An Overview of Colour LED & CFL Lighting Interference on the Low Voltage PLC Network

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***Abstract*—Light sources are being competitive in the current market. Several types of these products have been widely used in the last two decades. They play a major role on the low voltage network as they produce and inject undesired noise onto the transmission lines of the PLC channel. This noise can be of a serious and negative effect when using the power line communications system to control the automatic switching of lamps in residential areas and public places. The main colour low-energy indoor light sources that exist in the market, such as, LEDs and CFLs have been tested for the noise generation on the PLC channel and the results are analyzed and shown in this study. A mathematical analysis of LED bridge rectifier is introduced in this study.**

Keywords*— CFL; EMC; EN 50065-1; Harmonics; Interference; LED; Low Voltage Network; Noise; PLC.

I. Introduction

For the past two decades several types of light sources have been dramatically developed to suit the market needs. Different types of modern lamps have been introduced to the market in addition to the existing "old fashion" lamps.

There are several types of low energy lamps used as indoor lighting sources. Most of them are long life lamps and are seen as efficient and low cost lamps.

Almost all the indoor light sources, such as LEDs and CFLs inject undesired noise into the low voltage network [1], [2]. This noise can have a detrimental effect on the power line network when used as a communication channel. This can also have a strong and negative effect when using the smart-grid communications channel to control the automatic switching of lamps in small and large buildings and factories, as well as, homes and shopping centres. This can be one of the power-quality concerns in residential and industrial areas as the LEDs and CFLs are considered as serious interference sources on the low voltage PLC network [3].

The interference caused by the fluorescent tubes is likely to be similar to the one caused by the CFL lamps [2]. Therefore, this paper will investigate the behavior of the colour LEDs and CFLs when connected to the wiring system of the low voltage PLC network.

The LEDs and CFLs differ in design, shapes, colours, output wattage and manufacturing quality. They can be warm, cool, bright white or daylight, with or without colours and day/night motion switching sensors.

LEDs can achieve efficacy of over 40 lumens per watt (lm/W) and CFLs range between 50 – 70 lumens per watt. Both LEDs and CFLs can have a night vision sensor to automatically start after sunset.

Light Emitting Diodes (LEDs)

LED lamps can be divided into two classes (active and passive). They can have different effects in all sections of the emission spectrum which completely depends on the noise generating electronics that are used as LED drivers. Fig. 1 shows the simplest structure of LED drivers, the passive RC divider network and rectifier type where high frequency switching is not performed.

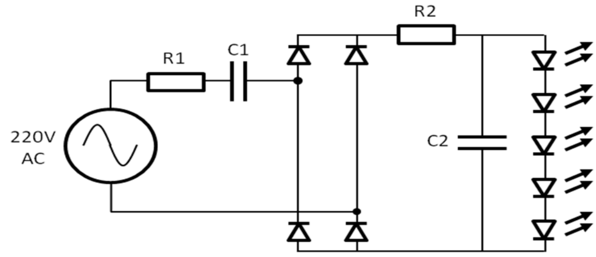

Fig. 1. RC divider and rectifier type LED lamp driver.

The active rectifier with power converter is the second driver type of LEDs. This is shown in Fig. 2. In this type of circuits, the rectifier actions will cause the LED lamp to produce harmonics and interference in the current drawn from the supply.

Colour LED lamps produce conducted and radiated signals that become a cause of interference problems. The noise can be categorized as intermittent or non-intermittent depending on the switching power supply circuit installed in the LED.

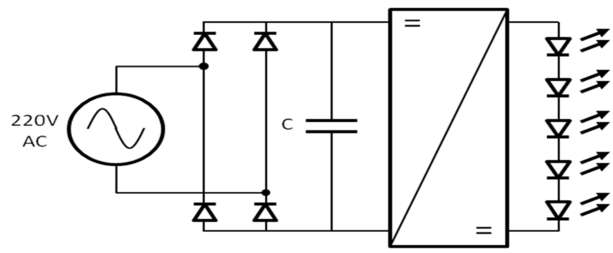

Fig. 2. Rectifier and converter type LED lamp driver.

Compact Fluorescent Lamps (CFL's)

Quality of Colour CFLs depends on brands and manufacturers of the lighting sources, therefore, harmonics in the band 3 kHz – 150 kHz are more likely to be produced by the low cost and quality brands and due to low cost filtering and the operational rectifiers used in the CFLs [4]. The main reason for interference caused by the CFLs in the 3 kHz – 150 kHz CENELEC bands is usually the power-electronics converter that makes part of all CFLs.

