Parameter identification and power quality analysis for compact fluorescent lamp

Enrique Jácome Lobo
Escuela Colombiana de Carreras Industriales
Universidad Nacional de Colombia
Bogotá, Colombia
ejacomel@ecci.edu.co

Andrés Pavas
Universidad Nacional de Colombia
Facultad de Ingeniería
Bogotá, Colombia
fapavasm@unal.edu.co

Helbert Eduardo Espitia
Universidad Distrital Francisco José de Caldas
Facultad de Ingeniería
Bogotá, Colombia
heespitiac@udistrital.edu.co

Abstract— **This paper shows the parameter identification and power quality analysis for a compact fluorescent lamp. The parameters identification was performed by the implementation and optimization of non linear system model. The power calculation and power index calculation was done for the electrical analysis in order to compare between the simulated and measured variables, for the validation of the optimized parameters.**

Keywords—non linear; model; optimization; power quality;

I. INTRODUCTION

Today there is a tendency to replace electrical devices applying the rational use of energy. In particular, the field of science and engineering seeks to optimize devices' energy without compromising the quality of their service and at the same time, reduce energy consumption, energy losses and waste production pollutants [1, 2, 3]. Lighting represents an important part of electricity consumption in a residential installation, commercial and industrial sectors, both public and private. Therefore, it is very important to apply the principles of rational use of energy in lighting, to produce a major impact with energy, economic and environmental benefits, [3, 4, 5].

At the present time, the use of incandescent and halogen bulbs is gradually declining, mainly due to their low luminous efficacy (14-22 lm / W), and they are being replaced directly by compact fluorescent lamps. Along with compact fluorescent lamps, high intensity discharge offers greater luminous efficiency (25-104 lm / w), reducing electricity consumption and promoting the rational use of energy [3,4,5,6].

Compact fluorescent lamps (CFLs) and the high intensity discharge lamps (HIDs), particularly metal halide (metal halide) are widely used in various applications in indoor lighting. However, the (CFLs) and (HIDs) are capable of causing various undesirable conditions, such as the deformation of voltage and current waveforms, causing low power factor due to harmonic distortion [7,13].

Additionally, discharge lamps have capacitors to compensate for the power factor. Along with the ballast, which is a nonlinear device, they form a ferroresonant circuit that can cause resonances affecting the system elements. The presence of both lighting technologies in the same circuit can amplify the electrical signals above tolerable levels, causing electromagnetic interference which can affect compatibility or even other devices.

To conduct a study of power quality and EMC, suitable models are needed for each of the lighting technologies that describe the behavior of electrical signals involved in lighting systems.

This document shows a compact fluorescent lamp's parameter identification and analysis of electric power. For the identification of the model parameters Implemented, the nonlinear system is optimized through genetic algorithms based in real measurements as a reference. To perform the analysis of electric power, power quality indices based on the IEEE 1097 are calculated. Finally, we present the comparison between the simulated and measured outcome.

Some references such as [11,15,16,17,18,] show different models proposed for CFLs. However, the model presented herein is different in that it uses an optimization technique to obtain the parameters, ensuring that the simulated response is the optimal for the model. Furthermore, the model is verified by calculating some indices of power quality.

II. COMPACT FLUORESCENT LAMP MODEL WITH ELECTRONIC BALLAST

A lamp with electronic ballast can be represented as shown in Figure 1 [9,10,11,12,18]. Sasaki Iwao Reid [18] proposes a model similar to simulate the behavior of a compact fluorescent lamp. In his paper, Reid mentions that this model is used to power quality studies because it faithfully reproduces the distorted current signal produced by this lamp. The model assumes that the bulb presents a resistive behavior, based on studies [14,15], which conclude that bulbs of compact fluorescent lamps with electronic ballast show a behavior close to linear because the voltage and current signals are directly proportional. Also other studies [16,17] state that the tube discharge can be modeled by a resistor because its voltage and current signals are in phase and without high harmonic content. For this reason in this document the bulb discharge is modeled as a linear resistance.

Figure 1 shows the model of the compact fluorescent lamp. This circuit can be divided into: low pass filter, rectifier and inverter.

