U.P.B. Sci. Bull., Series C, Vol. 72, Iss. 3, 2010 ISSN 1454-234x

MODELING DYNAMIC HIGH INTENSITY DISCHARGE LAMP CHARACTERISTICS

Florin Ciprian ARGATU[1], Costin CEPIŞCĂ[2]

Lucrarea propune un model de aproximare a caracteristicii tensiune-curent pentru lămpile HID bazat pe rezultatele măsurării curenţilor şi tensiunii. Conductanţa lămpii este aproximată prin polinoame de ordinal trei ce descriu corect neliniaritatea caracteristicii tensiune-curent a acestui tip de lampă. Modelul propus a fost testat la încercările unei lămpi de 70W cu vapori de sodiu la înaltă presiune. Din compararea rezultatelor măsurate cu cele simulate se observă o exactitate corespunzătoare a modelului propus, inclusiv pentru studii în regim nesinusoidal.

This paper proposes a model curve-fitting approach for modeling HID lamps voltage–current characteristics based on measured lamp voltage and current. The 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 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.

Keywords: model, HID lamps, cubic spline interpolation, *i-v* characteristic

1. Introduction

The last decade the light bulb has evolved. Nowadays, there are many types of light bulbs, each with their specific energy efficiency.

High efficacy, long life and color rendition have made the High Intensity Discharge (HID) lamp one of the most useful light sources, from large space lighting such as streets, sports arenas and industrial areas to specialized applications.

These lamps have a negative dynamic resistance behavior that makes necessary use a ballast to limit the current [1], [7]. A considerable difference in efficiency exists between the various ballasts found in the industry, but generally are 2 main categories: electronic and conventional electromagnetic ballasts. In

[1] Asist., Faculty of Electric Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: florin.argatu@upb.ro
[2] Prof., Faculty of Electric Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: costin.cepisca@upb.ro

some applications, electronic ballasts offer important improvements over the traditional electromagnetic ballasts.

To verify the performance of dimmable electronic ballast or traditional electronic ballast, the lamp model employed in PSPICE or others simulators becomes a useful tool [2]. Several studies proposed SPICE compatible models of fluorescent lamps [2], [4], [5] but the authors are unaware of earlier studies that present a SPICE compatible model of HID lamps. A number of papers presented mathematical models of High Pressure Mercury, Sodium and Metal-Halide Lamps [3], but they are not readily adaptable to the environment of common SPICE simulators.

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 [2], G. W. Chang [9], have used a fixed resistance to represent a lamp when simulating ballast circuits. This approach is valid only for one operating point since, in the normal operating range, the effective resistance of 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 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 [10]. In this model, the lamp voltage is a cubic function of the lamp current, but presents convergence errors.

This paper presents a mathematical models for HID lamps based on use of a cubic spline interpolation to interpolate the measured conductance data and then a set of piecewise cubic polynomials for describing the lamp dynamic conductance is obtained.

2. The 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 [6]. Consider a data acquisition of voltage and current lamp (fig.1 – HID lamp 70W).

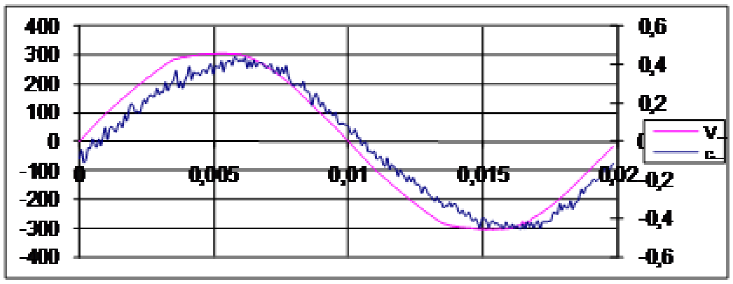


Fig. 1. Voltage and current acquisition data

The electrical conductivity, determinate by:

$$g(t) = \frac{i_{\text{lamp}}(t)}{u_{\text{lamp}}(t)} \qquad \textbf{(1)}$$

for one fundamental cycle with 250 sampling points, is presented in Fig. 2.

