Mathematical Model of Dynamic Lamp Characteristics

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Abstract - This paper proposes a curve-fitting approach for modeling fluorescent lamp voltage–current characteristics based on measured lamp voltage and current. The fluorescent lamp conductance is considered as a series of piecewise cubic polynomials that describes the nonlinear voltage-current characteristic of the lamp. The proposed model has been tested with a 32W conventional fluorescent lamp and a 70W high pressure sodium lamp. By comparing the measured and simulated results, it shows that the proposed model can accurately model the lamps for harmonic studies.

Key-Words: - Mathematical model, fluorescent and pressure sodium lamps, experimental study, cubic spline interpolation, voltage–current characteristic.

1 Introduction

Lamp characteristics must be well understood in order to properly design electronic ballasts. As a first approach to lamp modeling, one could measure the operating voltage of the lamp at the desired lamp current. The rms voltage can be divided by the rms current to obtain an effective lamp resistance.

Some authors, M. Sun and B. L. Hesterman [1], G. W. Chang [2], have used a fixed resistance to represent a fluorescent lamp when simulating ballast circuits. This approach is valid only for one operating point since, in the normal operating range, the effective resistance of fluorescent lamps decreases with increasing lamp current. An improvement over a fixed-resistance model is to make the lamp resistance a function of the average lamp power. It is also possible to create a variable-resistance model in which the rms lamp voltage is a function of the rms lamp current instead of the average power. The averaging process involved in computing the value of the average lamp power or the rms lamp current in variable-resistance models prevents the lamp resistance from changing much during a half cycle of high-frequency current. Consequently, the high-frequency i-v characteristics of such models are essentially linear. Although linear variable-resistance models are useful, they cannot accurately predict lamp power factor and lamp current crest factor because the...
instantaneous dynamic $i$-$v$ characteristics of fluorescent lamps and high pressure sodium lamp are nonlinear. The first model which presents a dynamic fluorescent lamp who directly models the nonlinear $i$-$v$ characteristics for high-frequency operation was developed by Mader and Horn [5]. In this model, the lamp voltage is a cubic function of the lamp current. Now we use the cubic spline interpolation to interpolate the measured conductance data and then a set of piecewise cubic polynomials for describing the fluorescent lamp dynamic conductance is obtained. By comparing the measured and simulation results, it shows that the proposed model is accurate for the harmonic assessment of fluorescent lamps.

2 Mathematical model

The shape of the dynamic $i$-$v$ curves suggests using a cubic polynomial to fit the low-frequency dynamic lamp data. Cubic spline interpolation is a spline constructed of piecewise third-order polynomials which pass through a set of data points without knowing slopes [4]. Consider a measured waveform of one fundamental cycle with 250 sampling points for the fluorescent lamp conductance, as shown in Figure 1.

$$G(x) = \begin{cases} 
  g_1, & x_1 \leq x < x_2 \\
  \vdots & \\
  g_{n-1}, & x_{n-1} \leq x < x_n 
\end{cases} \quad (1)$$

where $G_i$ is a third degree polynomial defined by:

$$g_i(x) = a_i(x - x_i)^3 + b_i(x - x_i)^2 + c_i(x - x_i) + d_i \quad (2)$$

for $i = 1, 2, \ldots, n-1$.

Our spline will need to conform to the following stipulations:
- function $G(x)$ will interpolate all data points;
- $G(x)$ will be continuous on the interval $[x_1, x_n]$;
- $G'(x)$ will be continuous on the interval $[x_1, x_n]$;
- $G''(x)$ will be continuous on the interval $[x_1, x_n]$.

3 Measurement and simulation results

There are two types of lamps: the first is the fluorescent one and operates at a low frequency and the second it’s a high pressure sodium lamp under test to verify the accuracy of the proposed model. Actual measurements are obtained by using a digital oscilloscope Metrix OX 7042-C with 250 sampling points per cycle. The equivalent circuits for the simulations are shown in Figure 2, where the lamps in both circuits are replaced by the proposed conductance model [6].

For the low-frequency fluorescent lamp, Figure 3(a) shows the measured and simulated lamp voltages, and the corresponding lamp currents are shown in Figure 3(b). Figure 3(c) and (d) illustrates the associated $v$-$i$
characteristics. The measured and simulated results for the high pressure sodium lamp are given in Figure 4. Tests results show that the proposed method is effective in modeling the $v-i$ characteristics of the fluorescent lamps for both low frequency lamps and high pressure sodium lamp.

![a) lamp voltages](image)

![b) lamp currents](image)

![c) measured characteristic $v-i$](image)

![d) simulated characteristic $v-i$](image)

Fig. 3. Experimental and simulated results for the fluorescent lamp

![a) lamp voltages](image)

![b) lamp currents](image)

![c) measured characteristic $v-i$](image)

![d) simulated characteristic $v-i$](image)

Fig. 4. Experimental and simulated results for the high pressure sodium lamp.

Spectral results for the lamps are shown in Figure 5. The corresponding total harmonic voltage and current distortions of Figures 3 and 4 are given in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>fluorescent lamp</th>
<th>HPS lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>THD$_V$ (%)</td>
<td>measure</td>
<td>simulate</td>
</tr>
<tr>
<td></td>
<td>37.46</td>
<td>38.34</td>
</tr>
<tr>
<td>THD$_I$ (%)</td>
<td>152.38</td>
<td>154.22</td>
</tr>
</tbody>
</table>
It is observed that the conventional fluorescent lamp presents worse harmonic distortions than the high pressure sodium lamp.

By observing Figures 3-6 and Table 1, it shows that the simulated and measured results agree well with each other. The adopted sampling rate is sufficient for obtaining accurate lamp $v$-$i$ modeling by the proposed method.

4 Conclusion

In this paper, the cubic spline interpolation method is proposed for modeling the $v$-$i$ characteristics of fluorescent lamp and high pressure sodium lamp. The curve-fitting technique not only effectively generates conductance function values at data points intermediate between those available measurements, but also produces a smooth function for which values are known only at discrete data points. As shown in the results, it is concluded that proposed method is an accurate and efficient modeling approach for determining lamp harmonic components and can be applied for modeling other similar arcing loads.

References:


