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A Comparative Analysis of Electrical and Photo Characteristics of LED Lights

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***Abstract*—An increasing shift from conventional incandescent lamps to CFLs followed by LED lights has taken place over the last few years. LED lights promise 80% energy conservation over existing lighting infrastructure and to a whopping 95% energy savings compared to the incandescent light bulbs. This paper presents a study conducted by authors on energy efficient lighting solutions in Pakistan. The study includes measurements of power and photo characteristics of a variety of LED lights obtained from international and local vendors along with an analysis and comparison with IEC standards. The work established a test bed to measure power and photo characteristics of different type of lights for comparative analysis. The results from measurements reveal a need of proactive regulatory authority to put restrictions on power characteristics and quality of available local lights. The work also demonstrates photo characteristics difference in local and international LED lights.**

***Index Terms*—Energy Efficiency, LED Lighting, Power Quality, Harmonics, Luminosity**

I. Introduction

Lighting is one key aspect of electrical energy utilization that touches the life of every industrial, commercial and residential consumer. Lighting comprises of almost 20% of world's electricity consumption [1]. Although a single lighting fixture has low power requirement, the overall lighting load is substantial and thus offers an opportunity of substantial savings through efficient lighting technologies. An increasing shift from conventional incandescent lamps to compact fluorescent lamps (CFLs) has taken place over the last couple of decades and government policies globally have supported this transition. Recent development in light emitting diode (LED) lighting has introduced a power efficient and environment friendly solution superior to CFLs in efficiency measures. LED lights are expected to take over CFLs and are regarded as the future lighting technology. A more comprehensive overview of LED lighting can be found in [1].

LED lights, by nature, are electronic loads and their current intake is inherently non-sinusoidal in nature unless designed properly. This behavior introduces current and voltage distortion in the distribution network which adversely affects the grid. Previous studies revealed that harmonics in load current can result in overheated transformers, overheated neutral lines, blown fuses and tripped circuit breakers [2]. Additionally the peak instantaneous power consumption of some of these lights is significantly higher than their average consumption. The peak instantaneous consumption occurs over a very short time and thus produces a small average power consumption over the entire cycle. As most of the energy metering is done on average real power consumption, the consumers reap the benefit of lower utility bills whereas the utility companies suffer the adverse effects on its wiring and distribution assets. Moreover, if designed from scratch, the rating of electrical wires has to be based on peak power flowing rather than the rated power on these devices when assessing the load. Therefore, introduction of LED lights in the electricity network can present power quality and reliability issues if standards outlined by IEC [3] and other regulatory authorities are not adhered to. Previous research has been done to study the impact of CFLs (also an electronic load) [4] & [5] and dimmable LED lights [6].

Developing countries like Pakistan present an example of such a situation where the absence of any proactive regulatory authority has resulted in the contamination of local market with low quality products. These low quality LED lighting products in the guise of efficiency improvement, harm the distribution network in many ways. These lights generate significant higher-order harmonics in the current and voltage waveforms which result in total current and voltage waveforms being far from sinusoidal.

Besides power characteristics, lights are mainly characterized by their photo parameters namely luminosity, color temperature, light spectrum, flickering, color rendering index etc. These parameters are fundamental to the true working of any LED lighting solution. Low quality products have issues like sub-standard light spread and low maintained lux (lumens/m^2).

Work has been done on LED lighting solution and their characteristics. The power quality concerns surrounding LED lighting have been explored in some studies. For example, Ronnberg et. al. has given a comparison of various factors determining power quality of incandescent, fluorescent and LED lights [7]. Bollen et. al. [8] have given a field measurement by replacing incandescent lights with LEDs and CFLs. However, most of the studies on LED lighting generalize their conclusions on measurements done for a few LED lights from a specific vendor. Moreover most of the studies don't

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consider the photo characteristics of LED lights. A need for a more comprehensive study exists which includes the power characteristics of a variety of lights and also analyses the photo characteristics of LED lights.

This paper presents a study of electrical and photo characteristics of LED lights available in Pakistan. The study includes measurements of power and photo characteristics of a variety of LED lights obtained from international and local vendors along with an analysis and comparison with IEC standards. The study investigates the fulfillment of standard requirements by these lights and presents possible adverse effects which can result if regulatory measures are not followed. The paper also presents and discusses the photo and spectral characteristics of LED lights. The paper is organized as follows: The details of the test bed designed for the measurement of a range of characteristics in the laboratory are presented in Section II. The results derived from power measurements of lights are presented, analyzed and discussed in great length in Section III. Section III also presents comparisons and analysis of lighting samples with respect to photo parameters such as LUX, luminous spread and light spectrum. Section IV concludes the paper by commenting on the power quality and performance of locally available LED lights in Pakistan.

