Research on LED driving power supply without electrolytic capacitor

Qiyan Yan*[,a], Lixin Ma[a,1], Lei Li[a,2], Zufeng Li[b,3]

[a]Mechanical and Electrical Engineering Department, Guangdong University of Science and Technology, Dongguan 523083, China; [b]Dongguan City Perfect Science & Technology Co., Ltd.

ABSTRACT

Aiming at the problem that the life of electrolytic capacitor is short, which restricts the life of LED drive power supply, this paper studies the LED drive power supply without electrolytic capacitor. Based on the analysis and research of the existing LED driving power supply, the method of organically combining the voltage stabilizing circuit of the non-polar capacitor with the linear control driving circuit of the partial voltage rectification is adopted. The non-polar capacitor is used to replace the electrolytic capacitor, which reduces the magnetic and thermal losses of the power supply, extends the switching frequency life of the LED lamp, and provides a new design method for the popularization and wide application of the LED driving power supply.

Keywords: without electrolytic capacitor, LED driving power supply, high power factor,AC-DC LED drive

1. INTRODUCTION

LED light source has the advantages of environmental protection, energy saving, long life, high reliability, etc. In recent years, LED lighting has become the leading product in the market and gradually replaced the traditional light source [1-2]. At present, LED drive power supply has the problems of low efficiency and short service life, which has been a difficult problem for technical researchers. When the temperature of the electrolytic capacitor, the key component in the power supply, is 75 ℃, the electrolyte evaporation causes the service life of the capacitor to decline, and its service life is 20% of the average continuous working life of the semiconductor device, which seriously affects the service life of the entire LED drive power supply [3]. It can be seen that the circuit components inside the driving power supply limit the energy efficiency and life of LED, and the elimination of electrolytic capacitor is the key to match the life of LED lighting system with that of LED [4].

In order to ensure the heat dissipation performance of LED power supply, the heat dissipation design should be emphatically analyzed and considered when designing LED power supply drive, so as to achieve the ultra-long service life of LED. At present, many manufacturers have introduced LED lighting systems without electrolytic capacitors or replaced electrolytic capacitor systems with high-capacity capacitors and ceramic capacitors. Because electrolytic capacitor increases the practicability and reliability of LED system, it cannot be removed separately. If there is no electrolytic capacitor or replacement capacitor in the power supply, the power supply system will be vulnerable to the interference of power grid fluctuations, and the failure caused by lightning stroke will greatly increase.

In order to reduce the ripple effect and improve the LED lighting effect, the current LED drive power supply is divided into two-stage and single-stage structures [5-6]. Compared with the two-stage structure, the single-stage structure has simpler control and lower cost, but there are problems of low power factor and large output voltage ripple [7]. In addition, the electrolytic capacitor with short service life is used as the energy storage element in both structures, thus affecting the overall life of the power supply. Therefore, it is of great significance to study a single-stage LED driver with high power factor and long life.

*84652886@qq.com;[1]904468001@qq.com; [2]390529669@qq.com; [3]1264341361@qq.com

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In order to improve the performance and life of LED drive power supply, two objectives need to be achieved: one is to have the power factor correction function, and the other is to reduce the ripple of output voltage. Because electrolytic capacitors with short service life are used in the method of reducing ripple, shortening the overall service life of the product will affect the use and promotion of LED lighting mode, so this paper studies the method of improving power factor and realizing the method of no electrolytic capacitor. The LED driving power supply without electrolytic capacitor studied in this paper uses non-polar capacitor instead of electrolytic capacitor to improve the life of LED driving power supply, and provides a new research idea for the development of LED driving power technology.

2. OVERVIEW OF LED DRIVE POWER SUPPLY WITHOUT ELECTROLYTIC CAPACITOR

2.1 Topology

Switched AC-DC LED drive power supply is often composed of rectifier, filter, power factor correction PFC, power conversion and other functional circuits, which can be divided into isolated and non-insulated, single-stage and multi-stage. Among them, the isolated type has the characteristics of variable voltage, multiple-output and electrical isolation. The multi-stage topology can better take into account the optimization design of indicators such as long life, low ripple, high power factor and high efficiency. Therefore, Isolated multilevel topology is more suitable for driving high-performance high-power LED light sources [8].

2.2 Mathematical model

LED load characteristics are nonlinear functions and greatly affected by temperature, which is not convenient for control design. Therefore, a large number of scholars have studied their approximate models, mainly including dynamic resistance model, multi-branch equivalent circuit model, Taylor series expansion model, state-space average model and thermoelectric model [9-10]. Among them, the DUR model composed of ideal diode, voltage source and dynamic resistance, although it is difficult to describe the true characteristics of the light source in the nonlinear region below 10 mA, can accurately reflect the volt-ampere characteristics of the cut-off and conduction sections, and has a simple structure, which has been successfully applied to the design of LED drive power source.

