MODELING OF COMPACT FLUORESCENT LAMP AND MITIGATION OF HARMONIC DISTORTION WITH PASSIVE FILTER

[1]Raghavendra L, [2]Shreeshayana R, [3]Parthasarathy L
[1,2] Assistant Professor, [3]Professor
[1]Department of Electrical and Electronics Engineering
[1]ATME College of Engineering, Mysuru, Karnataka, India

Abstract : Compact fluorescent lamps (CFLs) are gaining widespread acceptance due to energy conservation concerns. The CFL is a significant harmonic source since its current total harmonic distortion can exceed 100%. Although each CFL consumes only a small amount of power, mass deployed CFLs could become a significant harmonic source. In this paper a frequency domain harmonic model for the CFL using PSPICE is developed. Further passive filter is designed to reduce the harmonics in CFL model and experiments were also being conducted for the same to validate the models developed.

Index Terms - Compact Fluorescent Lamp, Passive Filter, Harmonics and Power Quality.

I. INTRODUCTION

In recent years, actions have been taken to reduce the greenhouse emissions from various sources. One notable development is the proposal to mandate the use of energy-efficient lighting devices such as CFLs. The International Energy Agency estimates that switching to CFLs would cut worldwide electricity demand by 18% and reduce greenhouse emissions significantly (Liang Chen et al, 2010). CFLs are well known to be harmonic sources with a current THD in excess of 100%. Mass adoption of CFLs would result in a significant increase of harmonic sources among residential loads. These harmonic sources, when combined in large quantities, could cause feeder-wide power-quality problems. Therefore, the power quality impact of CFLs needs to be clearly understood. One of the key steps to achieve this goal is to develop a CFL harmonic model suitable for large-scale harmonic penetration studies.

The initial work on understanding the CFL harmonics was done through measurements (D. J. Pileggo et al, 1993). Later, researchers focused on the interaction of voltage distortion and the CFL's non-linear characteristics by using either measurement studies or circuit level simulations using PSPICE or PSCAD. This work revealed that the harmonic currents produced by CFLs are affected by the supply voltage distortion and that the so-called attenuation effect occurs when a number of CFLs are installed at the same location (J. Cunill-Sola et al, 2007). In the past the harmonics injected into the network by CFLs has been ignored as each CFL's injection is very small. The combined effect however, of the widespread adoption of CFLs can be just as detrimental as one large harmonic source (Samir Moulahoum et al, 2013). One well known solution to mitigate harmonics is the use of passive filter (Bruno Pires de Campos et al, 2016).

In this paper a frequency domain harmonic model for the CFL using PSPICE is developed. Further passive filter is designed to reduce the harmonics in CFL model and experiments were also being conducted for the same to validate the models developed.

II. Simulation of CFL using PSPICE

2.1 A Generalized Typical Circuit for CFL

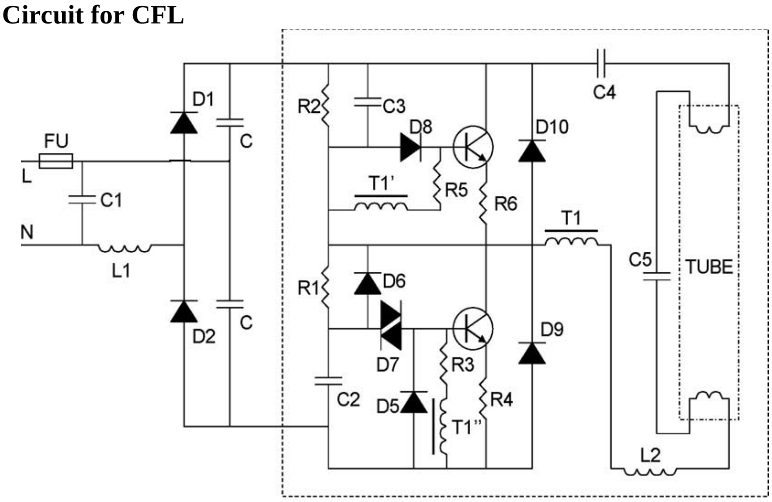

Fig.1 (a) A typical CFL circuit

A typical CFL circuit for a 230 V supply consists of a single phase diode bridge rectifier, two capacitors for smoothing the dc voltage, a high-frequency inverter, and a tube shown in Fig.1 (a) (Liang Chen et al, 2010). The measured current waveform is shown in Fig.1(b).

