Design and Implementation of a New Electronic Load for the Study of LED Driver

Tianhu Wang*#, Shanzhi Mou#, Yue Hu#, Yuntao Wu# and Tianyu Chen

Abstract—**Electronic load can be used to test the characteristics of LED driver in the field conditions. In this work, a new electronic load for LED driver is designed, which could simulate the nonlinear volt-ampere characteristics of LED module. In order to study the real-time control performance of the system when setting the working current, a PID controller and a fuzzy-PID controller were designed based on the flexible online programming and control of LabVIEW software. At the same time, the mathematical model of the electronic load is calculated based on the theoretical volt-ampere characteristic curve of the LED module. The results show that the combination of fuzzy logic and PID control can make the design of the new electronic load get better control effect and meet the needs of practical application.**

Index Terms—**LED driver, electronic load, PID control, fuzzy-PID control, current control**

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I. INTRODUCTION

In recent years, LED has gradually replaced traditional light sources and has become the main candidate products for future lighting, because of its superior energy efficiency, environmental protection, low price, and long service life [1]. An LED luminaire consists of an LED module, heat dissipation components and an LED driver. The function of LED driver is to convert alternating current into direct current suitable for the normal operation of LED light source [2]. Although the lifetime of the LED is as high as 100,000 hours, the LED driver directly restricts the luminous quality of the product and the overall performance of the lighting system [3]. In the design and experiment stage of the LED driver, researchers often choose a fixed resistor to replace the real LED module, but fixed resistor cannot simulate the non-linear volt-ampere characteristics of LED, which directly reduces the accuracy and reliability of the experimental results.

Electronic load is a kind of intelligent load designed with computer control technology as the core. It can simulate multiple types of loads [4]. It can be used in the terminal of self-excited induction generator to simulate the characteristics of voltage regulation and constant frequency [5]. At present, some manufacturers have developed electronic loads to test LED drivers, but these products are expensive and structurally fixed. When used in the research and development phase, the cost of the experiment will increase. In this paper, a low-cost, accurate and stable electronic load is designed according to the characteristics of LED driver.

The selection of control algorithm is the core of programmable electronic load controller [6]. It is necessary to select an appropriate control algorithm. At present, the PID algorithm is widely used in controllers because of its simple structure and clear physical meaning [7]-[8]. As the parameters of PID control are fixed, it cannot quickly adapt to the non-linear changes of the system. Fuzzy-PID control could automatically adjusts the parameters of the PID control based on the system deviation and rate of change of deviation to improve the performance of the controller. For example, the power-electronic Buck converter can be adjusted intelligently by using Fuzzy-PID control [9]. The electronic load controller designed in this paper combines fuzzy logic technology to automatically adjust the proportion, integral, and differential coefficients of the controller in order to obtain better control.

The organizational structure of this paper is as follows. Section 2 describes the overall design of the system. Section 3 explains the hardware design of the electronic load. Section 4 introduces the design of controller based on LabVIEW platform. Section 5 presents the experimental results and discussions. Section 6 summarizes this work.

II. SYSTEM DESCRIPTION

This article describes a new electronic load that can be used in LED driver research. Figure 1 is the structure of the electronic load system, including power module, data acquisition module, and control module. The USB-3102A multi-function data acquisition card is selected in this paper. It has 16 analog input and two analog output interfaces. The voltage range of the all interfaces is below 10V.

The current control module of the electronic load compares the collected current value with the set current value. The current adjustment value is obtained by using a control algorithm. The electronic load eventually works stably at the set current.

In addition, based on the measured data of the LED module, the system constructs a nonlinear simulation model in which the LED module operates within the rated parameters. This article takes an LED module with a rated power of 3W as an example. The DC power supply is used to output voltage signals of different amplitudes to measure the current value of the LED module. The test results are shown in Table I.