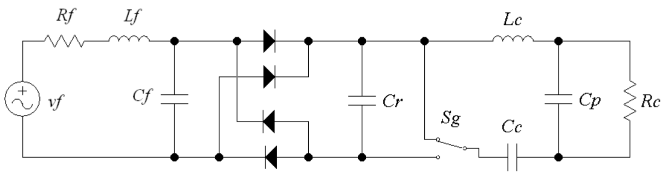

Figure 1. Circuit for a lamp with electronic ballast.

Figure 2 shows the module corresponding to the low frequency filter. The model of this part demonstrates the coil current, voltage in the capacitor and the current through the diode when running.

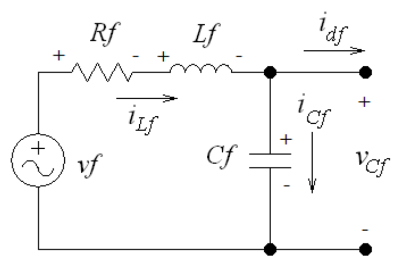

Figure 2. Model for the low-pass filter.

The equations for the low-pass filter at the input are:

$$\frac{di_{Lf}}{dt} = \frac{1}{Lf}(-R_f i_{Lf} - v_{Cf} + v_f) \qquad (1)$$

$$\frac{dv_{Cf}}{dt} = \frac{1}{Cf}(i_{Lf} - i_{df}) \qquad (2)$$

Where:

i_{Lf} : low pass filter current

R_f : branch circuit resistance

v_{Cf} : voltage capacitor low pass filter

v_f : supply voltage

i_{df} : current of the diodes

On the other hand in Figure 3 you can see the model considered for the rectifier circuit.

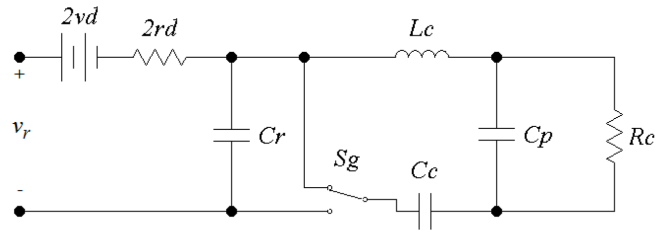

Figure 3. Model for the circuit after the bridge rectifier.

The governing equations for the rectifier are given by the conduction of the diodes, which depend on the voltage difference between v_{Cf} y v_{Cr}. To simplify the model when the diodes are active, they are modeled by a source v_d and a resistance r_d of a very small value. Additionally, the output voltage of the bridge rectifier can be modeled as the absolute value on the capacitor voltage $v_r = abs(v_{Cf})$.

The rectifier circuit equations are given by the capacitor voltage:

$$\frac{dv_{Cr}}{dt} = \begin{cases} \frac{1}{r_d c_r}(v_r - v_d - r_d i_r - v_{Cr}) & si (v_r - v_{Cr}) > v_d \\ -\left(\frac{1}{c_r}\right) i_r \quad si & (v_r - v_{Cr}) < v_d \end{cases} \qquad (3)$$

Where:

v_r : rectified voltage v_{Cf}

v_d : diode voltage

r_d : diode resistance

i_r : rectified current

c_r : rectifier capacitor

v_{Cr} : capacitor voltage rectifier

The current of the diodes is:

$$i_{df} = \begin{cases} \text{sgn}(v_{Cf}) \frac{(v_r - v_{Cr} - v_d)}{r_d} & si \quad (v_r - v_{Cr}) > v_d \\ 0 \quad si \quad (v_r - v_{Cr}) < v_d \end{cases} \qquad (4)$$

The model for the inverter circuit is given by the switching signal. The relationship between the rectifier and the inverter circuit is given by the coil current i_{Lc_i}, the voltage of the capacitor v_{Cc} and the capacitor voltage v_{Cp}.

The switching signal is associated with the variable S_g, which can be either 1 or 0.

