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Design of a Digital LED Driver with Auto-Identifying Open Strings

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***Abstract*-In this paper, a novel digital control topology for high bright LEDs is proposed. And this driver can identify the open strings in LEDs array automatically to increase the reliability of the LEDs. There are two stages in this topology. The front stage is a PFC circuit controlled by the chip MC33262, and the DC/DC stage is a half bridge circuit controlled by the micro-controller. The output current of the controller is adjusted according to the number of the strings in the open-circuit state, so the current of a single LED ring can keep a constant value even when the number of working LED strings is changed. In the paper, the design process of the system is presented, an 112W prototype is presented in the laboratory, and the experimental results verify the control method proposed in the paper.**

Keywords-LED driver; current closed-loop; resonant converter; constant current converter; open-circuit protection

I. INRUDUCTION

With the development of LED packaging technology and manufacturing process in the lighting field, high-power LED has been widely used. In 2009, the government plan of "10 City, 10000 LEDs" works to promote the development of China's LEDs. LED street lighting has been rapidly developed in many cities. And many cities have introduced LEDs demonstration Street.

The power of Street LED lights is between 100W-200W. Because a single LED has low power level, we can use series and parallel LED arrays. The optimum drive mode for LEDs is constant current power supply [1-2].However, many LEDs used in the street lighting are driven by constant voltage power, and this has a great influence on the life of the LEDs.

The most common failure for LEDs is open failure in the series branch. If there is an open-circuit fault in a signal LED, the whole series LEDs will be extinguished. In high-power lighting applications, more parallel branches are used .If each branch is driven by an independent constant-current power supply and has an open-circuit protection, it will make the size of LED driver too large. To the integrated driver, it is difficult to keep the current flowing through each LED string a constant value.

If total current loop is adopted, once the multi-parallel branch have a bunch of open circuit, current in the other parallel branch is bound to increase, it will cause a chain reaction that other branches start to appear open faults, until all the parallel branch open.

In order to solve this problem, a novel LED drive strategy based on auto-identifying open strings in LEDs array is proposed. The design method of the power circuit and control strategy is presented. Experimental results are also given to verifying the validation of the proposed driver.

II. CRICUIT ANYLYSIS

Fig.1 shows the proposed lighting system. The full power of the LED driver shown in Fig.1 is 112W. The system consists of eight parallel branches, with 14 LEDs in each branch. The driver has two power stages. The former is the power factor correction circuit, which can realize the power factor correction function and provide a stable dc bus voltage for the latter stage [3-4]. The latter is a resonant half bridge DC/DC current source converter, which supplies a constant total average current for LEDs array by adjusting the switching frequency. MC68HC908KX8 by Freescale is adopted here to control the LED lighting system. The open-circuit signals are detected by the MCU, and the MCU can adjust the working frequency to keep the total average current constant. The eight open-circuit signals are named as A, B, C, D, E, F, G, H. A sampling circuit consists of a current transformer, a half-wave rectifier and a low pass filter. The average current is sampled here to obtain the information of the total driving current for the array. With ADC module of the MCU, the value of the total current for the system is obtained by the MCU.

A. Design of the active power factor corrector

In the small and medium power applications, boost controller with a critical conduction mode (CrM) power factor correction is usually adopted to be the PFC circuit with 400V bus voltage. However, the input voltage for the LED array is usually 48V, which makes the voltage transfer ratio of the resonant half bridge DC-DC converter very low. So there is too much reactive power exchange in the half bridge and the output capacitor, and it also makes the adjustment frequency ranging scope for different open-circuit number too broad, which makes it difficult to design the EMI filter of the system. In this article, we mainly study the driving of LED array, so in spite of the problems, the boost CRM mode APFC circuit is still adopted. In the future work, some other PFC converter with lower bus voltage will be used to replace the boost CRM mode APFC.

B. Resonant DC-DC current source converter

Resonant DC-DC current source converter consists of a class-D resonant converter, a rectifier and the LEDs array as the load.

