Low-Frequency Square Wave Electronic Ballast for High Pressure Sodium Vapors (HPS) Lamp With Resonant Ignition

Mehrdad Jafari Nezhadian¹, Majid Dehghani², Masoud Jabbari³
1- Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran
Email: m.jafari.n@sel iaun.ac.ir
2- Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran
Email: dehghani@pel iaun.ac.ir
3- Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran
Email: jabbari.masoud@gmail.com

ABSTRACT:
In this paper, the low – frequency electronic ballast for high – pressure sodium (HPS) vapor lamps has been presented in order to release from the acoustic resonance. The offered ballast has been the cause of dimensions minimization and becoming more economical with combing the inverter part, voltage reducer and ignition. Some of ballast has been the cause of qualifications are the modifiability of power factor, fixed light output and ignition with controlled voltage in this article. The circuit performance of 70 (watt) sodium vapor lamp has been investigated and the simulation and experimental results have been presented. Transmitting output toward a lamp with low frequency and voltage and current controlled by high – frequency (about more Than ten (KHZ)) has been accomplished under the Half Bridge and buck converter.

KEYWORDS: Electronic Ballast, Acoustic Resonance, HPS Lamp, Resonance Ignition.

1. INTRODUCTION

High Pressure Sodium (HPS) lamps are extensively used for public lighting systems because of their long lifetime and high illumination efficiency [1], [2]. At first these kinds of lamps need a voltage about 4kv for lionizing the gas inside the lamp and then they need an intermediate for restricting current (because of negative resistance of lamp).

The present ignition of these lamps has been done by a set of inductive ballast and igniter. The vast use of these lamps and the faults of inductive ballast such as low efficiency (about 0.8), improper power factor (about 0.44), variable light output (according to network voltage and lamp life) and also high weight caused that the electronic ballast takes into consideration.

Electronics ballast can achieve 0.9 efficiency and 0.99 power factor on the average. This kind of ballast fix the sending voltage toward inverter by the circuit of power factor correction (PFC) and then control the impact of network voltage changes on sending output to lamp [4].

HPS lamp show different impedance with increasing the long life. This is a cause of receiving different output from resource and changing light output. Electronic ballast will be able to control the sending output to lamp and give the fixed light output from lamp [5], [6]. With all these qualifications, the electronic ballasts work in high – frequency and this is a cause of occurring a phenomenon which is called acoustic resonances [7], [8]. This phenomenon causes the light oscillation and appears flicker mode in lamps. Two factors will provide the acoustics resonance [9]:
1. Working frequency is near the natural frequency.
2. Sufficient energy is reached to lamp in this frequency.

Many defferent ways have been offered for repelling this phenomenon:
- Using ballast with sinusoidal low – frequency [10], [11] (inductive ballast) which has low efficiency and high volume and improper power factor.
- Going toward high – frequency (about 1 MHz) [12] which caused an increasing in switching loss and design complexity and EMI.
- Constructing ballast in fixed frequency and finding a safe frequency [13] with recognizing the gas type inside tube and filaments. These solutions weren’t useful because they had been designed for special lamp while all parameter were interchanged by changing the lamp life.
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- Constraining in electronic ballast with variable frequency [14]-[17] caused the different sending of output to lamp and reduce the light output.
- Another way of constructing electronic ballast is square – wave [18] - [20] this is one of the best way in order to release from acoustic resonance. In any case. Achieving to proper square – wave resource and high efficiency is difficult in designing this kind of ballast circuit.
- The common and accepted solution is the constructing of ballast with low frequency [21]-[26] about hundreds hertz to lamp is performed and it ascertains Buck converter in every cycle and controls the input.

In these designs, the first presented ballasts were in three-stage (according to Fig. (1-1)), but they have some problems such as increasing size, efficiency reduction, becoming expensive. Next setup was the combination of converter with each other (according to Fig. (1-2)), combining power factor correcting and reducer have a low efficiency. After combining full – bridge inverter part with buck converter (according to Fig. (1-3)) was offered that the economic justification of ballasts gets more difficult, because of the existence of many more switches and their control. The offered ballast (according to Fig. (1-4)) methods and this caused on increase in cost and volume in this ballast and part of a separate ignition. The resonance method has been used for ignition step in this article.