For the AC-DC LED drive control system, its closed-loop transfer function is based on the LED approximation model and the small signal model of the DC-DC converter, and fully considers the factors such as sampling, modulation, delay, etc. [11-12]. In 2018, Leng Minrui and others established an improved third-order discrete model of the system for the Buck-type LED drive power supply controlled by the peak current mode using the discrete time modeling method, which can effectively and accurately describe the dynamic characteristics of the system.

In short, due to the nonlinear, time-varying and discrete characteristics of LED light source and DC-DC converter, it is difficult to establish a mathematical model that can accurately describe the dynamic characteristics of the converter and is easy to design the controller. It is also the key to the design of high-performance LED drive power supply.

2.3 Control strategy

For AC-DC LED drive power supply, adaptive control can not only improve dynamic and static performance indicators, but also improve dimming characteristics, improve conversion efficiency and reduce ripple current [13-14]. The literature research shows that the composite control strategy of adaptive feedback and feedforward is adopted to implement the control, which can effectively improve the dynamic performance index and efficiency of the converter, and reduce the peak value of low frequency secondary ripple current to 4% [15-16]. Therefore, the adaptive digital predictive average current control mode based on the state observer is conducive to improving the closed-loop characteristics of the LED drive power supply. At the same time, the optimal design of performance indicators such as dynamic static characteristics, low ripple and high efficiency can be carried out, which represents a development direction of digital control strategy.

2.3.1 Adaptive digital current predictive control

The full digitalization of the driving power supply has many advantages. Its control performance is affected by high-speed sampling, modulation delay, model accuracy and other factors[17-18]. Adaptive digital predictive current mode control is beneficial to improve the closed-loop performance of the converter. The research focuses on current prediction and control algorithm. The state observer method is a good choice for current prediction, and its convergence, rapidity and prediction accuracy are relatively high. Adaptive PID is beneficial to improve the dynamic and static performance and robustness of the converter. Because the transfer function changes with the change of the working point, a lot of learning is required to complete the parameter calibration of the new working point[19-20]. Therefore, appropriate dimming gradient can be selected, the transfer function of the new working point can be quickly obtained by using the look-up table method, and the fuzzy adaptive algorithm can be selected to optimize and adjust the PID parameters. This method requires a lot of offline learning, but it can effectively reduce the amount of calculation in the process of operation, which is more conducive to engineering implementation.

2.3.2 ARC control strategy

The effect of ARC ripple compensation is limited by the control strategy, ripple transfer function and sampling accuracy, etc[21-22]. It is not easy to achieve good compensation effect in the whole dimming range. The research shows that the ARC with adaptive feedback and feedforward control can effectively reduce the low-frequency ripple component in a wide output range, but its implementation is difficult and not convenient for practical application[23-24]. For this reason, a half-cycle energy balance ARC control strategy is proposed. This strategy adaptively adds an amount of change in the reverse direction of the periodic low-frequency ripple on the reference duty cycle to balance the pulsating energy. The adaptive low-frequency ripple estimation and compensation parameter adjustment can be realized based on the aforementioned adaptive control idea.

2.3.3 Energy synchronous transmission control

For APFC, the large value of high-frequency switching ripple voltage at both ends of the filter capacitor will cause the equivalent series resistance to heat, thus reducing its reliability, life and efficiency[25-26]. To solve this problem, a control strategy of energy synchronous transmission is proposed, so that the large amplitude high-frequency pulse energy at both ends of the APFC filter capacitor can be synchronously transferred to the post-stage DC-DC, and then transferred to the post-stage output filter capacitor after voltage reduction [27]. In order to ensure the PFC and PC functions of the two-stage converter, this strategy can not achieve complete energy synchronous transmission, but can reduce the high-frequency pulse energy of the APFC output filter capacitor to a certain extent, and achieve the purpose of extending the life.

3. ANALYSIS OF LED DRIVE POWER SUPPLY WITHOUT ELECTROLYTIC CAPACITOR

3.1 Circuit principle block diagram

The schematic block diagram of the circuit is shown in Figure.1, which mainly includes three functional modules, namely, filter buck rectifier module, shunt sampling control module, and stabilized linear output module.

