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Research on Some Key Problems of Self-exciting Electronic Ballast

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Abstract

Based on the analysis of operation principles of conventional self-exciting electronic ballast, the cause of high switching loss has been researched. In order to reduce switch temperature and increase the reliability of the whole circuit, drive circuit of self-exciting electronic ballast has been improved to achieve soft switch. Circuit simulations and experimental results are coincided with the analysis of theory. In the end of this paper, the design procedure and winding method of self-excited transformer are introduced.

Keywords: *self-exciting electronic ballast, soft switch*

1. Introduction

Self-exciting electronic ballast was widely used in the general lighting field because of its simple operating principle and low cost. However, there are two problems to be solved. The main problem is the high switching loss and high temperature leading to increase of heat dissipation dimension and reduction of product reliability as result of the coupling of driving signals of upper and lower bridge arm supplied with self-excited transformer. Moreover, the other problem is how to design and choose self-excited transformer to aviod inconsistency causing switch’s current spike.

The following is operation principles of the conventional self-exciting electronic ballast and its operation principles.

The scheme of conventional self-exciting electronic ballast is shown in Figure 1. D1, D2, Q1, Q2, C3 and C4 make up half-bridge topology. Self-excited transformer T1 works like current transformer, which has two groups of secondary coils to drive Q1 and Q2 respectively. The inductor L1 is used to limit the output current while its coupling coil L2、D3 and D4 are used to reject unbalancing problem of neutral-point voltage due to the inconsistent of capacitors of half-bridge circuit. The key waveforms concerning are shown in Figure 2 and the track of the magnetic T1 is as shown in Figure 3. The working principles of circuit are as follows:

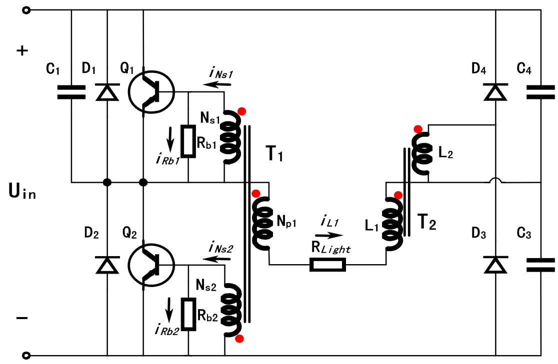

Figure 1. Schematic Diagram of Conventional Self-exciting Electronic Ballast

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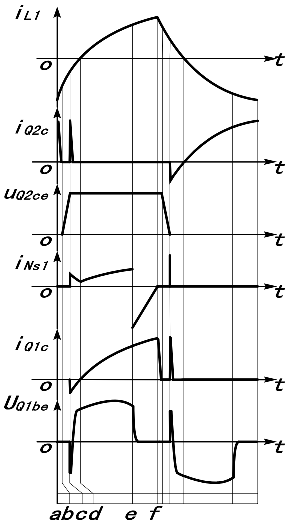

Figure 2. Key Waveforms of Conventional Self-exciting Electronic Ballast

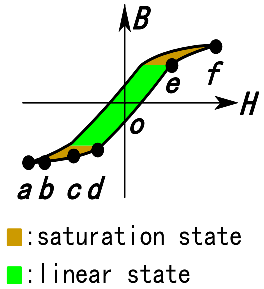

Figure 3. Track of the Magnetic T1 of Conventional Self-exciting Electronic Ballast

1.1. Stage [a,b]

The current of Q2 became low. Meanwhile, C1 began to be discharged and junction capacitance CQ2ce of Q2 began to be charged. In the end of this stage, as a result of current of Q2 declining in speed and the larger value of paralleling C1andCQ2ce, the voltage across C1 was almost not changed. It is assumed that the current of the inductor L1 remains constant because of small time-interval. The voltage across b–e of Q1 and b-e of Q2 are almost zero because of magnetic T1 deep saturation, leading to iNs1 and iNs2 closed to zero. According to Ampere's law, Np1iL1=Hlc, the absolute value of magnetic field strength reduced and corresponding operating point of the magnetic T1 moved from a to b.