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In the process of the current adjustment, the voltage change for the LED load is very little, so the LED array can be assumed as a constant voltage load, whose value is set to 46V.

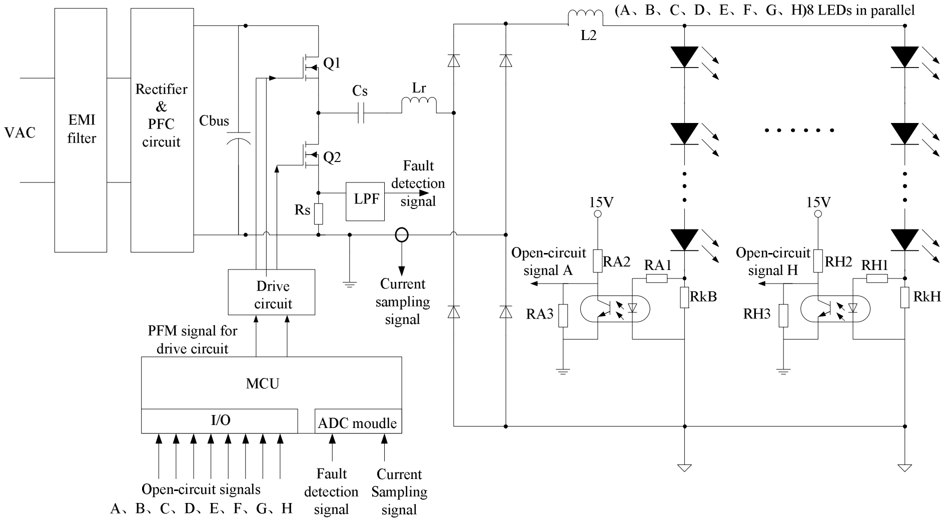

Fig.1 Proposed LED lighting system

We can also assume that the rated current of each LED is 330 mA. The equivalent impedance of each LED string can be approximated as 140Ω, so 8 strings can be equivalent to 17.5Ω.

The equivalent circuit is shown in Fig.2. The DC bus voltage is 400V, therefore the RMS value of the fundamental component of the voltage for the half-bridge midpoint is $\sqrt{2}U_{BUS}/\pi$ =180V [5].

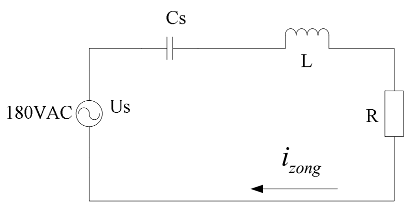

Fig.2 Equivalent circuit of the LED driver

Considering the characteristics of the series resonant circuit with LC type, we can see the parallel equivalent impedance increases and the total current decreases step by step, with increasing number of broken LED rings. We can find that the frequency will increase greatly.

The switching frequency under the full load is set to 35 kHz. In order to limit the high switching frequency, when 5 branches are all in the open-circuit state, the switching frequency is set to100 kHz.

Considering Cs has little effect on the result, it can be selected to 100 μF. The process of calculating inductor L can be got from the reference [6]. From the reference, we can see that $L = 507\mu F$.

Based on the parameters C_S and L calculated above, the figure if the average current flowing through LED with different working LED arrays can be drawn as Fig.3.

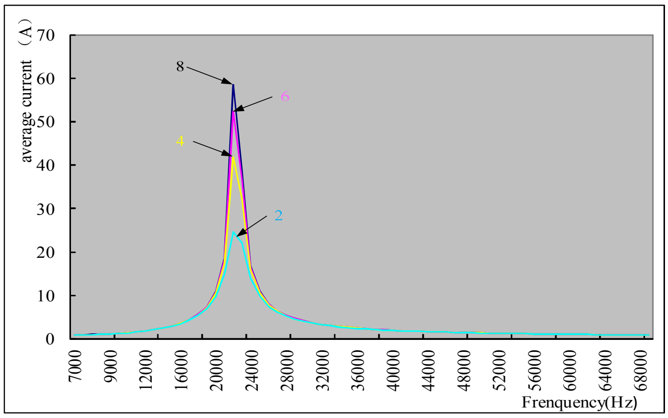

Fig.3 The average current flowing through LED with different working LED arrays.