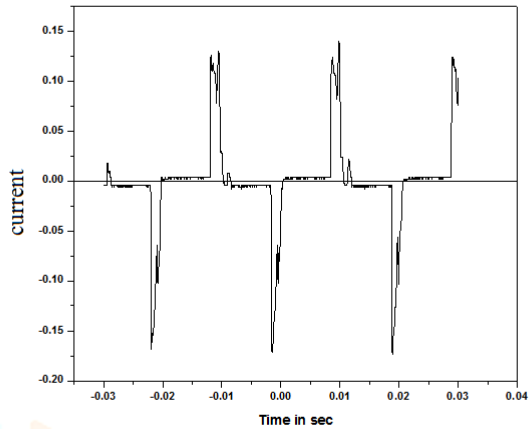

Fig.1 (b) Measured current waveform

2.2 Equivalent Circuit for CFL

A CFL tube operating under high-frequency voltage is known to behave almost like a resistor. As a result, as per ref. (M. K. Kazimierczuk et al, 1993) it is assumed that a CFL circuit can be represented by the equivalent circuit shown in Fig.2, in which the inverter and tube in Fig.1 (a) are replaced by an equivalent resistor R_2. The simulated current waveform is shown in Fig.4, which reveals a good agreement between the simulated and measured current waveforms, implying that the equivalent circuit is adequate.

(i) Derivation of CFL Harmonic Model

For the circuit of Fig.1 (a), the diodes of the rectifier are treated as ideal switches. The distorted supply voltage $v_{ac}(t)$ can be expressed as

$$v_{ac}(t) = \sum_{h}^{\infty}(v_h \cos(h\omega t + \psi_h) \qquad (1)$$

where h, ω and ψ_h are the harmonic order, fundamental angular frequency, and initial phase angle, respectively. Assuming $\psi_1 = 0$, h=1, 3, 5,…

when $\alpha/\omega \leq t \leq \delta/\omega$, where α and δ are the firing angle and extinction angle of diode, respectively, the voltage charges the dc link capacitor and equals the dc voltage, which can be determined as

$$V_{dc}(t) = V_{ac}(t) = \sum_{h=1}^{\infty} v_h \cos(h\omega t + \Psi_h) \quad (\alpha/\omega) \leq t \leq \delta/\omega) \qquad (2)$$

(ii) Parameters of the CFL Harmonic Model

Implementing the model requires knowing the parameters α, δ, C and R. As this subsection will show, these parameters can be determined by using limited information.

1. **Calculation of Extinction Angle:** The extinction angle corresponds to the instant when the current charging the dc link capacitor falls to zero. This event happens at every half-cycle of the fundamental frequency, when the equality t= δ/ω holds true. Thus, the charging circuit is disconnected at the angle δ, which can be obtained by solving

$$i_{dc}(t) = \sum_{h=1}^{\infty}(-v_h h\omega C \sin(h\omega t + \psi_h) + \sum_{h=1}^{\infty}(\frac{v_h}{R}\cos(h\omega t + \psi_h) = 0 \quad (\alpha/\omega) \leq t \leq \delta/\omega) \qquad (3)$$

2. **Calculation of Firing Angle:** After the disconnection of the diode bridge, caused by the extinction of the circuit current, the ac current remains equal to zero. During this time between the appearance of the extinction angle and the firing angle, the energy stored in the capacitor is discharged into the resistor and the voltage across the capacitor decreases. The firing angle corresponds to the time instant when the magnitude of the ac voltage exceeds that of the dc voltage. By using the information about the extinction angle from the previous fundamental frequency half cycle, the initial capacitor voltage is found by using Eq.4.

