Electronic System of Fluorescent Lighting for Two Lamps Operating in Complementary Form

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***Abstract* - This paper presents the development of an electronic ballast for two fluorescent lamp, operating in complementary form. This ballast has the advantages that each lamp is independent from the other, so when one lamp fails the other continues operating.**

I. Introduction

The selected topology, shown in Fig.2, presents several advantages over the conventional electronic ballast. Among them we can mentioned that this circuit allows sinusoidal voltage and current in the lamp. When the steady state is reached, it also operates in self oscillating form and the ignition voltage is obtained from the own resonant circuit.

The circuit admits the connection of two series lamp but this possibility it is not recommended because when one lamp fails both lamp fail.

A new driven transformer primary winding distribution is also proposed, replacing the emitter resistor by two primary driven winding, reducing the losses due to those resistors.

II. List of Simbols

i_{Lsr}	: Current through the resonant inductor L_{sr}.
V_{ab}	: Input voltage of the resonant network.
w_s	: Switching frequency in (rad/sec).
w_{os}	: Resonance frequency of L_{sr}, C_{sr} and the lamp.
w_{ot}	: Resonance frequency in starting-transient.
i_{Lsrcc}	: Maximum current through the resonant inductor.
I_{op}	: rms current of operation of the lamp.
E	: Input DC Voltage.
X_{Lsr}	: Resonant inductor L_{sr} reactance
X_{Csr}	: Resonant capacitor C_{sr} reactance
f_s	: Switching frequency in Hertz.

III. Proposed Circuit

From an economic and practical point of view, it is convenient to feed two or more fluorescent lamps with one ballast. Several circuit exist for electronic ballast feeding two lamps in series [1], but the problem with these topologies is that the lamps cannot operate independently one of the other, if one of them fails both fail.

The improved electronic ballast for two lamps, shown in the Fig. 2, based on the conventional topology is proposed. Basically it consists on using the present voltage in the switch Q_2 to feed a second resonant circuit and a second lamp. By the circuit disposition, the lamps will function in an independent way one of the other. Then when one of them fails, the other continue to operate.

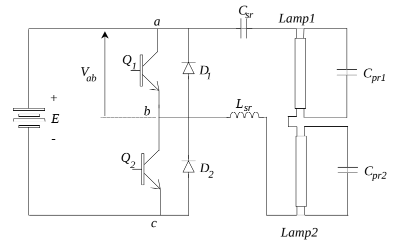


Fig. 1. Conventional circuit.

The component part of the circuit are described as follows:

E	: Input voltage.
Q_1, Q_2	: Bipolar transistor.
L_{sr1}, L_{sr2}	: Series resonant inductor with ferrite core.
C_{sr1}, C_{sr2}	: Series resonant capacitor.
C_{pr1}, C_{pr2}	: High voltage parallel resonant capacitors.
D_1, D_2	: Free-wheeling diodes.

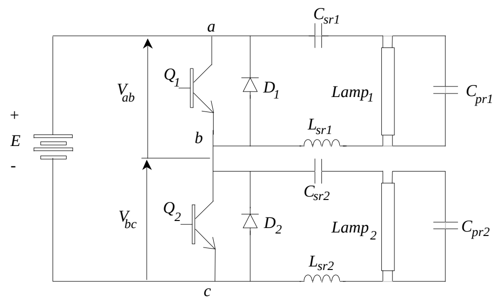


Fig. 2. Proposed topology for the electronic ballast for two lamps.

IV. Proposed Circuit Operation

The proposed steady state circuit operation is now described :

a) Switches Q_1 and Q_2 are driven to obtain square wave voltages at the points a-b and b-c (Fig. 2). On the interval when Q_2 is on, Q_1 is off, one resonant circuit has V_{ab}=E and the other V_{bc}=0. When Q_1 is on and Q_2 is off V_{ab}=0 and V_{bc}=E, i.e., voltages at these points are complementary one of another.

b) The fundamental components of V_{ab} and V_{bc} produce the circulation of sinusoidal currents through the resonant networks formed by L_{sr}, C_{sr}, C_{pr} and the lamp.

The fluorescent lamps are, therefore, operating in complementary form, such as shown in Fig. 4, when V_{ab}=E, the second circuit, is in free-wheeling mode and vice-versa, both circuits are then independent one of the other.

The theoretical waveforms for the current in the series resonant inductor i_{Lsr} and for input voltage (V_{ab} or V_{bc}) in steady-state are shown in Fig. 3.