Generally, drivers of the CFLs are commonly structured. They include a filtered circuit that has an active rectifier with a power converter. This structure is illustrated in Fig. 3.

The 220V AC, 50Hz input is filtered and rectified (by C) in Fig. 3. The DC high voltage is converted and current-limited where the switching power-electronic converter with the active power frequency plays a major role.

In this paper, the high frequency (150 kHz – 30 MHz) interference that is produced by the converter where the high frequency is filtered by the AC supply and rectifier, the amount of filtered interference and noise depends on manufacturers' design of the CFLs.

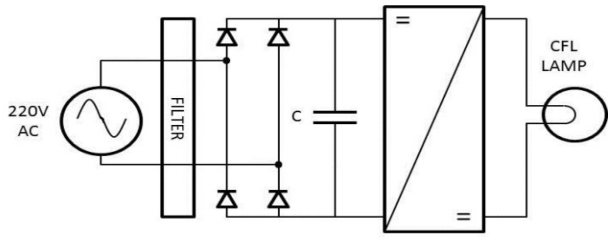

Fig. 3. Rectifier and converter type CFL driver.

II. Experimental Set-up

Fig. 4 shows the measurement setup used in this experiment. A Line Impedance Stabilization Network (LISN) and an isolation transformer are used in this measurement setup. The LISN causes an earth leakage current to flow; floating the LISN will rectify this fault condition, therefore, the isolation transformer is used. The LISN is used to filter the interference from the AC supply, as well as, to provide a "standardised" interference load to the conducted noise formulated by the LED/CFL lighting sources.

This paper makes a conclusion for measurements of two frequency regions of the emission spectrum:

- 3 kHz – 150 kHz CENELEC bands as stated in EN 50065-1 [5]. The conducted measurements in these bands result in current harmonics that can be seen "harmful" to the PLC network. The Common Mode (CM) currents are considered negligible in these measurements and only the Differential Mode (DM) measurements are taken in consideration – this is assumed in EN 50065-1. The results, then, are processed and a PC is used as shown in Fig. 4.

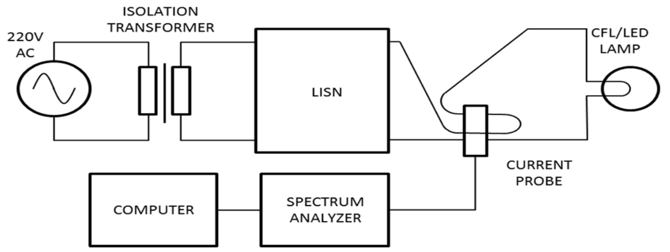

Fig. 4. Set-up for measurements in the 3 kHz – 150 kHz range and 150 kHz – 30 MHz range.

- 150 kHz – 30 MHz: The PLC *Broadband* spectrum spans the range used to measure and conclude the emissions as indicated in CISPR-16 [6].

III. Harmonics - CENELEC Bands

One of the challenges to the power line communications channel is the harmonics produced by LED and CFL lamps. These colour lamps do, unfortunately, inject undesired noise into the infrastructure of the PLC channel. This can negatively affect the communication over the PLC channel. When measurements are conducted, a current probe is used in order to determine the current harmonics that LED & CFL lamps cause to the PLC channel. The current harmonics (magnitude) will, then, be represented in frequency domain waveforms. This is done by performing a Discrete Fourier Transform (DFT) and multiplying the current harmonics with the LISN impedance values that are used for measurements (Figs. 5 & 6) to get the voltage values. The LISN characteristics are specified in EN 50065-1 [5].

The noise harmonics shown in Figs. 5 & 6 are well below the maximum allowable CENELEC band limits, which can, therefore, clearly be seen that in the band from 3kHz – 150kHz colour LED and CFL lamps are unlikely to interfere with the communications over the power line channel.