$$v_{dc}(t = \delta/\omega) = \sum_{h=1}^{\infty}(v_h \cos(h\delta + \psi_h) \qquad (4)$$

3. **Estimation of Capacitance C and Equivalent Resistance R:**
   Various CFLs are available in the market, and their capacitances and equivalent resistances are expected to be different. To overcome this problem for the present CFL model, as per ref. (M. K. Kazimierczuk et al, 1993) they have assumed that all CFLs have the same dc-link capacitance if their power rating is in the range of 5~ 30 W, the rating range for household applications. After investigation of various CFLs in the market, capacitance range is found to be 15-25 µF (Liang Chen et al, 2010). The next step is to estimate the equivalent resistance R. Considering that this resistance is related to the operating current of a specific CFL. Based on extensive measurements of various CFLs, the resistance is found to be approximated as follows

$$R = 3.927(V/I)\ \Omega \qquad (5)$$

Where V and I are the operating voltage and the measured fundamental current of the lamp, respectively. If measurements cannot be done, the rated voltage V_r and rated current I_r can be used as a good approximation, where $V=V_r$ and $I=0.85I_r$. Using Eq. 5 equivalent resistances for different CFLs can be calculated.

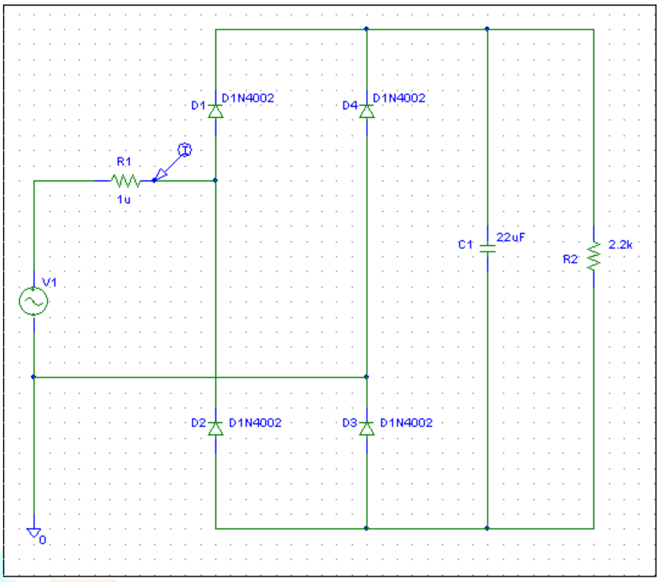

Fig.2 Equivalent CFL circuit without filter

III. DESIGN OF PASSIVE FILTER FOR CFL

The filter is designed for suppressing of 3rd order harmonic component. By using general formula as follows

$$f_r = 1/(2\pi\sqrt{(LC)}) \qquad (6)$$

Where f_r is the resonant frequency

L is the inductance

C is the capacitance

Calculation: Values of L and C are calculated as follows,

f_r= 50*3 = 150 Hz is the resonant frequency

To calculate L and C, in the present work L is assumed as 0.5 mH. Using Equation 6 value of capacitance C is found to be 2251 uF. Where the value of resistance R is independent of L and C, it is dependent on supply voltage and current, so it is assumed as 150 Ω.

