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Harmonics Monitoring Survey on LED Lamps

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Abstract - Light Emitting Diode (LED) lamps are being increasingly used in many applications. These LED lamps operate using a driver, which is a switching device. Hence, LED lamps will be a source of harmonics in the power system. These harmonics if not well treated, may cause severe performance and operational problems. In this paper, harmonics (amplitude and phase angles) generated by both LED lamps and conventional fluorescent lamps will be studied practically. Then they will be analyzed and evaluated. Compared to each other harmonics generated by both LED and conventional florescent lamps, self mitigation may occur based on the phase angle of these harmonics. All data will be measured using power analyzer and will be done on a sample of actual lamps.

Keywords — LED lighting; harmonics; power quality; conventional lighting;

I. INTRODUCTION

Recently, the LED technology is being applied in modern light sources which are now widely used in the lighting industry. They replace traditional bulbs, halogens, and fluorescent light sources for indoor lighting [1]. They are also used for outdoor lighting, building decoration, and vehicles applications. The main purpose of using LED lamps is energy saving because of their low energy consumption and overall efficiency augmentation [2].

Energy saving lamps due to their non-linear characteristics, inject harmonic currents into the network [3]. This may be a problem because, for a very high penetration level of these types of lamps, the overall voltage harmonic distortion may increase considerably [4]. LED lamps are modern technology hence; they may replace conventional light lamps for reasons of power quality improving [5]. In [6], a power quality (PQ) study on various number of LED lamps showed that they could damp the overall harmonics injected in the distribution network. Compared to other light sources a better improved THD could be achieved by mixing various light sources. Since LED lamps could mitigate each other harmonics, various types of light sources could also do the same.

In this paper, different types of lamps will be studied and their power quality will be analyzed. In section two, a LED lamps advantages and disadvantages will be illustrated. While, in section three, power quality was defined. Practical PQ results for different types of lamps were presented in section four. Finally, the conclusions and future work.

II. LED LAMPS

LED lamps have the potential to play a major role in developing commercial, residential, and public buildings just as compact fluorescent lamps (CFLs) did three decades ago. That's because LED lamps obviously offer great energy saving potential. For some LED lamps, their efficacies already exceed 100 lumens per watt.

LED lamps are much more complex than incandescent lamps. The main difference between both lamps is that LEDs requires direct current (DC) in order to operate which is supplied through power electronics driver, rather than the resistive incandescent filament which is a different type of load that operates on alternating current (AC). The LEDs' driver must convert AC to DC and decrease the voltage to more adequate level. There is also a phenomenon called "latency" which represents another difference between both LED and incandescent lamps. For the incandescent lamps, light is maintained for some period of time after the feed-in current is being cut. That's because the incandescent filaments do not cool down instantly. On the other hand, LEDs react very quickly to even small variations in current, also phosphor-converted or remote phosphor LEDs tend to have very small latency.

A. Advantages of LED Lighting

- LED lamps can be finely tuned to produce a wide range of color temperatures by mixing different colored LED chips in the same array. Incandescent and halogen lamps typically provide light with a color temperature in the range from 2600k to 3000k (2700k is the most common) while, LEDs generally have color temperature ranging from 2700k up to 6000k or higher.
- LEDs efficacy is being improved quickly.
- Dimmers are being used in the majority of LED bulbs.
- While, incandescent lamps have an average lifetime between 1000 and 2000 hours, most of LED Lamps have an average lifetime of over 35000 hours and a warranty of 5 years.
- LEDs do not tend to fail suddenly (as an incandescent lamp does), but instead their light output slowly decrease.
- Many LED lamps have almost no warm-up delay, while most of them turn on instantly at full brightness. This advantage is in corresponding to particular lamps such as fluorescent high intensity discharge, and high pressure sodium, which in order to reach full brightness consume time from a few seconds to several minutes.
- LED illumination has small amount of infrared and almost no ultraviolet emissions.
- LED lights can be dimmed which offers a flexible control, color, and distribution.
- LED lights can be switched on and off frequently without negatively affecting their lifetime of light emission.
- LED lights are still more expensive than CFL lights, but they are far less expensive than they were year ago.
- LEDs operate silently with no annoying flickering noises.
- LEDs provide a range of various colors for different applications and purposes.

The major and mandatory advantage of LEDs is the huge reduction in energy consumption they offer when replacing traditional lighting.

B. Disadvantages of LED Lighting

- LEDs do not concentrate a “point source” of light, hence they cannot be used in applications that requires highly collimated beam.
- On an initial capital cost basis, LEDs are currently more expensive than conventional lighting technologies.
- LEDs must be supplied with certain current value which requires applying series resistors or current-regulated power supplies.