II. Laboratory Setup

In this paper, two types of measurement setups were designed: one for power characteristics measurement and the other one for photo and spectral characteristics. Power characteristics such as steady state value of real power, reactive power, apparent power, power factor and fundamental power factor were measured using a power meter (EPR-04). Instantaneous waveforms of current and voltage along with their Fourier components, signifying harmonic frequencies and their magnitudes, were captured using a standard power analyzer (PF 9810) as shown in Figure 1. Spectral and lux readings of lights were captured using spectrometer (Stellar Net Blue-Wave-VIS) and lux meter (TES 1334) respectively. The power analyzer and spectrometer readings were exported to a PC through serial port communication (RS232).

Luminous intensity (LUX) readings were taken in a controlled environment with minimal background noise. Figure 2 shows the lux measurement points. Lighting source is placed at the origin and readings are taken at the following points: (0, 7, 0), (6.41, 7, 4.83) and (11, 7, 0). The last two points give an idea of the spread of light.

A wide variety of LED lights (>55) from local and international brands were acquired from the market. These light samples were selected from the market based on relative depth of market penetration in the city of Lahore, cost and brand value. The acquired lights from different vendors consisted of different samples of indoor and outdoor lights i.e. spot lights, bulbs, high bay lights, pole lights, street lights and ceiling panels.

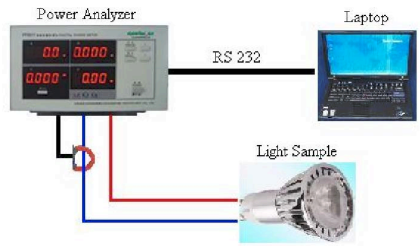

Fig. 1. Experiment Setup for Power Characteristic Measurement

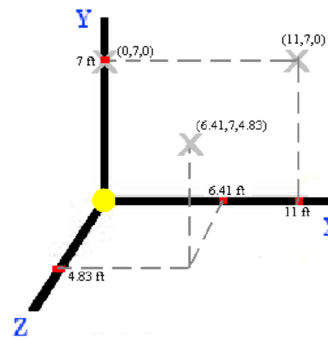

Fig. 2. Positions for Photo Characteristics Measurements. Yellow Spot marks the position of Light Sample while each Cross (X) marks the position at which LUX readings were measured. Light Sample was in the direction of positive Y-axis (x=0, z=0) for all readings.

TABLE I
Power Characteristics of Lights with Consumption below 25 W as measured by Power Analyzer & Power Meter

Product	Rating (W)	Real Power (W)	Apparent Power (VA)	Reactive Power (VAr)	Fundamental Power Factor	Power Factor
A	7	9	17.3	0.8	1	0.505
B	10	13.6	25.6	3.4	0.97	0.518
C	7	8	17.5	1	1	0.458
D	9	12.5	22.6	1.4	1	0.544
E	7	4.3	8.6	0.5	1	0.491
F	7	7.4	14.3	1	1	0.502
G	3	4.1	8.8	0.8	1	0.489
H	3	5.2	9.9	0.8	1	0.525
I	7	6.4	7.2	2.2	0.95	0.871
J	3	2.3	5.1	0.8	0.95	0.518

III. Comparative Analysis of Characteristics of LED Lights

A. Power Characteristics

Power characteristics as mentioned in Section II were measured for a wide variety of lights. The harmonic current emission guidelines for the standard EN 61000-3-2 as outlined by European Power Supply Manufacturers Association [3] defines separate set of rules for lighting equipment having

TABLE II
POWER CHARACTERISTICS OF LIGHTS WITH POWER CONSUMPTION ABOVE 25 W AS MEASURED BY POWER ANALYZER & POWER METER

Product	Rating (W)	Real Power (W)	Apparent Power (VA)	Reactive Power (VAr)	Fundamental Power Factor	Power Factor
A	25	28.6	29.3	6.1	0.97	0.95
B	30	36.4	38	9.3	0.97	0.95
C	120	136	137	20.2	0.99	0.986
D	80	93.2	95.6	20.2	0.97	0.972
E	40	42.4	43.5	8	0.98	0.964
F	173	160	166	36.9	0.97	0.964
G	120	126	130	31.1	0.97	0.948
H	40	36	37.7	11.2	0.95	0.942
I	50	50	51.5	11.2	0.97	0.955
J	95	94.2	94.7	11.9	0.99	0.985

consumption below 25 W and above 25 W. LED lights with power consumption below 25 W mostly include indoor lights like spot light, ceiling light, bulb, etc. while lights like street lights, high-bay lights, indoor panels usually have power consumption above 25 W.