IV. Broadband Spectrum

The broadband spectrum measurements where performed in a similar procedure to those of the CENELEC bands. Colour LED and CFL lamps do inject unwanted noise in the (150 kHz – 30 MHz) broadband PLC spectrum. This is shown in Figs. 7 & 8. However, harmonics from the colour LED lamps in Fig. 7 can be seen as "friendly" to the power line channel in comparison with the results obtained from the measurements performed for the colour CFL lamps, where the PLC channel gets more infected as shown in Fig. 8. This is the worst scenario for PLC. The obtained frequency domain harmonics in Fig.8 do exceed the highest allowed Electromagnetic disturbance levels (EMC).

The dedicated "maximum" signal-transmission levels in the 3 kHz – 150 kHz CENELEC bands do not exist in the 150 kHz – 30 MHz band and "maximum" signal-transmission is to be considered at the EMC limit levels for the broadband spectrum.

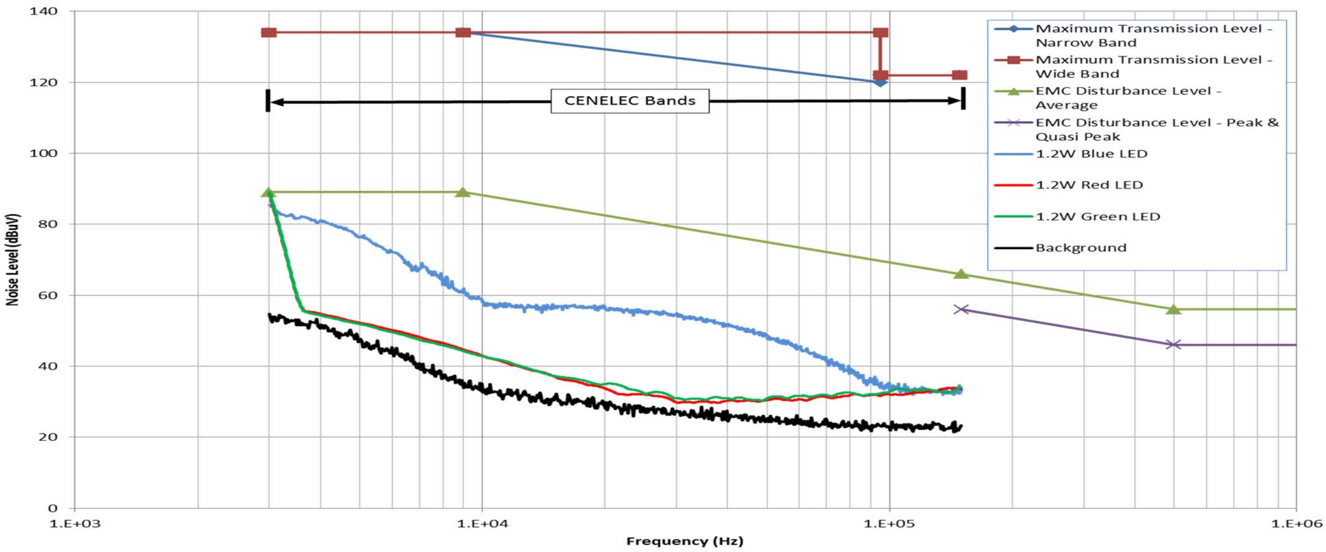

Fig. 5. LED frequency domain waveforms and harmonics for the 3kHz – 150kHz range.

