Electronic Ballast for 70W High Pressure Sodium Lamp

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***Abstract* - Nowadays street lighting is based on robust and resistant ballasts, with high losses and fast deterioration of their electric characteristics. The main lamps used for that are mercury vapour and high pressure sodium. Sodium vapour lamps present a superior gain on the one of mercury due the high brightness. The emergence of the electronic ballasts in that segment always had as barrier two factors: cost and reliability. This occurs due to the involved electronics devices to be expensive and high tax failure in the operation. Today the suppliers provide specific electronic devices to use in electronic ballasts with low cost and high reliability. That work presents the behavior of an electronic ballast for sodium vapour 70W with low losses.**

I. Introduction

The conventional ballasts or electromagnetics for sodium lamps 70W present losses as shown in Table I [1]:

TABLE I
LOSSES IN CONVENTIONAL BALLASTS

Parameter/Ballast	*Ballast A*	*Ballast B*	*Ballast C*	*Ballast D*
Input current [A]	0,42	0,43	0,41	0,42
Input power [W]	84,7	82,1	79,8	82,1
Power factor	0,92	0,87	0,89	0,88
Lamp voltage [V]	88,7	89,6	87,2	87,3
Lamp currente [A]	0,98	0,97	0,95	0,97
Lamp power [W]	67,8	66,5	65,7	67,0
Flux [Lm]	5490	5343	5183	5355
Loss [W] 15W max	17,5	15,0	15,9	15,4

It is importatn to say that all values above are for four samples each manufacturer of conventional ballast.

Its permanence is still possible due to the fact of they be robust, they resist to bad weather (atmospheric discharges, mechanical movements, etc) and they present costs relatively low. Those ballasts deteriorate their electric characteristics due to the capacitor, used for correction of the power factor, to present variations in its behavior in elapsing of the operation. The direct consequence of that phenomenon of deterioration of the capacitor is the expressive reduction of the power factor, that gets to reach a value of 0,80 or less. Figure 1 shows input voltage and current waveforms for a conventional ballast where the capacitor is damaged and does not operate correcting power factor.

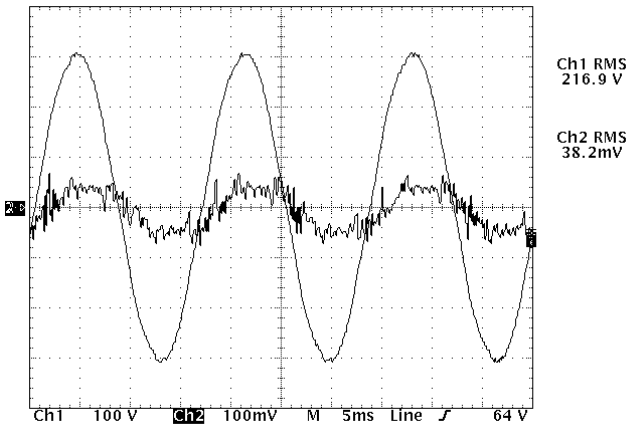

Fig. 1. Input voltage (100 V/div) and current (1 A/div) behavior for a conventional ballast

Note displacement of the input current in relation to input voltage. Here Power Factor (PF) is 0,85 and Total Harmonic Distortion (THD) is 32%.

Below, in Table [2], it can be observed input current harmonics compared with IEC 61000-3-2 Standard.

TABLE II
INPUT CURRENT HARMONICS AND IEC 61000-3-2 STANDARD

Frequency (Hz)	**IEC 61000-3-2 Limits (% Fundamental)**	**Conventional ballast**
180	25,5%	13,5%
300	10%	10,5%
420	7%	15,8%

This conventional ballast presents bad PF and input current harmonics exceeding international standard.

Other deterioration point is the electric resistance of the inductor used that, due to the excessive heating promoted by the losses, it has its altered value, harming the operation of the ballast and altering the brightness supplied by the lamp.

The conventional ballast is composed by an inductor in series with the lamp, a capacitor and an ignitor. Its behavior can be improved with use of material of better quality in the inductor core production.

