Designing of Protection Circuit for Self-Oscillating Electronic Ballast that Connected Two Wires to Fluorescent Lamp
การออกแบบวงจรป้องกันบัลลาสต์อิเล็กทรอนิกส์ที่ขับนำด้วยตัวเอง โดยมีการต่อสองสายไปยังหลอดฟลูออเรสเซนต์

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ABSTRACT

This paper proposes a protection circuit for self-oscillating electronic ballast that connected two wires to fluorescent lamp. The advantages of two-wire electronic ballast are fast setup and maintenance because it connected only two wires to the lamp, instead of ordinary electronic ballast that connected four-wire. However, the two-wire electronic ballast has a disadvantage that can not operate safely without lamp. Therefore, a protection circuit is required. The proposed protection circuit will cease ballast oscillation when the lamp is disconnected but will let the ballast works normally when operated with lamp. This paper also describes working method of the protection circuit, designing procedures, comparison between simulation and experimental result. Errors from experimental result can be presumably concluded of device limitation.

บทคัดย่อ

บทความนี้นำเสนอวงจรป้องกันบัลลาสต์อิเล็กทรอนิกส์ชนิดขับนำด้วยตัวเอง ที่มีการต่อสายเข้าขั้วหลอดฟลูออเรสเซนต์เพียงสองสาย ข้อดีของบัลลาสต์อิเล็กทรอนิกส์ชนิดนี้คือสะดวกในการติดตั้ง-ซ่อมบำรุง เนื่องจากต่อสายไปยังหลอดฟลูออเรสเซนต์เพียงสองสาย ขณะที่บัลลาสต์อิเล็กทรอนิกส์ทั่วไปต่อถึงสี่สาย แต่บัลลาสต์อิเล็กทรอนิกส์สองสายก็ยังมีข้อเสีย คือ จะเกิดความเสียหายที่ตัวบัลลาสต์เมื่อทำงานโดยไม่มีหลอดต่ออยู่ในวงจร จึงจำเป็นต้องเพิ่มวงจรป้องกันบัลลาสต์เข้าไป โดยวงจรป้องกันบัลลาสต์ที่นำเสนอนี้จะหยุดการทำงานของบัลลาสต์เมื่อบัลลาสต์ทำงานโดยไม่มีหลอดต่ออยู่ในวงจร แต่บัลลาสต์จะทำงานตามปกติเมื่อมีหลอดต่ออยู่ในวงจร บทความนี้ยังนำเสนอหลักการทำงาน ขั้นตอนการออกแบบ การเปรียบเทียบระหว่างผลการจำลองวงจรและผลการทดลองจริง ซึ่งพบว่า ผลการทดลองคลาดเคลื่อนจากการจำลองวงจรเล็กน้อย เนื่องจากขีดจำกัดของอุปกรณ์

Key Words : Fluorescent lamp, Two-wire electronic ballast, Protection circuit
คำสำคัญ : หลอดฟลูออเรสเซนต์ บัลลาสต์อิเล็กทรอนิกส์สองสาย วงจรป้องกัน

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1. Introduction

Nowadays, fluorescent lamps are very popular light source because of their high performance compared to the incandescent. However, the lamp operating needs ballast as ignition and current controller (Alonso 2001). There are two main types of ballast, electromagnetic and electronic ballast. The electronic ballast has some advantages compared to the electromagnetic ballast (Seidel, et al 2005) such as lower energy consumption, longer lamps' durability and better light's quality.

There are three methods for lamp ignition, instant start, rapid start, and programmed start (Yunfen and Robert 1997, Santos, et al 2005). Nevertheless two-wire connection can be achieved only with instant start method. Two-wire electronic ballast is short circuit proved (Kazimierczuk and Szaraniec 1993), but when operates with open circuit (no lamp connected) the ballast can be damaged from high ignition voltage and current (Lin, et al 2001). Most of the electronic ballasts are self-oscillating because they are simple and cost effective. Except that ceasing the ballast oscillation when operating with no lamp or the lamp end of life, the protection circuit is mandatory.

