Effect of Lamp Technologies on the Power Quality of Electrical Distribution Network

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***Abstract*— The increased use of non-linear loads such as lighting technologies (bulbs) has led to power quality variation of distribution networks. In recent times, different lighting technologies are finding their ways into the market. As such, it is paramount to evaluate the performance characteristics of these lighting technologies and the possible effects they might have on the power network. In this paper, three lamp technologies i.e. Light Emitting Diode (LED) lamps, Incandescent Lamps (IC) and Compact-fluorescent lamps (CFL) are analysed to check the impact of their usage on the power quality of a distribution system through a laboratory experiment. The result revealed that the LED lamps offer the highest savings in energy consumption compared to CFLs and ICs. However, they (LED lamps) constitute the highest harmonic pollution in comparison to the other lamps. From the study, it seems no single lamp is preferable when considering energy saving and power quality at the same time. The choice would have to depend on which of metrics is under consideration. In cases where power quality issues is of prime importance, traditional incandescent lamps are the most preferred, on the other hand when energy conservation is the focus, the LED lamps are the most favourable. CFLs offer moderate energy savings and produce fewer harmonics compared to the LED.**

Index Terms- Lamp Technologies, Harmonic, Distribution network, Power quality

I. INTRODUCTION

Lighting plays a vital role in regular human activities which may be artificial (lamps) or naturally (sunlight). Artificial lightings is adjudged to be one of the component of electrical system that affect the quality of life of people[1]. Adequate lighting system is required in work places, classrooms, offices etc. to achieve a given task comfortably. Hence, it should be functionally suitable for people working inside the task area. However, most recent light technologies are classified as non-linear load which may impact negatively on the power quality of the surrounding distribution network. Moreover, lighting accounts for 21% of the total electrical energy consumption in the world [1]. Therefore, reducing the electrical energy consumption by using energy efficient lamps is generally believed to be one of the important solutions to reducing electrical energy consumption. In an attempt to provide this solution, so many companies sprang-up to manufacture different lamps. Hence, different lighting technologies have found their ways into the market. As such, it is paramount to evaluate the performance characteristics of these lighting technology and the possible effects they might have on the power network.

Various lamp technologies have emerged since the invention of the incandescent, one of the most recent being the LED technology. The new lighting technologies have taken energy savings into serious considerations. The demand for energy-efficient lamps is on the increase not only because of its energy-saving benefits, but also for the laws applied in different countries to ban the use of incandescent bulbs[2]. Such lamps offer benefits as access to electricity is hampered by inadequate generation. One major benefit which is reduction in electricity cost has made them particularly attractive.

Although these modern lighting technologies offer these huge benefits, there is a tendency that they produce harmonics since they are non-linear load. Harmonics in power system poses negative consequences on the power system; it increases line losses and cause excessive heating of equipment which decreases their lifetime [3, 4]. Sub-harmonics could cause flickers that result in an uncomfortable visual effect on the eyes, imbalance and core saturation of transformers and thermal aging of induction motors[5, 6]. It is therefore necessary to evaluate the impact of these modern lamp technologies on the power system.

Considerable work has been done regarding the effect of several lighting technologies on a distribution network. The basic problem arising in the mass usage of CFLs and LEDs is the problem with the network voltage distortion that arises due to their distorted current which contains a high level of harmonic components. Moreover mitigation of harmonic distortion caused by CFLs is very difficult once they are widely distributed over the large power system network [7]. Increased harmonic distortion can cause excessive winding losses and hence abnormal temperature rise in transformers. So when non-linear loads such as LEDs and CFLs are the major energy consumers in a distribution network, early fatigue of transformer insulation and reduction of the useful life of transformer are some of the issues that could arise [8].