Based on the data of Table I, the second-order Gauss fitting function is selected by using MATLAB curve fitting tool. The fitting function expression (1) and its fitting curve (Fig. 2) of the test results are obtained.

$$y=a1*e^{-\left(\frac{x-b1}{c1}\right)^2}+a2*e^{-\left(\frac{x-b2}{c2}\right)^2} \quad (1)$$

Where a1=0.3666, b1= 9.791, c1= 0.8672, a2= 0.06386, b2=8.6, c2= 0.5447

TABLE I

VOLTAGE AND CURRENT VALUES OF LED MODULE

Voltage(V)	5.44	6.76	6.90	7.24
Current(A)	0	0	0.00005	0.00007
Voltage(V)	7.33	7.45	7.51	7.54
Current(A)	0.00013	0.00036	0.00065	0.00087
Voltage(V)	7.56	7.61	7.66	7.68
Current(A)	0.0011	0.0017	0.00274	0.00328
Voltage(V)	7.72	7.76	7.88	8.09
Current(A)	0.00416	0.00612	0.0175	0.03644
Voltage(V)	8.38	8.54	8.78	8.98
Current(A)	0.07844	0.109	0.15307	0.18998
Voltage(V)	9.19	9.39	9.43	9.47
Current(A)	0.2492	0.303	0.31103	0.32805

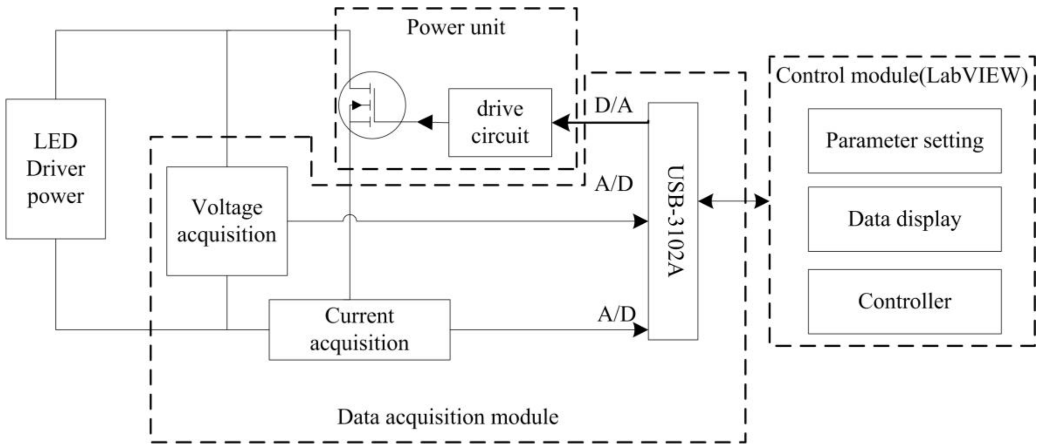

Fig. 1. Structural diagram of the system

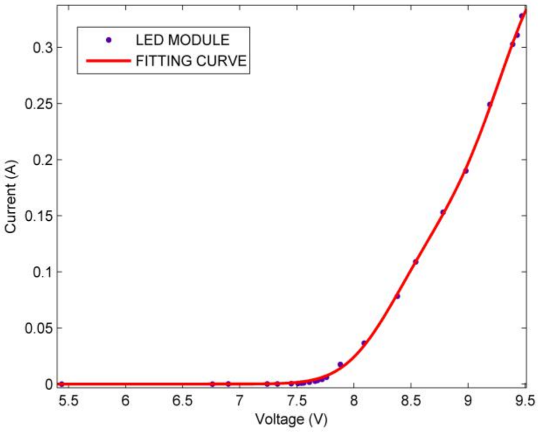

Fig. 2. Fitting curve of LED module

It can be seen from Fig. 2 that the fitting curve is very close to the actual measuring point. The mathematical model could be used to simulate the nonlinear volt-ampere characteristics of the LED.

III. CIRCUIT DESIGN

The circuit diagram of the electronic load is shown in Fig. 3. As an energy-consuming device, the MOSFET replaces the original power resistor and makes the output current controllable. The MOSFET used in this design is IRF540. The analog input interface of the USB3102A has a voltage range of less than 10V. The voltage value is obtained by a voltage dividing circuit in the voltage sampling circuit. In the current sampling circuit, the current is converted into voltage by the sampling resistor, and the voltage of the sampling resistor is amplified by the differential amplifier circuit.