2. Method of Self-Oscillating Electronic Ballast

Electronic ballasts have three important parts; there are rectifier stage, inverter stage, and lamp driving stage, as shown in Figure 1. First, the rectifier stage is used to convert the AC mains to DC and it can also be improved to correct power factor of the ballast. Second, the inverter stage is the stage that inverts DC to AC middle-band frequency. It consists of two power switches (T_1-T_2) that alternately work. Figure 2 shows the working method of this switching oscillator. When power switch T_1 "ON" (power switch T_2 "OFF"), the current will flow from DC link pass through oscillating transformer, load and C_2 capacitor then return to ground. The current that passes through primary winding in the middle of oscillating transformer will induce small voltage at secondary and tertiary windings to drive the power switches. Then the power switch T_2 "ON" (power switch T_1 "OFF"), the current will be discharged from C_2 capacitor then, it will pass through load and return to the capacitor. This is a procedure to generate middle-band frequency AC from DC link. However, the AC acquired from this procedure is square waved. A filter is required to change square wave to sinusoidal wave; therefore, it is the last duty of the ballast. The lamp driving stage is the stage consists of inductor and capacitor connected in series. Hence, it can be called series resonant circuit or series resonant filter. The filter is used to ignite the lamp and control lamp's current. One factor that determines harmonic distortion in lamp's current is crest factor. Crest factor is a fraction between the peak value and the RMS value of lamp current. It also defines the sharpness of LC filter, if the filter is sharper, it will allows a narrower bandwidth, then contamination of harmonics is lesser. The passing current will be more likely to be sinusoidal. Thus, the higher crest factor, the higher harmonic distortion in lamp current.

Ordinary self-oscillating electronic ballasts are always four-wire connection with the lamp as shown in Figure 3. When there is no lamp connected, lamp driving stage will be an open circuit and ballast oscillation will be ceased because there is no current flowing through primary winding of oscillating transformer. Hence, the induced voltage to drive power switch will not be generated.

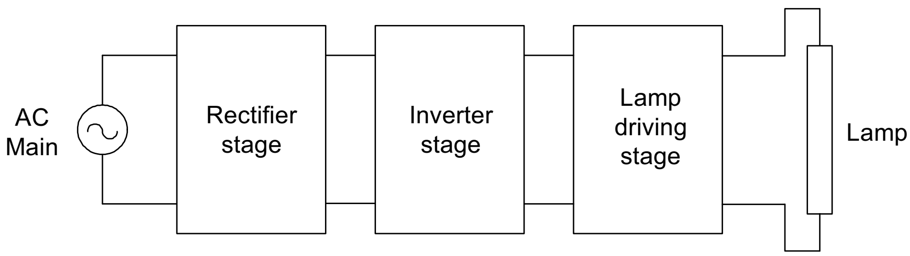

Figure 1 Parts of electronic ballast

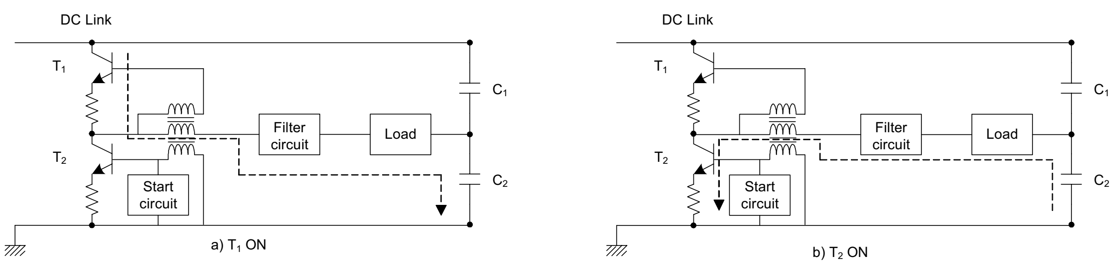

Figure 2 Self-oscillating electronic ballast

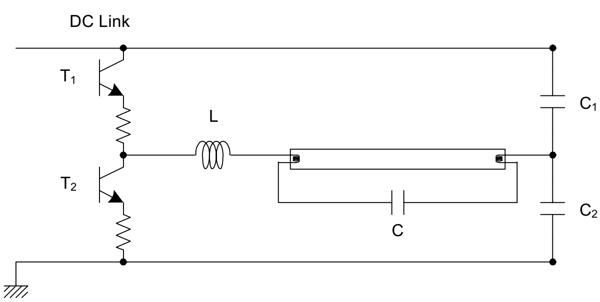

Figure 3 Ordinary electronic ballast

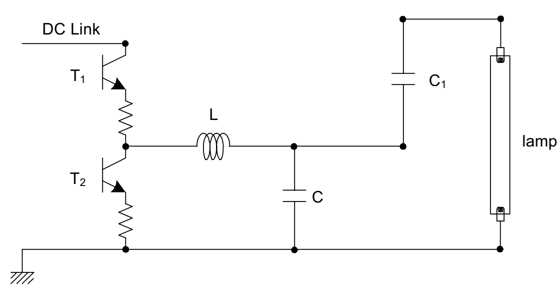

Figure 4 Two-wire electronic ballast

3. Two-Wire Self-Oscillating Electronic Ballast

Two-wire self-oscillating electronic ballast was designed for fast setup and maintenance. Its disadvantage is that it can not work safely without lamp and almost has the same working procedure as general electronic ballast. However, the difference is in the lamp driving stage shown in

