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Harmonic characteristics of lighting loads

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Abstract
An experimental work was undertaken to study the harmonic pattern of various lighting loads in use. A portable power quality meter, Fluke 435 connected to an experimental rack was used as the measuring devices. The logger was programmed to capture essential power data in a set of harmonic load bank such as compact fluorescent lamps (CFL), electronic ballast fluorescent lamps (T_5), magnetic fluorescent lamps (MFL), T_8. The results show that the level of harmonic distortions is dependent on the numbers and types of loads connected to the 240V receptacles and significant differences observed in the measured active power and engrave values.

Keywords: compact fluorescent (CFL), energy saving lamps, harmonics, power quality, fluke 435 logger

Introduction

The use of energy efficient lighting loads in the domestic feeders is becoming unavoidable. This is necessary to minimize high energy requirement of incandescent lamps even though there are ecosystem and safety issues associated with unprotected usage of some brands of the new lighting devices particularly those proved to have low mercury contents. Of paramount important however, is that majorities of these energy retrofitting loads are non-linear devices which can generate considerable amount of harmonics.

Harmonics are high frequency steady state power involving frequency between 50Hz and 3000Hz monitors on a power network which may adversely affect the system performance. In recent time, the classic incandescent lamps which produce negligible harmonic currents are being set aside in the European Union countries to be used only as special purpose lamps. Consequently, derogative tags such as 'lamps not suitable for household use' must be engraved on their packaging, Oramus, Smugała, & Zydroń (2013) [3]. This will keep electricity grid safe and secure so as to achieve substantial saving in spinning reserves from the standpoint of utility and affordable electricity bills for the consumers. Unfortunately, the adopted energy saving lamps such as CFL, T_5-fluorescent lamps and LEDs are major sources of harmonics in distribution power reticulation. A study established the prominent of harmonics when CFL and LEDs were used as lighting loads and suggested that the mixture of these lamps from different manufacturers could significantly decreases higher harmonic orders, Uddin, Shareef, Mohamed, & Hannan (2012) [5].

In this paper, the harmonic characteristics of two types of energy saving lamps (CFL and T_5-fluorescent lamps) are compared with magnetic fluorescent lamps using Fluke 435 power quality logger as harmonic monitoring devices.

Harmonic Distortion Indices

Due to the distortion in voltages and currents in power network, the RMS value of waveform has been standardized. The equations 1 and 2 introduce harmonic components of voltage and current (Grady, 2012).

$$V_{rm} = \sqrt{\sum_{h=1}^{\infty} V_h^2} \quad (1)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{\infty} I_h^2} \quad (2)$$

Where V_h and I_h are harmonic rms value of voltage and current. The total harmonic distortion of voltage and current THD indices are given in Eqns. (3) and (4). respectively.

$$T\ H_V = D \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \quad (3)$$

$$T\ H_I = D \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (4)$$

Analytical derivation in time or phase domain would yield different harmonic powers which essentially are products of eqns. (1) and (2). These are given from Eqns. (5) to (7).

The active power harmonics, P and reactive power Q are given in Eqns. (5) and (6).

$$P = \sum_{n=1}^{\infty} V_n I_n \cos(\theta_n - \delta_n) = \sum_{n=1}^{\infty} P_n \quad (5).$$

$$Q = \sum_{n=1}^{\infty} V_n I_n \sin(\theta_n - \delta_n) = \sum_{n=1}^{\infty} Q_n \qquad (6)$$

The apparent power S is defined in harmonic domain by Eqn. (7).

$$S^2 = P^2 + Q^2 + D^2 \qquad (7)$$

Where D is defined as the distortion voltamperes which corresponds to voltages and currents of different frequency components of Eqns. (1) and (2).
The power factor is defined in Eqn. (8)

$$pf = \frac{P}{S} \qquad (8)$$

The Eqn. (8) quantifies how efficiently a load utilities the current it draws from an ac system.
Other researchers have studied harmonic distortions in power systems (Blanco, Meyer, & Schegner, 2014; Uddin *et al.,* 2012) [1, 5].
Showing power electronic circuit supplying a load, R drawn in Figure 1, the RMS current I_{orms} is obtained in Eqns. (9) to (12).

