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A Comparative Studyon Harmonicsof Different Electric Bulbs

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ABSTRACT: *The aim of this paper is to represent coexistence of harmonics in the power system through an extensive comparison among the different electric bulbs. The Harmonics in the electrical distribution system are the by-products of modern electronics. They are especially prevalent where there are large numbers of personal computers, printers, copiers, medical test equipment, fluorescent lighting and adjustable speed drives. Harmonics are always generated in any non-linear electrical/electronic systems, and cause severe problems in terms of performance and operation. Harmonics do no useful contributions; they degrade the level of power quality and efficiency in a commercial building or industrial facility. Most people do not comprehend that harmonics have been around for a long time. Since the first AC generator went online more than 100 years ago, electrical systems have experienced Total Harmonic Distortion. The harmonics at that time were inconsequential and had no detrimental effects. Very often, the operation of electrical equipment may seem normal, but under a certain combination of conditions, the impact of harmonics is enhanced, with damaging results. In this paper, we have observed the effects of harmonics and performed a comparison amongthe three types of electric bulbs which are Light Emitting Diode (LED), Compact Fluorescent Lamp (CFL), and Incandescent. Here, we have evaluated the performance and characteristics of these three electric bulbs through Fluke 433 power quality analyzer and MATLAB. The results obtained during the experimental analysis exhibit the amount of harmonics produced during the operation of the bulbs to hinder fluent efficiency and better performance of a power system.*

Keywords : *CFL, Incandescent Bulb, Harmonics, LED, Total Harmonic Distortion.*

I. INTRODUCTION

Harmonics are electric voltages and currents that appear on the electric power system as a result of certain kinds of electric loads. These are the distortion of the utility supplied waveform and are caused by "non-linear"(distorting) loads, which include motor controls, computers, office equipment, CFLs, light dimmers, televisions and in general, most electronic loads. High harmonics increase lines losses and decrease equipment lifetime. Past to Present, power systems are designed to operate at frequencies of 50 or 60Hz. However, certain types of loads produce currents and voltages with frequencies that are integer multiples of the 50 or 60 Hz fundamental frequency. These higher frequencies are a form of electrical pollution known as power system harmonics.

Concern over harmonic distortion has ebbed and flowed during the history of electric power systems. Steinmetz published a book in 1916 that devoted considerable attention to the study of harmonics in three-phase power systems. His main concern was third harmonic currents caused by saturated iron in transformers and machines, and he was the first to propose delta connections for blocking third harmonic currents.

Later, with the advent of rural electrification and telephone service, power and telephone circuits were often placed on common rights-of-way. Harmonic currents produced by transformer magnetizing currents caused inductive interference with open-wire telephone systems. The interference was so severe at times that voice communication was impossible. This problem was studied and alleviated by filtering and by placing design limits on transformer magnetizing currents.

Today, the most common sources of harmonics are power electronic loads such as adjustable-speed drives (ASDs) and switch-mode power supplies. These loads use diodes, silicon-controlled rectifiers (SCRs), power transistors, and other electronic switches to chop waveforms to control power or to convert 50/60Hz AC to DC. In the case of ASDs, the DC is then converted to variable-frequency AC to control motor speed. Example uses of ASDs include chillers and pumps [1].

Due to tremendous advantages in efficiency and controllability, power electronic loads are proliferating and can be found at all power levels – from low voltage appliances to high voltage converters. Hence, power systems harmonics are once again an important problem. Power electronic loads control the flow of power by drawing currents only during certain intervals of the 50/60Hz period. Thus, the current drawn by the load is no longer sinusoidal and appears chopped or flattened. The non-sinusoidal current can interact with system impedance to give rise to voltage distortion and, in some cases, resonance.

In a 'stiff' power system, where the available fault current is high (thus the system impedance is low), the voltage distortion is usually small and does not present a power quality problem. However, in a weak system, where the system impedance is high, voltage distortion can be high and may cause problems [2].

Electrical power system harmonic problems are mainly due to the substantial increase of non-linear loads due to the technological advances, such as the use of power electronic circuits and devices, in ac/dc transmission links or loads in the control of power systems using power electronics or microprocessor controllers. Such equipment creates load-generated harmonics throughout the system. Prior to the appearance of power semiconductors, the main sources of waveform distortion were electric arc furnaces, the accumulated effect of fluorescent lamps and to a lesser extent electrical machines and transformers.

In this paper, our undivided focus is to analyze the characteristics of different harmonic components injected by Energy Saving bulbs to the power system. We will also use Incandescent and LED bulbs to compare the amount of harmonic components produced by Energy Saving, Incandescent and LED bulbs to the power system. We want to evaluate that which kind of bulb produce huge amount of different harmonic components in the power system and affect the electrical devices of our home appliances.

