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Compact modeling of electrical LED module for analysis of LED driver system

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ABSTRACT

A new nonlinear compact LED model is presented in this paper. The model is useful in the design stage of LED driver system. The parameter extraction procedure is presented step by step. Since the power of a single LED unit is very low, manufacturers often arrange LED units in the form of an array named LED module. On the basis of theoretical I-V characteristic curve of the LED module, the electrical performance of LED module can be tested according to the rated parameters provided by its manufacturers. Five fitting methods are used to obtain the fitting curves. The sum of squares due to error (SSE) and the coefficient of determination (R-square) are compared to choose a better fitting curve. Six terms gaussian fitting method, which has optimal fitting performance among the five methods, is chosen to construct the nonlinear mathematical model of the LED module, and then the simulation model is built with MATLAB/Simulink. A Boost converter simulation circuit adapts this model, and a 25 W dimming prototype is designed to verify the validity of the model. The simulation and test results show that the error of the model is small, and it meets the requirements of practical application.

1. Introduction

Owing to high luminous efficiency as shown in Table 1, light-emitting diode (LED) lightings are expected to occupy a large proportion in the field of lighting for the coming decades. Compared with other traditional lighting sources, with its special physical structure, electrical, and optical characteristics, LED possesses its own advantages, such as low power consumption, long lifetime, environmentally friendly, small size, easy dimming and so on [1–8]. Since the power of individual LED unit is limited by packaging technology and thermal management, LED module usually consist of many low-power LED units.

Besides, with the development of LED lighting key technology, the cost of LED decreased greatly and LED has been widely used in home lighting and decoration, urban landscape lighting, backlighting of display, road traffic lighting and other fields [9–15].

A fixed resistor of full load is often used to replace the actual variable resistor of LED module in the stage of simulation and design, greatly reducing the reliability of the simulation results and the fitness with practical application. Although the use of fixed resistance method is relatively simple, this method has more error in practical applications, especially in the LED module dimming applications. In particular, as the bias voltage on the LED increases gradually, the rate of change of the forward current increases exponentially, on the basis of the I-V characteristics of the diode [16].

Therefore, it is very important to establish a practical and accurate simulation model to simulate the I-V characteristics of the

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Table 1
Luminous efficiency of several lamps.

Light source	Luminous efficiency(lm/W)
Incandescent lamp	15
Mercury lamp	65
Fluorescent lamp	80
Electrodeless lamp	90
High voltage sodium lamp	120
LED lamp	180

actual LED module based on the parameters of the rated voltage and rated power provided by the manufacturer to optimize the design of LED driver system. In practical application, the LED module operates under its rated parameter range. In this interval, the I-V characteristic curve of the system is nonlinear. Apparently, the ideal simulation model of LED module should be able to show its nonlinear characteristics accurately. An approximate linear equivalent model is proposed in the literature [17], consisting of a diode, an equivalent power supplies and an equivalent resistance. But the I-V characteristics below the linear region cannot be accurately depicted in this model. Literature [18] did some improvement on the basis of literature [17], adding a series of branches with the same structure but different parameters in parallel. However, to show the LED I-V characteristics more accurately, more branches are needed. Literature [19] expands approximate expression in the form of Taylor expansion in the condition of knowing precise parameters and the approximate expression of LED beads. Then the method of looking-up tables was used to simulate LED I-V characteristics accurately in SIMPLIS. However, this method is not very suitable for LED module since the LED module manufacturers often do not give some detailed parameters to users.

Based on the measured data of LED module, this paper constructs a nonlinear simulation model of LED module working under the rated parameter range. The model assumes that the LED module is well dissipated. This paper only uses the voltage and current data tested under the rated voltage range to obtain the nonlinear mathematical model of the LED module. On this basis, the simulation model was built with MATLAB/Simulink, and the validity of the model was verified by 25 W Boost dimming LED test circuit.

2. Mathematical model and simulation model of LED module

This paper takes a solar street lamp as an example to establish its mathematical model and simulation model. The validity of the model is verified by simulation and experiment. The rated voltage of the street lamp is 18 V and the rated power is 25 W.

Firstly, Chroma DC source was used to measure the voltage and current data of the LED module, as shown in Table 2.

Then, several fitting curves and their expressions are attained by MATLAB based on the measured data.

2.1. Three terms Fourier fitting

The expression attained by three terms Fourier fitting is as follows.

$$f(x) = a_0 + a_1 \cdot cos(x \cdot w) + b_1 \cdot sin(x \cdot w) + a_2 \cdot cos(2 \cdot x \cdot w) + b_2 \cdot sin(2 \cdot x \cdot w) + a_3 \cdot cos(3 \cdot x \cdot w) + b_3 \cdot sin(3 \cdot x \cdot w) \tag{1}$$

Where $a_0 = 0.7612$, $a_1 = -0.4908$, $b_1 = 0.8581$, $a_2 = -0.02501$, $b_2 = -0.2524$, $a_3 = 0.003567$, $b_3 = 0.07159$, $w = 0.7811$ 。

Fig. 1 can be plotted according to (1).

2.2. Five terms sum of sine fitting

The expression attained by five terms sum of sine fitting is as follows.

$$f(x) = a_1 \cdot sin(b_1 \cdot x + c_1) + a_2 \cdot sin(b_2 \cdot x + c_2) + a_3 \cdot sin(b_3 \cdot x + c_3) + a_4 \cdot sin(b_4 \cdot x + c_4) + a_5 \cdot sin(b_5 \cdot x + c_5) \tag{2}$$

Table 2
Voltage and current data of LED module.

Voltage (V)	13.994	14.487	14.797	14.99	15.087	15.19	15.285	15.386	15.492
Current (A)	0	0	0.0007	0.0045	0.0082	0.014	0.0224	0.0352	0.0538
Voltage (V)	15.592	15.684	15.787	15.892	15.994	16.09	16.19	16.291	16.395
Current (A)	0.076	0.1015	0.1327	0.1695	0.21	0.2505	0.297	0.347	0.4
Voltage (V)	16.484	16.588	16.687	16.794	16.883	16.986	17.09	17.192	17.282
Current (A)	0.4476	0.5052	0.5625	0.6265	0.6814	0.748	0.814	0.883	0.945
Voltage (V)	17.386	17.485	17.576	17.68	17.78	17.889	17.976		
Current (A)	1.02	1.0937	1.1593	1.2382	1.3175	1.4035	1.4775		