LED lights are electronic loads with inherently non-sinusoidal current behavior. The apparent power utilized by LED lights is three dimensional i.e. active power, reactive power and distortion power. Table I and II show the real, reactive, apparent and rated power for lights with consumption below 25 W and greater than or equal to 25 W respectively. For lights with consumption below 25 W, a significant difference between real and apparent power can be seen despite a near unity fundamental power factor. This difference is accounted for by the presence of extraordinary harmonic content in current waveform which is also verified by the low value of power factor. For lights with power consumption above 25 W, difference between real and apparent power is relatively low and power factor is also high so the harmonic presence in these lights is expected to be moderate. Power factor, which is the ratio of total active power in all frequency components to the total apparent power, gives the ratio of the actual power to the maximum power that can be transmitted while keeping the same line losses and the load voltage constant as described in [9].

A detailed analysis of harmonic content is done by analyzing the individual magnitude of current harmonics. Total harmonic distortion (THD), which is generally used as an index to quantify current distortion, is given by

$$\% \text{ T.H.D.}_I = 100 * \sqrt{\sum_{h \neq 1} (\frac{I_h}{I_1})^2}$$

Where I_h corresponds to magnitude of h^{th} harmonic current. I_1 is the magnitude of fundamental component (50 Hz) of current.

EN 61000-3-2 imposes direct limits on individual harmonic components. Table III shows the magnitude of 3rd and 5th harmonic of LED lights with power consumption below 25W.

TABLE III
HARMONICS IN % FOR LIGHTS WITH POWER CONSUMPTION BELOW 25 W (% W.R.T FUNDAMENTAL COMPONENT (50 HZ) OF CURRENT)

Product No.	3rd Harmonic (%)	5th Harmonic (%)	THD (%)
Standard Limits	86	61	-
A	92.4	83.5	169.4
B	91.1	77.8	159.6
C	92.9	85.7	190.3
D	90.6	77.5	151.7
E	90.2	80.0	171.6
F	92.3	82.4	169.5
G	92.9	85.7	171.9
H	86.7	71.1	154.6
I	19.0	17.1	38.6
J	80.1	59.2	172.3

It also includes the limits imposed by standard EN 61000-3-2 on the magnitude of 3rd and 5th harmonic of such LED lights. Local LED lights, A-H, violate the constraints imposed by EN 61000-3-2, while one local light, J, satisfy the limits. Sample I is an international product which shows significantly lower harmonic magnitudes and correspondingly low THD. As explained earlier high harmonic content in current waveform is detrimental to the distribution infrastructure. This is especially significant in countries like Pakistan where energy saving measures are conceived and designed with only rated power consideration like the free distribution of CFLs without a thorough investigation on the relief provided to the grid.

In the context of developing countries like Pakistan, it also has a more subtle impact on sizing of backup energy systems. Electrical power is delivered by smaller captive generating units, renewable sources or energy storage devices like UPS for a 50% time in urban areas and >80% of time in rural areas. Current and voltage peak in LED lights occur at almost the same instance in time thus requiring almost an order of magnitude higher instantaneous power compared to the average rated power. If unregulated, this ever increasing percentage of critical load which is very high in harmonics, will require oversizing of these backup power sources if the only measure of power consumption considered in design is the active power averaged over each cycle. If these devices are designed more effectively, backup sources can be de-sized and this can be a significant advantage for energy depleted consumers.

Figure 3 & 4 show the current and voltage waveform of an international and local LED light with both lights rated at 4 W. A clear difference in current waveform can be seen. Although both lights have non-sinusoidal current waveform, the international light has a 7x reduction in current peak. This indicates a significant presence of harmonics in local light which is verified by the low power factor i.e. 0.489.

