

MATLAB Modeling,LTSpice simulation and Experimental Analysis of Electronic Ballast

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ABSTRACT : In this Paper the steady state oscillation of a BJT self-oscillating electronic ballast driven by a saturable transformer was analysed for a 36W fluorescent lamp. In the MATLAB modeling, the self oscillating operation of ballast is divided into four stages which reduced the complexity of the circuit. Analysis showed that the saturable transformer limits the lamp current and dominates the switching frequency. Results of MATLAB modeling were compared to the simulation results of LTSpice software and experimental analysis. Comparison showed similar results with stable phase margin and expected lamp current.

Keywords : Electronic ballast, phase margin, lamp current.

I. INTRODUCTION

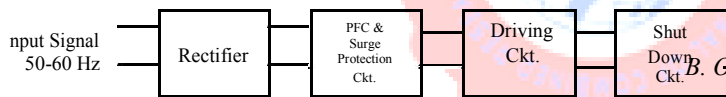


Fig. 1

High-frequency electronic ballasts are gaining popularity these days. They are much better than the traditional magnetic ballasts which are heavy, bulky and have low power factor. Electronic ballasts are light weight, high power factor (>0.9), no flick, high efficiency and decreased cost. These ballasts have overcome various indirect, direct and social economic impacts including interruptions, dips, surges and transient, harmonics and flickers.

Currently, the electronic ballast has to meet the regulation of IEC 1000-3-2.

The block diagram of a high-frequency electronic ballast with a bridge rectifier, power factor correction and surge protection circuit, driving circuit and shut down circuit is shown in Fig. 1.

Phase margin is a measure of stability in closed-loop, dynamic-control systems. It indicates relative stability, the tendency to oscillate during its damped response to an input change such as a step function.

II. BASIC CIRCUIT AND ITS OPERATION

A. Circuit

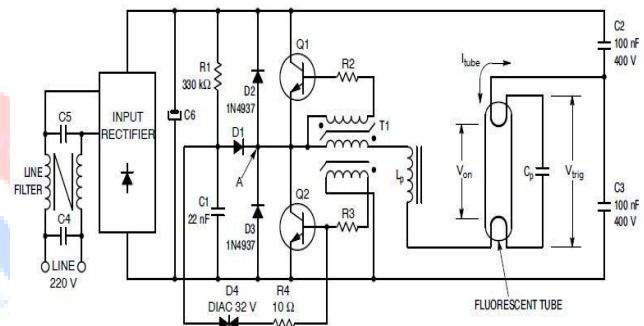


Fig. 2. Basic Circuit Topology for Electronic Ballast

B. Operation

The oscillations are generated by means of saturable transformer T1. Since the two transistors are biased in the off state through the low Base-Emitter impedance provided by the secondary of T1, this circuit cannot begin by itself, unless there is an imbalance between the low side and the high side of the converter. But, such an imbalance will badly degrade the operation once the converter starts. Henceforth, it is preferable to have a pair of matched transistors and to start the converter with the network built around the Diac D4, capacitor C1 and resistor R1.

When the line voltage is applied, capacitor C1 charges exponentially through resistor R1. Then the voltage across C1 reaches the trig value of D4, the diac turns on, discharging C1 into the Base-Emitter network of Q2. This transistor turns on and the change in collector current (di/dt) through the primary of T1 generates a voltage across each of the secondary of T1.

By arranging the windings as depicted in Fig 2, the voltage V_{BB} is negative for the upper switch and positive for the lower one. This forward biases Q2 and the Collector current of this transistor keeps raising until the core of T1 saturates.

From electromagnetic circuit theory, the magnitude of the current in the secondary of T1 is given by $I_B = I_C N_p/N_s$ (Equation 1):

$$I_B = I_C N_p/N_s \quad (1)$$

Of course, the value of I_B must be large enough to fully

saturate the transistor, even under worst case conditions. On the other hand, the V_{BB} voltage developed across the secondary must be limited to a value lower than the V

of the transistors, otherwise the Base–Emitter junction goes in avalanche and the global efficiency can be downgraded.

The V_{BB} voltage is given by another electromagnetic Equation 2:

$$V_{BB} = V_B * N_s / N_p \quad (2)$$

Designing a converter for the lamp ballast application is not very difficult, but there are many steps that must be performed first. The initial step is to define the chopper frequency, since most of the critical parameters depend upon this criterion.

The topology being a self oscillator, Half Bridge will allow the design to make the manufacturing of the electronic circuit as uncomplicated as possible. The selected core used to make the converter must meet the following specifications:

The core must be saturable and show a BH curve as square as possible. Number of turns is equally important to be considered. If the turns ratio is less than unity, the saturable core saturates quickly and then self-oscillating frequency increases.

III. MATLAB MODELLING FOR 36W-LAMP

A. Circuit

Mathematical model for the lamp driver circuit was first developed .

