

## Survey of Harmonics Measurements in Electrical Distribution System of a Technical Institution

Nandita Dey , Dr.A.K.Chakraborty

Lecturer, Electrical Engineering Department, Tripura University  
Suryamaninagar  
Associate Professor, Electrical Engineering Department, NIT, Agartala

### Abstract –

Growing use of non-linear loads give rise to power pollution in the three-phase four-wire distribution system. This has already become an alarming situation in an engineering institute where quality power is an essential requirement. To ensure quality power it is necessary that a harmonic study is carried out to identify the details of pollution that is polluting sources, the parameters or quantities they pollute in each instance. The paper includes a harmonic survey in the Electrical machine lab of National Institute of Technology, Agartala where various non-linear devices are used everyday. The level and type of the harmonics present in the system are identified. According to the measurement and analysis, the effect of most prominent harmonics are found out that could cause problem in the power quality. The harmonic survey is performed to improve the power quality.

**Index Terms—** Distribution system, harmonics, harmonic survey non-linear loads, power quality, power quality analyzer, total harmonic voltage distortion, total harmonic current distortion, three-phase, technical institution.

### I. INTRODUCTION

In a modern Technical institute, there are so many sophisticated and sensitive equipments in various Laboratories such as Laser lab, Control lab etc. This type of modern lab demands high quality power. In this type of institute, the usage of non-linear loads has increased day by day resulting in high level of harmonic distortion in the power supplied to that institute. Harmonic deteriorates the quality of power. As a result, student cannot get exact results while doing experiments in labs. It indicates that any kind of engineering institute needs quality power. So the necessity of detailed study has become more important for selection and design of mitigating equipments for harmonic reduction [1]-[4].

A harmonic survey has done in the Electrical Machine lab of National Institute of Technology, Agartala for its criticalities. The lab uses different types of non-linear loads such as computers, UPS, rectifier etc. The paper outlines the identification and effects of harmonics in the distribution system of this

lab. The paper also shows that where the harmonics originate and to what extent the harmonics should be suppressed.

Excessive usage of non-linear loads can cause dangerous problems specially overheating of conductors and malfunction of equipments, high neutral voltage and neutral current etc. So this kind of survey is needed for designing the specifications of mitigating devices to be installed in the institute to improve the power quality. The survey is carried out at 11kV/420 V distribution side of Electrical Machine lab, NITA using fluke view 435-power quality analyzer. We had taken data using various non-linear loads and based on the analysis several conclusions are found out.

### II. SOURCES OF HARMONICS

The Electrical Machine Lab where the tests are carried out is very close to the main distribution transformer of the building. We had collected data in Electrical Machine Lab, which consists of many machines and equipments such as UPS, Rectifier, Induction Motor, D.C Shunt Motor, Fluorescent light, Fan, Computers, Printer, Air conditioner etc. The analyses are carried out on several inspections taken at various timings through out the year including different loading conditions.

Table 8.1 Total number and types of the loads

Type of the loads	No of the loads
Fluorescent light	56
Fan	30
Computers	10
UPS	1
Rectifier	1
Induction motor	6
D.C Shunt motor	4
Printer	1
Air Conditioner	1

#### A. Equipment Ratings of the Loads Used In the Electrical Machine Lab

1. Induction motor: 3.7 KW, input voltage=400/440 volt, current rating=7.5 A.
2. Rectifier: input voltage= 220 volt, current=200 amp.

3. UPS: capacity=10 KVA, input voltage=230 volt.
4. D.C Shunt motor: 54 amp, 225 volt.
5. Fan: 80 watt.
6. Fluorescent light: 40 watt.
7. Computer: Monitor=100-200 volt and current=1.5 amp C.P.U=230 volt.
8. Air conditioner: 230 volt, single phase, current rating=0.3 amp

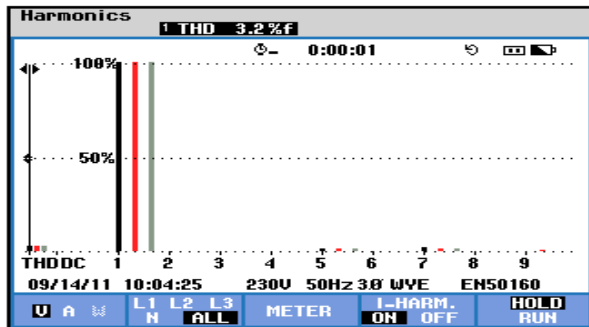
B. Monitoring Equipment



Fig. 1. Fluke view 435 Power Quality Analyzer

C. Snapshots of THVD and THID for Various Loading Conditions

Without the loads, the source current and voltage are distorted. Current distortion is much higher than the stipulated limit (20% limits for current distortion) than the voltage distortion. Source current contained all the harmonic components with significant range.