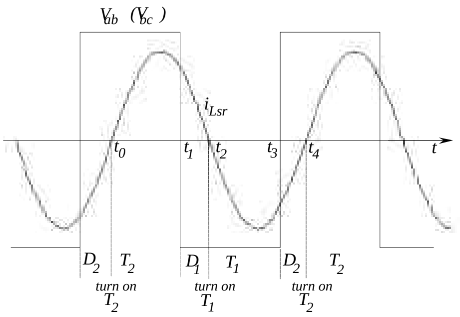


Fig. 3. Waveforms steady-state.

The topological states for one operation cycle are shown in Fig. 4.

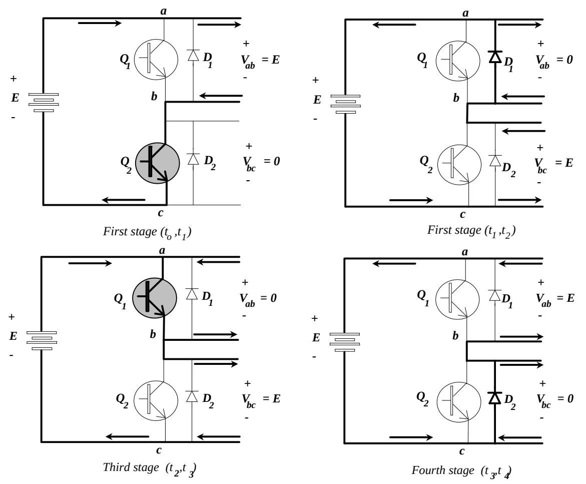
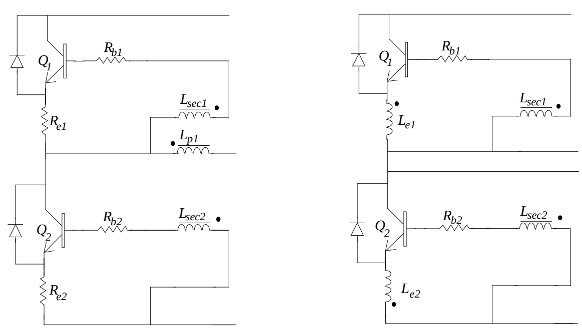


Fig. 4. Topological states of the proposed circuit.

V. In Relation to Driven Circuit

The self-oscillating operation of the circuit is achieved by means of a small driver transformer and the own resonant circuit.

Generally, in circuits with bipolar transistors, the necessary feedback must be included to get a transistor stable operating point. This is obtained by conecting a resistor in series with each of the transistor's emitter. Nevertheless, the addition of these resistances causes that the losses of the circuit increases. This arrangement is shown in Fig. 5a. The Fig. 5b presents another disposition, where the emitter resistances have been replaced by the control transformer primary windings (L_{p1}), now divided in two (L_{e1} and L_{e2}). The same circuital function is achieved doing this, but reducing the losses.



a) b)

Fig. 5. Driven circuit topologies: a) conventional, b) Proposed.

In Fig. 6 the control transformer windings disposition and its connection to the circuit are shown.. Due to their partition and localization, these windings will maintain the circuit's self-oscillation.

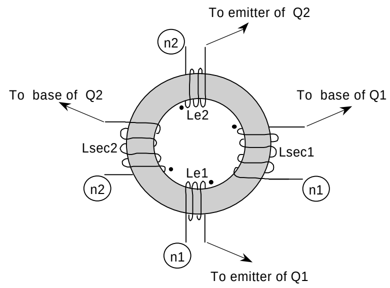


Fig 6. Control transformer windings.

VI. Design Methodology

A. Design conditions

When feeding a low pressure fluorescent lamp the electronic circuit should fulfill three main conditions:

1. To provide, at the starting, the necessary ignition voltage for the lamp.
2. To maintain in the steady-state, a constant current equal to the maximum operation current of the lamp.
3. The current through the resonant inductor i_{Lsr} should laggs the alternating component of V_{ab} or V_{bc}. This is done with the purpose of assuring a soft switches commutation. [1], [3], [4], [6].