III. POWER QUALITY ANALYSIS

A power quality (PQ) analysis has been performed by comparing the different luminaries’ performance. According to [7] and [8]:

Current harmonic distortion is a phenomenon arising from the operation of non-linear loads, which is caused by non-sinusoidal waveforms accompanied to sinusoidal wave with frequencies of integral multiples of the source frequency

The total harmonic distortion (THD) is a measurement of the harmonic distortion value and it is defined as the ratio of the sum of all harmonic components’ powers to the fundamental’s power. and it is defined for current and voltage respectively as follow [9]:

$$THD_i = \sqrt{\sum_{h=2}^{h=H} \left(\frac{I_h}{I_1}\right)^2} \qquad (1)$$

$$THD_u = \sqrt{\sum_{h=2}^{h=H} \left(\frac{U_h}{U_1}\right)^2} \qquad (2)$$

Where:

I_h = individual harmonic current
U_h = individual harmonic voltage

I_1 = Fundamental current
U_1 = Fundamental voltage
h = order of harmonics

Power factor (PF) represents the ratio of the average power converted by the device -real power- and the maximum average power that may be converted -apparent power- considering the same rms values of current and voltage. PF could be considered an indicator for the quality of the energy conversion.

A. Harmonics Emission Standard

Harmonic emission of individual lamps is restricted by the standard IEC 61000-3-2 [7]. Limitation are classified into two categories:

- Lamps with an active input ≤ 25 w
- Lamps with an active input > 25 w

Lamps with an active power ≤ 25 w have a higher margin for harmonic current in percentage. It is assumed that a large number of smaller lamps will emit less harmonic currents than a small number of bigger lamps. Table (1) shows the limited harmonic current of lighting equipments according to the mentioned standard (for P > 25 w).

B. *Recommended values for displacement factor*

The recommended values for displacement PF is presented by the standard IEC 62612-2013 [8]. Table (2) summarizes these values.

Table 1. LIMITS OF HARMONIC CURRENT OF LIGHTING EQUIPMENT ACCORDING TO IEC61000-3-2

Harmonic order (h)	Maximum harmonic current permitted (calculated in % compared to fundamental magnitude)
2	2
3	30*(power factor)
5	10
7	7
9	5
11< h≤ 39 (odd only)	3

Table 2. LED LAMP POWER FACTOR FOR LAMPS WITH INTEGRATED CONTROL GEAR

Power	Power Factor (PF)
P ≤ 2 w	No requirement
2 w < P ≤ 5 w	≥ 0.4
5 w < P ≤ 25 w	≥ 0.7
P > 25 w	≥ 0.9

IV. EXPERIMENTAL TESTS ON LED LIGHTS

Luminaries are generally nonlinear loads connected to the low voltage AC distribution network. Some kind of light sources, like fluorescent lamps and LEDs, require a power supply system (ballast or driver) to interface them with the electric network. Generally, the current waveform contains some amount of distortion, depending on the luminaries' technology.

A. Case Study (A)

The experimental tests, carried by the energy analyzer, have been performed on different kinds of indoor luminaries:

- LED bulbs
- LED Tubes
- LED Panels

The results of the power quality (PQ) analysis for the previous three types of lamps are presented in tables (3), (4), (5), and (6) respectively. Tables (3) and (4) shows the results of studying 12 samples of light bulbs.

Table 3. PQ ANALYSIS FOR LED BULBS (1)

Sample No.	1	2	3	4	5	6
Rated Power (w)	12	10	9	9	9	9
Measured Power (w)	11.5	9.1	10	7.9	8.9	9.2
PF	0.567	0.927	0.937	0.954	0.979	0.932
V_{rms} (V)	219.9	219.8	220	220.1	220	220
THD_V (%)	2	2.4	1.1	1.4	2.1	2.1
I_{rms} (A)	0.093	0.045	0.048	0.038	0.041	0.045
THD_I (%)	122.5	22.6	21.9	18.0	15.1	22.7
I_3 %	81.6	17.1	16.4	15.6	6.5	15.4
I_5 %	55.9	11.1	8.8	3.1	10.7	11.6
I_7 %	39	6.4	8.5	4.2	6.1	7.8
I_9 %	34.5	2.9	5.2	3.1	3.7	4.8
I_{11} %	30.5	4.0	3.1	4.0	1.7	1.9

Table 4. PQ ANALYSIS FOR LED BULBS (2)