2. THE OPERATION OF HALF – BRIDGE TRANSUDER IN

High pressure sodium (HPS) vapor lamps show high impedance at first, for lighting up they need a voltage about 3.8 (Kv) in order to ionizing the gas inside the tube. For making such a voltage the resonance circuit (under half – bridge transducer topology) has been used. In this resonance circuit is decreasing used dimension and cost. Based upon offered equations we can obtain this:

\[ \omega = \frac{1}{\sqrt{L_C}} \]  \hspace{1cm} (1)

\[ V_c (S) = V_m \times \frac{1}{C_s S + \frac{1}{R + L_s S + \frac{1}{C_s S}}} \]  \hspace{1cm} (2)

According to equations (1), (2), it is concluded that:

\[ V_c (j \omega) = \frac{V_m}{RC_j \omega} \]  \hspace{1cm} (3)

\[ |V_c (j \omega)| = Q |V_m| \]  \hspace{1cm} (4)

\[ Q = \frac{1}{\sqrt{L_C}} \]  \hspace{1cm} (5)

As a matter of fact and according to Fig. (2), \( C_n \), \( L_n \) are the inductor and capacitive of resonance circuit R is equivalent to ESR of capacitor and switches resistance and \( V_m \) is equal to \( V_j/2 \).

For reaching this voltage and for doing ignition process the quality factor (Q) should be large adequately this work requires small amount of R and C and being large of the inductor.

The offered ballast starts working with resonance frequency and then it enters in work frequency. The operation difference of offered ballast is in the way of its starting up. The low frequency depends on the capacitor amount in to sides of lamp in low-frequency electronic ballast.

In this way, we can minimize the amount of output ripple so we expect that this amount of capacitor may be significant.
The problem which is mode is the change in amount of quality factor. For removing this problem the other low frequency ballasts prepare the lamp working mode voltage firstly and then ionize the gas inside the lamp by sported igniter circuit.

In this paper, two head capacitors are used for removing this problem after entering frequency while the lamp is hale and the ionization works correctly so the ignition capacitor is exited from circuit by a relay and it enter working frequency.

3. HALF– BRIDGE TRANSDUCER IN LOW – FREQUENCY AND THE ARCHVEMENT OF TWO – SIDED BUCK

There are many different techniques for releasing from acoustic resonance phenomenon they are consisted of the continuous change of frequency. The frequency incensement more than 500 (MHz), designing the system for recognition and change of frequency and power. But the most common and reliable way for performing the power to lamp is in low – frequency.

The low – frequency square – wave has ascertained a Buck converter in every cycle and it can control the voltage and effective input current to lamp. The acoustic resonance phenomenon will happen in frequency more than 1 (KHz). But for more assurance, we perform a voltage square – wave and current in 200 (Hz). Capacitor $C_B$ was ineffective in resonance process. Because its amount is more than $C_r$ and the relay is open. After ignition, the relay is closed and capacitor $C_r$ Will be exited from circuit (according to Fig. (3)). The switches will be activate for achievement of two ways buck (According to Fig. (4)).

3.1 positive Buck

For reducing switching loss and increasing efficiency, we will analyze converter in DCM and CCM boundary in this way, the switch will be turn on in ZCS conditions. In positive buck process the $M_2$ switch turns off and $M_1$ performance Buck converter with high frequency (about tens kilo hertz) according to figure 4. The voltage and current in mode (I-I) will be offered in equation (6), (7) and based on Fig. (5) and (6).

\[
\text{Mode}(I-I): \quad V_L = V_s - V_o
\]  

\[
\text{Mode}(I-I): \quad \Delta I_L = \left(\frac{V_o - V_o}{L}\right)DT_S
\]  

The inductor voltage and current in mode (I – II) will be offered in equations (8), (9) relations and based Fig. (6) and (7). $V_o$ is the voltage of lamp's two heads. $V_s$ is equal to $\frac{V_{\text{Out,PFC}}}{2}$.

\[
\text{Mode}(I-II): \quad V_L = -(V_s + V_o)
\]  

\[
\text{Mode}(I-II): \quad \Delta I_L = \left(\frac{V_s + V_o}{L}\right)(1-D)T_S
\]
The voltage and current in mode \( II - I \) will be offered in equations (12), (13) and based on Fig. (7), (8).