978-1-5090-4746-8/17/$31.00 ©2017 IEEE

In this paper, three different lamp technologies i.e. Light Emitting Diode (LED) lamps, Incandescent Lamps (IC) and Compact-fluorescent lamps (CFL) are analysed to check the impact of their usage on the power quality of a distribution system through a laboratory experiment. The rest of the paper is organised as follows: section 2 described the effect of harmonic on the distribution network using the laboratory experimental set-up, section 3 compares the voltage and current characteristics of different lighting technologies, section 4 presents harmonic generation levels of the technologies, section 5 compares other performance characteristics of the technologies while section 6 concludes the paper

II. HARMONICS AND ITS EFFECTS ON AN ELECTRICAL DISTRIBUTION SYSTEM

The increasing usage of non-linear loads such as energy saving bulbs in recent years has aggravated the harmonic problem in the distribution network [9]. Harmonics is a distorted sinusoidal wave as a result of voltage or current having frequencies which exceed the fundamental frequency (50Hz). The distortion caused by the higher harmonics may be presented in the form of Fourier series expansion as (1)-(5) [9]:

$$f(t) = \frac{a_0}{2} + \sum_{h=1}^{\infty} a_h \cos h\omega t + \sum_{h=1}^{\infty} b_h \sin h\omega t \quad (1)$$

where $\omega = \frac{2\pi}{T}$

$$a_h = \frac{2}{T}\int_0^T f(t)\cos h\omega t \, dt \quad (2)$$

$$b_h = \frac{2}{T}\int_0^T f(t)\sin h\omega t \, dt \quad (3)$$

$$c_h = \sqrt{a_h^2 + b_h^2} \quad (4)$$

$$\varphi_h = \tan^{-1}\frac{a_h}{b_h} \quad (5)$$

III. COMPARISON OF THE VOLTAGE AND CURRENT CHARACTERISTICS

A laboratory experiment following the schematic diagram of Figure 1 was set up to assess the voltage and current characteristics of the three lamp technologies (LED, CFL, and incandescent). The three lamp technologies used in the experiment were the popularly used ones in Nigeria and were purchased of the shelf. The experimental set up was powered through a variac, set to provide 220 V. Each of the lamp technology was tested one after the other. A Fluke 1735 power quality logger equipment was connected to the experimental set to measure the voltage, current drawn by the respective lamp technology and the harmonics in the supply. Each phase of the experimental setup was loaded with the same lamp technology, and from the same manufacturer. Switches were introduced in between lamps on a phase to allow for evaluation for a single lamp and also increase the number of lamps when necessary. The various waveforms representing the voltage and current characteristics of the various lamp technologies were obtained from the power analyser and the results are presented in Figure 2. The y-axis is represented as the voltage or current axis while the x-axis is the time axis.

The figures revealed that all the three technologies present sinusoidal voltage wave form. However, only the incandescent lamp presents a near sinusoidal current wave form. The experimental setup revealed that different lamp technologies will inject different level of current harmonic into surrounding distribution system.

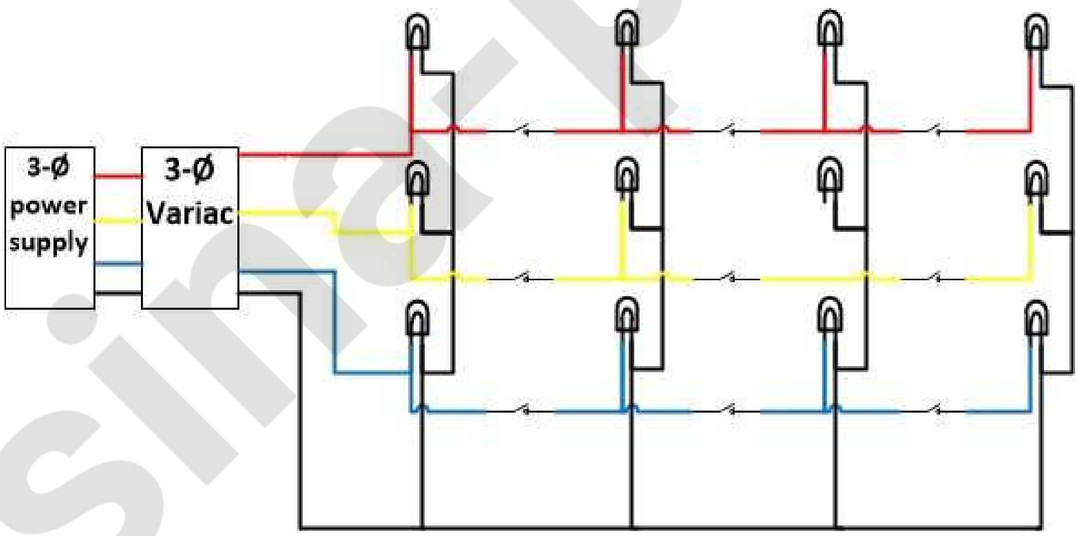

Figure 1: Schematic diagram of the experimental setup comparing different lamp technologies