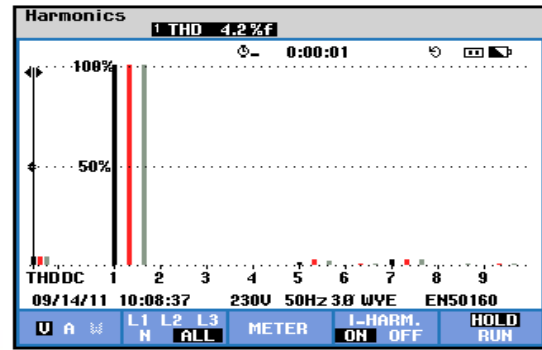


(a)

Amp	L1	L2	L3	N
THD%f	61.5	90.5	19.5	46.4
H3%f	21.4	42.3	8.5	21.8
H5%f	12.8	23.7	7.9	6.3
H7%f	13.2	15.8	4.0	8.5
H9%f	4.1	11.9	4.0	6.6
H11%f	6.9	13.8	3.2	5.3
H13%f	5.8	5.8	2.3	2.9
H15%f	3.8	6.4	1.8	4.2

(b)

Fig. 2. Measurement of (a) THVD and (b) THID when load is not connected.



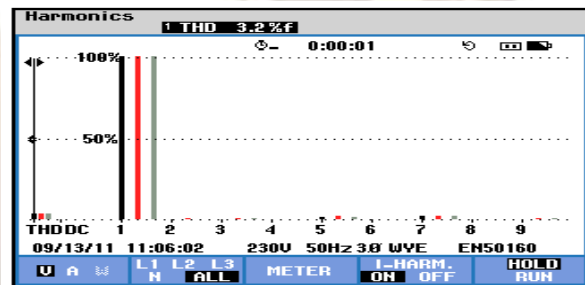
(a)

Amp	L1	L2	L3	N
THD%f	122.4	131.1	153.1	93.2
H3%f	21.1	22.7	2.9	25.4
H5%f	75.6	81.6	76.6	47.0
H7%f	58.4	58.3	58.5	39.9
H9%f	13.0	14.5	3.1	3.4
H11%f	19.3	21.3	13.1	7.6
H13%f	4.6	5.4	1.1	2.9
H15%f	1.3	2.6	1.5	2.2

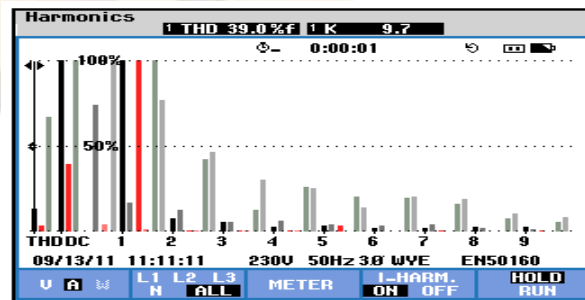
(b)

Fig. 3. Measurement of (a) THVD and (b) THID when load is connected.

When the loads are connected to the source both voltage and current harmonic distortion are increased from 3.2% to 4.2% and 46.6% to 93.2%. The voltage distortion limit is within the range but current distortion violates the acceptable range.



(a)

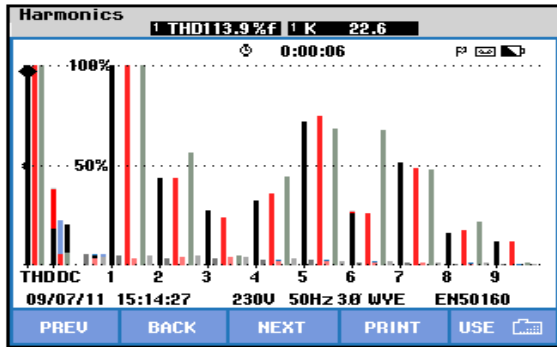


(b)

Fig. 4. Measurement of (a) THVD and (b) THID when Induction motor is not connected.