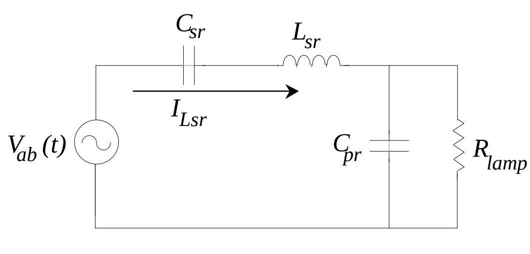
The first condition is fulfilled by means of the resonant circuit formed by L_{sr}, C_{sr} and C_{pr}. At the starting transient (R_{Lamp} tends to be infinite), the voltage at the capacitor C_{pr} will grow up without control, with a frequency given by (1), until the lamp's ignition voltage is reached .

$$w_{ot} = \frac{1}{\sqrt{L_{sr} \cdot \frac{C_{sr} \cdot C_{pr}}{C_{sr} + C_{pr}}}} \tag{1}$$

The equivalent circuits model shown in the Fig. 7 represents the resonant circuit in steady-state for the second and third design conditions.

The following facts are considered for the analysis

1. Only the fundamental component of the input voltage to resonant circuit (V_{ab}) was considered.
2. The lamp was modeled as a resistor.



$$V_{ab}(t) = \frac{4}{2 \cdot p} \cdot E \cdot sen(w_s \cdot t)$$

Fig. 7. Steady-state equivalent circuit model.

In relation to Fig. 7, the maximum current through the resonant network occur at R_{lamp}=0, and it given by (2)[7].

$$i_{Lsrcc} = \frac{V_{ab}}{X_{Lsr} - X_{Csr}} \tag{2}$$

To satisfy the second condition :

$$i_{Lsrcc} = \sqrt{2} \cdot I_{op} \tag{3}$$

From (2) and (3) can be obtained:

$$L_{sr} = \frac{V_{ab}}{\sqrt{2} \cdot I_{op} \cdot w_s} + \frac{1}{w_s^2 \cdot C_{sr}} \tag{4}$$

In order to the third design condition to be fulfilled:

$$w_s = b \cdot w_{os} \tag{5}$$

The choice of β, in (5), it is directly related to the characteristics that should have the resonant circuit, i.e., inductive characteristic for β>1 or capacitive characteristic if β <1.

If the circuit operates with β>1, soft-commutation at the transistors turn on is obtained and the lamp current becomes sinusoidal reducing radio-interference. However, β cannot be too large because of the reactive currents (regeneration stages for the source) produce additional losses. These currents must be large enough to obtain soft switching without increasing the losses. Therefore an appropriate value of β is 2.

Thus:

$$w_s = 2 \cdot w_{os} \tag{6}$$

But,

$$w_{os} = \frac{1}{\sqrt{L_{sr} \cdot C_{sr}}} \tag{7}$$

Then, substituting (7) in (6):

$$C_{sr} = \frac{4}{L_{sr} \cdot w_s^2} \tag{8}$$

And substituting (8) in (4) gives:

$$L_{sr} = \frac{4}{3} \cdot \frac{V_{ab}}{\sqrt{2} \cdot I_{op} \cdot w_s} \tag{9}$$

Moreover,

$$V_{ab} = \frac{4}{p} \cdot \frac{E}{2} \tag{10}$$

Replacing (10) in (9) yields:

$$L_{sr} = \frac{4 \cdot \sqrt{2} \cdot E}{3 \cdot p \cdot I_{op} \cdot w_s} \tag{11}$$

Now, forcing the resonant frequency given by (1) equal to the switching frequency ω_s, of (1), (6) and (7) C_{Pr} can be obtained:

$$C_{pr} = \frac{1}{3} \cdot C_{sr} \tag{12}$$

VII. Design Example

The resonant circuit parameters were determined using the design equations obtained in the former section for two lamps with the following specifications:

P= 40 (W), I_{op}= 0.4 (A), E= 310 (V), f_s= 50 (KHZ)

With these specifications the following values were obtained:

L_{sr} = 1.48 (mH), C_{sr} = 27.37 (nF), C_{pr} = 9.12 (nF)

Several simulations to obtain the circuit behavior were made. The simulated circuit is shown in the Fig. 8. The turn off soft-commutation capacitor C_Z was designed by means of the methodology given in [4]. The main waveforms are presented in the following figures.

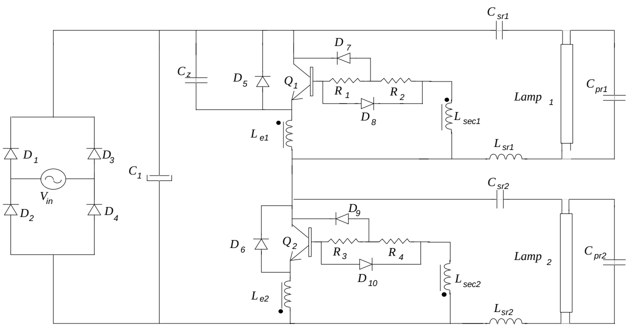


Fig. 8. Simulated circuit

In Fig. 9 the resonant inductor steady-state currents are shown. There can be noted the complementary operation of the resonant networks and also is observed when one lamp fails the other continues in operating. The oscillation frequency obtained, when two lamps are operating , is 49 (KHZ) which practically agrees with the designed frequency.