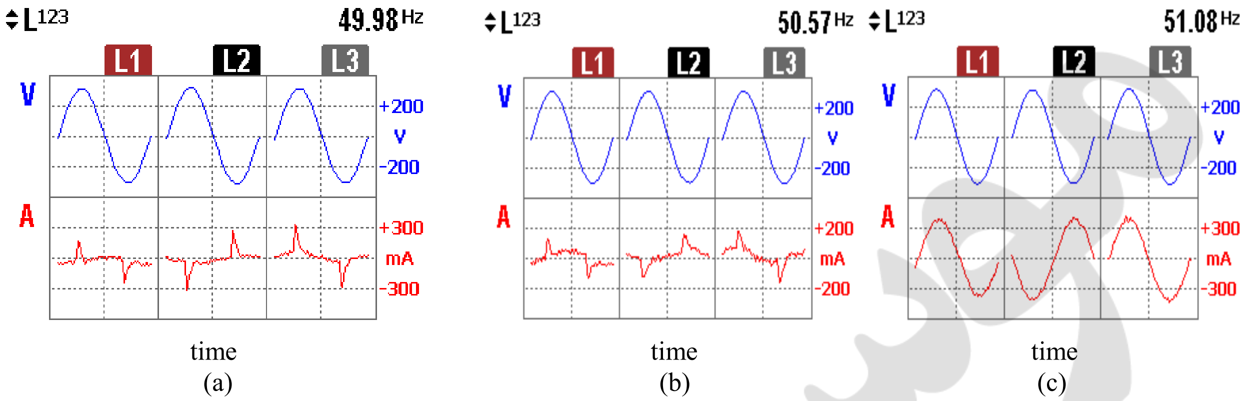

Figure 2: Voltage and current characteristic obtained during experimental setup using (a) LED technology (b) CFL technology (c) incandescent technology

IV. COMPARING HARMONICS GENERATION LEVELS

In view of the observation above (different lamp technology injects varying level of current harmonic to the surrounding distribution network), there is need to quantify and compare the current harmonic generated by these technologies. To achieve this, the lamps were again connected as shown in Figure 1 and then the harmonic content in each phase of the lines were measured. The harmonics generated on the neutral line were also taken into consideration. Figures 3-5 depict the current harmonic content in each phase of the line as well as the neutral for the different lamp technologies. The y-axis represents the percentage of current harmonic distortion while the x-axis represents the order of the harmonics.