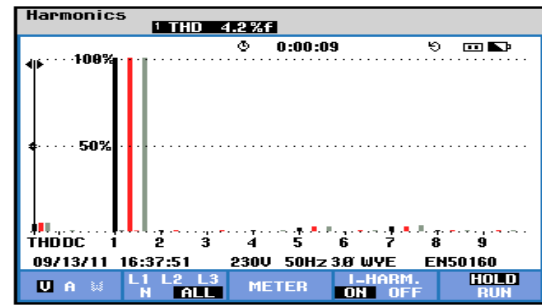
HARMONICS TABLE				
Vol	L1	L2	L3	N
THD%f	4.2	4.5	64.3	100.3
H3%f	0.5	0.6	20.6	32.0
H5%f	2.0	2.4	11.6	15.9
H7%f	3.0	2.9	12.6	18.0
Amp	L1	L2	L3	N
H3%f	22.1	20.0	4.7	45.7
H5%f	71.0	74.6	69.3	66.2
H7%f	51.1	48.7	47.9	52.4

(a)



(b)

Fig. 5. Measurement of (a) THVD and (b) THID when Induction motor is connected to supply system.

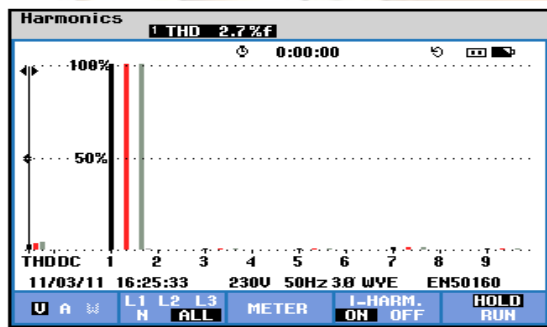


(a)

HARMONICS TABLE				
Amp	L1	L2	L3	N
THD%f	96.0	96.5	112.2	85.3
H3%f	27.4	26.9	1.5	28.2
H5%f	62.2	63.8	59.4	52.1
H7%f	36.5	34.8	32.4	32.6
H9%f	5.3	6.0	1.0	5.0
H11%f	4.5	5.6	6.7	7.8
H13%f	12.5	11.5	11.5	12.6
H15%f	4.7	4.4	0.4	5.7

(b)

Fig. 7. Measurement of (a) THVD and (b) THID when more no (8 no) computers are connected.



(a)

HARMONICS TABLE				
Amp	L1	L2	L3	N
THD%f	28.4	22.3	32.9	25.6
H3%f	12.4	17.4	18.4	20.3
H5%f	7.3	9.2	10.3	10.3
H7%f	4.6	2.8	5.4	3.5
H9%f	3.7	3.0	4.9	3.0
H11%f	3.9	4.9	6.2	5.2
H13%f	3.1	5.4	9.4	5.6
H15%f	3.0	2.8	4.7	3.1

(b)

Fig. 6. Measurement of (a) THVD and (b) THID when single computer is connected.

We can conclude that when loads are connected to source it is highly polluted and some of the loads are pollution (in terms of harmonics) injecting loads.

From the various data collected during the survey in the machine lab, several different sources of harmonic voltages and current are identified. These are

- Fluorescent lighting.
- Computers
- Induction motor
- UPS
- Rectifier
- Air conditioner
- Fan

### III. IDENTIFICATION OF HARMONICS

Data are collected on various loading of the distribution network of machine lab using power quality analyzer. All odd harmonics up to 15<sup>th</sup> order are present

#### A. Fluorescent Lighting

There are various no of fluorescent lamps used for lighting in the campus which have magnetic choke. They are non-linear loads and give rise to odd ordered harmonic currents in low voltage distribution system. These magnetic choke produces a large amount of harmonic currents to low voltages like 230V.

We had taken measurements at the mains in the Electrical Machine Lab where 42 no of lighting loads are connected .All of these have magnetic choke. Some of the lighting loads are frequently used in a day and some of them are used according to the lighting requirement.

The Fig. 8 shows the variation of harmonic voltage and current for the fluorescent lighting loads (42 no) with magnetic ballasts. The harmonics in the current waveform are caused by the non-linearity of the lamp-arc itself in series with the ballast [5].