The analog output interface outputs the control voltage (V_{ref}) of the hardware circuit. When the voltage of the no-inverting input of the operational amplifier (*U3*) is greater than that of the inverting input, the output of *U3* is increased, and the conductivity of MOSFET is increased, thus the current flowing through R0 is increased. Therefore, the function of the circuit can be changed by controlling the value of V_{ref}.

Since the hardware circuit of the manual soldering has some uncertainties, in order to obtain the actual conversion formula of the circuit, the hardware circuit can be tested under while the MOSFET is turned on. The value of V_{ref} is adjusted by software to obtain the current (I_q) of the sampling resistor. The specific values of V_{ref} and I_q are shown in Table II.

TABLE II

CURRENT AND VOLTAGE VALUES OF THIS HARDWARE CIRCUIT

Vref (V)	1	2	3	4	5
Iq (A)	0.101	0.198	0.295	0.392	0.488
Vref (V)	6	7	8	9	10
Iq (A)	0.584	0.680	0.776	0.872	0.967

The relationship between V_{ref} and the acquisition current I_q is obtained as (2) by data fitting.

$$V_{ref}=10.39*I_q-0.063 \quad (2)$$

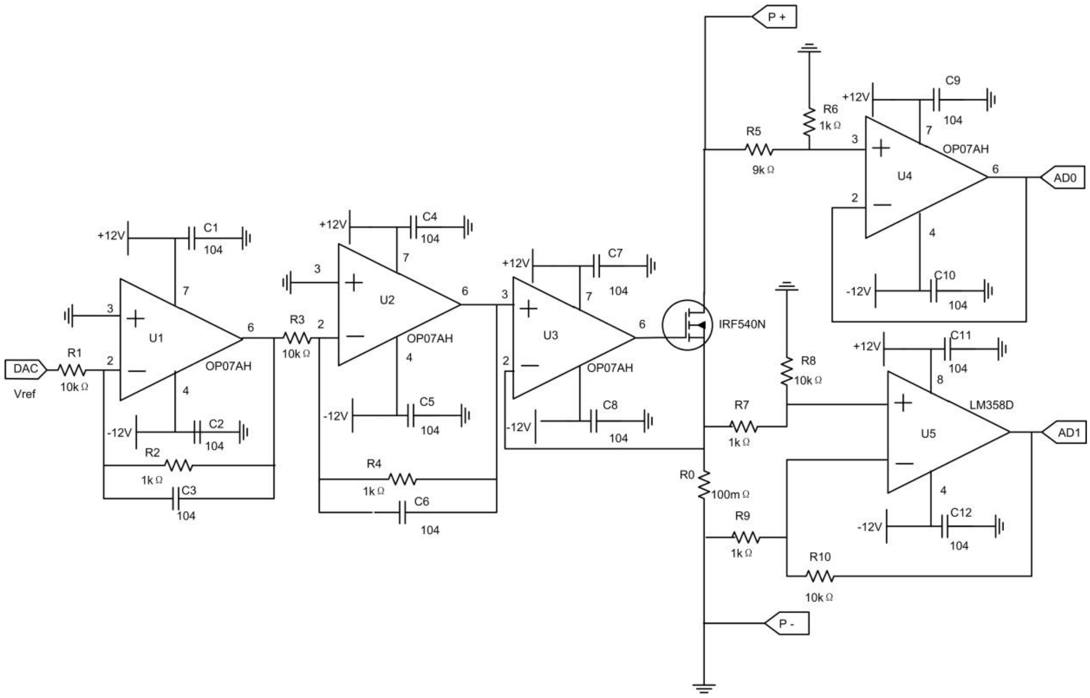

Fig. 3. Detailed circuit diagram of electronic load

In order to simulate the volt-ampere characteristics of the LED module, the voltage (U_q) and current (I_q) of the electronic load are brought into (1) to obtain (3).

$$Iq=0.3666*e^{-\left(\frac{Uq-9.791}{0.8672}\right)^2}+0.06386*e^{-\left(\frac{Uq-8.6}{0.5447}\right)^2} \quad (3)$$

Formula (3) shows that by setting different U_q, the corresponding I_q can be calculated. Then the value of the control voltage of the hardware circuit is obtained by (2).