Figure 4. When two-wire self-oscillating electronic ballast works without lamp, the lamp driving stage is not an open circuit. Then, the fundamental current still flows through the LC filter like short circuit. Hence, the oscillating transformer uninterruptedly generates current to drive power switches. This will result in severe damage to the switches.

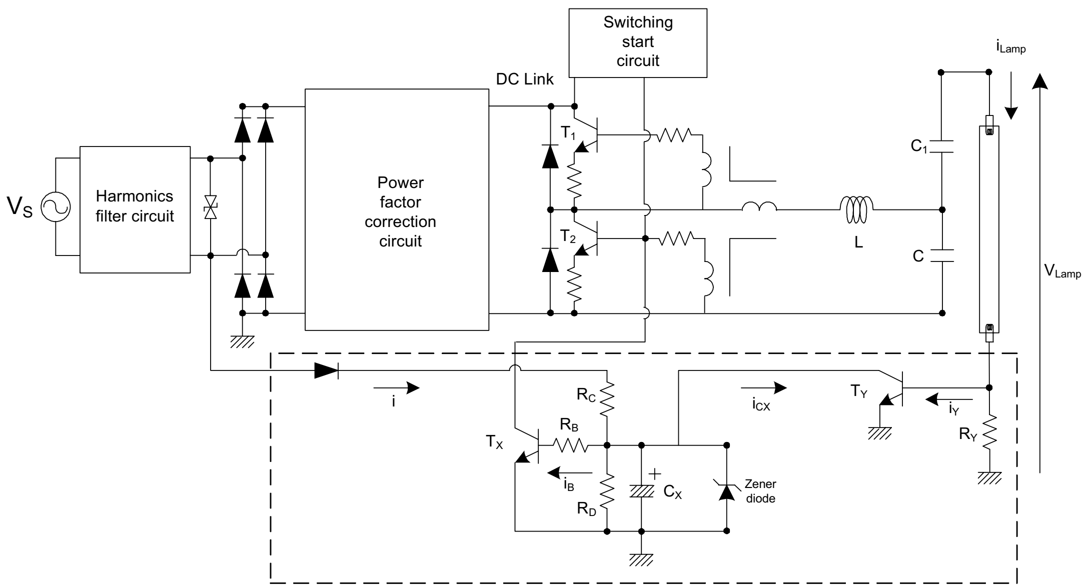

Figure 5 Proposed protection circuit

4. Proposed Protection Circuit

4.1 Method of proposed protection circuit

Figure 5 shows the proposed protection circuit in dash line box. The protection circuit will cease ballast's oscillation when there is no lamp connected. However, the ballast will operate normally when lamp is connected. The working of the protection circuit is simple and have two working conditions, when there is no lamp connected and when there is lamp connected.

a) When there is no lamp connected.

The current i from AC mains flows through R_C resistor and charges the C_X capacitor. When C_X is charged, the voltage across it is increased. Hence, the i_B current that flows through the base of T_X transistor will also be increased. When i_B is large enough, it will result in short circuit between base and ground of power transistor T_2, and the oscillation is ceased.

b) When there is lamp connected.

The current i from AC mains flows through R_C and charges the C_X. However, the lamp current (i_{Lamp}) will flow through R_Y and the base of T_Y transistor. This will result in current discharging of C_X. Then, C_X voltage will be decreased, iB is not large enough to activate T_X transistor. The switching oscillator will operate as normal.