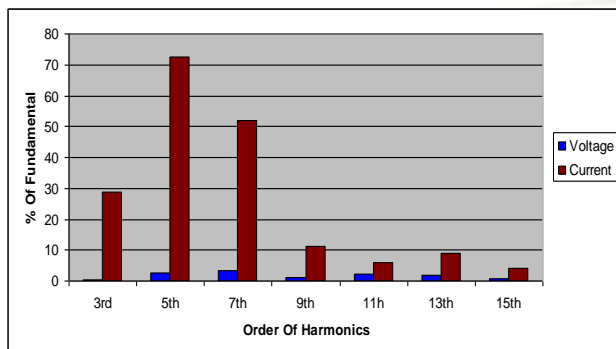


Fig. 8. Harmonic spectrum of voltage and current of fluorescent lighting loads (42no).

It is clear that the percentage of total harmonic voltage distortion (THVD) is 4.9% which is less than 5% and the percentage of total harmonic current distortion (THID) 124.5%.The 7th order harmonic voltage is highest with a value of 3.55% and the 5th order harmonic current has a highest value of 72.4%.When the lighting load is connected through UPS its THVD increases to 5.3% and THID increases to 131.83%.Both the value violate the IEEE-519 limit.

### B. Computers

The use of computers in the campus has been increasing day by day in order to meet the requirements in the modern laboratory and to improve the administrative work. The main drawback of this computer is that it produces a large amount of harmonics to the low voltage network as it uses mainly switched mode power supply.

The computer equipment contains both linear and non-linear loads. The linear loads include cooling fans, printer motors and disk driver. The non-linear load consists of phase controlled power supplies and switching power supplies with bridge rectifiers.

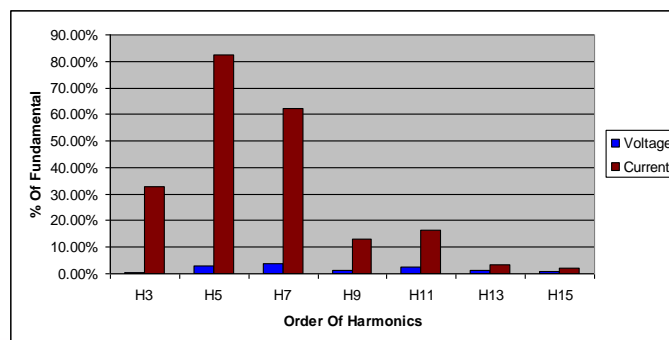


Fig. 9. Harmonic voltage and current spectrum of computer (8 no) load.

The main component of switch mode power supply is a large capacitor, which maintains a near constant voltage for the D.C supply. The capacitor draws current during charging at the peak of the voltage waveform. Therefore, the computer loads become non-linear [6].

The campus has so many computers out of which the survey is done in the electrical machine lab where 8 no of computers are connected. All of these are used continuously in various times of the day. Based on the readings recorded, it is observed that THVD is 4.4% and THID is 136.8 % ( very much greater than 20%), When they are connected through UPS the value of THVD increases to 4.5% and THID becomes 167%.

Whereas the 5<sup>th</sup> order current harmonic itself is 82.5% as shown in Fig. 9. 7<sup>th</sup> order harmonic voltage is the highest with acceptable value of 3.9%.In this case the level of higher order harmonics is higher than the lower order harmonics. Even though the magnitudes of higher order component are low, sometime it may disturb near by communication signals.

HARMONICS TABLE				
Amp	L1	L2	L3	N
THD%f	121.3	123.0	136.8	73.3
H3%f	26.5	23.2	3.2	15.9
H5%f	76.1	77.1	70.2	39.3
H7%f	57.1	54.4	50.8	29.7
H9%f	12.3	12.3	1.7	8.7
H11%f	15.5	15.5	9.9	8.6
H13%f	1.0	1.6	3.0	3.3
H15%f	1.9	0.4	2.0	3.0

09/13/11 16:46:40 230V 50Hz 3Ø WYE ENS0160  
 U V W HARMONIC TREND HOLD  
 U&A GRAPH RUN

Fig. 10. Total Harmonic current Distortion table of 8 no of computers.

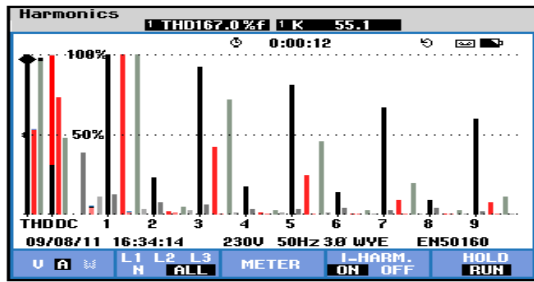


Fig. 11. Total current harmonic distortion of computer (8 no) load connected through UPS.