The unknown conductance function $G(x)$, whose values are known only at the n + 1 points that are defined:

$$G(x) = \begin{cases} G_1, x_1 \le x \le x_2 \\ G_{n-1}, x_{n-1} \le x < x_n \end{cases} \qquad (2)$$

where G_i is a third degree polynomial defined by:

$$G_i(x) = a_i(x - x_i)^3 + b_i(x - x_i)^2 + c_i(x - x_i) + d_i \quad \text{where} \quad x \in [x_i, x_{i+1}] \qquad (3)$$

for i =1,2….n-1.

The first and second derivatives of these n-1 equations are fundamental to this process, and they are:

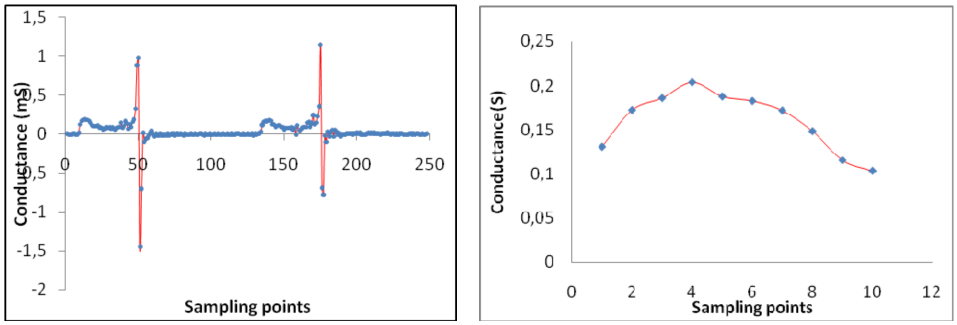
$$g_i^{'}(x) = 3a_i(x - x_i)^2 + 2b_i(x - x_i) + c_i \qquad (4)$$

$$g_i^{''}(x) = 6a_i(x - x_i) + 2b_i \qquad (5)$$

for i =1,2….n-1.

The interpolation require the conductivity estimation for any point $x \in [x_0, x_n]$

Our spline will need to conform to the following stipulations:



a) b)

Fig. 2. a) Measured conductance of the 50Hz fluorescent lamp with its interpolated curve for one fundamental cycle; b) the first 10 points of a)

- function G(x) will interpolate all data points:

$$G_i(x_i) = y_i \qquad G_i(x_{i+1}) = y_{i+1} \qquad i = 0,1,2,\ldots,n-1 \tag{6}$$

- $G(x)$ will be continuous on the interval $[x_1,x_n]$:

$$G_{i+1}(x_{i+1}) = G_i(x_{i+1}) \qquad i = 0,1,2,\ldots,n-1 \tag{7}$$

- $G'(x)$ will be continuous on the interval $[x_1,x_n]$:

$$G'_{i+1}(x_{i+1}) = G'_i(x_{i+1}) \qquad i = 0,1,2,\ldots,n-2 \tag{8}$$

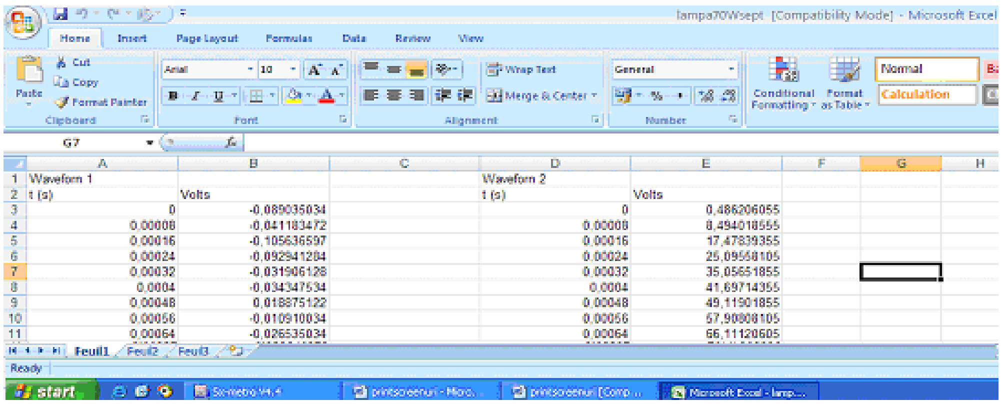
- $G''(x)$ will be continuous on the interval $[x_1,x_n]$:

$$G''_{i+1}(x_{i+1}) = G''_i(x_{i+1}) \qquad i = 0,1,2,\ldots,n-2 \tag{9}$$

The coefficients of model conductance of the lamp were obtained, through the voltage and current acquirement (fig.3), with the Matlab software:

$$a_i = 8147 \qquad b_i = -0{,}2113 \qquad c_i = 1433 \qquad d_i = -0{,}05353 \tag{10}$$

Fig. 4 presents the simulation circuit, where the lamp is replaced by this model for conductivity.



	A	B	C	D	E
1	Waveform 1			Waveform 2	
2	t (s)	Volts		t (s)	Volts
3	0	-0,089035034		0	0,486206055
4	0,00008	-0,041183472		0,00008	8,494018555
5	0,00016	-0,105636597		0,00016	17,47839355
6	0,00024	-0,092941284		0,00024	25,09558105
7	0,00032	-0,031906128		0,00032	35,05651855
8	0,0004	-0,034347534		0,0004	41,69714355
9	0,00048	0,018875122		0,00048	49,11901855
10	0,00056	-0,010910034		0,00056	57,90808105
11	0,00064	-0,026535034		0,00064	66,11120605

Fig.3. Results of data acquisition for voltage and current

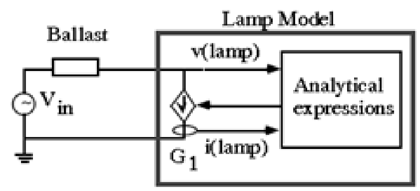


Fig. 4. Equivalent circuit for simulation

3. Measurement and simulation results

The lamp under test, to verify the accuracy of the proposed model, is a high pressure sodium lamp. System measurement and data acquisition is based by using a digital oscilloscope Metrix OX 7042-C with 250 sampling points per cycle (Fig. 5).

Fig.5. Measurement system

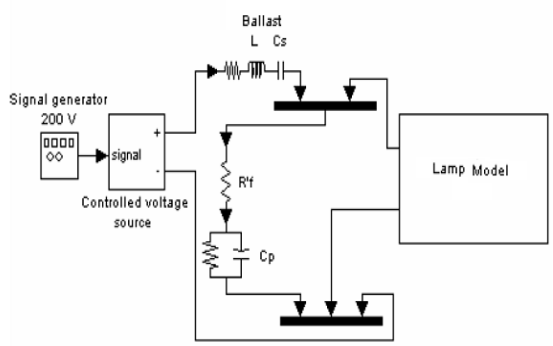


Fig.6. Simulation with Simulink

Simulink simulation circuit is shown in Fig. 5 and Fig. 6 present the integration of proposed lamp model in to Simulink circuit. Table 1 shows the parameters of circuit.