\[
Mode(II - II) : \quad V_L = (V_s - V_o) \quad (12)
\]

\[
Mode(II - II) : \quad \Delta I_L = \left(\frac{V_s - V_o}{L}\right)DT_s \quad (13)
\]

We will obtain equation (14) for making a balance. When we suppose that \( D \rightarrow 1-D \) in equation (15) is entered CCM, SO eleventh relation will be made:

\[
\int V_L = 0 \Rightarrow \int V_L + \int V_L + \int V_L = 0 \quad (14)
\]

\[
M = \frac{V_o}{V_s} = \frac{D - D'}{D + D'}
\]

\[
D = \frac{M + 1}{2} \quad (15)
\]

3.2 negative Buck

The current and voltage will be reversed in making negative Buck process. \( M_1 \) switch turns off and \( M_2 \) will perform buck converter with high frequency conversely.

The negative Buck will be made in this way (according to figure 4). This process is in half – bridge converter because the load sets (inductor, capacitor and inductor and lamp) are floating.

The inductor voltage and current in mode \( II - I \) will be offered in equations (10), (11) and because on Fig. (7), (8).

\[
Mode(II - I) : \quad V_L = -(V_s + V_o) \quad (10)
\]

\[
Mode(II - I) : \quad \Delta I_L = \left(\frac{V_s + V_o}{L}\right)DT_s \quad (11)
\]
Theoretical analysis of the half-bridge Buck Converter

In mode (I-II) and mode (II-II) inductor will return some of received energy to Cs capacitor (we called this Vs have). If the Circuit has no loss and the efficiency let to be equal one, the equation (16) will be achieved based on energy law. The equation (17) will be achieved based on law (16).

\[ L_{\text{min}} = \frac{V_o^2}{RV_oD} + \frac{\Delta Q^2}{2C_sV_oDT_s} = \frac{V_o^2}{R} - T_s \]  

If we want to keep transducer in CCM and DCM boundary \( I_{\text{min}} \approx 0 \) should be considered so that the switches will be turned on we can obtain the quantity with solving eightieth equation. The quality of will be calculated by solving equation (19).

\[ M^2f_s \frac{(1-M)}{RD^2} = \frac{(1-M)}{128C_s} \]  

\[ L = \frac{2(1-M)(16RD^2C_s + \sqrt{2C_s(8R^2D^2C_s - M^2)})}{128C_sM^2f_s} \]  

According to Fig. (9), output voltage ripple depends on the amount of input load (current) to capacitor. So based on ripple amount, we will obtain the amount of capacitor. The equation (20) shows the amount of output capacitor.

\[ C = \frac{(1-M)}{8Lfv_o} \]  

4. SIMULATION RESULTS

The simulation results are extracted from orcad 16.5 software and its amount is calculated and inserted by computing losses in circuit.

According to EN60662 standard input voltage and current to sodium vapor lamp (for a 70 watt lamp) should be according to table (1).

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Objective</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>0.98</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The lamp has negative resistance But for simulating we must consider to lamp resistance in constant mode \( R_{\text{lamp}} = \frac{V_{\text{objective}}}{I_{\text{objective}}} - \frac{\lambda}{\lambda} \) in constant made.

Lamp current wave in Fig. (10), voltage and received power of lamp in Fig. (11), Buck inductor current in Fig (12) efficiency and output – input powers in Fig. (13) have been shown the obtained efficiency in simulate is equal to 0.97.
5. EXPERIMENTAL RESULTS

It’s necessary to mention that the lamp has negative resistance and non-linear load too. It’s not expected that the simulation results were the same as operational results about we search an operation near that. The operational circuit work as a controlling opened – ring. Voltage, current and power measured shown in Fig. (14), (15) and our proposed ballast shown in Fig. (16).

6. CONCLUSION

In this paper, we analyze low – frequency electronic ballast in order to release from acoustic resonance and then offer simulation and laboratorial results of a buck transducer which is combined with half – bridge topology. The characteristic of mentioned ballast has been integration of igniter part with buck and half – bridge part according to the vast use of sodium lamps in families we have tried to take steps in designing and constructing low – frequency, economical electronic ballast with high efficiency we have that we can offer an industrial sample of this kind of ballast to our dear countrymen. This offered ballast has been designed and implanted for 70 (watt) sodium vapor lamp. Its efficiency is. 91, its power factor is 99 so it's a suitable replacement for inductive ballasts.

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