The measured value of current and its THD for R, Y, B phase of the main is given in the table below. Since the three phases of the main is not simultaneously loaded, the current become highly unbalanced. Hence, the high THD is obtained as shown in the TABLE 1. It should be reduced. Otherwise, it may lead to the failure of the associated electrical components and subsequently the entire system black out.

TABLE 1  
 CURRENT AND ITS THD OF 8 NO OF COMPUTER LOAD

I1=8 amp	THD1=121.3%
I2=8 amp	THD2=123%
I3=7 amp	THD3=136.8%

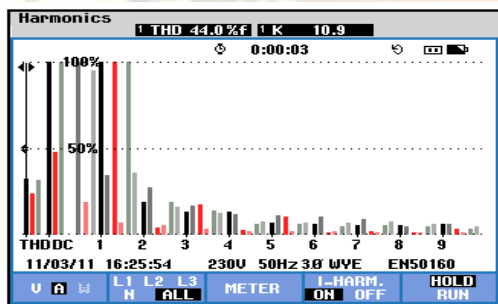


Fig. 12. Total current harmonic distortion of a single computer.

TABLE 2  
 CURRENT AND ITS THD DF SINGLE COMPUTER LOAD

I1=2 amp	THD1=28.4%
I2=1 amp	THD2=22.3%
I3=0 amp	THD3=32.9%

**C. Induction Motor**

In induction motor, the magnetizing current has harmonic content and is therefore a source for the system concerned. The induction motor when connected to the supply system gives maximum 4.5% of THVD and 113.9% of THID. Current harmonic

distortion value is much higher than the stipulated limit. In the lab when students do the experiment on induction motor, it injects harmonics into the system during that period.

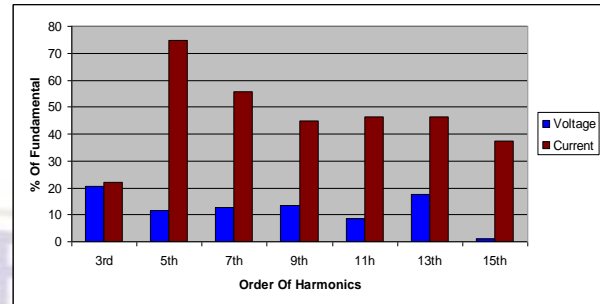


Fig. 13. Harmonic spectrum of voltage and current waveforms of single phase Induction Motor (1 no).

The period is supposed to 11 a.m to 1p.m and 2p.m to 5 p.m in 3 days of the week. In Electrical machine lab, 2 no of 10 HP and 4 no of 5 HP induction motors are used for lab purpose. The 3rd order harmonic voltage is the highest with a value of 20.6% and the 5th order harmonic current has a highest value of 74.6%.

**D. UPS (Un- interrupted power supply)**

The un-interrupted power supply draws large amount of harmonic current from supply causing distortion in voltage. In addition, they also draw current at low power factor. Therefore, it is important to control the supply from the ill effects caused by UPS since they produce significant harmonics, which leads to additional loading resulting in the raise of temperature [7]. Many of the on-line UPS's demand current that has considerable harmonics content and or supply a voltage to the load that has distortion. Several data for voltage and current are recorded at the load side of 10 KVA, 230 input and output UPS located in the electrical machine lab. All the lighting, Fan, A.C, Computer loads are connected through this UPS. It is on for 24 hours.

We had observed from the readings that the THVD and THID is 4.2% (less than 5%) and 153.1% (very much greater than 20%) respectively. Because of this harmonics, the current waveform becomes non-linear.

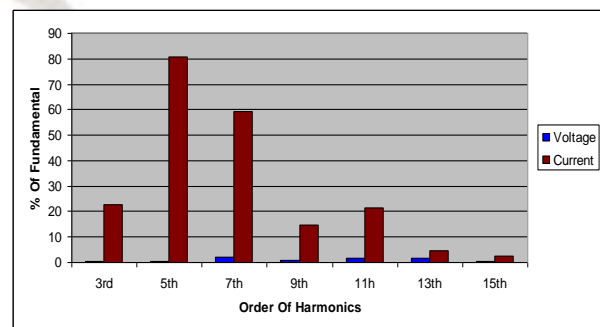


Fig. 14. Harmonic spectrum of voltage and current waveform of UPS.