Table IV shows the magnitudes of individual current harmonics for lights with consumption above 25 W. EN 61000-3-2 limits are also shown in the table IV. For this category

TABLE IV

HARMONICS IN % FOR LIGHTS WITH POWER CONSUMPTION ABOVE 25 W (% W.R.T FUNDAMENTAL COMPONENT (50 HZ) OF CURRENT)

Product	1st	2nd	3rd	5th	7th	9th	$11 \leq n \leq 39$	THD (%)
Standard	-	2	30*p.f	10	7	5	< 3	-
A	100	0.6	13.2	6.6	2.1	1.7	< 3	15.3
B	100	0.2	21.5	4.3	3.7	2.1	< 3	22.4
C	100	0.0	8.6	1.7	2.5	1.7	< 3	9.5
D	100	0.2	21.5	4.3	3.7	2.1	< 3	12.3
E	100	0.0	8.6	1.7	2.5	1.7	< 3	18.0
F	100	0.1	7.3	1.0	3.6	3.3	< 3	9.6
G	100	0.2	8.6	2.1	5.7	2.8	< 3	11.3
H	100	0.0	8.9	9.7	1.4	4.1	< 3	14.4
I	100	0.3	12.0	2.0	4.1	3.1	< 3	13.7
J	100	0.1	6.1	0.4	3.4	3.6	< 3	8.2

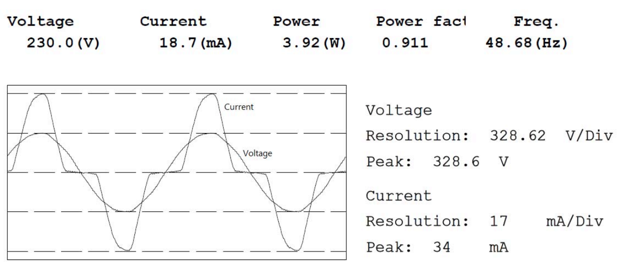

Fig. 3. Current & Voltage Waveform of an International LED Light as measured by Power Analyzer

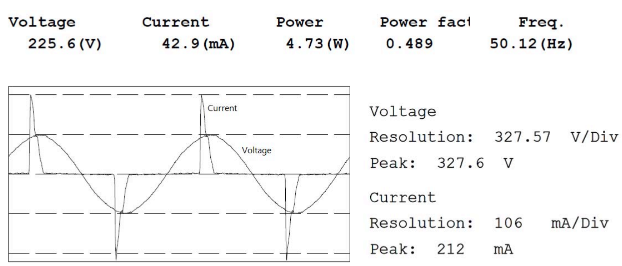

Fig. 4. Current & Voltage Waveform of a Local LED Light as measured by Power Analyzer

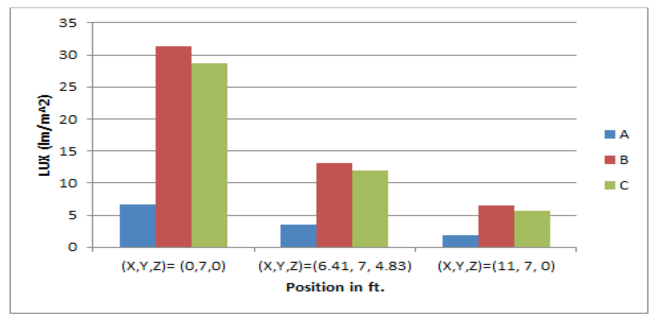

Fig. 5. LUX Readings of LED Bulb Lights Rated at 7 Watt each

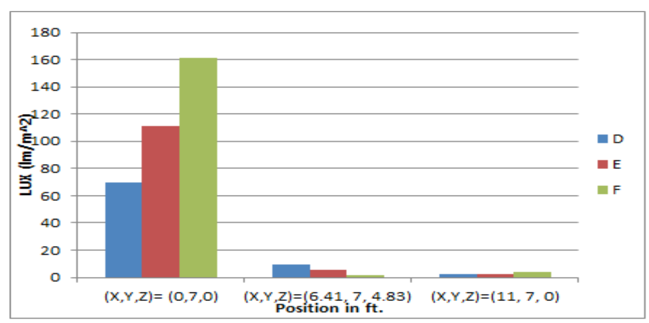

Fig. 6. LUX Readings of Spot Lights Rated at 7 Watt

of lights the limits are on a larger number of frequency components and also strict in nature. All lights have harmonic content within the limit. The THD is also observed to be less than 20% for most of the lights.

A detailed analysis of power characteristics of LED lights along with a more effective way of characterizing the performance of electronic loads will be presented in a subsequent paper by the authors.

B. Photo Characteristics

The study also examined and explored the photo characteristics of lights from local and international vendors with respect to two main parameters: luminous intensity (LUX) and the spread of light. For these measurements, lights with similar wattage and application were compared. Generally the local lights had good luminous intensity at vertical heights and in this regard they were comparable to international lights. The spread for some of the local lights was below par, with some lights showing a sharp decrease in luminous intensity with change in beam angle.