4.2 Circuit analysis

The proposed protection circuit can not use main DC link because the current continually flows through C_X all the time and it is hard to decrease voltage across C_X. The R_Y resistor does not involve with C_X charging time, however it has two main duties. First, it works as current divider that let small current flow through the base of T_Y transistor. Second, it protects T_Y transistor from reversing current that flows from ground to lamp. When the proposed circuit works under constant AC mains condition (220 V_{RMS}, 50 Hz), four parameters that affect the protection circuit are C_X, R_B resistor, R_C resistor and finally R_D resistor. The zener diode is connected for ensure safety of C_X by limiting voltage across it. The relation between

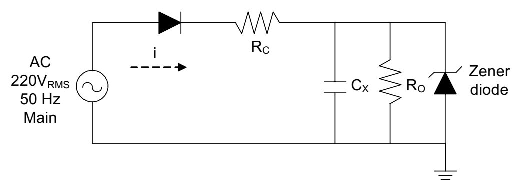

Figure 6 Equivalent circuit of the protection circuit

voltage across C_X and time can be determined from integration of the current that pass through C_X. The protection circuit from Figure 5 can be transformed to equivalent circuit in Figure 6. When using current divider analysis on circuit in Figure 6. The relation between voltage across C_X and time can be written as

$$v_{CX} = \frac{1}{C_X}\int(i - \frac{v_{CX}}{R_O})dt \qquad (1)$$

When,

R_O resistant is the equivalent resistance of R_B and R_D in parallel.

The relation (1) can be used to determine R_D, R_B, and C_X as explained in the next paragraph.

4.3 Circuit design and simulation

Designing of proposed protection circuit in Figure 6 will focus on T_S which is the time that switching oscillation will be ceased. The charging of C_X is essential because if the voltage across it increases very fast, the push-pull amplifier will be stopped before the lamp is ignited even the lamp is properly connected. And if the voltage across C_X increases very slowly, the electronic ballast can be damaged because the protection circuit can not terminate the ballast's oscillation. The instant s tart electronic ballast has no pre-heating procedures, thus the time used to ignite lamp depends on lamp driving circuit and the lamp itself.

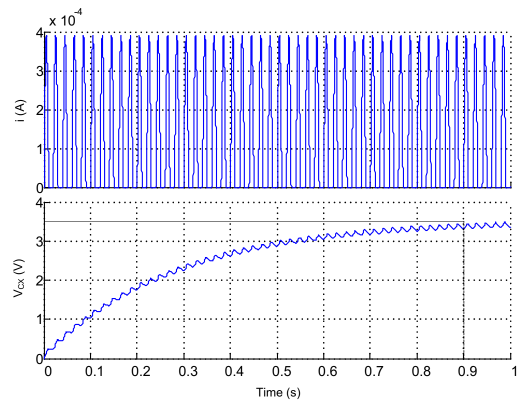

Figure 7 Simulation result

There are several parameters that affect voltage across C_X. Therefore, the designing procedures will have to choose some parameters and calculate for the rest. The determination of T_S is quite easy, because the T_S can not be strictly fixed, lamp ignition time depends on lamp's durability, Hence the older lamp uses more ignition time. From experience, TS should not be lower than 500 ms and should not be higher than 1 s.

After determining T_S, the next procedure is to determine base current of T_X transistor. To determine T_X base current, base current of power switch T_2 must be known first. Then, T_X transistor can completely short circuit between base and ground of power switch T_2. This research uses BC337 transistor as T_X, hence the h_{FE} of T_X transistor is 400. If the base current of power switch T_2 is 55 mA then 0.12 mA base current of T_X is needed to completely stop power switch T_2.

The next procedure is to determine amplitude of half-wave current i. This parameter can be calculated from base current of transistor T_X as

$$i_B = (amplitude\ of\ i) \times 0.318 \qquad (2)$$

Next procedure is to determine R_C resistor from amplitude of half-wave current i from

$$v_{S\max} = (amplitude\ \ of\ i) \times R_C \qquad (3)$$

When, $v_{S\max}$ is amplitude of AC mains.

After value of R_C resistor is determined, next procedure is to determine voltage across C_X that will stop the ballast (will be called V_{CX}(off)). The V_{CX}(off) voltage depends on R_B resistor as

$$v_{CX}(off) = i_B \times R_B \qquad (4)$$

Next parameter is R_D resistor, it works as C_X discharge resistor when the ballast's power is off and only works after no-lamp operation. This resistor will affect V_{CX} if it has less or great value. Hence, the appropriate value is just about ten times greater than R_B.

The last parameter is C_X that can be determined through trial and error simulation of equation (1). The satisfied result should be stopping voltage V_{CX} at time T_S.

After designing procedures have been described, this research chooses parameters R_C, R_B, R_D, C_X, and V_{CX}(off) to be 80 kOhms, 3 0 kOhms, 560 kOhms, 1 uF, and 3.6 V respectively. The simulation result is shown in Figure 7.

The simulation result can be determined that V_{CX} will reach V_{CX}(off) in 900 ms, or the ballast will completely off in 900 ms after no-lamp operation.