The filter step-down rectifier module uses a step-down rectifier circuit composed of resistors, non-polar capacitors and rectifiers. According to the load demand, the appropriate voltage drop is selected for the initial step-down, and then rectified to convert 220 V AC into pulsating DC. The module circuit can filter most of the interference ripple in the output voltage after step-down rectification. For the selection of rectifier bridge, the maximum voltage stress of rectifier diode is equal to the maximum value of circuit input voltage, and the calculation formula is shown in Formula 1. Where U_{dmax} is the maximum voltage of the rectifier diode; U_{in} is the circuit input voltage.

$$U_{dmax}=\sqrt{2}\,U_{in}=311\text{ V} \tag{1}$$

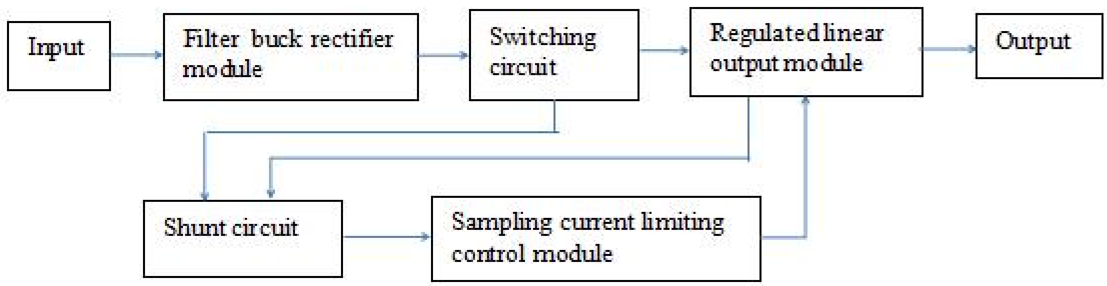

Figure 1. Circuit principle block diagram

The shunt sampling control module controls the charging and discharging of the switch tube to the capacitor by sampling the output voltage, so as to stabilize the output voltage. According to the characteristic that the voltage of the regulator tube is almost unchanged with the change of current within a certain range, the regulator linear output module adjusts the CMOS tube in series with the regulator tube to control the switch tube, thus controlling the charge and discharge of the capacitor. The change of its frequency changes the series capacitive reactance value, thus realizing the control of the capacitor voltage drop.

The circuit schematic uses its linear following characteristic to make the output current change slowly and linearly with the change of input signal; When the AC input voltage is higher than the output DC voltage, the capacitance in the shunt circuit immediately charges the capacitance in the voltage stabilizing circuit, and the load output voltage is effectively compensated, thus stabilizing the output voltage. In the circuit design, because no transformer, electrolytic capacitor and other components are used, the LED drive power circuit has design advantages in energy consumption and reliability.

3.2 Experimental analysis

Table.1 shows the comparison of output parameters of LED drive power supply without electrolytic capacitor and other two mainstream drive power supplies; Table.2 shows the main performance comparison between the LED drive power supply without electrolytic capacitor and the same power drive power supply of other brands. It can be seen from Table.1 and Table.2 that compared with the common resistance-capacitance step-down drive power supply and constant-current drive power supply, the LED power supply has outstanding advantages in efficiency. At the same power, the brightness of the efficient LED drive power supply has significantly improved.

Table. 1 Comparison of output parameters with other two main driving power supply with the same power.

Power supply type	DC output voltage(V)	Output current(mA)	power(W)	efficiency
LED drive power supply without electrolytic capacitor	77.6	184.7	12.20	0.942
Constant current LED drive power supply	34.3	567.8	12.05	0.849
Resistance-capacitance step-down drive power supply	89.9	155.8	12.55	0.885

Table. 2 Main performance comparison of the same power drive power supply with other two brands

Power supply type	**electrolytic capacitor**	**transformer**	**Secondary pressure rise and fall**	**volume**	**Output ripple**	**Linear output**	**Impact on power grid**
LED drive power supply without electrolytic capacitor	No	No	No	Small	More small	Yes	Small
Drive power supply 1 of a certain brand	Yes	No	Yes	Small	More large	No	More large
Drive power supply 2 of a certain brand	Yes	Yes	Yes	More large	More small	Yes	More large

4. CONCLUSION

As a new generation of green energy products, LED lamps have a service life of 100000 hours. Under normal working conditions, the electrolytic capacitor in the LED driving power supply has a service life of several thousand to ten thousand hours. Due to the temperature in the use environment and its own heating, the electrolyte of the electrolytic capacitor gradually volatilizes over a long period of time, resulting in the increase of the equivalent series resistance of the electrolytic capacitor and the intensification of internal heating. The life of the electrolytic capacitor will be reduced by one time when the temperature increases by 10 ℃. It can be seen that the life of the electrolytic capacitor and the life of the LED lamp are seriously mismatched, and the LED drive power supply without electrolytic capacitor can solve the above problems.

This paper summarizes and analyzes the key technology and ripple compensation control strategy of the non-electrolytic capacitor LED drive power supply, analyzes the rationalization index requirements of the non-electrolytic capacitor LED drive power supply, and puts forward the corresponding circuit design method for engineering applications. The test results show that the LED power supply has outstanding advantages in efficiency compared with the commonly used resistance-capacitance step-down driving power supply and constant-current driving power supply. At the same power, the brightness of the LED drive power supply without electrolytic capacitor is significantly improved, while maintaining the constant output current and output voltage, meeting the requirements of LED power supply, which has practical reference value for the design of efficient and reliable LED drive power supply.

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