II. THEORETICAL ANALYSIS

2.1 Higher-Harmonic Generation in Fluorescent Lamps

Harmonic distortions affect sensitive equipment connected to the power networks and are especially problematic for compact fluorescent lamps. Recent tests indicate that the harmonic distortions due to power systems are compounded by the generation of higher harmonics by fluorescent lamps. In what follows, we address the higher harmonics generated in these lamps. These harmonics depend significantly on the type of ballast used (electromagnetic or electronic) and directly affect the lamp's light output [3] [4]. Temperature also has an effect on the lamp's light output, especially the time to luminous equilibrium.

2.2 Harmonics and thermal characteristics of LED lamps

The highlighting feature of Light Emitting Diodes (LEDs) Lamps is that it has almost 2 times better efficiency compared to Compact Fluorescent Lamps (CFLs) and 8to10 times more efficient then incandescent lamps. However, like CFLs, a compact AC/DC converter should be used in the lighting fixture to supply DC current to LED chips which introduce nonlinearity to the system. Due to the non-linear characteristic, LED bulbs produce highly distorted currents. This distorted current can penetrate into the power system network. Although the input power of a single LED bulb is quite low, a large number of customers using LED bulbs and CFLs per premises could create significant power quality problems [5]. It is found that most of the new design of LEDs with lower power rating (<25 Watt) have a power factor (PF) up to 0.6 and current total harmonic distortion (THDI) between 100-140 % [6]. Even if the individual effect is very small on a distribution feeder, a large number of LED lamps connected to a single feeder may introduce considerable harmonic current distortion and power quality problems. But it should be noted that arithmetic sum of individuals may lead to wrong estimation of current harmonic distortion levels. Therefore it is necessary to measure the diversity factors to know the impact of large number of LED lamps on power quality. It is also known that the efficiency and reliability of LED strongly rely on successful thermal dissipation due to it's inherit low junction temperature in the LED chip [7] [8]. So, the junction to thermal resistance is an important factor. Later, a LED junction temperature measurement technique was introduced for LED lighting system which can measure accurate junction temperature for LEDs. These measurements are important to know the reduction of device luminosity and extra power consumption due to heat generation in air-conditioned buildings [9] [10].

2.3 Harmonic standard of LED lamps

Similar to any other appliances, LED lamps also must comply with several directives which are applicable to the product. The IEC 61000-3-2 standard assesses and sets the limit for equipment that draws input current ≤16A per phase. Harmonic emission limits for lamps are subdivided based on their active power up to 25W and above. Lamps having an active input power less than or equal to 25W must satisfy at least one out of the two following criterions. One of the criteria is that the third harmonic current should not exceed 86% of the fundamental and the fifth harmonic current should not exceed 61%. This gives the value of the current THD approximately equal to 105%. The recommended voltage distortion limit for class C equipment is 3% and 5% for individual harmonics and total harmonic distortion (THDV) respectively [11] [12].

III. METHOD AND EQUATIONS

Harmonics are a mathematical way of describing distortion to a voltage or current waveform. The term harmonic refers to a component of a waveform that occurs at an integer multiple of the fundamental frequency. Fourier theory tells us that any repetitive waveform can be defined in terms of summing sinusoidal waveforms which are integer multiples (or harmonics) of the fundamental frequency. For the purpose of a steady state waveform with equal positive and negative half-cycles, the Fourier series can be expressed as follows:

$$f(t) = \sum_{n=1}^{\infty} A_n . \sin(n\Pi t/T)$$

Where,

$f(t)$ = time domain function

n = harmonic number (only odd values of n are required)

A_n = amplitude of the nth harmonic component

T = length of one cycle in seconds [1].

As we know for the better quality of power the voltage and current waveforms should be sinusoidal, but in actual practice it somewhat non sinusoidal and this phenomena is called Harmonic Distortion. Voltage Harmonic Distortion which is generally present in supply of power from utility. The distortion in current waveform is called as current harmonic distortion which is generally injected by the nonlinear loads to the supply of utility and corrupts it [13]. A common term that is used in relation to harmonics is THD or Total Harmonic Distortion. THD can be used to describe voltage or current distortion and is calculated as follows:

$$THD(\%) = \sqrt{\left(ID_1^2 + ID_2^2 + \ldots ID_n^2\right)}$$

Where,

ID_n = magnitude of the nth harmonic as a percentage of the fundamental (individual distortion). Another closely related term is Distortion Factor (DF) which is essentially same as THD.

It may be interesting to note that fundamental and third harmonic waveforms for two cases (in phase and out of phase) result in two distinct waveforms with no change in corresponding amplitude. In the first instant, when the odd harmonics are in phase with fundamental, distorted resultant waveform becomes more like a square wave. In the other case, when the harmonics are shifted by 90 degrees phase, the distorted resultant becomes more like a positive and negative spike.

Name	**F**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**
FREQ	50	100	150	200	250	300	350	400	450
SEQ	+	-	0	+	-	0	+	-	0

Table 1.1: Harmonic Components with Frequency and Sequence.