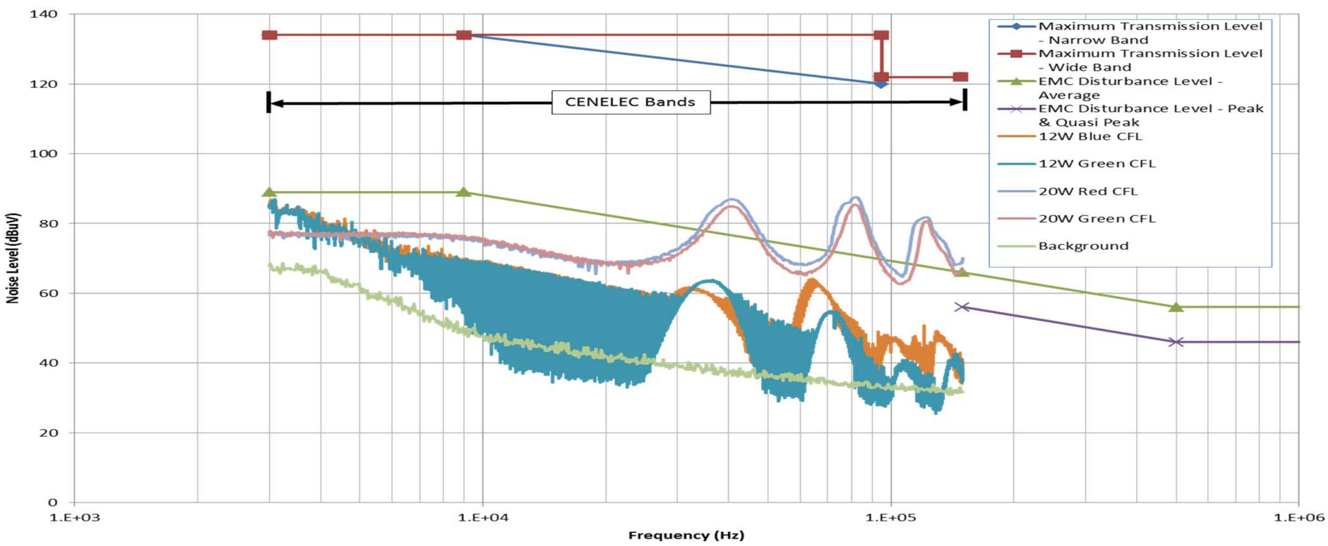

Fig. 6. CFL frequency domain waveforms and harmonics for the 3kHz – 150kHz range.

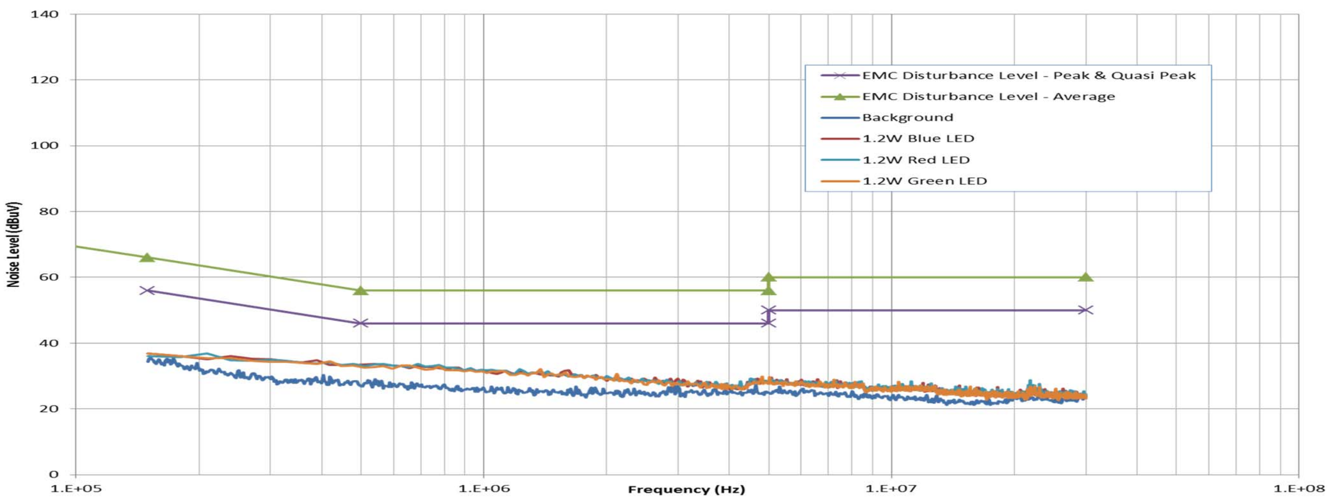

Fig. 7. LED frequency domain waveforms and harmonics: 150kHz – 30MHz range.