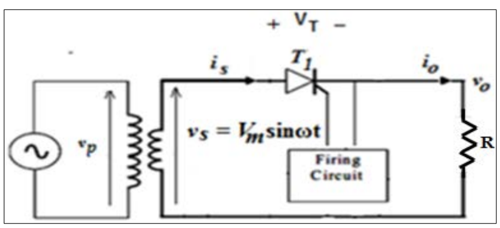

Fig 1: Typical power electronics circuit supplying a resistive load

Set $R = 1\Omega$ and $\alpha = 60°$

$$I_{orms} = \frac{V_{rms}}{R} = \frac{1}{R}\sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} (V_m sin\omega t)^2} = \frac{1}{R}\sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} \left(V_m{}^2 sin^2 \omega t\right) d\omega t} \qquad (9)$$

$$= \frac{1}{R}\sqrt{\frac{V_m{}^2}{2\pi}\int_{\alpha}^{\pi} \frac{1}{2}[1 + cos2\omega t]d\omega t} = \frac{1}{R}\sqrt{\frac{V_m{}^2}{4\pi}\left[\omega t + \frac{sin2\omega t}{2}\right]_{\alpha}^{\pi}} \qquad (10)$$

$$= \frac{1}{R}\sqrt{\frac{V_m{}^2}{4\pi}\left[\left(\pi + \frac{sin2\pi}{2}\right) - \left(\alpha + \frac{sin2\alpha}{2}\right)\right]} \qquad (11)$$

$$= \frac{V_m}{2}\left[\frac{1}{\pi}\left(\frac{2\pi}{3} + \frac{\sqrt{3}}{4}\right)\right]^{\frac{1}{2}} \qquad (12)$$

A theoretical crest factor (CF) of this circuit is given in Eqns. (13) through (15).

$$CF = \frac{peak\ value\ of\ current\ or\ voltage\ waveform}{RMS\ average\ value\ of\ current\ or\ voltage} \qquad (14)$$

$$CF = \frac{V_m}{\frac{V_m}{2}\left[\frac{1}{\pi}\left(\frac{2\pi}{3} + \frac{\sqrt{3}}{4}\right)\right]^{\frac{1}{2}}} \qquad (15)$$

Eqn. (15) obtained the CF for a typical firing angle, α of 60°. Figure 2 shows the trend of CF with the RMS index for the possible values, $0 \le \alpha \le 165°$. The CF will be much higher than nominal value obtained for resistive load assumed, if the actual resistance, less than 1 Ω is used.

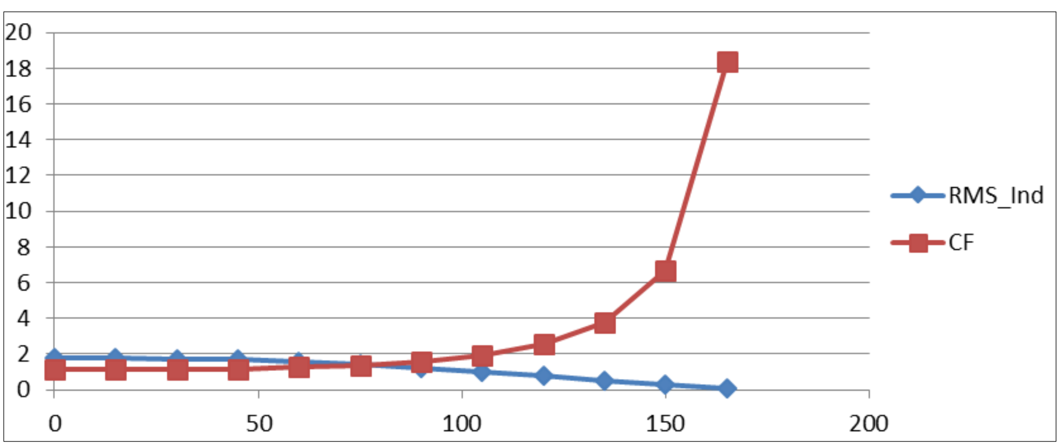

Fig 2: Circuit Performance Characteristics of CF and RMS Index

In a building service design, periodic monitoring of Voltage CF is a sure way of detecting problems associated with building wiring (https 1). The maximum power transfer capability limit of the installation will become apparent if during no load condition, the electrical branch circuit shows a Voltage CF of near 1.4 and then changes to some number less than 1.1 when an electronic load is plugged in. The problem is common when wire length is too long for the wire gauge used. In this case, the remedy would be to run a new wire using a larger wire gauge (https 1). This is a part of maintenance schedules that needs to be carried out in building power facility for improved power quality. The problems of crest factor are now restricted to call centre and commercial building installations with high density computers when power factor was not properly corrected (Rasmussen, 2006) [4].
Crest factor measurements detect potential wiring and loading concerns that a simple voltage measurement will not identify. For example, a basic voltage measurement may yield 228 V, which is