IV. CONTROL STRATEGY

This system uses LabVIEW software to design control module. In this paper, two real-time controllers, ordinary PID control and Fuzzy-PID control, are adopted respectively.

A. Ordinary PID control algorithms

PID control is a combination of proportional, integral and differential control, which is a relatively mature and widely used control. The PID control block diagram of LED electronic load is shown in Fig. 4.

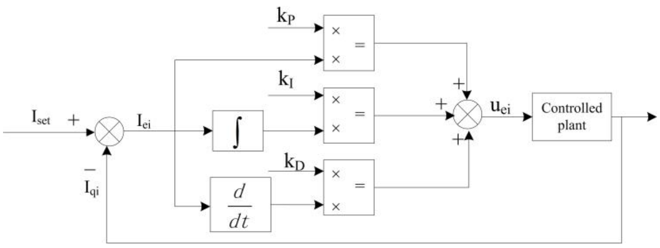

Fig. 4. PID control block diagram

The PID controller generates the control signal U_{ei} according to the deviation (I_{ei}) in formula (4) and the PID control algorithm given in formula (5). In formula (4), I_{set} is the set current and I_{qi} is the collected current value. Through the built-in graphical user interface module in LabVIEW, the calculation and identification of deviations are realized. After setting the proportional gain k_P, integral gain k_I and differential gain k_D of the controller manually for many times, the performance of the controller is compared and the optimal coefficients are selected.

$$I_{ei}=I_{set}-I_{qi} \quad (4)$$

$$u_{ei}=k_P I_{ei}+k_I\int_0^t I_{ei}dt+k_D\frac{d}{dx}I_{ei} \quad (5)$$

B. Fuzzy-PID control algorithms

The detailed block diagram of the Fuzzy-PID is shown in Fig. 5. It estimates the three coefficients of PID according to the input deviation and rate of change of deviation. Deviation (I_{ei}) and rate of change (I_{eci}) are the input of the fuzzy controller. The proportional gain $k_P=k_{P0}+\Delta k_{Pi}$, integral gain $k_I=k_{I0}+\Delta k_{Ii}$, and differential gain $k_D=k_{D0}+\Delta k_{Di}$ in PID control are adjusted online by fuzzy reasoning, where k_{P0}, k_{I0} and k_{D0} are initial PID gains. The range of I_{ei} (unit: mA) and I_{eci} are determined to be [-15, 15] and [-3, 3], and the range of Δk_{Pi}, Δk_{Ii} and Δk_{Di} are [-9, 9], [-0.9, 0.9] and [-0.3, 0.3].

In the design of fuzzy controller, triangle membership function is selected. The fuzzy sets of input and output are {NB, NM, NS, O, PS, PM, PB}. I_{ei} and I_{eci} are transformed into fuzzy variables E and EC. Based on the E and EC rule base, the conditional statements such as "IF E IS NB AND EC IS NM THE Δk_{Pi} IS PB, Δk_{Ii} IS NB AND Δk_{Di} IS NS". The area center method is used to de-ambiguity the estimated fuzzy output. Finally, combined with the PID controller, the system calculates the control command signal based on the feedback deviation.