1.2. Stage [b,c]

C1 was discharged and CQ2ce was charged by inductor L1. In the end of this stage, the voltage across C1 was almost zero and the voltage across CQ2ce was almost 300V. During this period, magnetic T1 was still saturated but begin to exit deep saturation and the absolute value of magnetic field strength continue to reduce just like stage [a,b]. Therefore, corresponding operating point of the magnetic T1 moved from b to c.

1.3. Stage [c,d]

At point c, inductor L1 remain discharged. If it is assume that D1 starts to conduct, UD1on≈1.2V. However, magnetic T1 was still saturated and UQ1b-e is almost zero and the on state voltage of p-n junction of Q1 is only 0.7V, it is obvious that the diode D1 is clamped and p-n junction provide free-wheeling path instead. The inductor L1's current reduce to zero after discharging in this stage. During this period, according to Ampere's law, it is obtained that:

$$N_{p1}i_{L1} + N_{s1}i_{Ns1} = N_{p1}i_{L1} + N_{s1}i_{L1} = Hl_c \qquad (1)$$

Therefore, the absolute value of magnetic field strength increased suddenly at the point c. However, with the reduction of L1's current, the absolute value of magnetic field strength decreased gradually. According to Faraday's law, $U_{Q1be} = -N_{s1}d\Phi / dt$, so U_{Q1be} was negative at the point c and U_{Q1be} was positive at the point d, however, U_{Q2be} is just reverse. It is probable that as result of the Q2 transistor–conduction at the point c, the reverse recovery surge current flow through the Q1 in several microseconds, meanwhile, it withstands high dv/dt voltage, thereby, causing high switching loss of two transistors.

1.4. Stage [d,e]

At the point d, Q1 starts to conduct. The magnetic T1 leaves the saturated state soon and operates in the linear region in virtue of positive feedback effect. During this period, UQ1b-e≈0.6V and $i_{Rb1} = U_{Q1be} / R_{b1} \approx 0$, $i_{Rb2} = U_{Q2be} / R_{b2} \approx 0$. According to Ampere's law, it is obtained that:

$$N_{p1} i_{L1} - N_{s1} i_{Ns1} \approx Hl_c \approx 0 \quad (2)$$

$$i_{Ns1} / i_{L1} = N_{p1} / N_{s1} = 1/(h_{ef} + 1) \quad (3)$$

Where hef is current gain of transistor. At the same time, $U_{Q1be} = N_{s1} d\Phi / dt > 0$, which shows that the magnetic flux doesn't increase linearly until reaching the point e.

1.5. Stage [e,f]

The magnetic T1 became saturated during this period, so UQ1B-E is near zero, nevertheless, transistor is still on because charge carriers have not restored yet during this period called storage times ts. The junction capacitance CQ1b-e doesn't charge until reaching the point f, at that time, Q1 is turned off.

Above knowable, high switching loss and high temperature lead to increase of heat dissipation dimension and reduction of product reliability as result of the coupling of driving signals of upper and lower bridge arm supplied with self-excited transformer. With the above problems in mind, a novel drive circuit of electronic ballast is proposed in this paper.

2. The Proposed Novel Self-exciting Electronic Ballast and its Operation Principles

The scheme of novel circuit is shown in Figure 4. The key waveforms concerning are shown in Figure 5 and the track of the magnetic T1 is as shown in Figure 6.