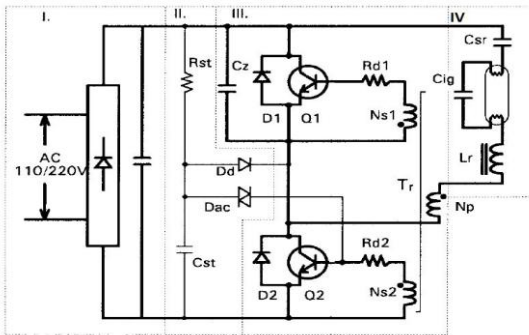


Fig.3 Mathematical Model

The circuit shown above represents a BJT self-oscillating ballast driven by a saturable transformer. The transformer plays the important role of alternatively switching the two BJTs, one at a time. The working is divided into 4 stages, which are clearly separated and accounted for in the MATLAB code.

B. Analysis

Due to the nonlinear behavior of the power transistors, the discharge

lamp and the saturable transformer, it is difficult to exactly study the steady-state oscillation of the ballast. In

order to decrease the analytical complexity, some simplifications are adopted in this analysis. First, based on the fact that the effect of ignition capacitance on the resonant current is small and the current harmonics arisen from the nonlinearity of discharge lamps are bypassed by the ignition capacitor and utilized for heating the two filaments, therefore, the lamp tube and the ignition capacitor can be globally viewed as an equivalent resistive component. Secondly, in view of the inductance of the series inductor is normally greater than ten times of the inductance of the driving transformer , the series-connected driving transformer can be viewed as a current transformer driven by sinusoidal resonant current. Thirdly, the loss of iron cores and the junction capacitance of bipolar junction transistors are neglected because their effects on the self-oscillating inverter are very small. Fourthly, the employed large-signal parameters, such as the value of inductance, capacitance, resistance, transit time and minority carrier lifetime, are all assumed nearly constant.

C. Circuit Parameters used

Parameter S	Description	36 W TLD Lamp
P_{lamp}	Lamp power in watts	32 W
I_{lamp}	Lamp current in mA	450 mA
L_r	Lamp inductance coil	1.1 mH
C_s	Series capacitor	18 F
C_z	Transistor capacitor	1.2 nF
R_d	Discharge resistance	10.909
N_p	Primary coil turns	6
N_s	Secondary coil turns	4
B_s	Magnetic field in tesla	0.4
E_{be}	Base to emitter voltage	0.65 V
I_{be}	Base to emitter current	10 mA
C_b	Basestorage capacitance	10 nF
β_{fe}	Current gain	20
E_{BES}	Saturation base emitter voltage	0.75 V
V_i	Input source voltage	300
V_{CO}	Capacitor voltage	0

Table 1

D. Results

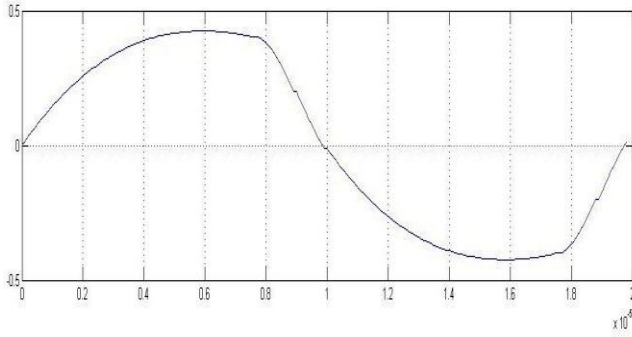


Fig. 4 Lamp Current

IV. SIMULATION THROUGH LTSPICE

A. Circuit

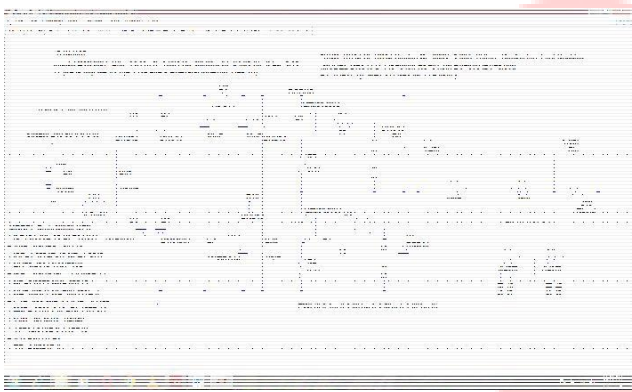
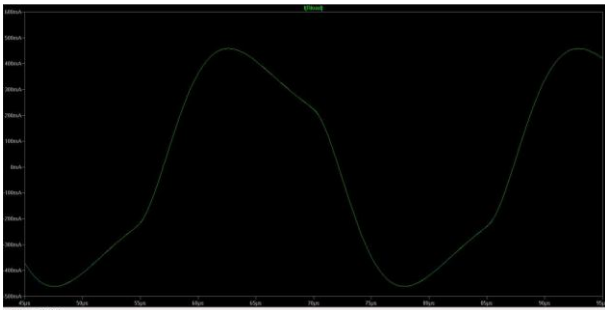


Fig. 5.