The electronic ballasts come absorbing the demands of the market in a reliable way and assuring to the user a series of advantages:

- High power factor, that stays in this case for a lifetime useful of the ballast;
- Low losses due to the consumption of the electronics and of the devices of high power (transistors, inductors and capacitors);
- Better efficiency of the lamp in high frequency with regard to the brightness. The direct consequence of this phenomenon is a smaller amount energy used for obtaining of the same brightness, that in the case, it is reference level;
- Weigh of the ballast, that is significantly smaller than the conventional. That allows to reduce its volume and, even, to incorporate it inside of a luminaries (common fact in the most modern luminaries);
- Incorporated ignitor, what reduce the price.

II. Electronic Ballast

As it is a commercial product, some details will not be shown, according patent laws.

The electronic ballast is represented in the Fig. 2.

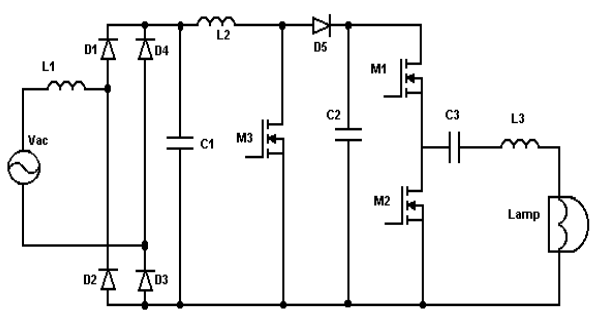

Fig. 2. Representation of the electronic ballast

Electronic ballast is divided in three blocks: input, boost converter and half-bridge inverter.

Input has for function the elimination of the noises by means of a LC filter and the rectification through a diodes bridge.

The boost converter operates in critical conduction mode, allowing the reduction of the external components to control it and improving power factor [2].

Boost converter is a classical structure, then we will not explain all equations, because they are known. This conduction mode is assured by integrated circuit, which operates controlling boost voltage.

Voltage balance on the inductor L1 provides the static characteristic for that conduction mode, according (1):

$$V_0 = \frac{V_p . sin(wt)}{1-d} \qquad (1)$$

where:

V_0 = voltage of the boost converter
V_p = peak input voltage
δ = duty-cycle of the boost converter

In this conduction mode the electronic ballast operates with variable frequency. Figure 3 shows current through the input inductor and transistor voltage of the boost converter.

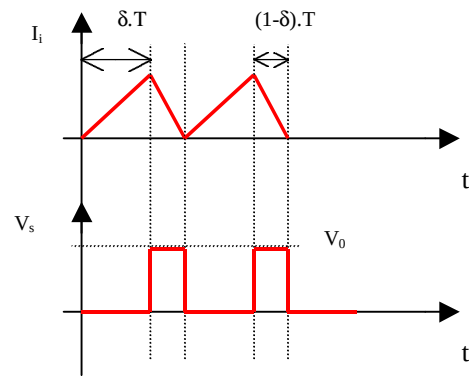

Fig. 3. Waveforms for critical conduction mode

where:

Ii = inductor current L1
T = switching period
V_S = voltage on the transistor M3
V_0 = output voltage

The half-bridge inverter generates a square wave alternated for operation of the sodium vapour lamp. The inductor in series with the lamp should operate with high frequency, what reduces its volume drastically. When we analyse lamp in steady state, we can consider that it behaves like a resistance. Considering it has two equivalent circuits, when M1 is switched on and when M2 is switched on, it can normalize the lamp power and gets inductor value L3, as shown in (2):

$$L_r = \frac{R_0}{k.f_S} \qquad (2)$$

where:

R_0 = equivalent resistance of the lamp
k = impedances factor
fs = operation frequency on the lamp

III. Experimental Results

Results obtained with the prototype of electronic ballast for 70W present an efficiency of 94,5%. However if it takes an account of lamp supplied by a same manufacturer it is possible find many diferent value for power lamp. This diference in the losses is significant, and it can reach for 2W. In this ballast prototype it is obtained a power factor of 0,99. Fig. 4 shows as input current and voltage behave.