The working frequency based on the range of the average current can be determined as Fig.4 which is a partial enlargement. The labels and units are the same as that of Fig.3.

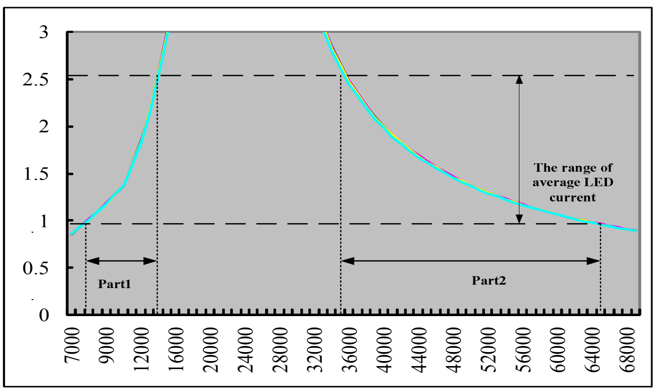

Fig.4 Working frequency determined by the range of current

From fig.4, we can see there are two parts that can be chosen. We call the left range part1 (700Hz~1.5kHz), the right range part 2 (35kHz~63.2kHz). If we choose the part 2 as the working part, there are two advantages. First, The volume of the switching power supply can be greatly reduced if it works at high frequency. Second, it can realize Soft-switching environment to reduce Switching losses.

The switching frequency under different open-circuit number can be calculated and listed in Tab.1.

Tab.1 Calculated parameters with different open strings

Number of branches operated normally	**Total current (mA)**	**Equivalent impedance of LED array (Ω)**	**Calculated switching frequency (kHz)**
8	2640	17.5	35
7	2310	20	37.1
6	1980	23.33	40.1
5	1650	28	44.4
4	1320	35	51.2
3	990	46.67	63.2

C. *Protection circuit for the open-circuit fault*

The detection circuit for the open-circuit fault for each branch is shown in Fig.5. An optical coupler is adopted for sampling the open-circuit state of the LED ring, and it can also realize the isolation of the output side and the input side. As shown in Fig.3, if all LEDs are working normally in the branch, the diode of the optical coupler turns on, and the transistor of the optical coupler also turns on, then the corresponding I/O is in the low level condition. In this circuit, the parameters are shown as follows: Rkx = 5Ω, Rx1 = 200Ω, Rx2=20kΩ, Rx3=10kΩ [6].

When the LED in the branch is in the open-circuit state, the diode of the optical coupler is turned off, and the transistor is also turned off. The open circuit detecting signal for MCU Kx changes to high level.

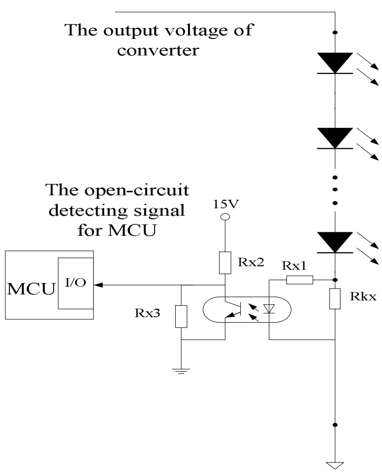

Fig.5 Circuit of detecting open LED strings

The open circuit detecting signals for MCU Kx (x=A,B,C,D,E,F,G,H,I) are connected to eight pins of MCU. Once the level of one pin changes to high level, the number of the open-circuit branches will plus 1. Through detecting number of the pins in the high lever state, the MCU will know the number of the branches that are in the open-circuit state.

D. *Current sampling and the design of closed-loop controller.*

With the increasing of the branches in the parallel circuit, it is difficult to keep each branch with a constant current, so it's suitable to keep the total current of LED rings a constant value.