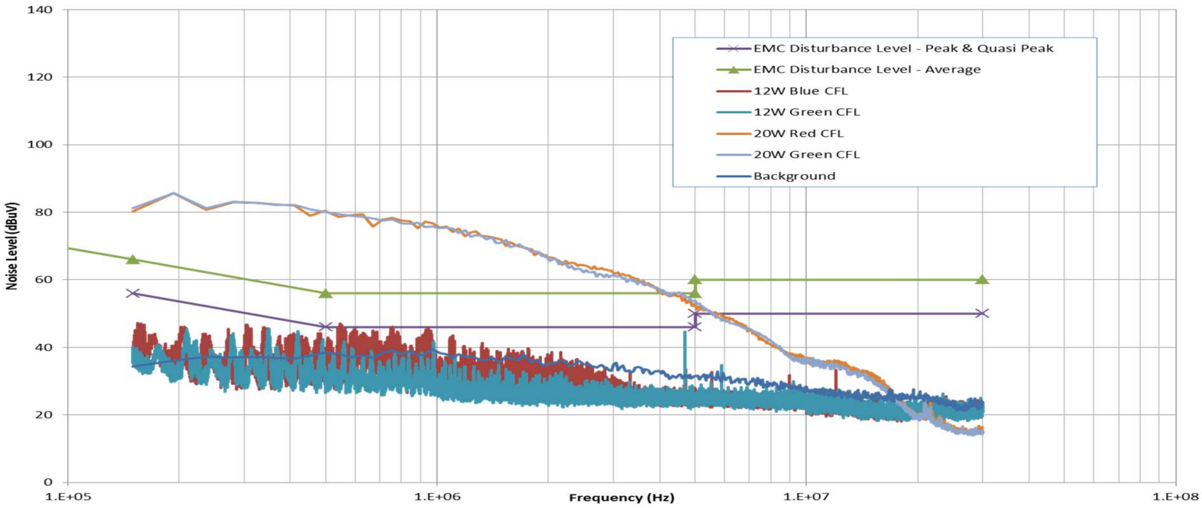

Fig. 8. CFL frequency domain waveforms and harmonics: 150kHz – 30MHz range.

V. Bridge Rectifier

The circuit in Fig. 9 is connected to the bridge rectifier (AC-DC converter), and R_{10} has the value R_2 and C_7 has the value C in the following. The detailed circuit on the other side of the AC-DC converter can be found in [7 & 8].

$$R_t = R_{th} + R_1 \;,\quad L_t = L_{th} + L_1$$

KVL: $V_{th}(\theta) = R_t i_s + \omega L_t \frac{di_s}{R_\theta} + V_0(\theta)$

KCL: $i_s(\theta) = \omega c \frac{dV_c}{d_\theta} + i_1 = \omega c \left(\frac{\frac{1}{j\omega c}}{\frac{1}{j\omega c}+R_2}\right)\frac{dV_0(\theta)}{d\theta} + i_1$

Define: $Y = \begin{bmatrix} i_s(\theta) \\ V_0(\theta) \end{bmatrix}$, $V = \begin{bmatrix} V_{th}(\theta) \\ i_1 \end{bmatrix}$

$$Y' = \alpha Y + \beta V$$

$$\alpha = \begin{bmatrix} -\alpha_1 & -\alpha_2 \\ \alpha_3 + j\alpha_4 & 0 \end{bmatrix} \qquad \beta = \begin{bmatrix} \alpha_2 & 0 \\ 0 & -\alpha_3 - j\alpha_4 \end{bmatrix}$$

where

$$\alpha_1 = \frac{R_t}{wL_t} \;,\; \alpha_2 = \frac{1}{wL_t},\; \alpha_3 = \frac{1}{wc},\; \alpha_4 = R_2$$

By performing Laplace Transform:

$$Y(S) = (S\,I - \alpha)^{-1}$$

$$Y(\theta_1) = (S\,I - \alpha)^{-1}\;\beta V(s)$$

Where initial value:

$$Y(\theta_1) = (S\,I - \alpha)^{-1}\;\beta V_{(s)} \begin{bmatrix} 0 \\ \sqrt{2}\,E \sin\theta_1 \end{bmatrix}$$

Characteristic roots S_1 and S_2 are complex since

$$S_{1,2} = \frac{-\alpha + \sqrt{\alpha_1^2 - 4\alpha_2(\alpha_3 + j\alpha_4)}}{2}$$ and $j\alpha_4$ is complex.

Therefore: $S_1 = \frac{\alpha_1}{2} + \frac{A}{2} + j\frac{B}{2}$; $S_2 = \frac{\alpha_1}{2} - \frac{A}{2} - j\frac{B}{2}$

Where

$$B = \frac{\sqrt{-\alpha_1^2 + 4\alpha_2\,\alpha_3 + \sqrt{\alpha_1^4 + 16\alpha_2^2\alpha_3^2 - 8\alpha_1^2\alpha_2\alpha_3 + 16\alpha_2^2\alpha_4^2}}}{2}$$

$$A = -2\alpha_2\,\alpha_4\,B^{-1}$$

Therefore, by inversing the Laplace Transform, a solution of $i_s(\theta)$ and $V_0(\theta)$ can be obtained in the similar way as described in the literature [8 & 9].