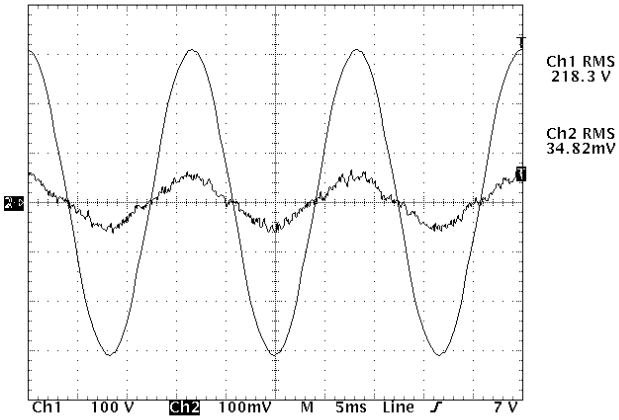

Fig. 4. Input voltage (100 V/div) and current (1 A/div)

Note current waveform for electronic ballast when it is compared with Fig. 1. Electronic ballast allows that waveform input current will be very close to sinusoidal waveform. Input power, in this case is 75,2W.

Electronic ballast does not violate international standard for low frequency harmonics in the input current (IEC 61000-3-2) [3], according Table III.

THD in input current is 12%. THD of input voltage is 1,8%.

TABLE III – INPUT CURRENT HARMONICS AND IEC 61000-3-2 STANDARD

Frequency (Hz)	IEC 61000-3-2 Limits (% Fundamental)	Electronic ballast
180	29,7%	11,5%
300	10%	2,8%
420	7%	0,5%

Figure 5 shows behavior of the half-bridge inverter voltage and lamp current.

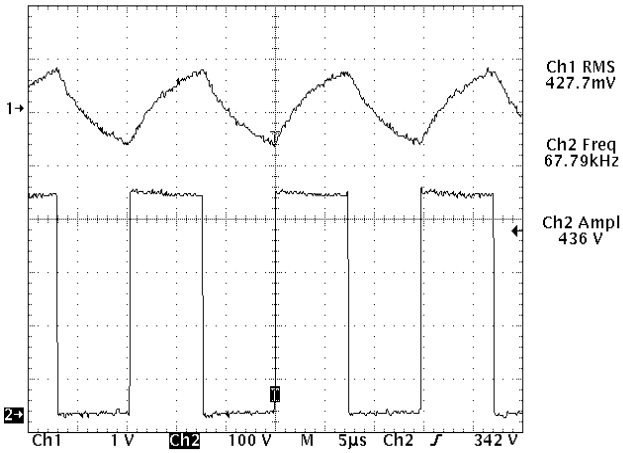

Fig. 5. Half-bridge inverter voltage (100V/div) and lamp current (2A/div)

Note in Fig. 5 that this frequency is not fixed because all ballast output is dependent the set components. An example of this is output inductor L3, that when it is manufactured it presents a tolerance and ballast is mounted containing that. Then ballast is adjusted according all components value, because main objective is that input power will be 74W and power lamp 70W.

As commented this ballast has incorporated ignitor and it presents pulse which does not return to line when lamp does not start correct. Its value is according limits stabilished by IEC 60662 [5].

Below are shown input current and voltage for another operation point possible for electronic ballast, where input voltage is 127V, Fig. 6.

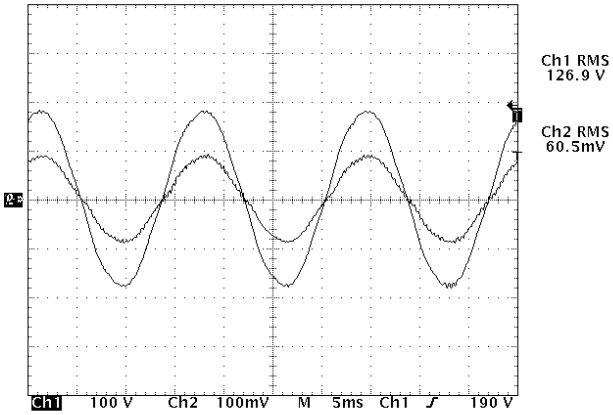

Fig. 6. Input voltage (100 V/div) and current (1 A/div)

Above it can be noted that electronic ballast maintains its behavior concerning power factor and waveforms, but input power increase because input current increase too. In this case input current THD is 4,2% and input voltage THD is 2,4%; while power factor is 1,00.

Electronic ballast for sodium vapour lamp 70W was evaluated with regard to IEC-CISPR 15 standard [4]. Results shows that it is in accordance with this standard, which can be observed in Fig. 7.