As shown in Fig.1, a current transformer (CT) is used to sample the current, the AC current passes through the half-wave rectifier with a diode, then the current signal is changed to the voltage signal, the voltage signal passes through a RC type low pass filter, then we can get the information of the total current through all the 8 LED branches. This analog signal is send to MCU, and a digital value which is used as the practical total current signal for the total current close-loop control is gotten by the use of the ADC module of the MCU.

During the close-loop control processing, the reference current value is redefined according to the number of the branches in open-circuit state, the suitable switching frequency is obtain to adjust the total current of the branches which are still working through comparing the practical total current with the defined reference value. The control diagram is shown in Fig.6 [6].

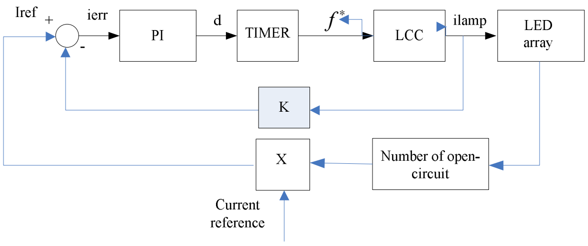

Fig.6 Block graph of the closed loop current control

III. EXPERIMENT RESULT AND ANALYSIS

Fig.7 shows the prototype used in the laboratory. The waveforms of the voltage and the current for one branch are shown in Fig.8 when 8 branches work together.

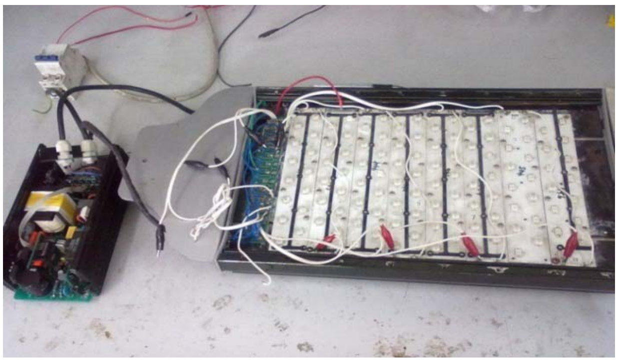

Fig.7 Prototype used in laboratory

The waveforms of the voltage and the current are shown in Fig.9 when 4 branches work together.

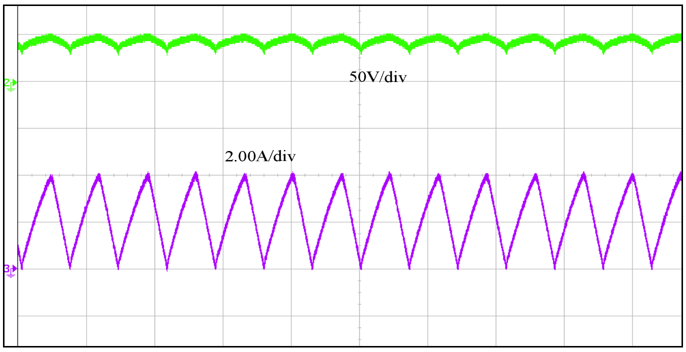

Fig.8 Waveforms of one LED string while 8 branches operated well

It is evident that with the increase in the number of the branches in the open circuit state, the current of every branch keeps constant and the voltage of the parallel circuit is with little change. It is evident that the LED load is not a pure resistive load.

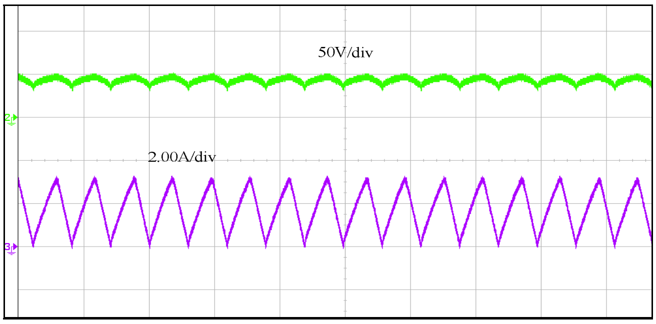

Fig.9 Waveforms of one LED string while only 4 branches operated well

Fig.10 shows the voltage of the rectifier in the input side, and the total current of the system when all of the 8 branches operate normally. It's evident that there is a certain phase shift between them. The different is decided by the load network consisted of Cs, L, the rectifier and the LED load. Fig.11 shows the voltage of the rectifier in the input side when only 4 branches operate normally.