Moreover, Power Factor (PF) in The presence of Harmonics is an essential element to characterize Distortion Factor (DF). There are two different types of power factor that must be considered when voltage and current waveforms are not perfectly sinusoidal. The first type of power factor is the Input Displacement Factor (IDF) which refers to the cosine of the angle between the 60 Hz voltage and current waveforms. Distortion Factor (DF) is defined as follows:

$$DF = \frac{1}{\sqrt{1 + THD^2}}$$

The Distortion Factor will decrease as the harmonic content goes up. The Distortion Factor will be lower for voltage source type drives at reduced speed and load. Total Power Factor (PF) is the product of the Input. Displacement Factor and the Distortion Factor as follows:

$$PF = IDF \times DF$$

Where,

IDF = Input Displacement Factor & DF = Distortion Factor.

In order to make a valid comparison of power factor between drives of different topologies, it is essential to look at Distortion Factor. The Displacement Power Factor may look attractive for certain types of drives, but the actual power factor may be somewhat lower when the effect of harmonics is taken into account.

Different harmonics produced by different kinds of lamps have been observed and measured by an experimental setup.

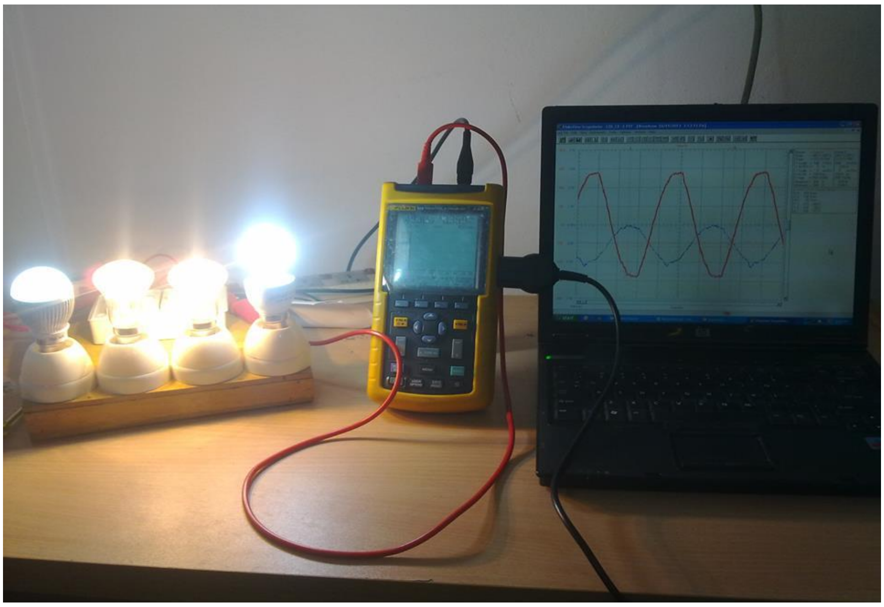


Fig 3.1: Experimental setup of harmonics measurement with Fluke 433 power quality analyzer

The analysis was done by two method:

1. Using Fluke 433 power quality analyzer and Fluke view software. Fluke-View Scope Meter is an application to use with Fluke 433 power quality analyzer. The device allows to connect the Scope Meter to a computer, provide access to the observe reading of the device. A Computer was connected to observe and record the different waveforms and harmonics components of different lamps with the help of the fluke view software.
2. Collecting data from power quality analyzer and using Fourier Transformation with numerical analysis software (Matlab). First Fourier Transformation (FFT) is the most important algorithm to convert time domain to Frequency domain and Vice–versa. To plot the harmonics in frequency domain FFT code was generated and imported the data from Fluke-view software. Fluke-view files (.fvf) were converted to Microsoft Excel format (.csv) and then extracted to MATLAB. Sampling frequency for each lamp was collected from data.

IV. FIGURES AND TABLES

Following theoretical analysis in Sec III, experimental analysis of harmonic components of LED, CFL, incandescent bulb and different combinations of load are done in this section.

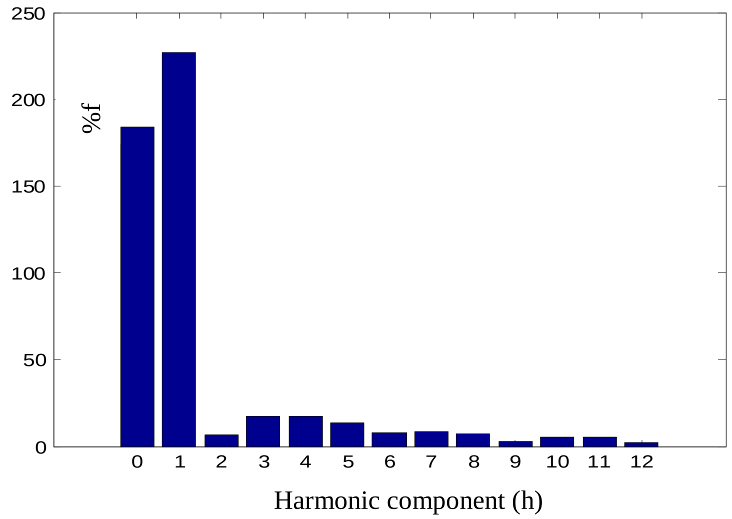


Fig 4.1: Harmonic components of compact fluorescent lamp (CFL)