A few comparisons for photo characteristics of lights are explained here. Comparison of three light samples from different vendors, each rated at 7 Watt and designed for general indoor illumination is given in Figure 5. A continuous decrease in luminosity is observed in all three lights. A similar comparison for 7-Watt spot lights shown in Figure 6 reveals a sharp decrease in luminosity. This decrease is expected as spot lights are designed for spot illumination.

Figure 7 shows an interesting comparison between two local LED street lights, sample G & I, with an international brand street light, sample H. The international brand street light

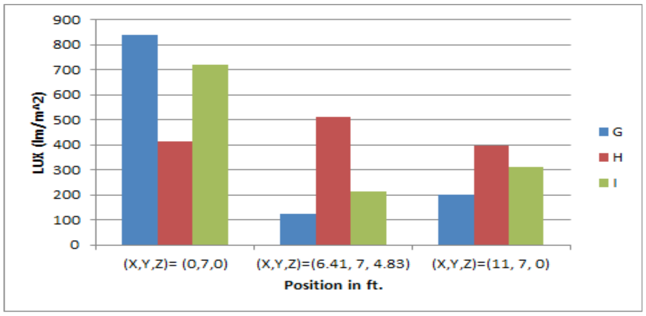

Fig. 7. LUX Readings of LED Street Lights Rated at 95, 96 & 100 Watt respectively

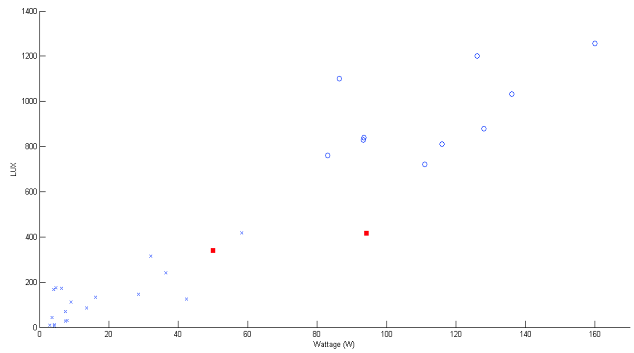

Fig. 8. LUX Readings of LED Lights plotted against Wattage(W) for Measurement Position (0, 7, 0)

shows a very smooth and maintained illuminance at all three points. However the local lights gradually show a notable decrease in lux as the measurement distance is increased from the light. Measured lux readings are high and should be used for comparative analysis only as these readings correspond to indoor measurements in the lab test-bed. Absolute luminosity readings are taken by placing the fixtures on street light poles.

Figure 8, 9 & 10 show the lux readings for a number of lights plotted against their rated wattage for the three measurement positions described in laboratory setup. International and local lights below 60 Watt show similar luminous behavior. However a difference in performance between international and local vendors is visible for lights above 60 W. For example the red dot around 94 Watt in Figures 8, 9 & 10 corresponds to an international light which shows a maintained luminosity at all three measurement positions while all local lights show a general decrease in luminosity. This emphasizes the performance deficiency in terms of luminaire design for local outdoor LED lights.

C. Spectral Characteristics

Spectral analysis was done for a variety of lights. These tests were conducted to analyze the spectral content in visible, UV and IR regions. These tests were also conducted to measure and characterize flicker in these lights. More than 80% of tested lights had stable light output with negligible flicker. Few

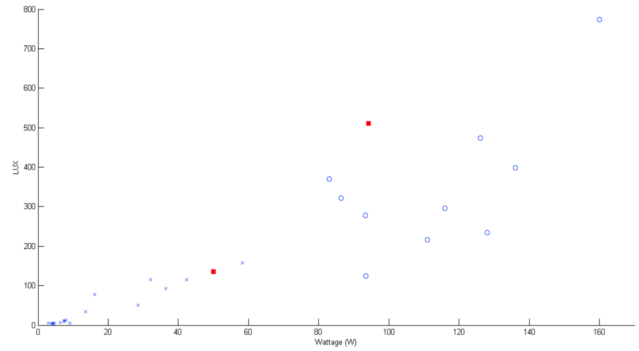

Fig. 9. LUX Readings of LED Lights plotted against Wattage(W) for Measurement Position (6.41, 7, 4.83)