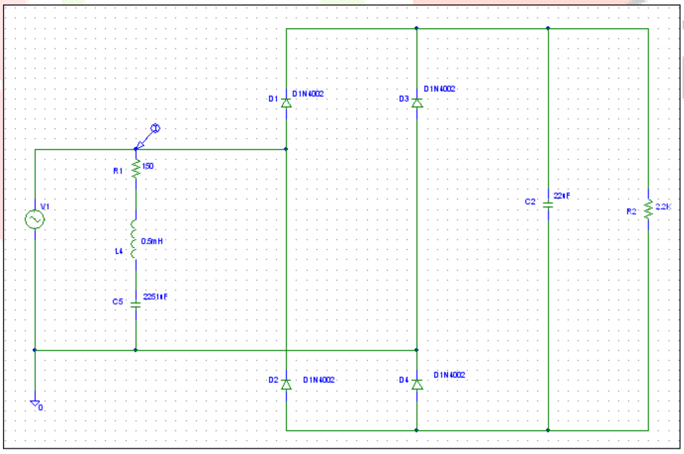

Fig. 3 Equivalent CFL circuit with filter

IV. RESULTS AND DISCUSSION

4.1 Simulation results without and with filter

Fig.4 (a) and Fig.4 (b) shows the simulated waveform obtained for the CFL without filter along with its FFT analysis. It is clear from the waveform obtained from simulation is highly distorted giving rise to a THD of about 72.16 %.

Fig.5 (a) and Fig.5 (b) shows the waveform obtained from simulation for the CFL_8 W with filter along with its FFT analysis and it is observed that THD is about 6.2 %.