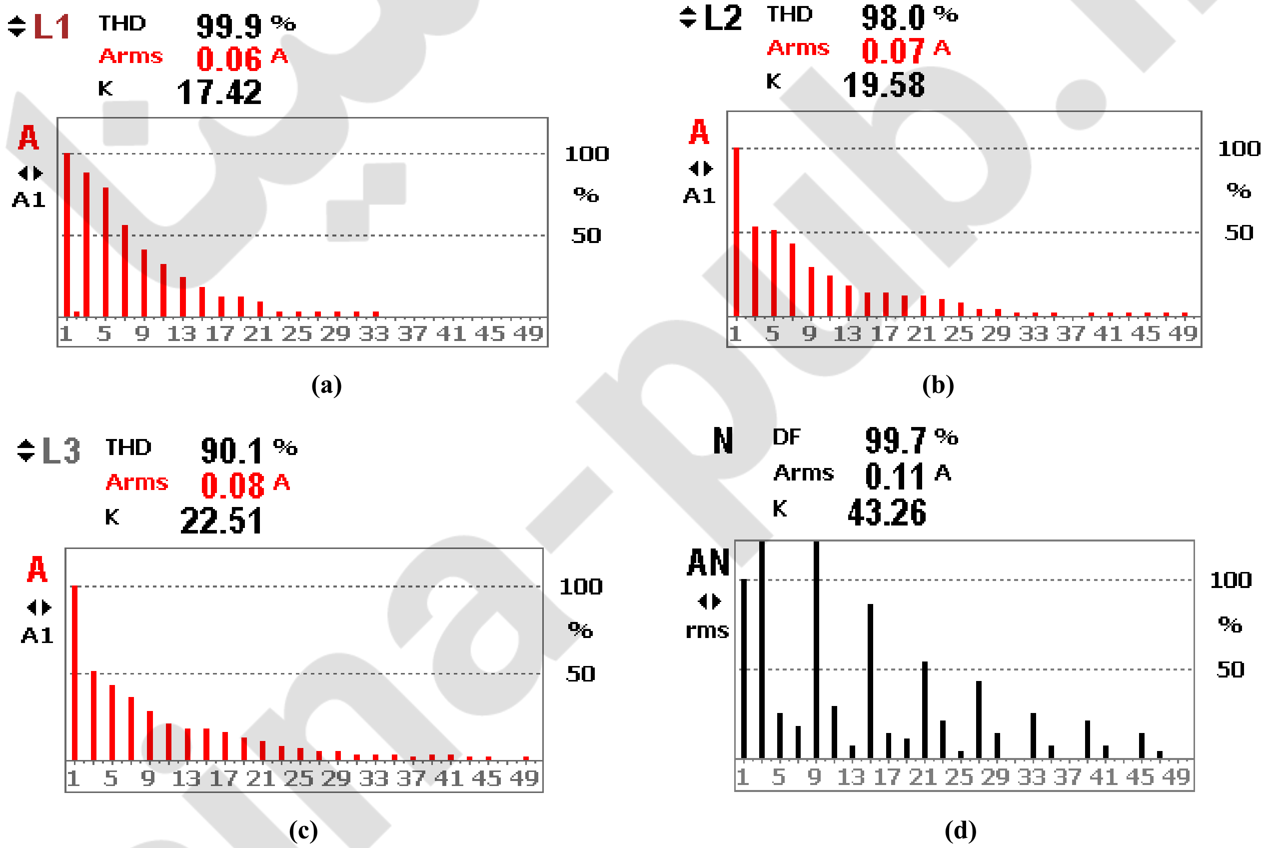

Figure 3: Current harmonics levels for LED technology for (a) phase 1 (b) phase 2 (c) phase 3 (d) neutral line