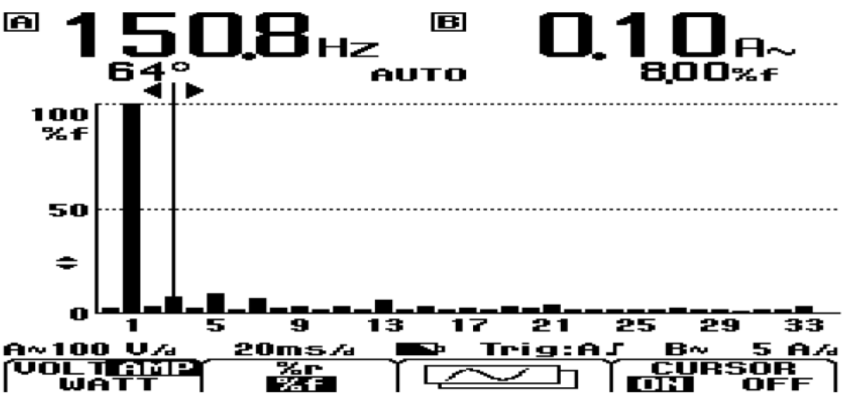


Fig 4.2: Harmonics in CFL (4 lamps-32 watt)

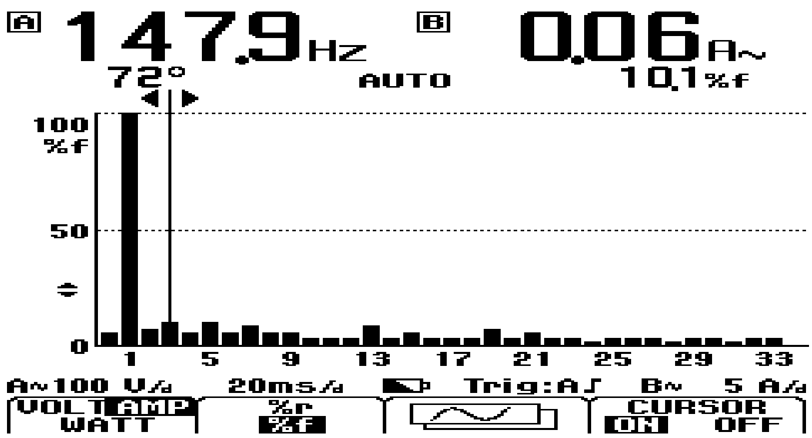


Fig 4.3: Harmonics in CFL (2 lamps-16 watt)

In fig. 4.1harmonic components ofcurrent in compact fluorescent lamp (CFL) is shown. This figure is plotted by collecting data from Fluke-view softwareand using Matlab with Fast Fourier transformation algorithm. Harmonics components ofcurrent for 4 compact fluorescent lamps(32 watt) are shown in Fig

4.2where currentis 0.10A and 3rd component is 8% of total harmonics. From these figures, it can be observed thatthe system has significant amount of odd harmonics than even components.

Harmonics components ofcurrent for 2 compact fluorescent lamps are presented in fig 4.3. It can be noticed that with load reduction the 3rd harmonic component was increased from 8% to 10.1% of total harmonic distortion.

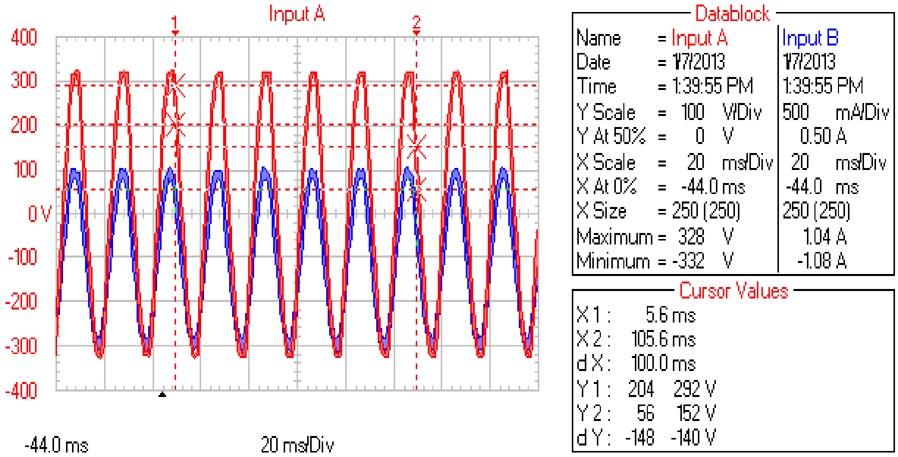


Fig 4.4: Waveform of voltage and current of Incandescent lamps (4 lamps-4*60watt)