It is seen from the Fig.14 that the 7<sup>th</sup> order harmonic voltage is the highest with a value of 2.1% and 5<sup>th</sup> order harmonic current is the highest with a value of 80.9%.

#### E. Rectifier

The use of Rectifier and the drives based on this produces discontinuities in the current waveform result in lot of harmonics [11]. We had collected data from 220 V/200 amps Rectifier used in electrical machine lab. The THVD and THID are 5.8 % and 157.1% respectively. It is used during the lab period 3 days in a week from 11 a.m-2 p.m or 2.30 p.m to 5.30 p.m.

The Fig. 15 shows that the 7<sup>th</sup> order harmonic voltage is the highest with a value of 2.4% and 5<sup>th</sup> order harmonic current is the highest with a value of 102.5%.The rectifier having diodes, thyristors etc non-linear load is the major source of harmonic

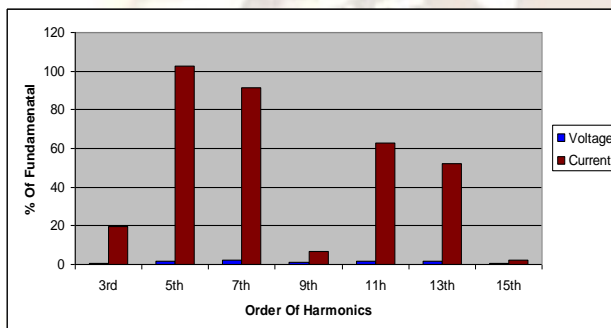


Fig. 15. Harmonic spectrum of voltage and current waveform of rectifier.

#### F. Air Conditioner

There are significant amounts of air conditioners are used in his campus. In the electrical machine lab one no of air conditioner is used, supplied through UPS. The presence of this type of load results in distorted non-sinusoidal voltage and current waveform. The THVD and THID are 2.9% and 9.7% respectively.

The value of THVD and THID increases to 4% and 119.3% respectively when air conditioner is supplied through UPS. In the Electrical machine lab the air conditioner is supplying through UPS through out the working period i.e. from 9.30 am to 5.30 p.m.

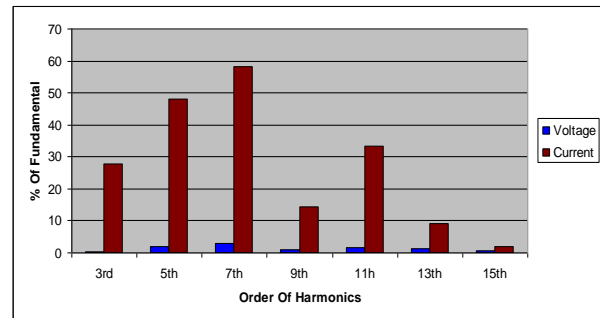


Fig. 16. Harmonic spectrum of voltage and current waveform of air conditioner.

It is observed from the Fig.16 that the 7<sup>th</sup> order harmonic voltage is the highest with a value of 2.9% and 7<sup>th</sup> order harmonic current is the highest with a value of 58.2%.

#### G. Fan

There are 23 no of ceiling fans used in the Electrical machine lab. The value of THVD and THID of these fans are 4.3% and 42.1% respectively. These fans are supplied through UPS and give significant amount of harmonics. When connected through UPS the THVD and THID increase to 5.2% and 124.7% respectively.

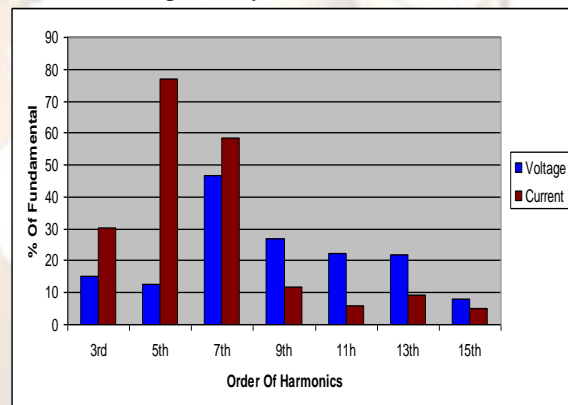


Fig. 17. Harmonic spectrum of voltage and current waveform of Fan (23 no) load.