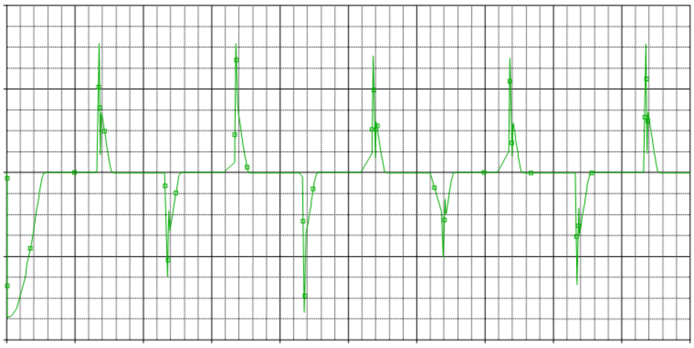

Fig.4 (a) Simulated current waveform of CFL without filter

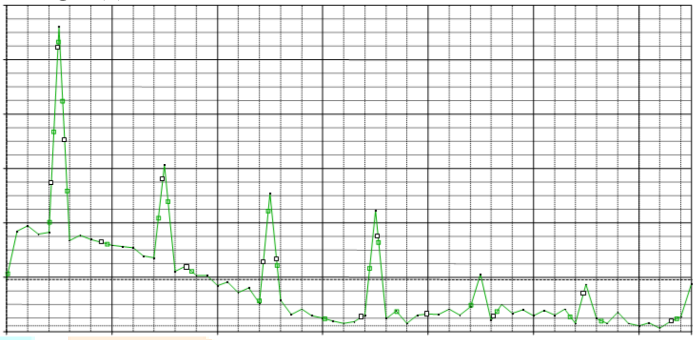

Fig.4 (b) Simulated FFT analysis of CFL without filter

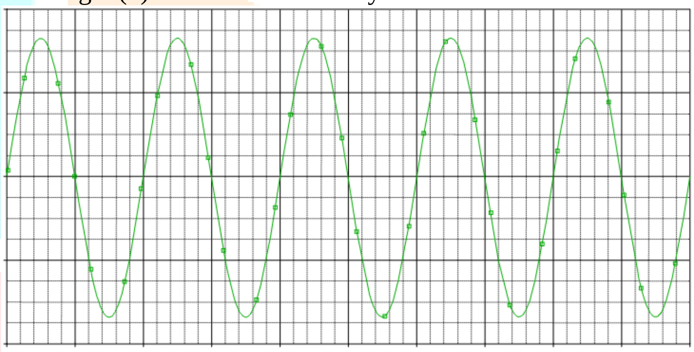

Fig.5 (a) Simulated current waveform of CFL_8 W with filter

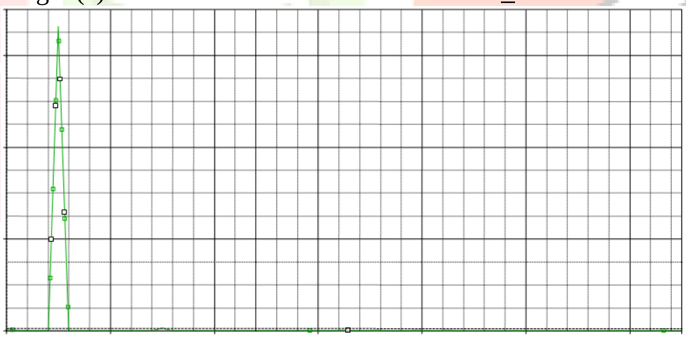

Fig.5 (b) Simulated FFT analysis of CFL_8 W with filter

V. EXPERIMENTAL SETUP

5.1 With and without filter for CFL_8 W

The experimental setup prepared for the present work is shown in Fig.6. It consist of SPST switch, Rheostat (150 Ω, 5 A), Inductor of 0.5 mH, Capacitor of 2215 uF, Digital Storage Oscilloscope(DSO), CT (10/5), shunted with a non-inductive wire wound resistor (1 Ω/20 w) and terminals to connect load. The output of the DSO is interfaced to computer.

Experimental procedure

Initially keeping the filter switch S in open position. A single phase supply was given to the circuit after connecting the lamp across the load terminal, thus waveform was observed and stored in DSO. The stored waveform was then converted into data file using ULTRASCOPE software. The data thus obtained is used in origin software and Fast Fourier Transform (FFT) analysis was performed, and THD was calculated. In the next step filter switch S is closed and the above procedure is repeated.

In this paper, CFL_8W has been considered and a singly tuned filter for 3rd harmonic components as been designed and implemented in the experimental studies. The Fig.6 shows the experimental setup of CFL_8 W lamp with and without filter.