Sample No.	7	8	9	10	11	12
Rated Power (w)	9	6	6	5	4	3
Measured Power (w)	8.9	6.3	5.9	5.1	4.0	1.6
PF	0.955	0.917	0.663	0.437	0.541	0.109
V_{rms} (V)	220.1	220.9	218.9	220	220.2	220.2
THD_V (%)	2.2	1.3	1.4	1.2	0.7	1.3
I_{rms} (A)	0.042	0.031	0.041	0.053	0.033	0.067
THD_I (%)	20.5	24.5	60.8	63.0	137.7	19.3
I_3 %	18.2	18.3	50.1	44.2	87.3	10.3
I_5 %	5	10.8	25.1	27.6	73.3	7.8
I_7 %	2	9.3	15.2	20.2	54.9	8.5
I_9 %	2.5	3.9	10.7	13.2	38.4	1.8
I_{11} %	2.8	3.2	10.1	3.5	25.1	4.1

Table 5. PQ ANALYSIS FOR LED TUBES

Sample No.	1 (120 cm)	2 (120 cm)	3 (60 cm)	4 (60 cm)
Rated Power (w)	18	18	10	9
Measured Power (w)	18	16.8	9.9	8.8
PF	0.947	0.906	0.927	0.966
V_{rms} (V)	220.1	220	220.2	220.2
THD_V (%)	2.1	1.2	2.3	1.2
I_{rms} (A)	0.086	0.084	0.048	0.041
THD_I (%)	20.2	43.6	22.1	16.1
I_3 %	14.6	19.8	14.0	8.8
I_5 %	9.6	11.3	11.1	7.5
I_7 %	8.2	31.7	10.6	6.4
I_9 %	4.1	10.5	3.6	5.6
I_{11} %	2.6	7.0	2.1	3.4

Table 6. PQ ANALYSIS FOR LED PANELS (60×60)

Sample No.	1	2	3	4
Rated Power (w)	42	42	32	32
Measured Power (w)	43.3	41.3	31.4	31.6
PF	0.953	0.973	0.927	0.929
V_{rms} (V)	220.3	220.9	220.2	220.6
THD_V (%)	1.3	1.2	3.1	1.1
I_{rms} (A)	0.208	0.192	0.154	0.153
THD_I (%)	15.9	11.8	12	10.5
I_3 %	14.5	10.8	8.5	8.1
I_5 %	3.6	3.4	5.8	3.9
I_7 %	1.1	1.4	1.1	1.3
I_9 %	2.2	1.8	3.6	3.5
I_{11} %	2.1	1.1	2.4	1.9

From Tables (3), (4), (5), and (6) the PQ analysis has led to these considerations:

1. The THDV is only related to the harmonic background already existing into the grid. All values are in complying with IEC standard limits (< 5%).

2. Most of PF values are almost close to the unit value, which means that fundamental voltage and current have a small phase shift. Hence, current harmonics do not have a strong impact on the quality of the energy conversion [2].

3. PF in samples 1 & 12 -in Tables (3), (4) - are not accepted according to IEC standard limits. Shown in Figs. (1), (2)

4. In samples 1 & 11 -in Tables (3), (4) - the current waveforms are affected by distortion, while voltage is almost sinusoidal, as indicated by THD indices and waveforms in Figs. (1), (3).

5. Fig. (4), (5) for waveforms of sample 4 & 2 in Table (5) & Fig. (6) for sample 3 in Table (6), they all contain current harmonics.