The Fig.17 shows that the 7<sup>th</sup> order harmonic voltage is the highest with a value of 46.84% and 5<sup>th</sup> order harmonic current is the highest with a value of 76.8 %.

### IV.SUMMARISED REPORTS ON HARMONIC SURVEY

The intent of the survey of harmonics in the Electrical Machine lab is to determine the extent of harmonics in the distribution side and to apprise whether the level of harmonics could lead to an electrical problem in the near future.

TABLE 1  
 MEASUREMENT OF THID AND THVD UNDER  
 DIFFERENT LOADING CONDITION

Load conditions	THID(% )in phases(all)	THVD(%f)in phases(all)
UPS off	19.5%-90.5%	3.2%
Light	32.4%-124.5%	3.3%-4.9%
Fan	24.6%-42.1%	3.2%-4.3%
Computer	33.5%-136.8%	2.6%-4.4%
Light and Fan	17.8%-35.7%	2.8%-3.9%
Light, Fan and Computer	20%-40.9%	2.8%-4.3%
Air Conditioner	9.8%	2.7%-2.9%
UPS On without Load	76.38%-152.3%	3.8%-5.3%
UPS loaded with Light	104.6%-131.83%	4%-4.8%
UPS loaded with Fan	106.8%-124.7%	3.4%-5.2%
UPS loaded with Computer	116.1%-167%	3.6%-5.9%
UPS loaded with Light and Fan	101.1%-136.8%	4%-4.5%
UPS loaded with Light, Fan and Computer	92.2%-105.25%	4.2%-5.4%
UPS loaded with Air Conditioner	76.3%-119.3%	3.7%-4%
Single phase Induction Motor	113.9%	3.2%-4.5%
Rectifier	77.4%-157.1%	3.3%-5.8%
Rectifier with single machine	32.6%-51.5%	3.8%-4.9%
UPS and Rectifier on with load	38.8%-102.8%	4.7%-5.7%
UPS, Rectifier and Induction motor on	103.7%	4.8%-6.2%

According to IEEE-519, the voltage and current distortion should not more than 5% and 20% respectively. However, the percentage compatibility limit for that harmonic order according to IEEE-519 standard is violated [8]-[10].

The results from the survey can be summarized as follows:

1. All loads contribute harmonics. Lighting load contributes minimum pollution, even in

combination with other loads e.g. with fan load or with fan and computers.

2. The impact of light load can be neglected as other loads dominant the resultant figure.
3. The computer load and fan load have the highest THID more than 100% of their respective values.
4. 5<sup>th</sup> and 7<sup>th</sup> harmonics are the highest. Therefore, in any load combination these two harmonics are of highest magnitudes.
5. Where there are phase to neutral loads, a rich harmonic current spectrum is shown comprising mainly of 3<sup>rd</sup>, 5<sup>th</sup> & 7<sup>th</sup> harmonics with the 5th harmonic being predominant though the 3<sup>rd</sup> and 7<sup>th</sup> harmonics are also troublesome.
6. Phase-phase and 3-phase loads show a predominance of 5<sup>th</sup> and 7<sup>th</sup> harmonics with a high presence of 3<sup>rd</sup> harmonic.
7. There are such loads (e.g. UPS, Rectifier) in which 11<sup>th</sup> and 13<sup>th</sup> harmonics are present in a high level. These types of loads have 5<sup>th</sup> harmonic dominating the spectrum.
8. Also in case of triplen harmonics, 3<sup>rd</sup> harmonic is predominating.

So we can summarize from this information that harmonic spectrum are consistent, predictable and dominated by only 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> harmonics.

## V. CONCLUSIONS

In the last few years, harmonics is a big problem for the electrical distribution design in the modern technical college as it pollutes the power. From this survey, it is possible to identify that which loads are responsible for high level of distortion and we can find out their distortion level. The survey provides the background information on system harmonic levels before the new non-linear loads bring into operation and helps in deciding the specification of new equipments to be installed in the college. The results of harmonic measurements also help to define electrical environment and base line for future harmonic surveys to analyze the quality of power. From this information one can know whether the harmonics do a significant hazard to the electrical system and steps should be taken to mitigate the harmonics in order to improve the quality of power.

## ACKNOWLEDGMENT

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