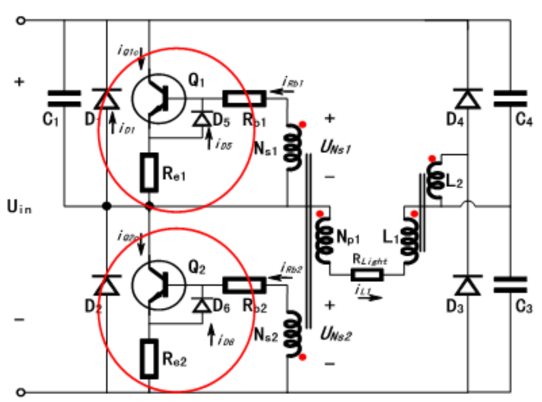

Figure 4. Ballast Schematic Diagram of Novel Circuit

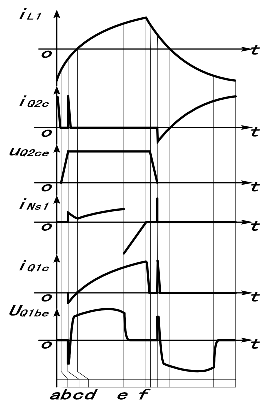

Figure 5. Key Waveforms of Novel Circuit

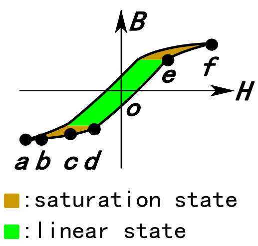

Figure 6. Track of the Magnetic T1 of Novel Circuit

The working principles of circuit are as follows:
Operation principle of novel ballast in stage [a,b] and [c,d] are same as conventional ballast's.

2.1. Stage [c,d]

Both diode D1 and p-n junction of Q1 provide free-wheeling path as result of placing series resistance Rb1 in this stage. At point c, D1 is turned on, and UD1≈1.2 V. It can be seen that:

$$\begin{cases} -I_{Q1c} = I_{D5} + I_{Rb1} = \dfrac{U_{D1} - U_{Q1bc} - U_{D5}}{R_{e1}} + \dfrac{U_{D1} - U_{Q1bc} + U_{Ns1}}{R_{b1}} \\ I_{D1} - I_{Q1c} = -I_{L1} \end{cases} \quad (4)$$

At the point c, magnetic T1 was still saturated, according to Ampere's law and Faraday's law, same conclusions can be found that U_{Q1be} was negative at the point c and U_{Q1be} was positive at the point d, further more , the current IRb increase while U_{Ns1} increases from (3.1). It is the same as above conclusion in the conventional self-exciting electronic ballast that U_{Q1be} was negative while U_{Q2be} was positive at the point c in novel self-exciting electronic ballast, but the turn-off loss of the switch has been reduced greatly as result of the base current is relatively small and Q2 keeps off owing to the placement of series resistance Rb1.

2.2. Stage [d,e]

At the point d, Q1 starts to conduct. The magnetic T1 leaves the saturated state soon and operates in the linear region in virtue of positive feedback effect. During this period,

$$N_{p1} i_{L1} - N_{s1} i_{Rb1} - N_{s2} i_{D6} = Hl_c \approx 0 \quad (5)$$

$$\Rightarrow N_{p1} i_{L1} = N_{s1} (i_{Rb1} + i_{D6}) \quad (6)$$

Assume that iRb1 and ID6 satisfy following equation:

$$i_{Rb1} / i_{D6} = 1/2 \quad (7)$$

One can yield the following formulas,

$$N_{p1} / N_{s1} = 3 i_{Rb1} / i_{L1} = 3/(h_{ef} + 1) \quad (8)$$

2.3. Stage [e,f]

During storage times ts, became of saturation of magnetic, UQ1B-E is near zero, the charge current of junction capacitance CQ1b-e can be calculated by the following equation,

$$I_{Rb1} = -U_{Q1be(sat)} / R_{b1} \quad (9)$$

In addition, thanks to the introduction of the two schottky diodes D5 and D6 in the circuit, as shown in Figure 4, low impedance passes were provided for the flow of reverse base current when transistor is off, which reduced the coupling between each transistor and made self-excited magnetic not very deep saturated leading to easy commutation of magnetic at knee point such as point a and f in Figure 6.

3. Result analysis

In order to have a better comparative analysis, two ballast circuits are simulated and tested in this paper.

Take fluorescent lamp----GE F40/T12 for example: the output current is about 1A, the output voltage is about 70V, and self-excited frequency is about 22kHz at input rated voltage 220Vac.

3.1. Conventional Self-exciting Electronic Ballast and its Key Waveforms

Turn-on and turn-off switching simulation waveforms are as shown in Figure 7 using ORCAD10.5 software.

The experiment results are shown in Figure 8 and Figure 9 respectively.