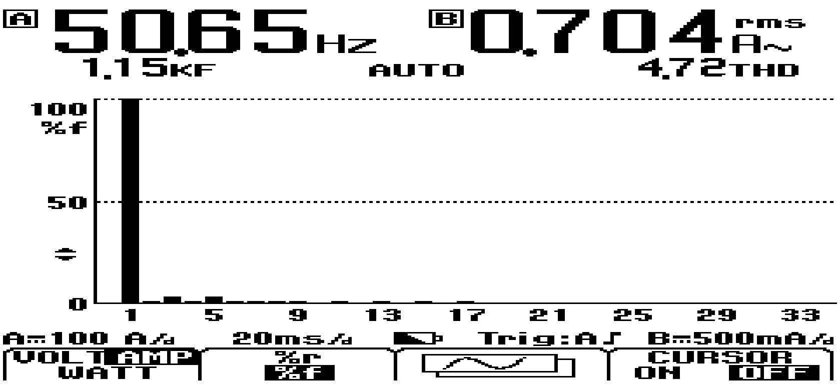


Fig 4.5: harmonic components of incandescent bulb

As in incandescent bulb, because of itspure resistive in nature, harmonics in this type of bulb is minimum which is close to zero. The unity power factor of these lamps also indicates its zero harmonics. The waveform in fig 4.4 also depicts that only system frequency is present and the current (Blue) and voltage (Red) have zero phase difference.In fig 4.5,harmonic components of incandescent bulb generated by fluke-view software has been shown. Hereno harmonic componentis present only fundamental frequency (e.g. 50 Hz) is present.

By experimental data, harmonics components of LED bulbs were found comparatively excessive than CFL. Fig 4.6 depicts that there is a large phase difference between current (Blue) and voltage (Red)when 4 LED lamp (20 watts) were connectedin series as LEDs have diodes that draw current as non-linear loads.As a consequence of this non-linear behavior, LED lighting solutions exhibit poor power quality scores in terms of both power factorand total harmonic distortion.

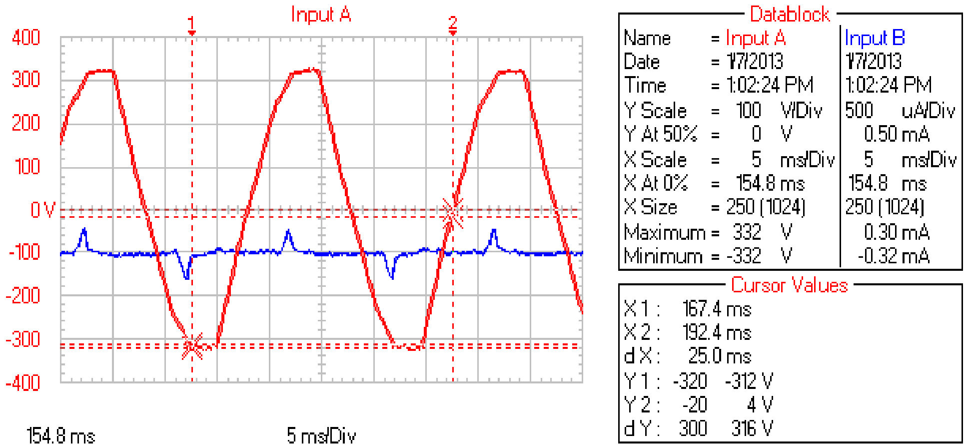
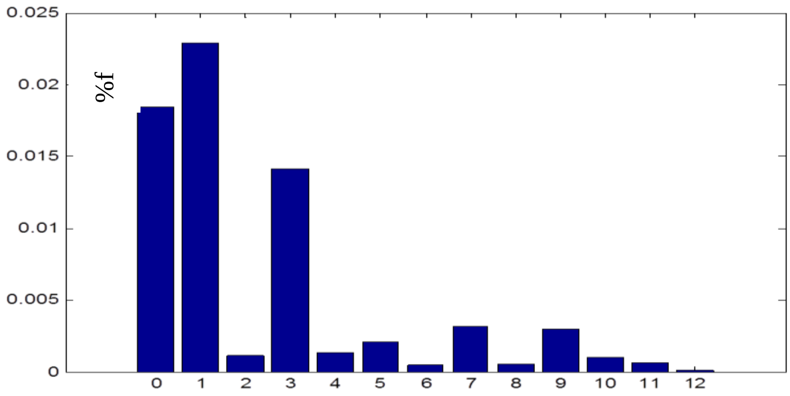


Fig 4.6: phase difference between current and voltage of LED



Harmonic component (h)

Fig 4.7: Harmonic components of Light Emitting Diode (LED)