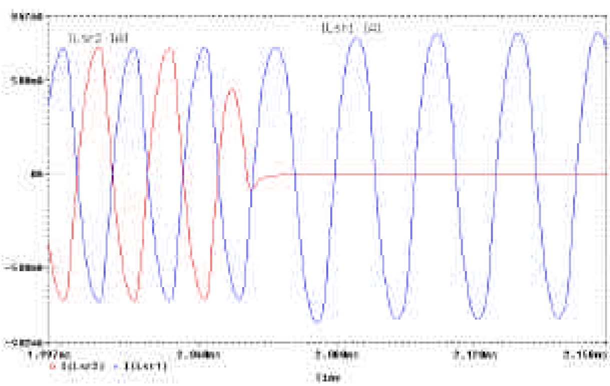


Fig. 9. Resonant inductors current.

In fig. 10 the frequency spectrum for the resonant inductors currents are shown, where a frequency drop can be noticed when a lamp fails. This is due to the self-oscillation now depends only one resonant network.

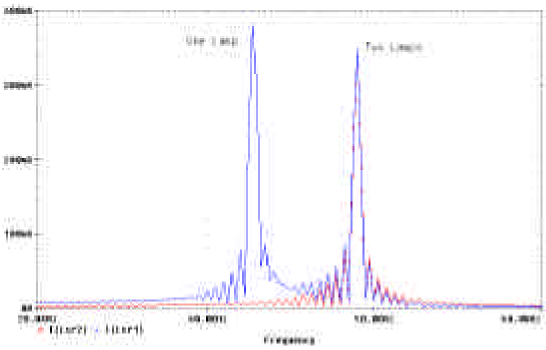


Fig 10 Frequency spectrum of currents.

The Fig. 11 shows the resonant inductor steady-state current and the input steady-state voltage, Vab, at one of the resonant circuit. Here can be observed the inductive characteristic of the circuit.
These result implies that these equations are numerically well behaved.

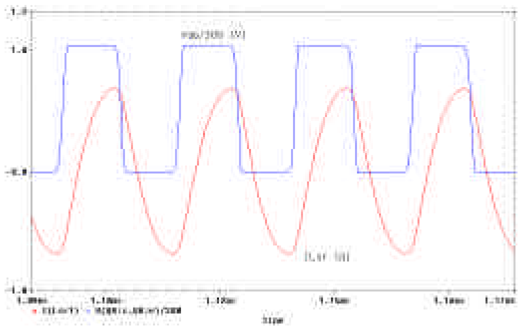


Fig. 11. Resonant inductor current and input voltage (Vab), steady-state.

This operation mode gives the possibility of working with more than two lamps, for example feeding two lamps in series in each resonant circuit, this topology is shown in Fig. 12.

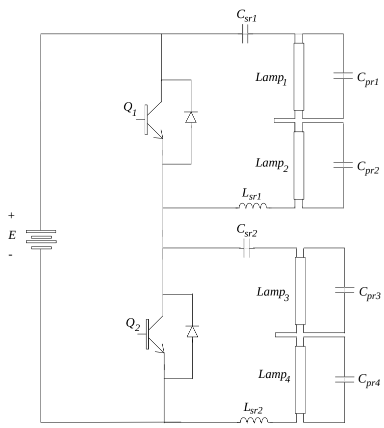


Fig. 12. Proposed scheme for a four lamps electronic ballast.

VIII. Experimental Verification

To verify the above analyses, a half-bridge self-excited ballast have been built and tested.

The load is two 40W fluorescent lamps. Circuit parameters are regulated to obtain 40W lamp power under 310V DC bus voltage. The parameter values are listed in Table I:

TABLE I
THE PARAMETER VALUES OF CIRCUIT

D1, D2, D3, D4	*1N4007*
D_5,D_6, D_8, D_{10}	*FR104*
D_7, D_9,	*FR157*
L_{sr} (measured)	*1.3 (mH)*
C_{sr}	*33 (nF)*
C_{pr}	*5.8 (nF)*
R_1=R_3	*6.2 W*
R_2=R_4	*12 W*
C_z	*3.3nF*
C_1	*220 mF*
Ferrite toroidal core, NT-15	*N_{e1}=N_{e2}= 2, N_{sec1}=N_{sec2}= 4*
Transistors	*BU508*

Figure 13 shows the main waveform experimentally obtained. Current in the resonant inductor when ballast operates with two lamps is shown in Fig. 13. The frequency of operation is 39 (KHZ).