6. Individual current harmonics I3, I5, I7, I9, I11 are dominated.

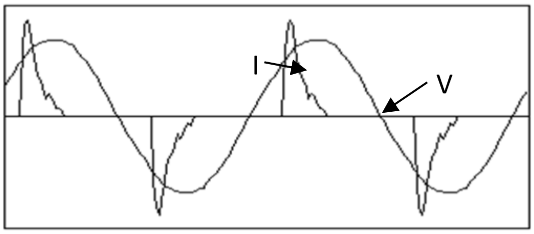

Fig .1. LED bulb 12 w

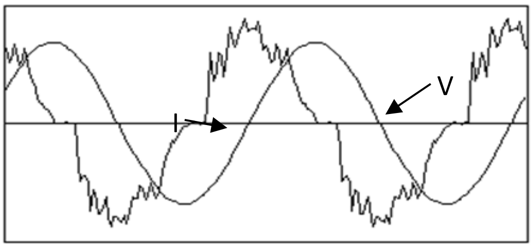

Fig .2. LED candle 3 w

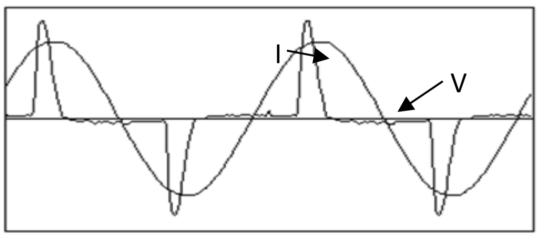

Fig .3. LED candle 4 w

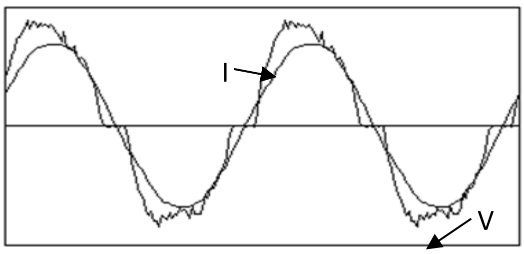

Fig .4. LED tube 9 w

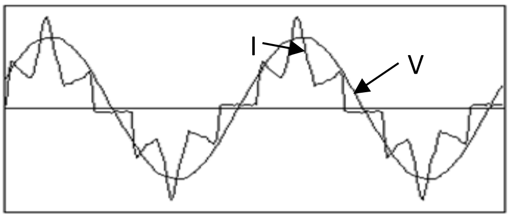

Fig .5. LED tube 18 w

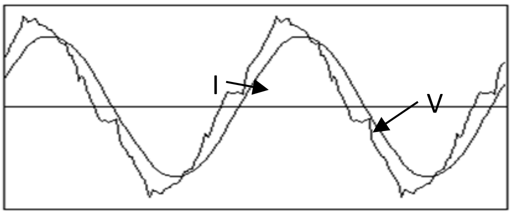

Fig .6. LED panel (60×60) 32 w

B. Case Study(B)

Power quality analyzer model HIOKI 3196 has been used in this step of testing in order to measure both magnitude and angle for each harmonic order. It is anticipated that if the same harmonic order generated by various electric equipments has different phase angle, it may be self mitigated. Hence, various types of lamps were tested in order to prove this hypothesis. The lamps' samples that have been tested were as follow:

- LED 18w Tube 120 cm
- 40w fluorescent lamp with electronic ballast
- 40w fluorescent lamp with magnetic ballast
- LED bulb 9w
- CFL 26w

In Table (7) PQ test results for these 5 samples are shown.

The following figures show the magnitude and angle for each harmonic order tabulated in complex form for all the samples. In Fig. (7) the 3rd harmonic for 4 samples is shown and because CFL 26w lamp has the largest level of harmonics it was excluded from the charts in order to give adequate space for the other samples to be shown clearly. In Fig. (8) the 5th harmonic for 4 samples are shown. For Figs. (9), (10), and (11) there are not homogenous distribution for the five samples although in Fig. (11), the 11th harmonic of both magnetic and electronic ballast will mitigate each other.

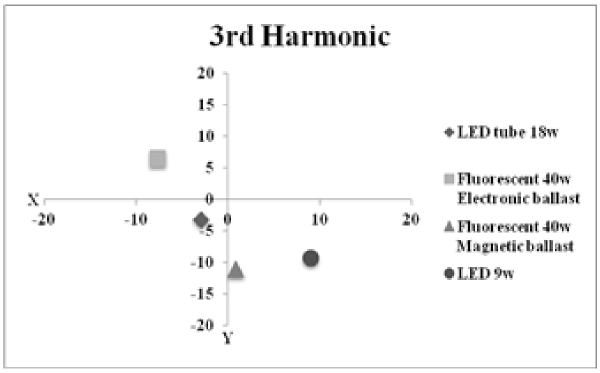

Fig .7. 3rd Harmonic of Current

Table 7. PQ ANALYSIS FOR VARIOUS LAMPS

Sample No.	1	2	3	4	5
Rated Power (w)	18	40	40	9	26
Measured Power (w)	18	36.00	49.5	8.10	11
PF	-0.95	-	-	-0.76	-0.59
V_{rms} (V)	225.230	224.48	225.72	211.28	211.15
THD_V (%)	2.720	2.78	2.02	2.73	2.73
I_{rms} (A)	0.082	0.16	0.22	0.05	0.09
THD_I (%)	13.640	14.66	11.18	16.88	116.08
I_3 %	4.42	9.68	11.03	13.00	73.64
Phase I_3	-132.23	141.76	-85.3	-45.74	-152.58
I_5 %	8.23	5.88	0.94	6.52	42.63
Phase I_5	56.82	66.55	69.71	120.44	-52.41
I_7 %	7.28	6.68	0.7	2.18	37.01
Phase I_7	120.85	125.73	43.37	125.90	-9.84
I_9 %	4.78	4.47	0.33	3.78	40.22
Phase I_9	13.03	-32.96	131.86	52.30	67.83
I_{11} %	1.30	2.88	0.29	2.02	33.05
Phase I_{11}	-95.06	79.39	-52.61	-104.38	166.57