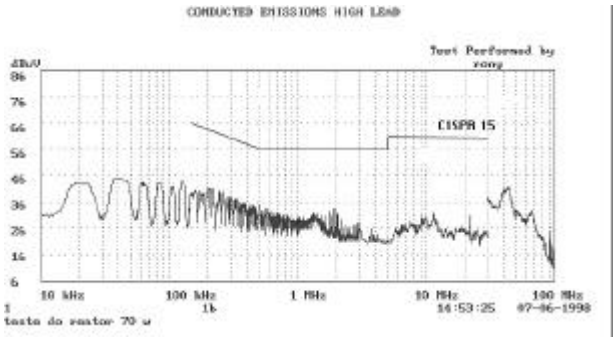

Fig. 7. Electronic ballast behavior and IEC-CISPR 15 standard limits

It can be observed that conducted electromagnetic interference limits are above from signal provided by electronic ballast. Durability of the lamp electrodes is also evaluated [6]. Figure 8, an enlarged photo is still had of one of the lamp electrodes of sodium vapour without operation.

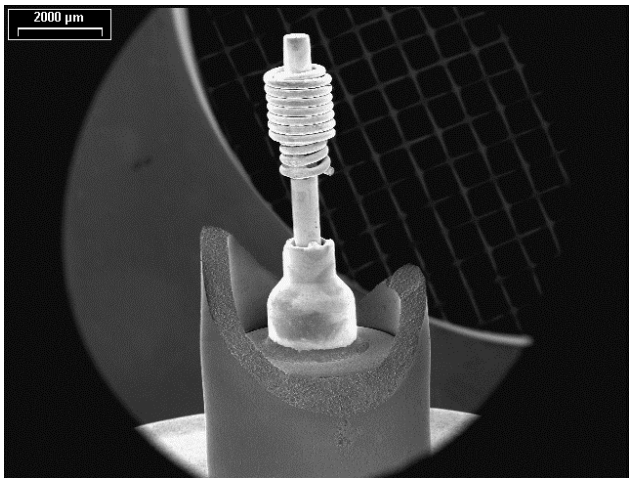

Fig. 8. 70W sodium vapour lamp electrode without operation

Results of a long operation period are presented in Fig. 9 (a) and (b), comparing operation of the lamp in low and high frequencies.

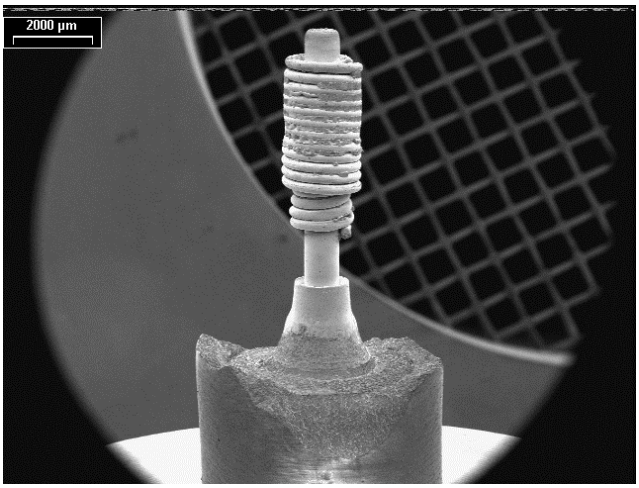

Fig. 9. (a) Sodium vapour lamp electrode after 1000 hours operations with conventional ballast

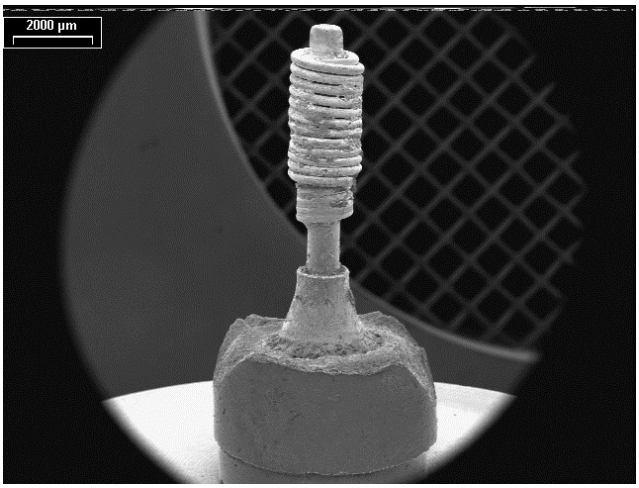

Fig. 9. (b) Sodium vapour lamp electrode after 1000 hours operations with electronic ballast

Note above that both electrodes are not damaged after 1000 hours, what it allows to say that when lamp is operated in high frequency it does not have your operation prejudiced. Below, Fig. 10 (a) and (b), it can be observed with more details the base of the electrode, comparing two situations, one of them where the lamp is without operation and another the lamp was operated by an electronic ballast.