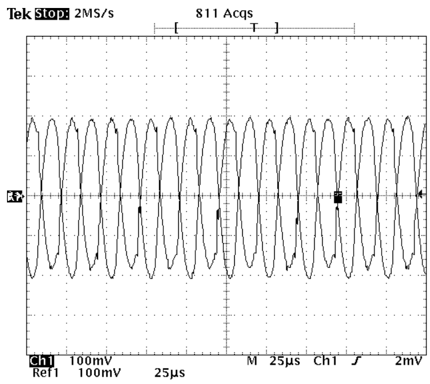


Fig 13. Resonant inductive current, for both lamps, steady-state. Scale: 0,4 A/div.

The current in the resonant inductor when the circuit operates with one lamp is shown in Fig. 14. A variation in the operating frequency is observed, now is 33 (KHZ), moreover an increase in the current of the resonant network is observed too, this is because of impedance reduction.

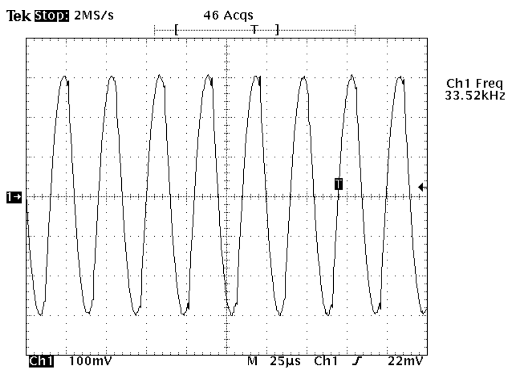


Fig 14. Inductor resonant current, steady-state. Scale: 0,4 A/div.

Voltage and current in one of the lamps, when circuit operates with both lamps, is shown in Fig. 15. Resistive behavior of the lamp in high frequencies can be observed.

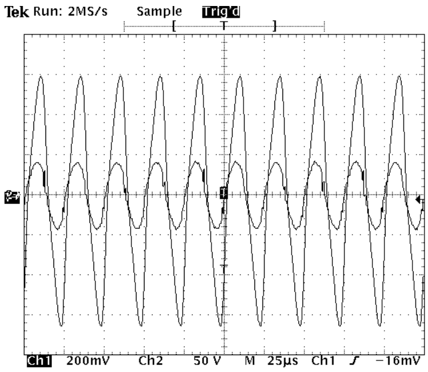


Fig 15. Lamp voltage and current. Scale: 50 V/div, 0,8 A/div.

Figure 16 shows input voltage to the circuit (Vab or Vbc) and current in the resonant inductor. As seen in Fig. 16, the emitter collector saturation voltage is high, reaching a maximum value of 20V, where the conduction losses of the transistor can be significant.

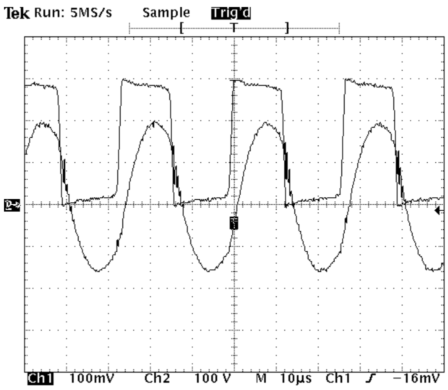


Fig. 16. Steady-state inductor resonant current and input voltage (Vab). Scale: 100V/div, 0.4 A/div.

IX. Conclusion

An improved electronic ballast topology feeding two fluorescent lamps, based on the resonant converter, has been presented and studied. A calculation methodology for the resonant circuit parameters was developed and the design of a for feeding two 40W fluorescent lamps was realized.

The independent operation of both lamps was validated through an experimental prototype, which implies a best use of the resonant inverter circuit characteristics.

Could be considered a disadvantage the inclusion of another resonant inductor in the proposed electronic ballast for two lamps, however this asseveration is relative, because a division of the resonant inductor in two minors was made, therefore its cost and its volume do not increases significantly.

Finally as comment, we can to say that the base circuit should be optimized in order to reduce losses in the switches.

IX. References

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