, fans, etc.) in such a manner that the current in each phase is almost equal; i.e. load is balanced among three phases.
- Install DT meter or use other measuring instruments for continuous monitoring of the load which is variable in nature on each phase at an interval of 30 minutes online or depute a person that take readings of

load current phase-wise using clamp-on meters at least twice a day and proper record of the data should be maintained. This helps in identifying the load imbalance and immediate action can be taken for load balancing.

5. Conclusion

A comprehensive study in Saraswati complex of DCRUST Murthal was carried out to study the electrical layout of Saraswati complex, load details and input data collection of various electrical & mechanical parameters using measuring instruments. Then, the Power Quality Assessment was done at the LT side of distribution transformer of Saraswati complex. The harmonic components were measured, recorded and analyzed with the help of harmonic analyzer. With the help of measured data, total harmonic distortion (THD %) and total harmonic distortion (TDD %) were calculated at LT of the distribution transformers. From the calculated THD% and TDD%, it was found to be within permissible limit but recommendations are suggested for load balancing that helps in reducing the overall losses and improvement in the energy savings.

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