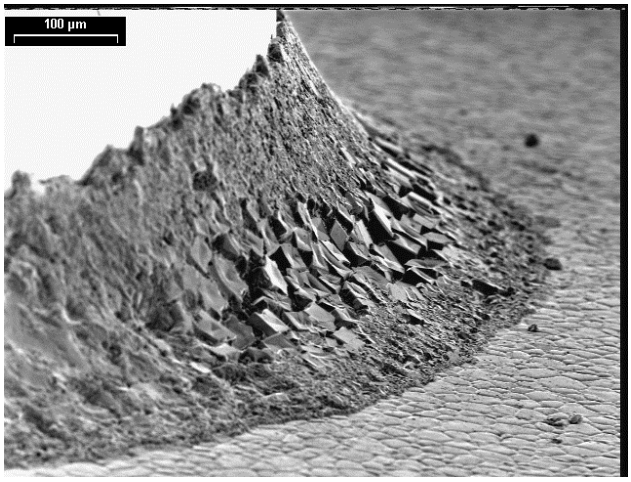

Fig. 10. (a) Electrode detailed for a sodium vapour lamp without opration

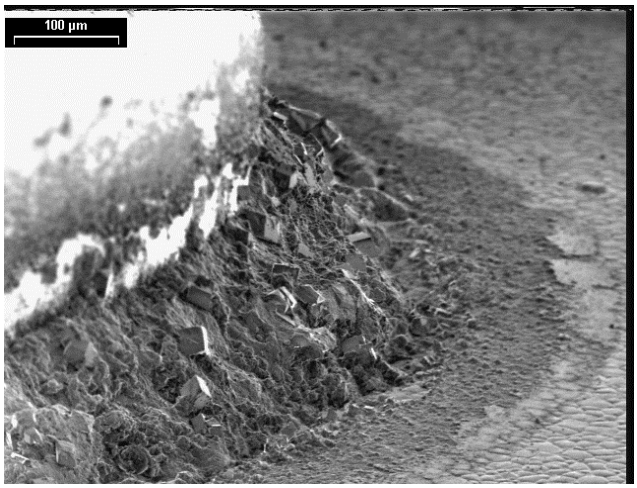

Fig. 10. (b) Electrode detailed for a sodium vapour lamp with 4000 hours operated by electronic ballast

Figures 10 (a) and (b) show that electronic ballast, which operates the lamp in high frequency does not cause damages in structure of the electrodes. It is important because lamp life depends of this fact. It will be made tests with conventional ballast considering 4000 hours of operation and theirs results will be presented later.

In this frequency has literature commenting about instability in lamp arc. Here, in all tests made, it did not have been found anything relationed with this fact. However it will be analyzed and results concerning these instabilities will be presented.

IV. Conclusion

This paper analyzed an electronic ballast for 70W sodium vapour lamp in many aspects concerning tests and situations where it will be in operation.

It presented a possible solution for street lighting where main objective is high brightness, minimum loss and maxim useful of the lamp life. Electronic ballast can provide that and more: high power factor during all lamp life, index of brightness constant when it is in operation independent of input voltage. Wide range of input voltage, 127 up to 265 V.

Another advantage brougth by electronic ballast it is weight, what it respresents 30% of conventional ballast weight.

All tests performed until now aprove electronic ballast with regard reliability, point outstanding before mentioned as a critical point because electronics devices.

V. References

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[5] "*High-pressure sodium vapour lamps*", Publications IEC 60662, International Eletrotechnical Commission, Standard IEC, 1997-04.

[6] M. Cantão, "*Images of Electronic Microscope of Sweeping*", LAC–UFPR/COPEL Images.