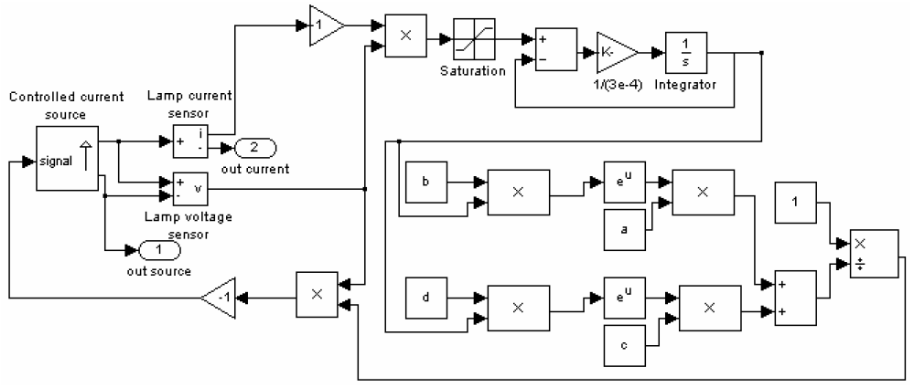


Fig.7. Lamp model in the Simulink software

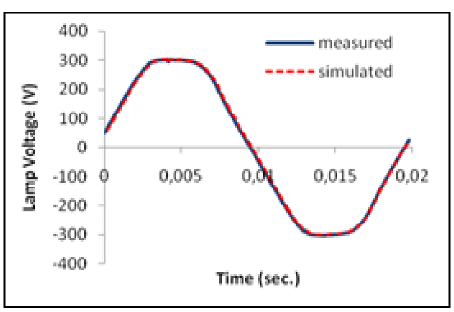
Table 1

Parameters of simulation circuit

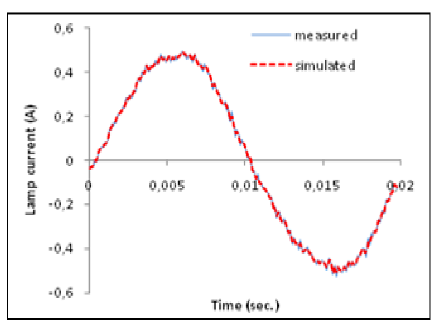
a_i=8147 b_i= - 0,2113 c_i= 1433 d_i= - 0,05353
R_f = 2x9,6Ω
C_p=3.1639x10^{-9}F
$V_{s,1} = 800/\pi * \sqrt{2}$V
L_s=2.2358x10^{-3}H
C_s=2.4207x10^{-8}F

For the high pressure sodium lamp, Fig. 7(a) shows the measured and simulated lamp voltages, and the corresponding lamp currents are shown in Fig. 7(b). Fig. 7(c) and (d) illustrates the associated *v-i* characteristics.

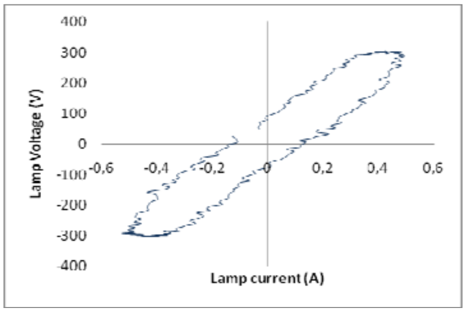
Tests results show that the proposed method is effective in modeling the *v-i* characteristics of the fluorescent lamps and high pressure sodium lamp.



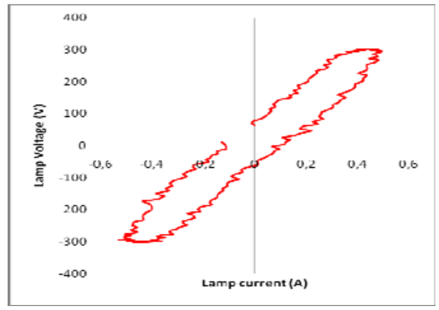
a) lamp voltage



b) lamp current



c) measured characteristic *v-i*



d) simulated characteristic *v-i*

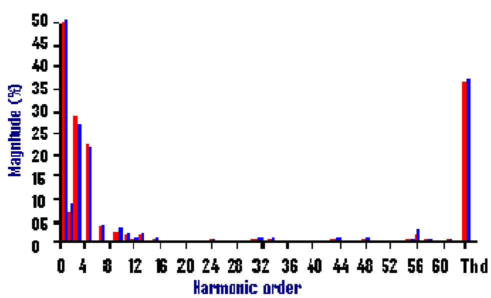
Fig. 8. Experimental and simulated results for the high pressure sodium lamp.