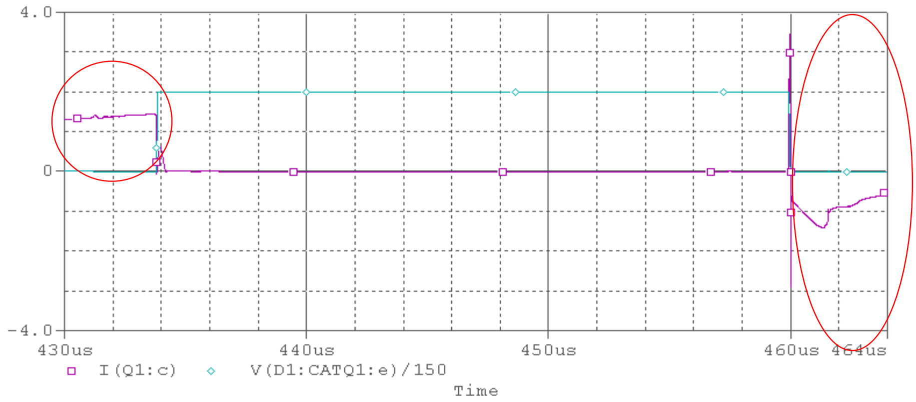

Figure 7. Swithing Waveform of Transistor Q1

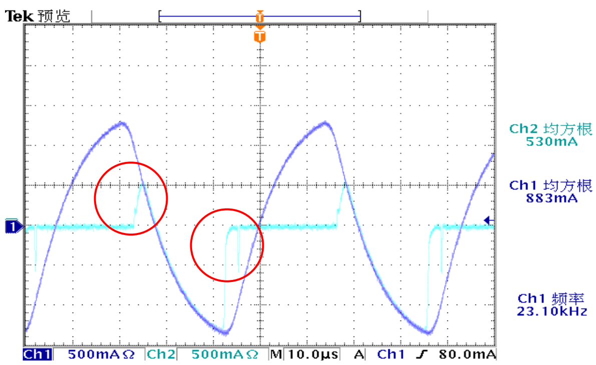

Figure 8. Current of Transistor's Current and Tank Current

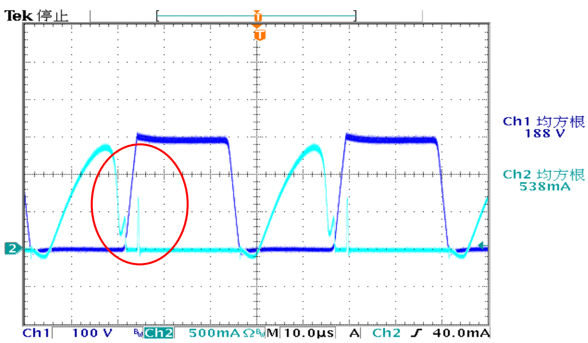

Figure 9. Waveform of Transistor Q1

Observing simulation and experiment results, it is proved true that p-n junction of Q2 provides free-wheeling path at the place marked with a green circle and the Q2 transistor abruptly turned on at the place marked with a red circle in Figure 4. It turned out that common conduction of two transistors cause high switching loss in Figure 5.

3.2. Novel Self-exciting Electronic Ballast and its Key Waveforms

Turn-on and turn-off switching simulation waveforms are as shown in Figure 10 using ORCAD10.5 software.

The experiment results are shown in Figure 11 and Figure 12 respectively.

Compared with Figure 8, the current in the collector of a transistor in stage [c,d] is reduced, which proves that not only p-n junction of Q1 but also diode D1 provide free-wheeling path in the Figure 11. Compared with Figure 9, all switches in the novel circuit are soft switching, and then loss of the switching are minimized in the Figure 12.

