Parameter identification and power quality analysis for compact fluorescent lamp

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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 efficacy (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 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.

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

\[
\begin{align*}
\frac{di_{lf}}{dt} &= \frac{1}{L_f}(-R_f i_{lf} - v_{cf} + v_f) \\
\frac{dv_{cf}}{dt} &= \frac{1}{C_f} (i_{lf} - i_{df})
\end{align*}
\]

(1) (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 \(v_{cf}\) and \(v_{cr}\). 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:

\[
\frac{dv_{Cc}}{dt} = \begin{cases} 
\frac{1}{r_d c_r} (v_r - v_d - r_d i_r - v_{cr}) & \text{si}(v_r - v_{cr}) > v_d \\
0 & \text{si}(v_r - v_{cr}) < v_d 
\end{cases}
\]

(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:

\[
\begin{align*}
i_{df} &= \begin{cases} 
\frac{\text{sgn}(v_{cf}) (v_r - v_{cr} - v_d)}{r_d} & \text{si}(v_r - v_{cr}) > v_d \\
0 & \text{si}(v_r - v_{cr}) < v_d 
\end{cases}
\end{align*}
\]

(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 \(i_{lc}\), 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.
Considering the action of the switch, the equations for the inverter circuit are:

\[
\frac{di_{Lc}}{dt} = \frac{1}{L_c} (S_g v_{Cr} - v_{Cc} - v_{Cp}) \tag{5}
\]

\[
\frac{dv_{Cc}}{dt} = \frac{1}{c_c} i_{Lc} \tag{6}
\]

\[
\frac{dv_{Cp}}{dt} = \frac{1}{c_p} (i_{Lc} - \frac{v_{Cp}}{R_c}) \tag{7}
\]

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:

\[
i_r = S_g i_{Lc} \tag{8}
\]

### III. PARAMETER IDENTIFICATION WITH OPTIMIZATION

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

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.

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

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

\[
x_{k+1} = x_k - \frac{f'(x_k)}{f''(x_k)} \tag{10}
\]

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

\[
f'(x_k) = \frac{f(x_k + \Delta x) - f(x_k - \Delta x)}{2\Delta x} \tag{11}
\]

\[
f''(x_k) = \frac{f(x_k + 2\Delta x) - 2f(x_k) - f(x_k - 2\Delta x)}{(\Delta x)^2} \tag{12}
\]

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:

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

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.

A. Identification of parameters by optimization

The methodology described in the previous section was used to identification the model parameter, the non-linear 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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_r$</td>
<td>10.307e-006 F</td>
</tr>
<tr>
<td>$L_c$</td>
<td>0.77905e-003 H</td>
</tr>
<tr>
<td>$C_c$</td>
<td>0.10260e-006 F</td>
</tr>
<tr>
<td>$R_c$</td>
<td>40.0000 Ohm</td>
</tr>
<tr>
<td>$C_p$</td>
<td>55.601e-009 F</td>
</tr>
<tr>
<td>$L_f$</td>
<td>0.33110e-003 H</td>
</tr>
<tr>
<td>$C_f$</td>
<td>0.43615e-006 F</td>
</tr>
<tr>
<td>$R_f$</td>
<td>4.2236 Ohm</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Electrical variables</th>
<th>Measured values</th>
<th>Simulated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rms value of the voltage</td>
<td>119.9 V</td>
<td>120.2082 V</td>
</tr>
<tr>
<td>Rms value of the current</td>
<td>171.75 mA</td>
<td>186 mA</td>
</tr>
<tr>
<td>Active Power</td>
<td>10.71 W</td>
<td>12.7687 W</td>
</tr>
<tr>
<td>Power factor</td>
<td>0.52</td>
<td>0.5712</td>
</tr>
<tr>
<td>THDi</td>
<td>132.45%</td>
<td>106.6%</td>
</tr>
</tbody>
</table>

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...


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