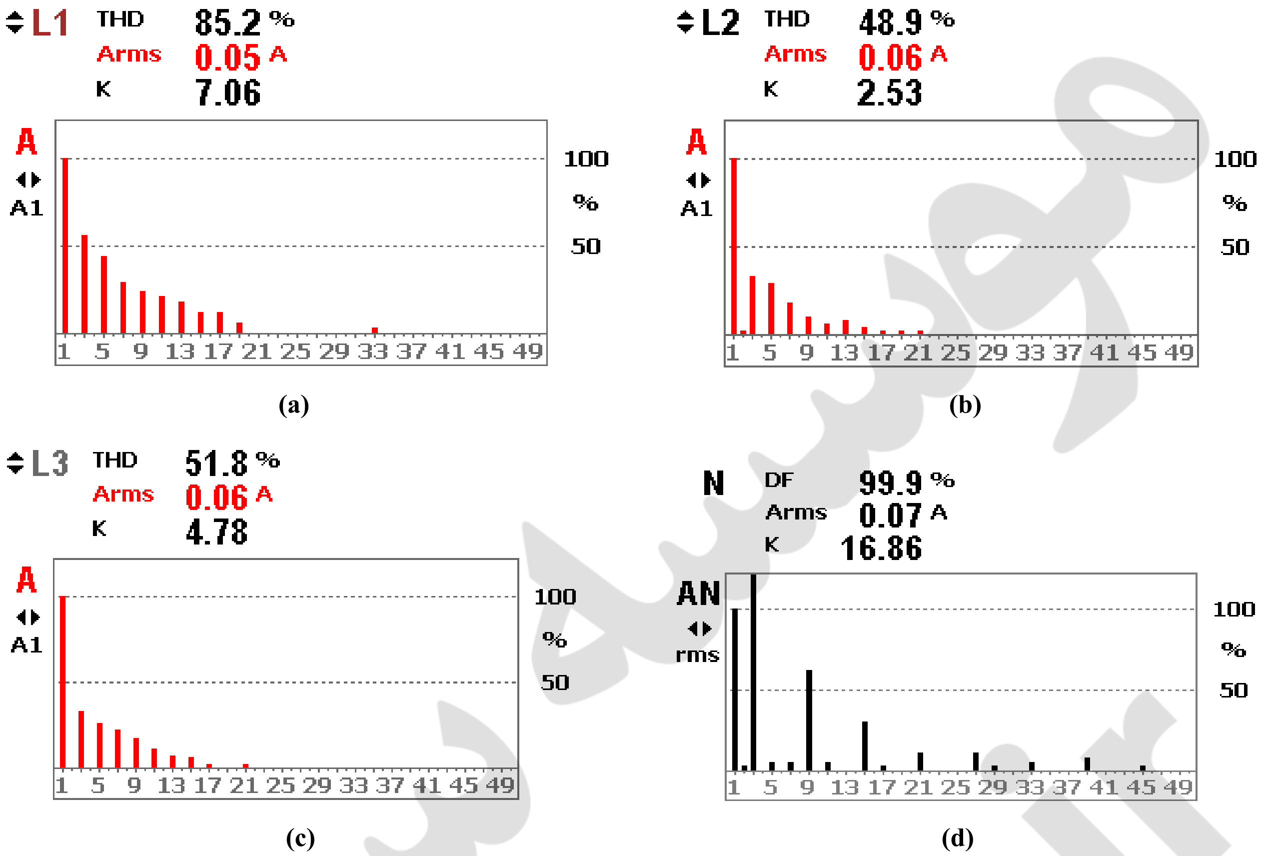

Figure 4: Current harmonics levels for CFLs technology for (a) phase 1 (b) phase 2 (c) phase 3 (d) neutral line