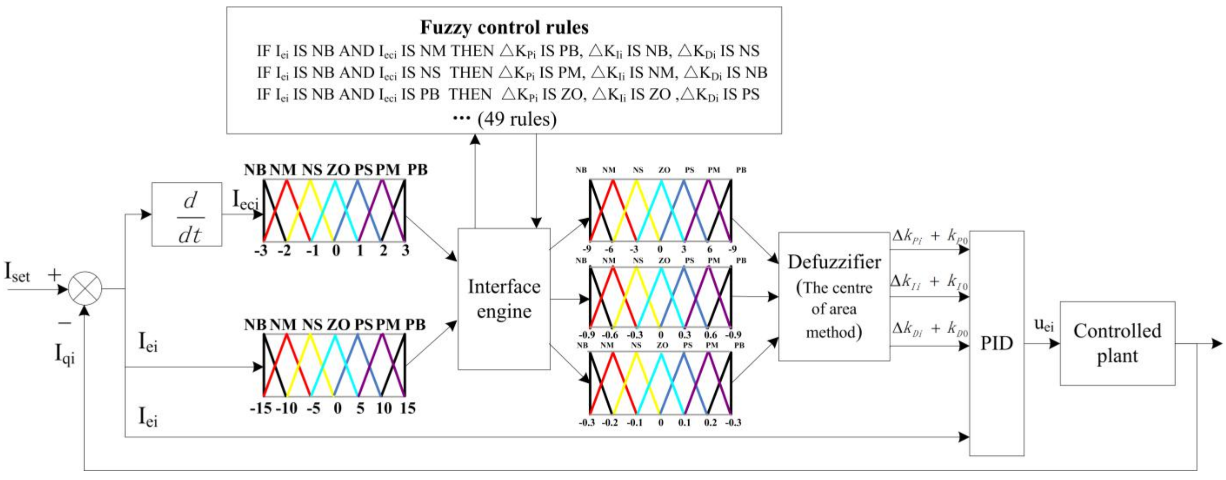

Fig. 5. Fuzzy-PID control block diagram

V. RESULTS AND DISCUSSIONS

When studying the LED constant current driver, Figure 6 and Figure 7 respectively show the system response of the LED electronic load using the normal PID control and the Fuzzy-PID control when determining the current value (I_{set}). A current requirement of 400 mA is set in both cases, represented by a continuous black line.

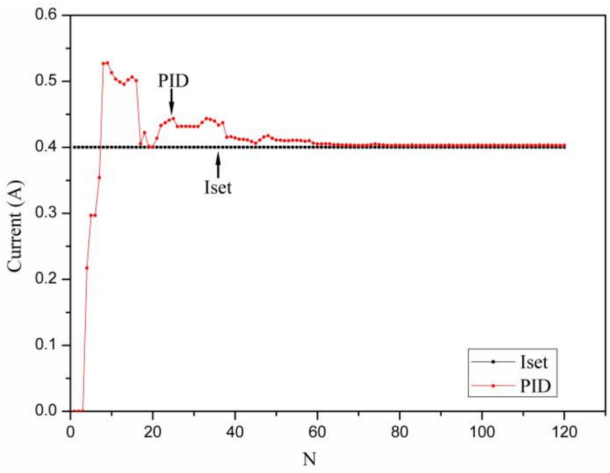

Fig. 6. Response curve of PID

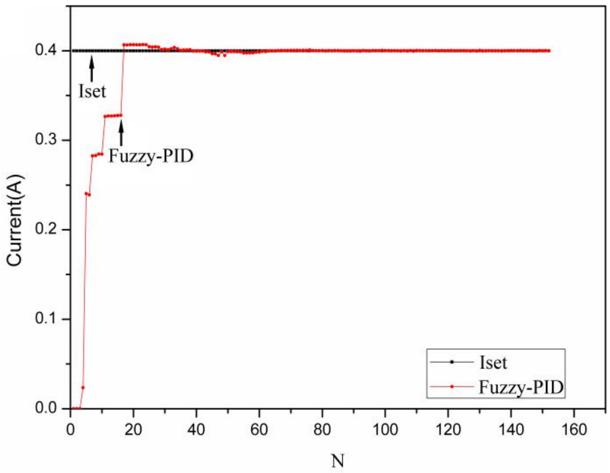

Fig. 7. Response curve of Fuzzy-PID

The experimental results show that under the same sampling conditions, the time for the PID controller to reach the stable state is longer than that for the Fuzzy-PID controller. On the other hand, the overshoot of the ordinary PID controller is large. Because the three parameters of the Fuzzy-PID controller can be adjusted online according to the deviation and rate of change of deviation, the Fuzzy-PID controller has smaller overshoot and the transition process is more stable. Since the control effect of the Fuzzy-PID in the LED electronic load is better than that of the PID controller, the system selects the Fuzzy-PID control for the next analysis.