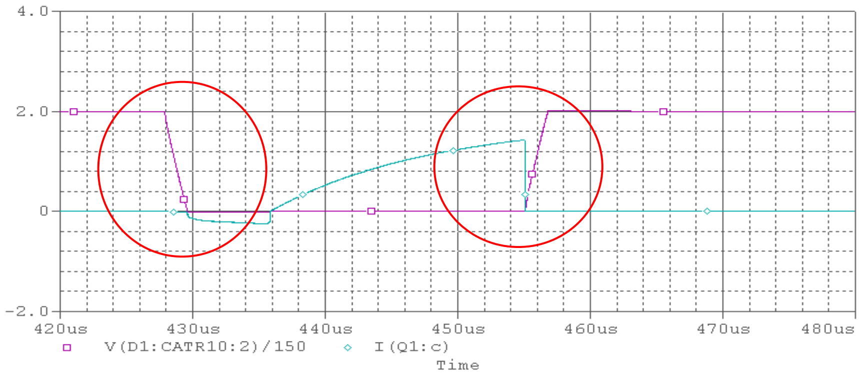

Figure 10. Swithing Waveform of Transistor Q1

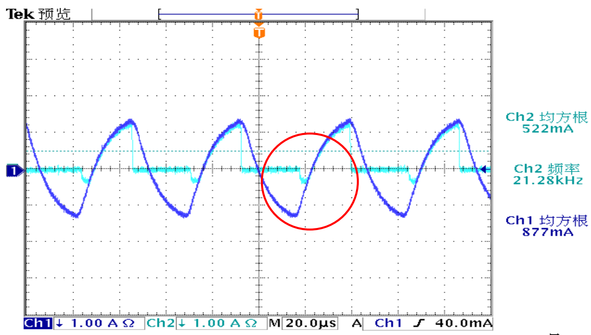

Figure 11. Current of Transistor's Current and Tank Current

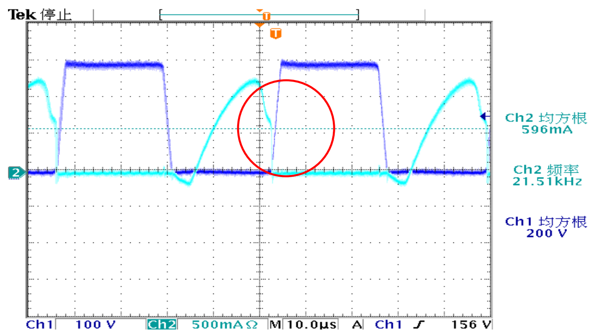

Figure 12. Waveform of Transistor Q2

4. The Design Procedure and Winding Method of Self-excited Transformer in Novel Electronic Ballast

Assume that: (1) Self-excited frequency is about 20kHz. (2) The waveform of the inductance current is approximated into a sine wave, and rms value is IL1. (3) The waveform of UNs1 is a sine wave, and rms value satisfies the following equation:

$$\begin{cases} V_{Ns1} = \{I_{Rb1}[R_{b1} + (1 + h_{ef})R_{e1}] + V_{be(sat)} \\ I_{Rb1} = \dfrac{I_{L1}}{h_{ef} + 1} \end{cases} \quad (10)$$

According to Faraday's law, it is obtained that the windings of secondary coils can be expressed by the following formula:

$$N_{s1} = N_{s2} = \frac{V_{Ns1}}{K_f f_s B_{ms} A_e} \quad (11)$$

Kf is the wave coefficient, and equal to 4.44 as a sine-wave. Thus based on (3.5), the windings of primary coils can be calculated by:

$$N_{p1} = \frac{3N_{Ns1}}{h_{ef} + 1} \quad (12)$$

The following is about method how to wind self-excited magnetic: winding method of single toroid is as shown in Figure13. The problem with the single- toroid drive is that the turn-on waveform of one transistor is the exact inverse of the turn-off waveform of the other. So there is no possibility of driving them appropriately and differently, and thereby efficiently.

To conquer the limitations of the single- toroid drive, use the double-toroid approach. as shown in Figure 14. However, if the permeabilities and dimensions of the two toroids are not well-matched, here are again discrepancies during the crossover, resulting in losses. It is advisable to use an innovative 'balun' core as shown in Figure 15 to drive the transistors.

In addition, it is sensible not to select high relative permeability (greater than 6000) in power ferrite material, which has poor performance in permeability under the temperature change.