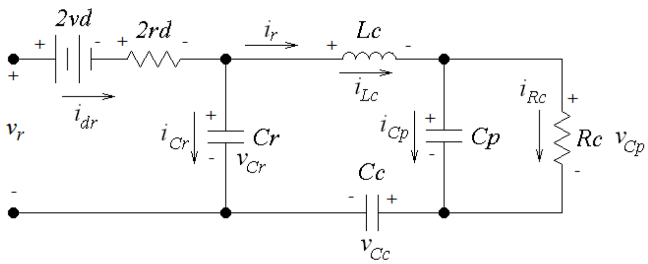

Figure 4. Model for the circuit when $S_g = 1$.

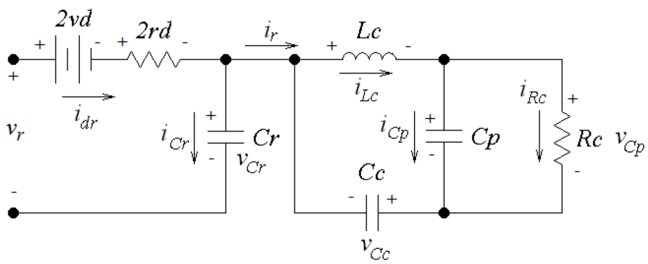

Figure 5. Model for the circuit when $S_g = 0$.

Considering the action of the switch, the equations for the inverter circuit are:

$$\frac{di_{Lc}}{dt} = \frac{1}{L_c}(S_g v_{Cr} - v_{Cc} - v_{Cp}) \quad (5)$$

$$\frac{dv_{Cc}}{dt} = \frac{1}{c_c} i_{Lc} \quad (6)$$

$$\frac{dv_{Cp}}{dt} = \frac{1}{c_p}(i_{Lc} - \frac{v_{Cp}}{R_c}) \quad (7)$$

Where:

L_c : inductance of the resonant circuit

c_c : inductance of the resonant circuit

R_c : resistance of the resonant circuit

c_p : capacitor for power factor correction

Finally, the current in the rectifier preceding the inverter can be calculated as:

$$i_r = S_g i_{Lc} \quad (8)$$

III. PARAMETER IDENTIFICATION WITH OPTIMIZATION

The method for identifying model parameters are shown in Figure 6.

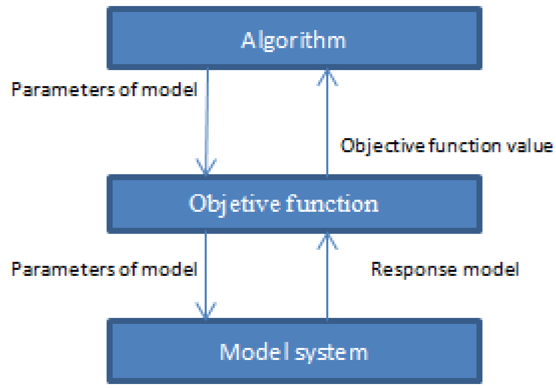

Figure 6. Process for identification of model parameters.

Figure 6 shows the implementation of a function that calculates the dynamic response of the system, as well as the calculation of the respective performance index for the optimization as performance index mean square error is considered.

$$J(X) = \frac{1}{N}\sum_{n=1}^{N}[r(n) - s(n, X)]^2 \quad (9)$$

Dónde:

- J : Objective function
- X : Parameters.
- n : Discrete time index.
- r : Actual data measured.
- s : Data obtained from the simulation.
- N :Total number of data taken.

IV. METHOD BASED GRADIENT MINIMIZATION

The minimization tools employed are based on Newton's method [19], which in the case of a variable provides that

$$x_{k+1} = x_k - \frac{f'(x_k)}{f''(x_k)} \quad (10)$$

x_{k+1} is a point that looking for to minimize f . When you perform this operation on the computer, and is know the derivates of f , then can take numerical approximations of the derivates as:

$$f'(x_k) = \frac{f(x_k + \Delta x) - f(x_k - \Delta x)}{2\Delta x} \quad (11)$$

$$f''(x_k) = \frac{f(x_k + \Delta x) - 2f(x_k) - f(x_k - \Delta x)}{(\Delta x)^2} \quad (12)$$

When using numerical approximations of the derivatives, the method takes the name of Quasi-Newton.