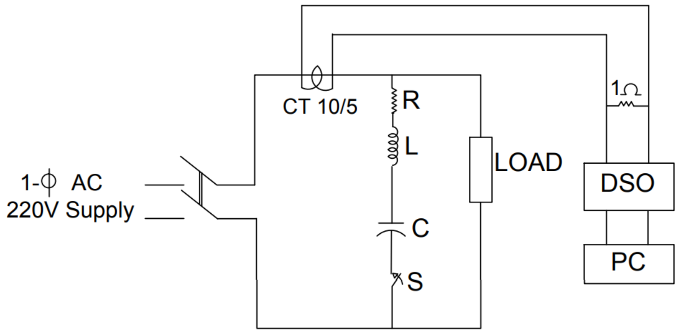

Fig.6 Schematic diagram of with and without filter for CFL_8 W

5.2 Experimental results without and with filter

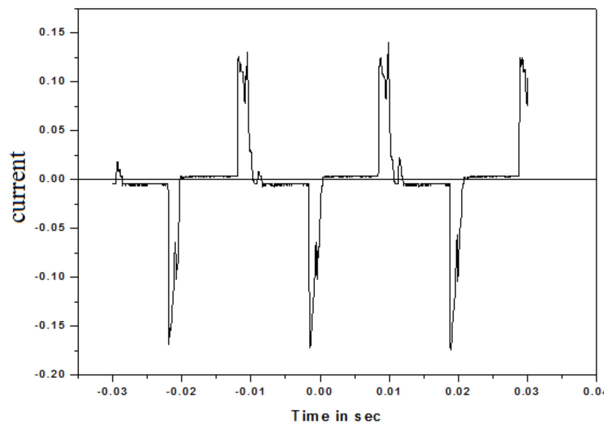

Fig.7 (a) Wave shape of the CFL_8 W without filter

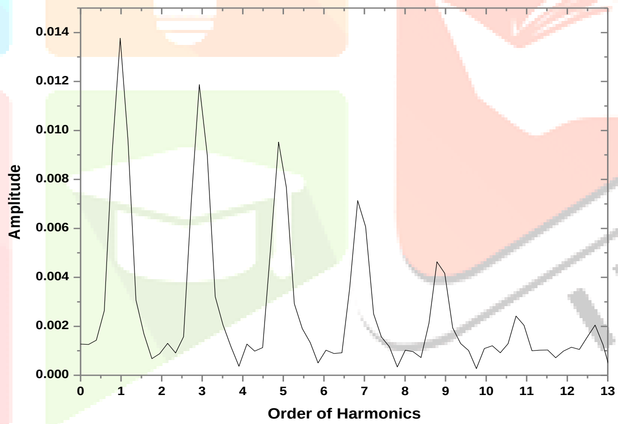

Fig.7 (b) FFT analysis of the CFL_8 W without filter

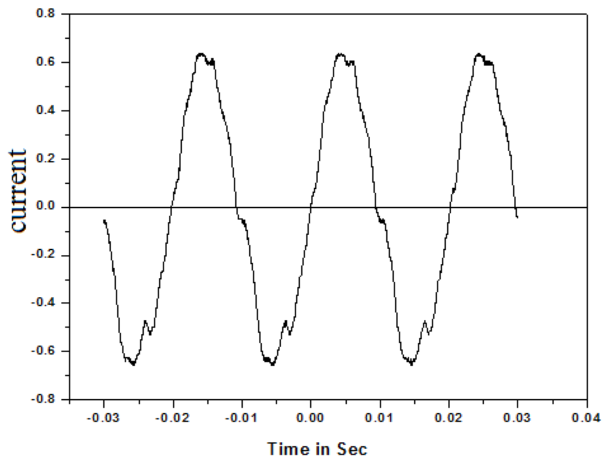

Fig.8 (a) Wave shape of CFL_8 W with filter

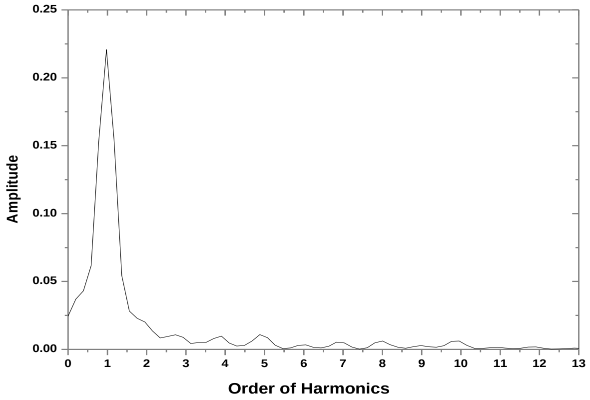

Fig.8 (b) FFT analysis of CFL_8 W with filter

Fig.7 (a) and Fig.7 (b) shows the experimental waveform obtained for the CFL_8 W without filter along with its FFT analysis. It is clear from the experimentally obtained waveform that, it is highly distorted giving rise to a THD of about 79.81%.

Fig.8 (a) and Fig.8 (b) shows the experimental waveform obtained for the CFL_8 W with filter along with its FFT analysis and it is observed that THD is about 15.4 %.

Table.1 THD values for experimental and PSPICE simulation

Particular		%THD
Experimental	Without filter	79.81
	With filter	15.4
PSPICE Simulation	Without filter	72.16
	With filter	6.2

It can be observed from Table.1 that, THD of CFL is high when compared to the standard (< 10) (IEEE-519). The THD of CFL with filter designed in the present study gives 15.4 %. This THD is also slightly high as compared to the standard value mentioned above, it is because of the reason that the current and voltage are kept within the limits while deciding the value for R, L and C. The simulated results with and without filter are also comparable with the experimental values of THD. This shows the validity of the equivalent circuit for CFL model in the paper.

VI. CONCLUSION

From the experimental and simulated results the following conclusions are drawn,

1. Individual harmonic component estimated in case of CFL_8 W does not follow the IEEE 519 standards i.e., 3rd and 5th harmonic component are significantly high when compared to the percentage of fundamental (i.e. 3rd harmonic component is less than 5% and 5th harmonic component is less than 2.5% of the fundamental).
2. It is found from the experimental results that for CFL_8 W with filter, THD is reduced from 79.81% to 15.4%.
3. It is observed that the experimental and simulated results obtained for CFL_8 W without filter is of close approximate.
4. The manufacturers and users must pay attention that in some types of lamp, the current waves contain odd harmonics distortion more than the values recommended by (IEEE 519/1992).

VII. REFERENCE

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