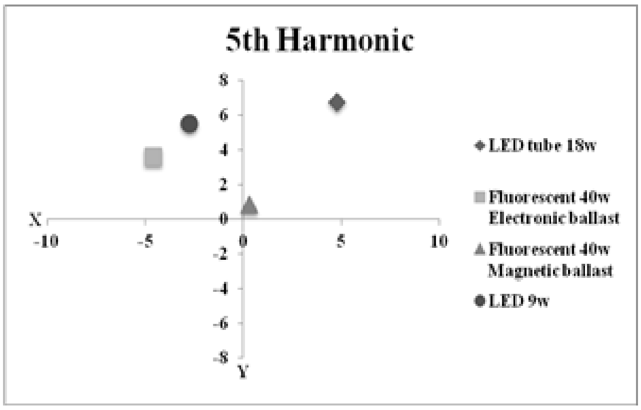

Fig .8. 5th Harmonic of Current

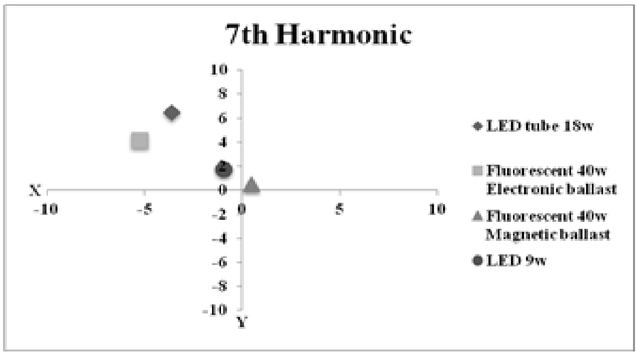

Fig .9. 7th Harmonic of Current

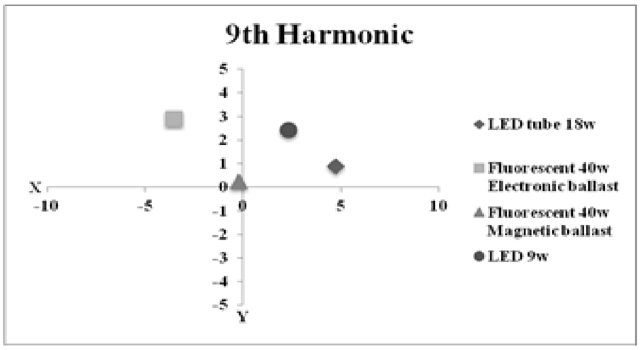

Fig .10. 9th Harmonic of Current

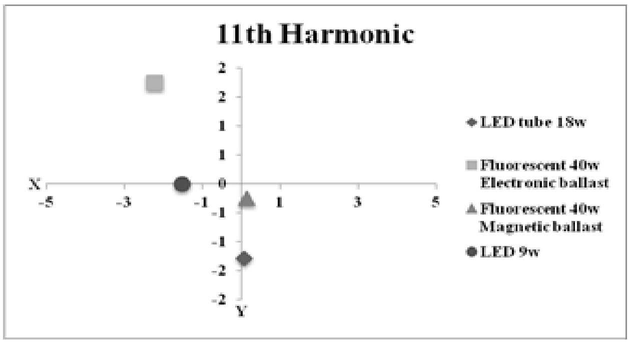

Fig .11. 11th Harmonic of Current

From previous figures, I3 for fluorescent lamp with electronic ballast and for LED 9W are in opposite directions. For the other harmonic orders which could not be mitigated completely, various devices could reduce THD in current waveform generated by each other, if they are not pure opposite to each other.

V. CONCLUSION

Harmonics generated by various loads could be a serious problem if not well treated. In this paper an analysis study for different kinds of lamps such as LED, CFL, and fluorescent showed the power quality performance for each type. If the harmonic order of certain types of lamps could be controlled in order to stand up to the one generated from its alternatives, this will certainly reduce the size of the problem. As a future work, these studies could be repeated for a group of lamps in order to investigate the effectiveness of the results of this research.

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