The Fourier transforms of the time domain waveforms are represented in Fig. 10. A simulation study was performed and analysis of the harmonics of the current is shown and a conclusion can be given about the harmonics where the current increases as the value of the capacitor increases. This is shown in Fig. 10.

VI. Conclusion

Colour LED and CFL light sources were tested against noise generation on the PLC network. Both light sources produce conducted noise when connected to the existing infrastructure of the PLC channel which can be of a serious risk to the PLC channel. A mathematical introduction to the bridge

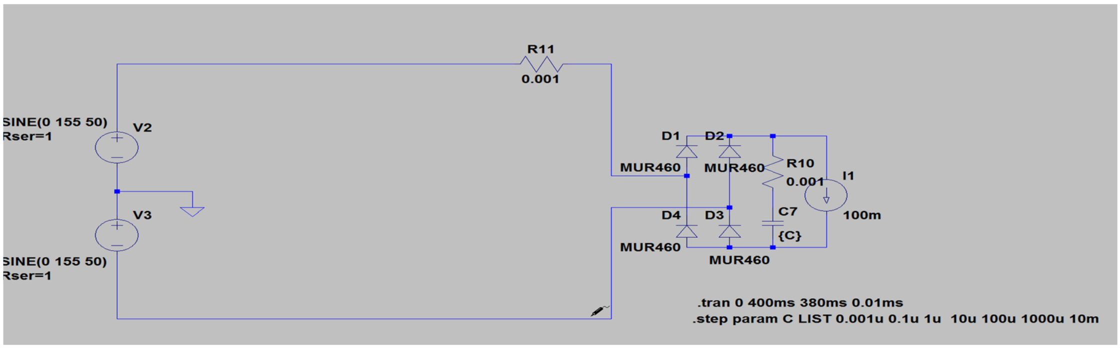

Fig. 9. LED/CFL electronic circuit with bridge rectifier.

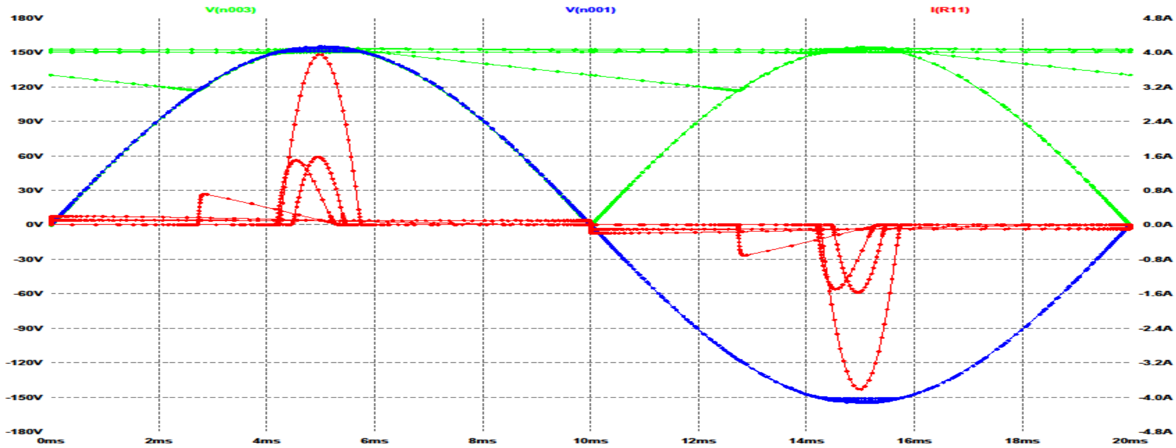

Fig. 10. Current harmonics of different capacitors in the bridge rectifier circuit.

rectifier design was given and a general model to be studied as future research work.

For light sources with active power electronic converters, the signal to noise ratio (SNR) can be equal to zero where PLC signals compete with EMC "maximum" signal levels. This leads to performance degradation on PLC transmission.

Unless designers and manufacturers of colour LED and CFL lamps upgrade the quality of electronic components and rectifiers that lamps are made of, PLC will suffer hindrance of communications.

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