In order to verify whether the system can simulate the nonlinear volt-ampere characteristics of the LED module, a DC power source is used as the power source to be tested. The real-time current of the electronic load is obtained by changing the power supply voltage.

Figure 8 is an I-V curve of the LED electronic load. The black curve in the figure is the I-V curve of the real LED module in Table I.

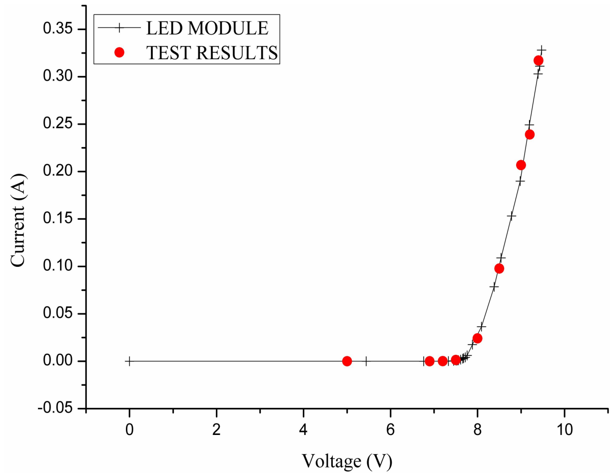

Fig. 8. Comparison of test result and fitting curve of LED module

It can be seen from Fig. 8 that all test results are near the fitted curve. So the system can simulate the volt-ampere characteristics of LED modules under steady state conditions.

VI. Conclusion

In this paper, an electronic load for the research of LED driver supply is designed by using low-cost hardware circuit and LabVIEW software. According to the characteristics of the system, a general PID controller and a Fuzzy-PID controller are designed and compared. In the case of setting the same target value, compared with the PID controller, the Fuzzy-PID controller can make the system more smoothly and faster to achieve a stable state.

At the same time, the mathematical model of the system can be obtained according to the measured voltage and current of the LED module. It can be seen from the experimental results that the electronic load can simulate nonlinear volt-ampere characteristics very well and can be used as an alternative to the LED module in the research of LED driver.

References

[1] S. Pimputkar, J.S. Speck, S.P. Denbaars, and S. Nakamura, "Prospects for LED lighting," *Nature Photonics*, vol. 3, no. 4, pp. 180–182, 2009.

[2] W. D. Van Driel, X.J. Fan and G. Q. Zhang, *Solid state lighting reliability part 2*. Switzerland: Springer, 2017, pp.433-454.

[3] M. H. Chang, D. Das, P. V. Varde and M. Pecht, "Light emitting diodes reliability review," *Microelectronics Reliability*, vol. 52, no. 5, pp. 762-782, 2012.

[4] S. Upadhyay, S. Mishra and A. Joshi, "A Wide Bandwidth Electronic Load," *IEEE Transactions on Industrial Electronics*, vol. 59, no.2, pp. 733-739, 2011.

[5] B. Singh, S. S. Murthy and S. Gupta, "Analysis and design of electronic load controller for self-excited induction generators," *IEEE Transactions on Energy Conversion*, vol. 21, no. 1, pp. 285–293, 2006.

[6] U. K. Kalla, B. Singh and S. S. Murthy, "Modified Electronic Load Controller for Constant Frequency Operation with Voltage Regulation of Small Hydro-Driven Single-Phase SEIG," *IEEE Transactions on Industry Applications* vol. 52, no. 4, pp. 2789-2800, 2016.

[7] P. Shah and S. Agashe, "Review of fractional PID controller," *Mechatronics*, vol. 38, pp. 29-41, 2016.

[8] Y. Li, K. Ang and G. C. Y. Chong, "PID control system analysis and design," *IEEE Control Systems Magazine*, vol. 26, no. 1, pp. 32-41, 2006,

[9] A. N. Al-Rabadi and M. A. Barghash, (2012). "Fuzzy-PID control via genetic algorithm-based settings for the intelligent DC-to-DC step-down buck regulation," *Engineering Letters,* vol. *20*, no. 2, pp.176-195.