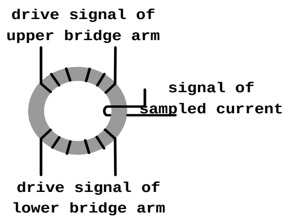

Figure 13. Wind Diagram of Single-toroid

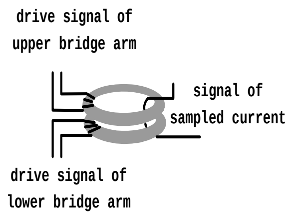

Figure 14. Wind Diagram of Double-toroids

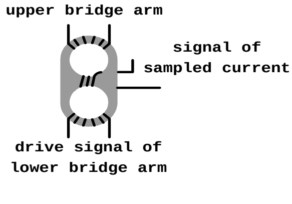

Figure 15. Wind Diagram of Balun-toroid

5. Conclusion

Based on the analysis of operation principles of conventional self-exciting electronic ballast, the cause of high switching loss of the upper and lower transistors has been researched. So the drive circuit of self-exciting electronic ballast has been improved to achieve soft switch, as a result, the temperature of tube is lower than that of before and the reliability of power supply is improved greatly. It is shown in experiment that without arrangement of heat-sink, collector temperature is just 25℃ higher than ambient temperature, basically meeting project requirement.

It is especially crucial to design self-excited transformer. Combining with the operational principle of novel self-excitation electronic ballast, how to choose and wind magnetic toroid in novel self-exciting electronic ballast and the design procedure were provided in this paper.

References

[1] Fengfeng Tao, Qun Zhao, Lee FC, Onishi N. *Self-oscillating electronic ballast with dimming control.* Power Electronics Specialists Conference. 32nd Annual. 2001; 4: 1818-1823.
[2] Fengfeng Tao, Qun Zhao, Zhou J, Lee FC, Onishi N. *Self-oscillating single-stage power-factor-correction electronic ballast with duty-ratio and frequency modulation.* Applied Power Electronics Conference and Exposition, Sixteenth Annual IEEE. 2001; 2: 683 – 687.
[3] Fengfeng Tao, Qun Zhao, Zhou J, Lee FC, Onishi N. *A self-oscillating drive for single-stage charge-pump power-factor-correction electronic ballast with frequency modulation.* Industry Applications Conference. Conference Record of the 2000 IEEE. 5: 3367 – 3373.
[4] Xiao Hong, Gao Liang, Wu Kaiwei. Dynamic characteristics analysis of mats of ballasted track on bridge. *TELKOMNIKA Indonesian Journal of Electrical Engineerin*g. 2012; 10(7).
[5] Han Yang. A Pedagogical Approach for Modeling and Simulation of Switching Mode DC-DC Converters for Power Electronics Course. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2012; 10(6).
[6] Chien-Ming Wang, Chang-Hua Lin, Hsin-Yi Lin, Yu-Hao Lai, Maw-Yang Liu. A soft-switching inverter using a voltage clampsoft-switching step-up/down DC link. *Sustainable Energy Technologies (ICSET), IEEE Third International Conference*. Year: 2001; 16: 336–344.
[7] Yu H, Lai J, Zhao JH, Wright BH. Gate driver based soft switching for SiC BJT inverter. *Power Electronics Specialist Conference, 2003. PESC '03. 2003 IEEE 34th Annual,* Publication Year 2003; 4: 1857-1862.
[8] Thongkullaphat S, Liutanakul P, Chunkag V. Improvement of self-oscillating electronic ballast with high power factor: A combination of charged-pump and valley-fill. *Power Electronics and Drive Systems (PEDS), IEEE Ninth International Conference on.* 2011: 1090 – 1093.
[9] Prado RN, Seidel AR, Bisogno FE, Costa MAD. A design approach of the self-oscillating electronic ballast. *Power Electronics and Motion Control Conference. Proceedings. IPEMC 2000. The Third International.* 2000; 3: 1127 - 1131.
[10] Seidel AR, Bisogno FE, Marchesan TB, do Prado RN. Designing a self-oscillating electronic ballast with bipolar transistor. *Industry Applications Conference. 37th IAS Annual Meeting. Conference Record.* 2002; 2: 1078 - 1083.
[11] Xingwu Mao, Dawei Zhu. The working principle and design of electronic ballast. Beijing: Post &Telecom Press, 1999.
[12] Colonel WM T Mclyman. Transformer and inductor design handbook. Beijing: China Electric Power Press, 2009.
[13] Sanjaya Maniktala. Switching power supplies a to z, Edition 2. Beijing: Post &Telecom Press, 2008.
[14] Weixun Lin. modern power electronics. Hangzhou: China Machine Press, 2006.
[15] JM Peter. Transistors & diodes in power processing. Beijing: Textile Industry Press, 1991.