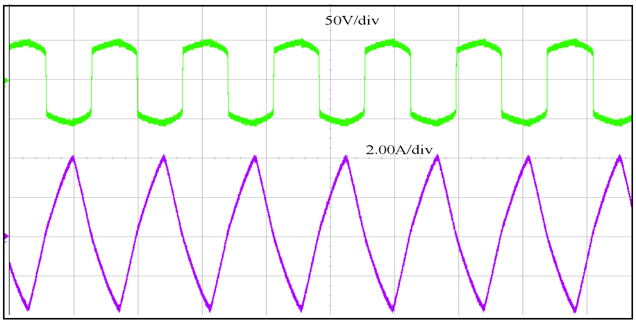

Fig.10 Waveforms of the input voltage of the rectifier and the total current while all paralleled branches operate well

It is evident that with the increase in the number of the branches in the open-circuit state, the load is lower and the switching frequency is higher while the phase shift between them is with little change, and the total current gets smaller and changes step by step.

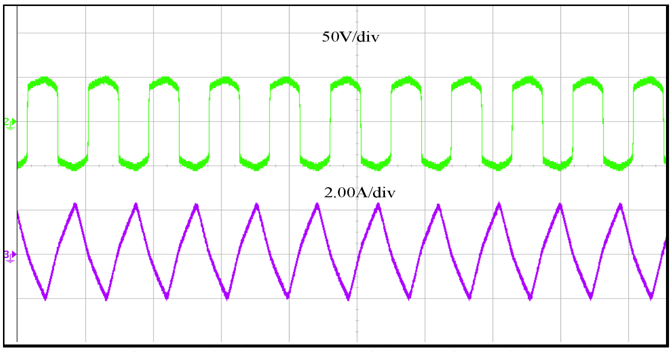

Fig.11 Waveforms of the input voltage of the rectifier and the total current while only 4 branches operate well

IV. CONCLUSION

A novel LED driver with digital control for high power level lighting based on auto-identifying open-circuit strings in LEDs array is proposed. The total drive current of the LED array is adjustable according to the identified number of the strings in the open-circuit state. With this control method, the current of each LED string is nearly constant no matter which branch is in the open-circuit state. The design method is presented in the paper. The experimental results verify the effect of the constant current driver with different numbers of open strings.

REFERENCES

[1] D. Montuand Z. Regan. "Digital architecture for driving large LED arrays with dynamic bus voltage regulation and phase shifted PWM," IEEE Proc. on Applied Power Electronics. 2007: 287-293.

[2] N. Narendran, Y. Gu, J. P. Freyssinier, H. Yu and L. Deng. "Solid-state lighting: failure analysis of white LEDs," Journal of Crystal Growth. 2004, 268(3-4):449-456.

[3] Prathyusha Narra, and Donald S. Zinger. "An effective LED dimming approach," IEEE Proceedings on Industry Applications. 2004: 1671-1676.

[4] Wang Yi-Jie, Zhang Xiang-Jun, and Wang Wei. "Asingle-stage AC/DC converter for LED street lighting system," Electric Machines and Control. 2010, 14(12): 68-74.

[5] Weiqiang Zhang, Wang wei, and Dianguo Xu. "Starting of HPS lamps driven by electronic ballast," Journal of Harbin Institute of technology. 2001, 8(4):353-356.

[6] Xu Dianguo, Zhang Xiangjun, and Liu Huaiyuan. "Study of Digital LED Driving Technology based on Auto-identifying Open Strings in LED Array". IECON 2011-37th Annual Conference IEEE Industrial Electronics Society, 7-10 Nov. 2011, Page(s): 2964 – 2968.