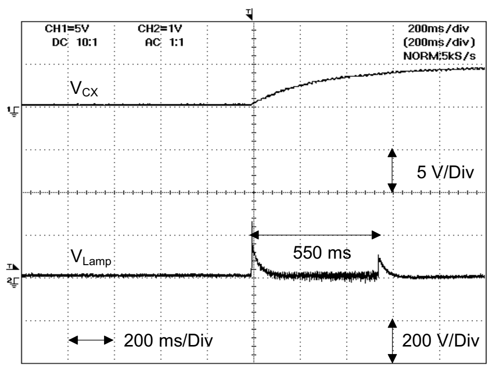

Figure 8 V_{CX} versus V_{Lamp}: no-lamp operation

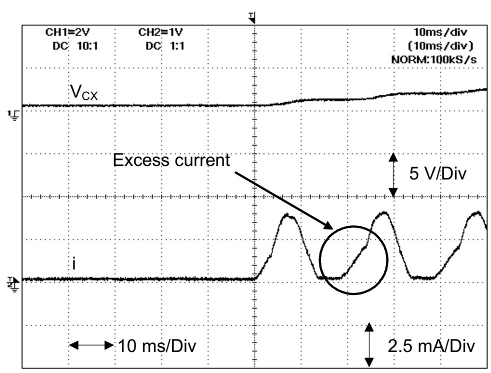

Figure 9 V_{CX} versus i: no-lamp operation

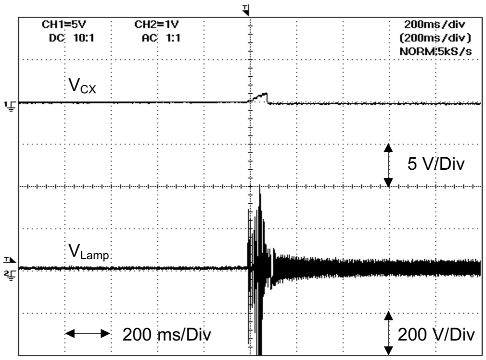

Figure 10 V_{CX} versus i: no-lamp operation

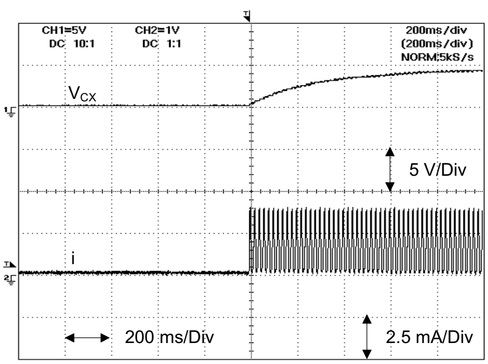

Figure 11 V_{CX} versus V_{Lamp}: operation with lamp

5. Experimental Results

To understand real behavior of the protection circuit, an experiment should be held. This research uses an 18-watt tubular fluorescent lamp as a test lamp and uses the same parameters as simulation. When R_Y is 2 Ohms, the simulation results are shown in Figures[KKU61] 8-11.

Figure 8 demonstrates V_{CX} and V_{Lamp} when ballast operates without lamp. Notice that the V_{CX}(off) is about 3.5 V, very close to 3.6 V of simulation result. However, ballast terminating time in this figure is 550 ms, which is quite differed from simulation result because of leakage current through diode. The leakage current waveform is shown in Figure 9

Figure 9 attests V_{CX} and i current waveform. The current waveform is not exactly half-wave because of some leakage of current through half-bridge rectifying diode. The ideal half-wave DC from this circuit should have a straight front wave. This error effect V_{CX} rise time because V_{CX} is the integration of i, the more current, the faster V_{CX} rise time.

Figure 10 presents V_{CX} and V_{Lamp} when ballast operate with lamp. V_{CX} is reduced near zero after the lamp is ignited. The current that flows through the lamp activates T_Y transistor, then T_Y transistor is on, C_X is discharged.

Figure 11 exhibits V_{CX} and i current waveform. Notice that the signals have the same shape of the simulation result.

6. Conclusion

This paper proposes the designing of protection circuit of self-oscillating two-wire electronic ballast for fluorescent lamp. The advantages of two-wire electronic ballast are fast setup and maintenance because it connects only two wires to lamp. However, the ballast can not operate safely without lamp. Thus, the protection circuit that will terminate the no-lamp operation is mandatory. This paper describes how the proposed protection circuit works, circuit analysis, designing procedures then compare between simulation result and experimental result. Afterward concludes that the proposed protection circuit has some errors from device limitation.

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