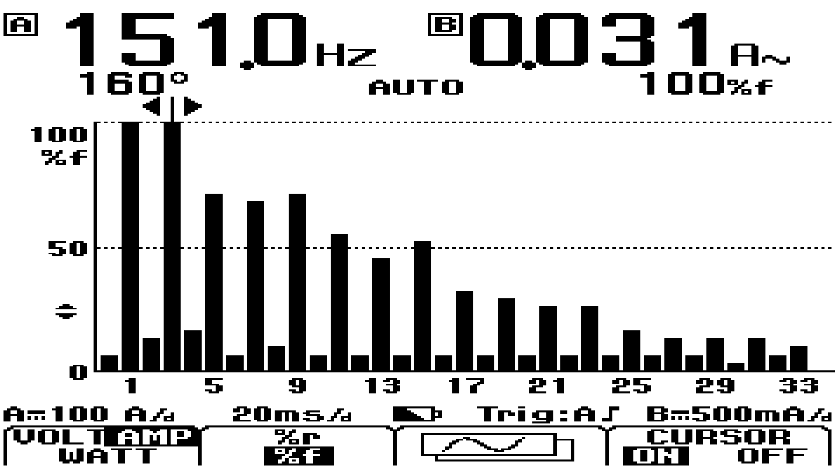


Fig 4.8: Harmonics in LED (By Fluke-view software)

Harmonics components ofcurrent for LED are presented in fig 4.7 and fig 4.8.Fig 4.7 is plotted by collecting data from Fluke-view software and using Matlab with Fast Fourier transformation algorithm.In fig 4.8, harmonic components of LED generated by fluke-view software has been shown. The harmonics component are in larger magnitude and total harmonics in prior to maximum, also it is noticed that the 3rd harmonic component is largest component of all.

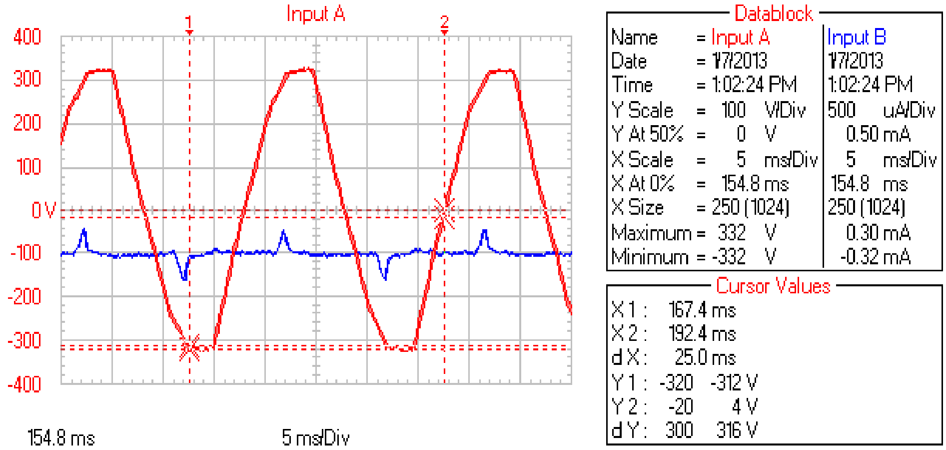


Fig 4.9: Waveforms of voltage and current of full load (20 watts)

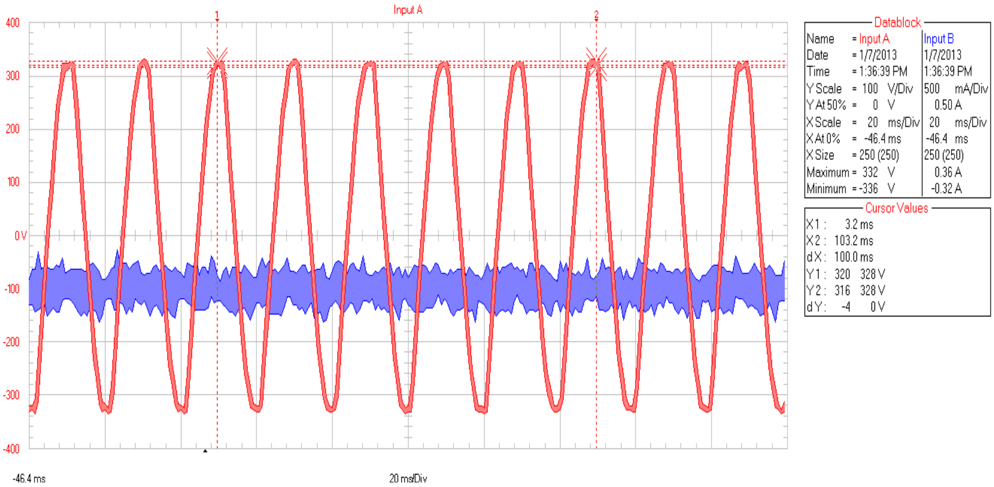


Fig 4.10: Waveforms of voltage and current of half load (10 watts)