When the function to be minimized is of several variables, Newton's method takes the form:

$$X_{k+1} = X_k - (f''(X_k))^{-1} f'(X_k) \qquad (13)$$

Where f is the function to minimize, X is the vector formed by the independent variables, f' is the vector of first derivatives also called gradient and f'' is called the Hessian matrix, whose elements are the second derivatives of f.

The gradient vector and Hessian matrix in Newton's method are determined by the numerical approximation of first and second derivatives respectively [19]. However, there is another orientation in which successive approximations for the Hessian's inverse are made mainly because these kinds of computations could be highly time consuming and demanding of computational resources.. These methods, including the method of DFP (Davidon-Fletcher-Powell) and the BFGS method (Broyden-Fletcher-Goldfarb-Shanno [19], are called quasi-Newton.

V. SIMULATION AND RESULTS

In order to identify the electrical parameters and the power quality analysis was taken as reference the measurement of the current from a compact fluorescent lamp. Thus, the proposed model was verified and it was obtained a comparison between measured and simulated electric variables.

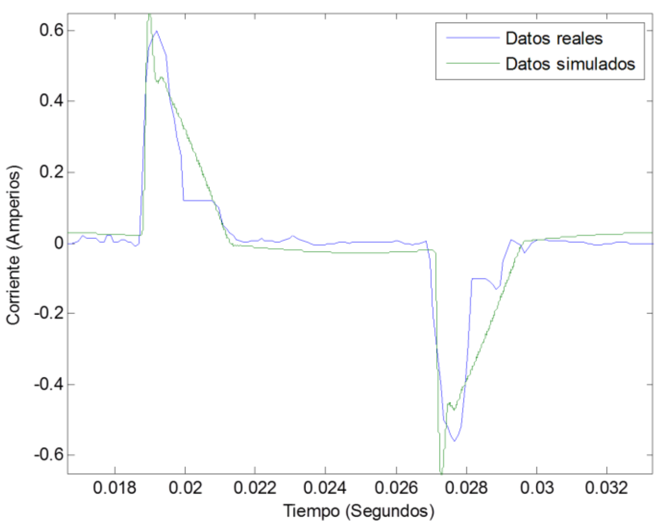

Figure 7. Current signal measured and simulated

A. *Identification of parameters by optimization*

The methodology described in the previous section was used to identification the model parameter, the no lineal model was optimized from measurements of the current.
Figure 7 shows the signal current measured and simulated in MATLAB ®, Table 1 shows the parameters obtained from the optimization.

TABLE 1. OPTIMIZATION PARAMETERS IDENTIFIED

Parameter	Value
Cr	10.307e-006 F
Lc	0.77905e-003 H
Cc	0.10260e-006 F
Rc	40.0000 Ohm
Cp	55.601e-009 F
Lf	0.33110e-003 H
Cf	0.43615e-006 F
Rf	4.2236 Ohm

B. *Power quality analysis*

To perform a verification of the model were calculated these power quality indices: active power, power factor and total harmonic distortion (THDi).

TABLE 2. COMPARISON OF MEASURED AND SIMULATED DATA FOR THE COMPACT FLUORESCENT LAMP.

Electrical variables	Measured values	Simulated values
Rms value of the voltage	119.9 V	120.2082 V
Rms value of the current	171.75 mA	186 mA
Active Power	10.71W	12.7687 W
Power factor	0.52	0.5712
THDi	132.45%	106.6%

VI. CONCLUSIONS

Can be determined that the non-linear model and the method of optimization implemented in this article achieves a proper representation of the condition of the current producing a compact fluorescent lamp.

The proposed model represents the shape of the current signal and was verified by calculating some power quality indices, such as: rms value of the voltage, rms value of the current, active power, power factor, THDi as shown in Table 2.

This model can be used for studies of power quality and electromagnetic compatibility

VII. REFERENCES

[1] UPME. Universidad Nacional de Colombia. Informe Ejecutivo: Caracterización de las bombillas para uso interior comercializadas en

Colombia. Contrato 1517-23 de 2007. Bogotá, Colombia, Abril 28 de 2008.