Spectral analysis results for the lamp are shown in Fig. 9. The corresponding total harmonic voltage and current distortions of Fig. 8 are given in Table 2.

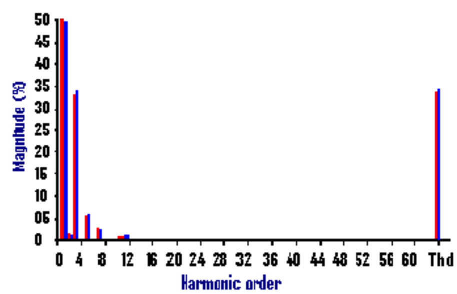
Table 2

Distorsion coefficients

	HPS lamp	
	measure	simulate
THD_U (%)	6.74	6.95
THDI (%)	5.71	5. 96



a)



b)

Fig. 9. Measured (left) and simulated (right) harmonic spectra:
(a) Lamp currents (b) Lamp voltages

By observing Figs. 8 and 9 and Table 2, 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. The approximations do not affect the performance of the model, eliminating convergence errors and becoming the simulation easier and faster, without reducing the lamp model performance. Simulation shown in this paper validates the model when compared to experimental results. This model presents the easiest and fastest way to simulate a HID lamp considering its negative resistance feature, without convergence errors.

R E F E R E R E N C E S

[1] *E.E. Hammer, C. Ferreira*, "F40 Fluorescent Lamp Considerations for operation at High Frequency", Journal of the Illuminating Engineering Society, **vol. 15**, N° 1, pp. 63-74, 1985
[2] *M. Sun, B.L. Hesterman*, "PSpice high-frequency dynamic fluorescent lamp model", IEEE Trans. Power Electron., **vol. 13**, no. 2, pp. 261–272, Mar. 1998
[3] *W. Yan, S.Y. Hui*, "A universal PSpice model for HID lamps", IEEE Trans. Ind. Appl., **vol. 41**, no. 6, pp. 1594–1602, Nov./Dec. 2005
[4] *M. Sun, B.L. Hesterman,* "PSpice high frequency dynamic fluorescent lamp model", IEEE Transactions on Power Electronics, **vol. 13**, Issue 2, Mar 1998, pp.261 – 272
[5] *R.N. Do Prado, M. Cervi, Á. Seidel, F. Bisogno,* "Fluorescent Lamp Model Based on the Equivalent Resistance Variation", IEEE Ind. Appl. Soc., **vol. 1**, pp. 680- 684, Oct. 2002
[6] *E.M. Gisela, U. Frank*, Numerical Algorithms with Fortran. Berlin, Germany, Springer, 1996
[7] *C. Cepisca, H. Andrei, S. Grigorescu, M. Perpelea, L. Stancu, V. Dogaru,* "Computerized expert system for lighting grid", Proceedings of the 7th WSEAS International Conference on Circuits, Systems, Electronics and Signal Processing,pp.133-138, Spain, December 2008
[8] *M.D. Teixeira, G. Paulillo, A.R. Aoki, D.L. Archanjo*, "Harmonic Distortions Produced by Compact Fluorescent Lamps in Distribution Networks", Proceedings of the 4th WSEAS International Conference, Prague, Czech Republic, March 13-15, 2005
[9] *G.W. Chang,* "Characterizing harmonic currents generated by fluorescent lamps in harmonic domain", IEEE Trans. Power Del., **vol. 20**, no. 4, pp. 1687– 1689, Oct. 2003
[10] *U. Mader, P. Horn*, "A Dynamic Model for the Electrical Characteristics of Fluorescent Lamps", IEEE - IAS'92, Anais, pp 1928-1934
[11] *P. Mihai, M.O. Popescu*, "Mathematical models used in quality management of the electrical energy", U.P.B. Sci. Bull., Series C, **vol.70**, pp.111-121,2008.