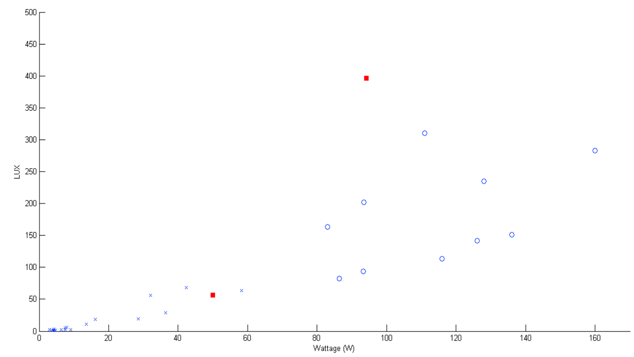

Fig. 10. LUX Readings of LED Lights plotted against Wattage(W) for Measurement Position (11, 7, 0)

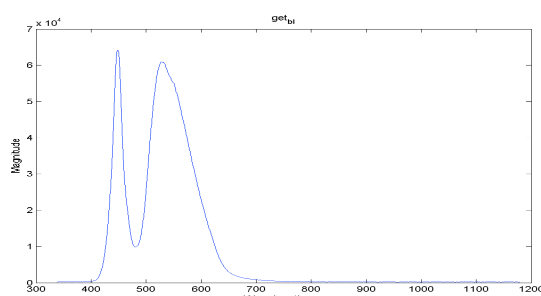

Fig. 11. Spectrometer Results for a LED Bulb

of the generic brands available in the local market, however, had some flicker and can be detrimental if people are sensitive to it. The spectral intensity results showed the different wavelengths emitted by LED lights. The distribution of energy in different wavelengths determine the color temperature of lights. For all the lights tested the spectrum was found to be good with minimal intensity in the infrared and ultra violet region. This signifies low losses for LED lights as compared to incandescent bulbs which have significant part of emitted wavelength in the infrared region. Spectral results for some of the local lights are showed in Figure11, 12 & 13.

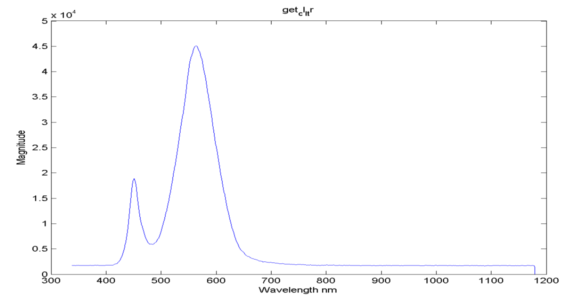

Fig. 12. Spectrometer Results for a LED Ceiling Light

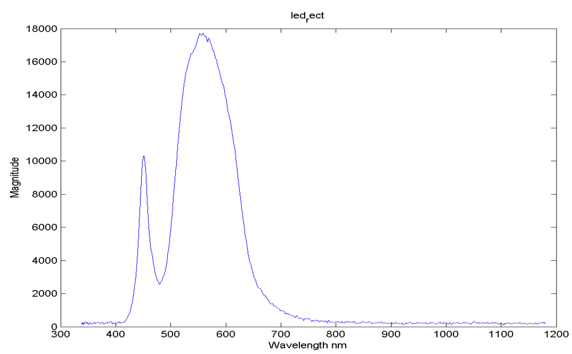

Fig. 13. Spectrometer Results for a LED Indoor Lighting Panel

IV. Conclusion

The paper presented experimental results on electrical, photo and spectral characteristics of a wide range of LED lights along with their comparisons in terms of power quality parameters, luminous intensity, spectral analysis. The results reveal power quality issues as significant current harmonics were observed in local LED samples with rated power below 25 W. The limits defined by standard EN 61000-3-2 were not strictly followed. In sharp contrast to international vendors, these lights had intensely non sinusoidal current waveforms. This can cause detrimental effects on distribution infrastructure if large number of local LED lights are employed in the network. Moreover high current peaks in local LED lights were observed and unnecessary over-sizing of backup power storage is required if such lights are used.

The study also revealed that luminous intensity of LED lights was generally promising. However, the international light samples had favorable spread of light whereas the local lights possessed concentrated luminous intensity. This gap between the photo characteristics of lights was observed significantly in lights rated above 80 W. The spectral analysis concluded that sample pool comprised of lights with wide spectrum of color temperatures. Most of the samples had peaks in visible region of the spectrum with minimal emission in infrared and ultra violet region. It is recommended that the gap between international and local lights should be bridged and pro-active regulation be enforced to ensure that local market is not contaminated with products which in guise of improvement cause harm to the electrical network.

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