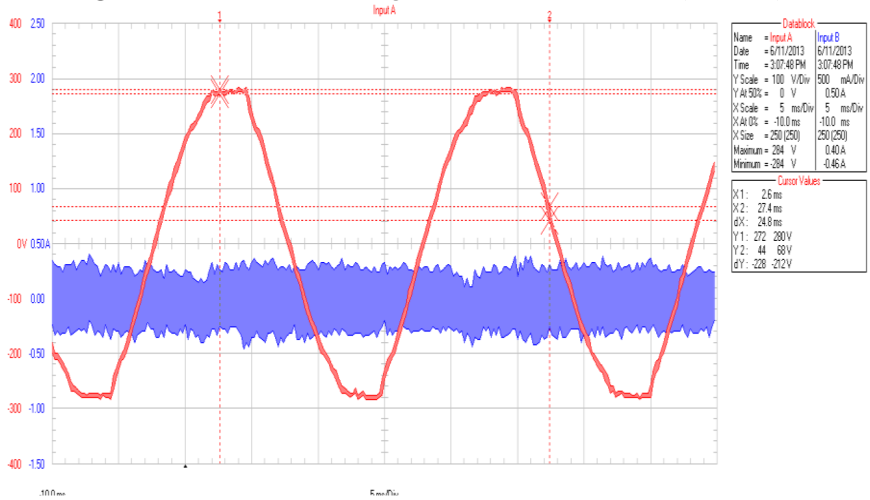


Fig 4.11: Waveforms of voltage and current of a single LED (5 watts)

The Fig 4.9-4.11 show different changes in the shape of current due to load variation from 20 watts to 5 watts. As load reduced, the harmonic components had greater effect in system. In fig 4.9, four LED bulbs were used, each having 5 watts. In fig 4.10 two LED bulbs, total 10 watts were used as load. Waveforms of voltage (red)and current(blue)of a single LED have shown in fig 4.11.

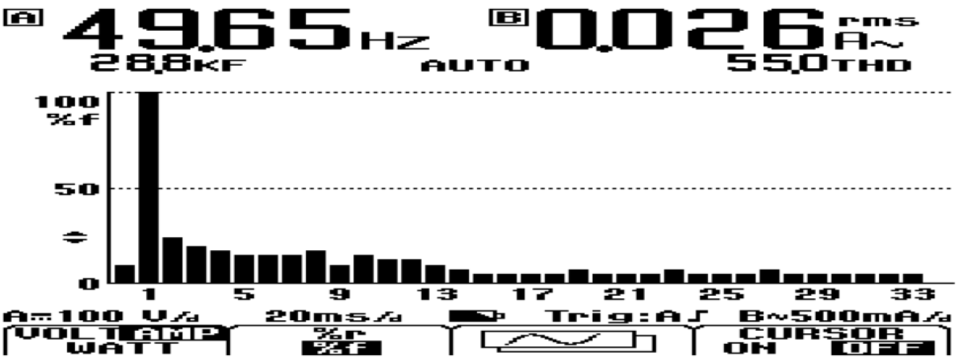


Fig 4.12: Harmonics component exerted from LED and CFL combination (5+4= 9 watts)

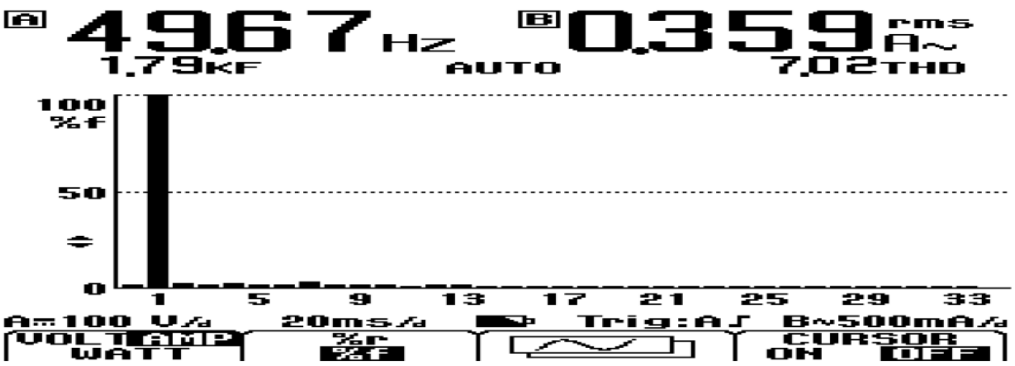


Fig 4.13: Harmonics components exerted from LED and CFL and Incandescent light combination (5+4+40+40= 89 watts)

In fig 4.12, harmonics components exerted from LED and CFL combination (5+4= 9 watts) system generated by fluke-view software have been shown. In fig 4.13, Harmonics components exerted from LED and CFL and Incandescent light combination (5+4+40+40= 89 watts)generated by fluke-view software have been shown.