B. Results

After simulation, the following waveform of lamp current was obtained. $I_{lamp} = 450\text{mA}$



V. EXPERIMENTAL VERIFICATION

A. Theory

To verify the accuracy and efficiency of the analysis, the numerical simulation is performed and results are compared with experiments. The lamp is a 36-W fluorescent lamp, having the lamp current of 0.45 A. In the following circuit design, the turns ratio is greater than unity.

Basically, in the experiment it is being determined that the stability of phase margin is of utmost importance. Here, Phase margin is considered as the difference between the phases of V_{CE} (Voltage between collector and emitter) and I_C (Current flowing through collector), measured in microseconds.

B. Waveforms

(1) At 180 V—

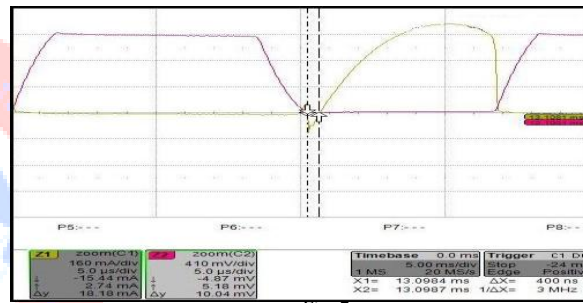


Fig. 7.

(2) At 200 V—

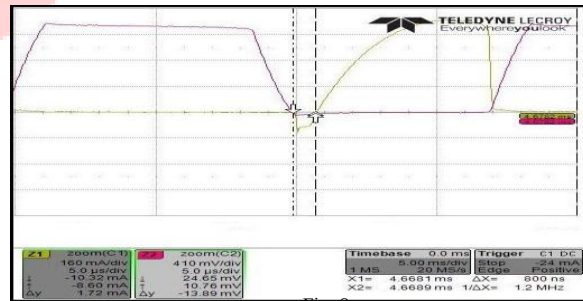


Fig. 8.

(3) At 220 V—

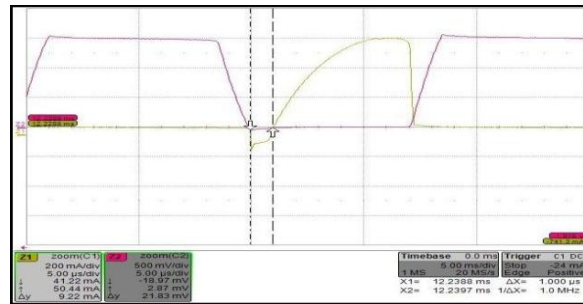


Fig. 9.

(4) At 240 V—

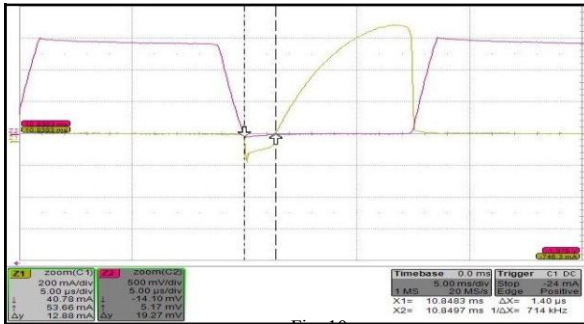


Fig. 10.

(5) At 260 V—



Fig. 11.

(2) Lamp Current

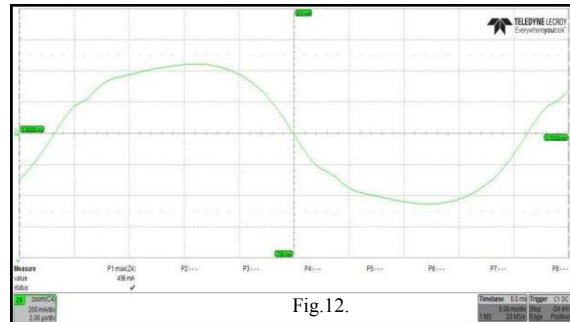


Fig.12.

C. Observation Table

(1) Phase Margin

VOLTAGE(V)	PHASE MARGIN(μ s)	PHASE MARGIN(ns)
180	0.4	400
200	0.8	800
220	1.1	1100
240	1.4	1400
260	1.65	1650

Table 2

VI. CONCLUSION

This paper presented the analysis of a high-frequency electronic ballast. MATLAB modeling was done by dividing the circuit into four stages for reducing the complexity. Then, the circuit was simulated on LTSPICE, after which experimental analysis was done.

On comparing the results, Lamp current in MATLAB modeling was observed to be 450 mA, in LTSPICE, it was 460 mA and 456 mA in experimental verification. As can be seen, lamp current from the three methods is almost equal.

The ballast showed a stable phase margin. It indicates relative stability, the tendency to oscillate during its damped response to an input change.

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