within -5% of a nominal 240 V, and seemingly implies a normal, healthy circuit. But if the CF measurement is 1.38-1.39-this implies an overloaded or underserved circuit whose equipment may be experiencing a more severe voltage reduction during the time they pull power, which is at the peaks.

Experimental set-up

The experiment was set-up as shown in Fig. 3. It comprises of the Fluke 435, a three phase power quality analyzer and the harmonic load banks as well as Laptop for retrieving data from the logger. The logger, which complies with IEC/EN61010-1-2001 and IEC61000-4-30, 2003 standards, has extra memory for logging data. It finally works in conjunction with Laptops using some special software tools such as the Power log and Spreadsheet Excel.

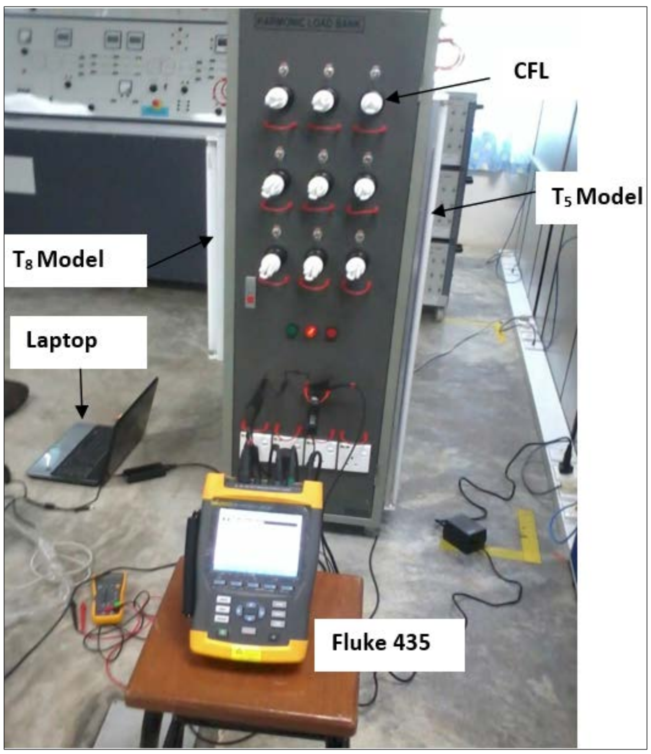

Fig 3: Experimental Rig.

The load composition and specifications of lamps shown in Fig. 3 are presented in Table 1.

Table 1: Numbers of Lamps and Specifications

Equipment Name	Name plate power rating (W) per Unit	Number
Compact Fluorescent Lamp	14	9
Electronic Fluorescent Lamps (T5 Model)	16	5
Magnetic Fluorescent Lamps (T8 Model)	20	3

Results and Discussions

The experimental set up in Figure 3 was conducted under laboratory precautions and guidelines. For instance, a few segment of the switching pattern is provided in Table 2 and the harmonic distortion values are determined. The data row 5 is the worst case scenario having fairly constant dominant 7^{th} volt harmonics and 3^{rd} current harmonics of 0.70% and 70% respectively corresponding to CFL devices.

Table 2: Harmonic Load Bank Operations

Periods	Duration Code	Lighting Connection	Dominant Volt harmonics	Dominant Current harmonics
10:10am-10:15am	D_1	3 Nos. T8 Only	0.55^b	10.00^a
10:15am-10:20am	D_2	9 Nos. CFL	0.55^b	70.00^a
10:20am-10:25am	D_3	5 Nos. T5 Only	0.55^b	70.00^a
10:25am-10:30am	D_4	One set of T5	0.60^b	70.00^a
10:30am-10:35am	D_5	One Set of CFL	0.70^b	70.00^a
10:35am-10:40am	D_6	One Set of T8	0.55^b	10.00^a

NB: Index letters a and b stand for 3^{rd} and 7^{th} harmonic orders respectively

During the experiment, the harmonic load banks were controlled one after the other to monitor the individual harmonic characteristics of the lamp loads and power harmonic analyzed accordingly. The experiment took one hour with the relevant targeted periods D_1 to D_6 being exclusive.