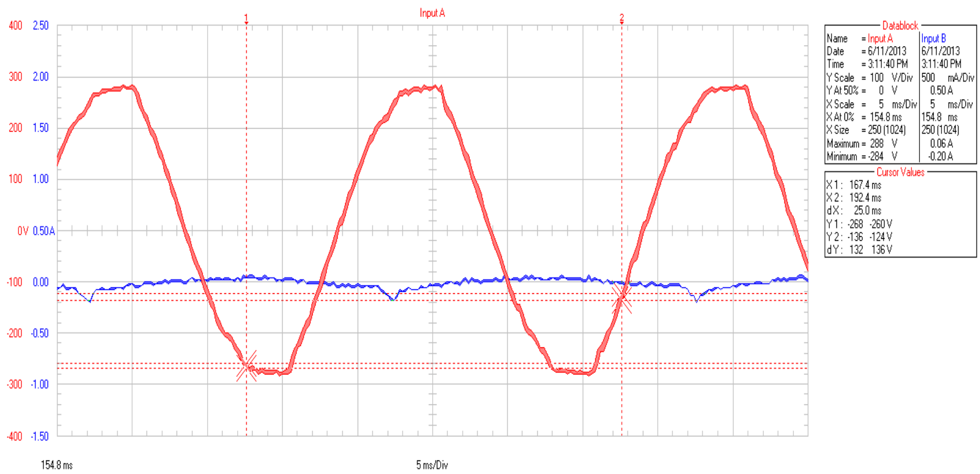


Fig 4.14: Waveforms of voltage and current of combined loads (5+4 watts)

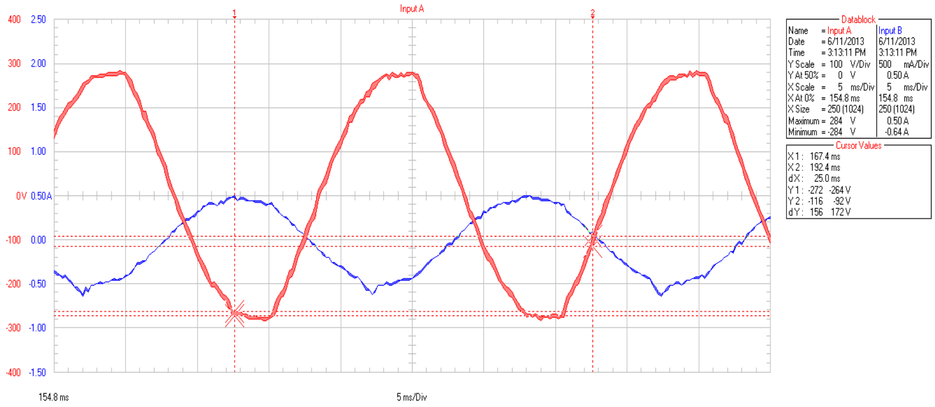


Fig 4.15: Waveforms of voltage and current of combined load (5+4+40+40= 89 watts)

The Fig 4.14 and Fig 4.15 depict different waveforms of combined load with LED,CFL,Incandescent lamps. In fig 4.14, Waveforms of voltage and current of combined loads of LED and CFL bulbs (5+4 watts)are shown. And fig 4.15 consists of Waveforms of voltage and current of combined load of one LED, one CFL and two Incandescent lamps (5+4+40+40= 89 watts). From the above two figures it can be inferred that, Led produces huge amount of harmonics and so in the first figure shows great amount of harmonics combining with CFL lamp. On the contrary, combining these 3 types of lamps have lower harmonics mainly because of two Incandescent lamp which compensate harmonics in a great extent.

V. CONCLUSION

Harmonics is detrimental to power system. It affects our entire home appliances and gradually degenerates their functions .The paper is mainly focused on harmonics of three types of lamps (LED, CFL, and Incandescent). From overall analysis and observations, it can be seen that the different types of lamps differ from each other by their corresponding characteristics. The waveforms and harmonics are distinct to their shape and magnitude respectively. LED lamps inject large amount of harmonics than any other bulbs and thus degrade power quality.The experimental analysis from Fluke 433 power quality analyzer using Fluke view software and Matlab shows different amount of waveform and harmonics in different types of lamps. From the experimental analysis, it is observed that only CFL and LED individually inject more harmonics than combining LED, CFL and Incandescent lamps together in power system. Incandescent lamps do not have any harmonics and it can compensate the harmonics of other lamps like LED, CFL.LED lamp individually exhibits more harmonics than any other lamp in ac system. Where, LED lamps will be efficient in Dc system with minimum harmonics. Moreover, harmonic filters can also be added to the system which shunt specific harmonic currents away from the power system with the added benefit of supplying leading KVARs and thus provide power factor correction. So, a LED lamp fitted with a filter can be a solution to minimize the harmonics components produced by non-linear loads.

VI. ACKNOWLEDGEMENTS

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