[2] UPME. Universidad Nacional de Colombia. Caracterización de las bombillas para uso exterior comercializadas en Colombia. Contrato 1517-27 de 2007. Bogotá. Colombia, Abril 28 de 2008.

[3] UPME. Universidad Nacional de Colombia. Guía didáctica para el buen uso de la energía: Alumbrado interior de edificaciones para entidades públicas. ISBN: 978-958-8363-00-4. Bogotá Colombia, 2007.

[4] UPME. Universidad Nacional de Colombia. Guía didáctica para el buen uso de la energía: Alumbrado público. ISBN: 978-958-8363-01-1. Bogotá. Colombia, 2007.

[5] UPME. Universidad Nacional de Colombia. Guía didáctica para el buen uso de la energía: Alumbrado interior de edificaciones residenciales. ISBN: 978-958-98138-9-8. Bogotá. Colombia, 2007.

[6] Ministerio de Minas y Energía. Reglamento Técnico de Instalaciones Eléctricas, RETIE. Colombia, 2007.

[7] William Camilo Cortés Jiménez, "Identificación y análisis de componentes de frecuencia entre 10kHz y 200kHz causadas por lámparas compactas fluorescentes", Proyecto de Grado para optar a título de Ingeniero Electricista, Universidad Nacional de Colombia, 2011.

[8] Abdel-Gawad, A.F. "Studying the impact of different lighting load some both harmonics and power factor", IEEE, Universities Power Engineering Conference, 2007. UPEC 2007. 42nd International.

[9] THE IESNA. Illuminating Engineering Society of North America. Lighting Handbook. Reference and application, Ninth Edition, 1997.

[10] Manual único de alumbrado público para Bogotá, Resolución U.E.S.P. No. 17, Febrero de 2004.

[11] Wei, Z.; Watson, N.R. y Frater, L.P. "Modeling of compact fluorescent lamps". En: 13th International Conference on Harmonics and Quality of Power (ICHQP 28 September - 1 October), Australia, 2008.p1 -6.

[12] Ana María Blanco Castañeda, "Efecto sobre los circuitos de distribución secundarios debido al uso intensivo de bombillas fluorescentes compactas y LEDS", Trabajo de tesis para optar por el título de Magister en Ingeniería Eléctrica. Universidad Nacional de Colombia, 2010.

[13] E. O. A. Larsson, C. M. Lundmark and M. H. J. Bollen, "Measurement of current taken by fluorescent lights in the frequency range 2 - 150 kHz". IEEE, Power Engineering Society General Meeting, 2006.

[14] YAN, Wey; TAM, Eugene y HUI, S.Y.R. "A versatile semi-empirical Pspice fluorescent Lamp model", presented at the Power Electronics Specialists Conference (PESC, Junio 2006). Memorias: 2006. P. 1-7.

[15] Yen, H.C.; Huang, Z.J. y Lee, K.H, "A fluorescent lamp model for high-frequency, Electronic ballasts", presented at the International Conference on Power Electronics and Drives System. Memorias. Taiwan: IEEE PEDS, 2005. P. 1184-1189.

[16] Moo, Chin S, "A fluorescent lamp model for high-frequency electronic ballasts". Industry Applications Conference (8-12, October). Conference Record of the 2000 IEEE. vol. 5, 2000. p. 3361-3366.

[17] Wakabayashi, F.T., "Fluorescent Lamp Model based on Equivalent Resistances, Considering the Efects of Dimming Operation", presented at the Power Electronics Specialists Conference (PESC, Junio 2005). IEEE 36th, 2005. p. 1136-1141.

[18] Sasaki, Reid Iwao, "The impact of electronic ballast compact uorescent lighting on power distribution sistems". Indiana: Purdue University, 1994.

[19] Mora Escobar Hector Manuel, "Optimización no lineal y dinámica", Universidad Nacional De Colombia.

[20] Ministerio de Minas y Energía, Reglamento Técnico de Iluminación y Alumbrado Público - RETILAP. Colombia, 2007.

[21] Requisitos de desempeño para bombillas fluorescentes compactas con balasto integrado para servicios generales de iluminación, NTC 5849, 2011.