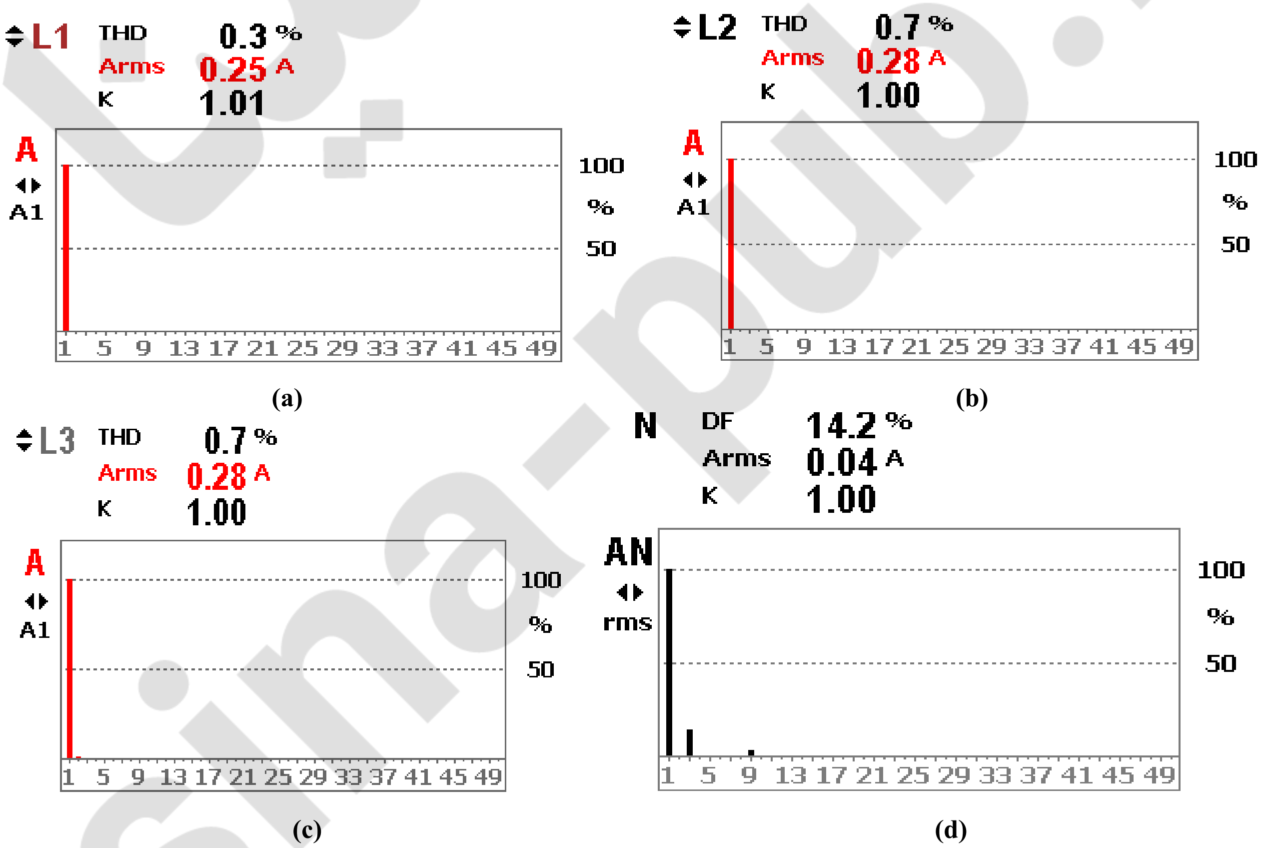

Figure 5: Current harmonics levels for incandescent technology for (a) phase 1 (b) phase 2 (c) phase 3 (d) neutral line

V. DISCUSSION OF RESULTS

In this section, the three lamp technologies are compared in terms of their energy consumption and current harmonic content. This is to give an insight into the claim of most of the companies which produce these bulbs.

A. *Energy Consumption*

From Figure 2, it can be observed that the light-emitting diode (LED) technology consumes least the current. This indicates that LED technology save more energy compared to other technologies. This is because LED bulb uses a semiconductor as its light source, and is currently one of the most energy-efficient and quickly developing types of bulbs for lighting in recent time. However, it is relatively more expensive compared to other types of bulbs, but are very cost-effective because they use only a fraction of the electricity of traditional lighting methods and can last far longer.

Of the three technologies, the incandescent technology consumes the highest current indicating that it has the highest energy consumption. This is expected as this technology makes use of electricity to heat up a wire filament, causing it to glow and give off light. More than 90 percent of the energy produced by incandescent lights is heat, not light, hence, incandescent are inefficient light sources.

B. *Harmonic Content*

Concerning the possible current harmonics that could be injected into the surrounding network, we noticed that the LED lamps have very high Total Harmonic Distortion (THD) values. The harmonics pollution from the LED lamp used in the experiment are very high with the K-factor values of 17.42, 19.18, 22.51 and 43.26 for the phases 1,2,3 and neutral, respectively. The K factor is an index developed to indicate the amount of harmonics that the load can generate. The K index is extremely useful when designing electric systems and sizing components and can be expressed as:

$$K_{factor} = \sum (I_h) h^2 \quad (6)$$

where I_h is the total harmonic current of particular harmonic and is expressed pu.

The CFLs have lower THD values, which indicate lesser harmonics generation compared to the LED lamps. The k factor values for phases 1, 2, 3 and neutral are 7.06, 2.53, 4.78 and 16.86, respectively. This is contrary to the general belief that LED lamps are better in term of harmonic content. The experiment showed that the incandescent technology produces the least current harmonic with K factor of about 1 in each of the phase and neutral. This indicates that this kind of technology has the characteristics of a linear load

VI. CONCLUSION

In this paper, some of the beliefs concerning lighting bulbs have been verified and ascertained through an experimental setup. Three different light technologies (LED, CFL and incandescent) were considered. The results of the experiment indicate that whilst the LED lamps have been said to be energy-efficient, it may not be true in its entirety. This is very notable when the issue of power quality variation is to be considered. The high harmonics levels injected into the network by these lamps can be harmful to the surrounding power system network. Although there are filters available that can help out or greatly reduce the effect of these harmonics, it is not totally safe to say that the energy-efficient lamps are the best technology to implement in most residential and commercials buildings. The experiment also indicates that the CFLs bulbs are moderate in terms of energy consumption and harmonic content while the incandescent lamps consumes the highest energy but are the best in term of power quality (harmonic content).

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