The results of real power calculated and measured are presented in table 3.

Table 3: Analysis of Harmonic Loads Bank

Lamp Name	Name plate Power rating (W) per each lamp	Measured Power (W) per each lamp	Number	Total Power (Calculated) (W)	Total Power (Measured) (W)
Compact Fluorescent Lamp	14	18	9	162	153.3
Electronic Fluorescent Lamps (T5 Model)	20	24.5	5	122.5	118.3
Magnetic Fluorescent Lamps (T8 Model)	20	30	3	90	91
				374.5	362.6

Table 3 presents the expected values of lamp wattage when summed up analytically and measured values. This is provided in column 5 and column 6 data read off from the meter. It was observed that the calculated values of real power are greater than the measured values except for the T_8 lamp model. When correlated with eqns. (1) and (2), the higher order components of the voltage and current would have been ignored and set to zeros. This will thereby cause the gaps of Wattage deviation obviously seen from the results in columns 2 and 3.

The Crest Factor (CF) of the current waveform is shown in Figure 4 for combination of loads specifications in the Table 1. It takes a value between 1.0 and 7.0 for the series of loads considered. The higher value of CF indicates the load peak current value is much higher than the true RMS value due to harmonic distortion characteristics of the AC devices.

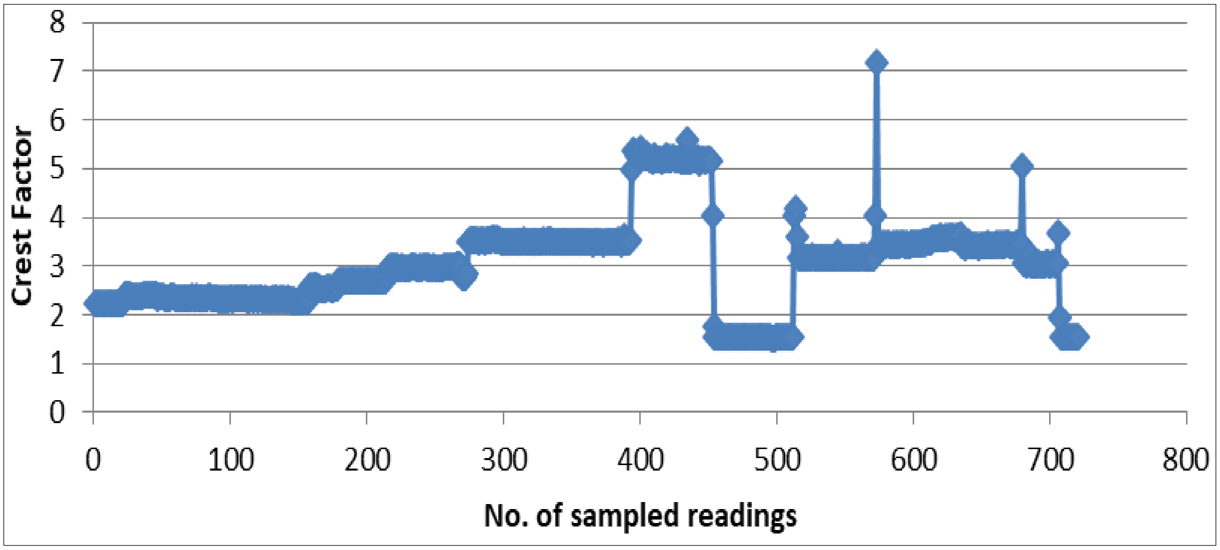

Fig 4: Trend of Measured CF in the experiment

The screen shot of the logged harmonics data for the lighting loads is provided in appendix I.

Conclusion

The characteristics of power harmonics have been developed for the energy efficient lighting lamps commonly used in the distribution reticulation under laboratory scenarios for a value more than 300 Watts lighting loads. The dominant harmonics of 0.70% and 70% respectively for 7th volt harmonics and 3rd current harmonics were obtained to CFL devices. The CFL exhibits the worst case scenario for distortion level. The use of other energy efficient lamps together with the CFL reduces significantly the power harmonics due to diversity in their harmonic characteristics while the current crest factor improves greatly under this condition.

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