SWITCHING CONVERTERS FOR LINE VOLTAGE REGULATION IN HID-LAMP LIGHTING SYSTEMS

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This paper discuss the application of voltage regulation in HID lamp lighting systems, using an AC-AC switching converters. Two main topologies of bi-directional switch regulators are investigated in order to obtain better results in harmonic spectrum of input and output variables and low active power losses. Different modulation strategies of switching regulators and their impact on quality properties are shown below in the proposed paper.

Keywords: AC-chopper, HID-lamp dimmer, line voltage regulator

1. INTRODUCTION

High-intensity discharge (HID) lamp dimming has grown in popularity in recent years. HID light sources can be found in numerous applications, from retail to industrial to public spaces. Dimming HID lamps can result in energy savings, peak demand reduction and greater flexibility in multi-use spaces. Dimming reduces energy costs by reducing the input power to the lighting system. It can be used to reduce peak demand and therefore reduce costly utility demand charges that can be a significant component of the total utility cost. And it offers greater flexibility to adapt spaces to different uses. Dimming can be used to save energy during periods when the space is unoccupied but needs to stay lighted for safety and security reasons. Dimming can be achieved either manually via input from a switch or automatically via input from a control device.

HID lamps have some special features, which had to be predicted in lighting system building. High-pressure sodium lamps can take 3-5 minutes to warm up; they take less than a minute to hot-restrike but don't reach full light for 3-4 minutes. Metal halide lamps take 2-10 minutes to warm up and 12-20 to hot-restrike, while pulse-start metal halide lamps take 1-2 minutes. Given these characteristics, it is not practical to shut off and restart the lamps based on occupancy if the space must be made usable again quickly. In these situations, the lamps must be operated continuously, resulting in energy waste. In addition, most lamp manufacturers rate HID lamp life at a minimum of 10 hours per start. Any reduction in burn time per start below this minimum will result in shorter lamp life [8,9].

2. HID LAMPS DIMMING - BASIC STRATEGIES

Consider the requirements of HID lamps safe operation conditions, public and industrial light dimming systems uses two main dimming technologies: Step-level and Continuous (line-voltage) dimming[10].

Step-level dimming enables wattage reduction, usually at 100% and a step between 100% and 50% of rated power, causing step-level dimming systems to often be called two-level or bi-level dimming systems. However, some systems, often called tri-level dimming systems, can operate at three fixed light levels. Step-level dimming is ideal for saving energy and providing lighting for safety and security during hours of non-occupancy. Tri-level dimming provides this benefit but offers a greater degree of flexibility to address multiple uses of the space. This dimming method usually employs a constant-wattage autotransformer, magnetic ballast with one or two additional capacitors added to the circuit, depending on whether the ballast provides bi- or tri-level dimming.

In line-voltage dimming a number of technologies are available for smooth, continuous reduction of lamp wattage, including switching regulators HID dimming and relatively new electronic HID ballasts. Ideal applications include anywhere it is advantageous to adapt the lighting system to a wide range of light levels to meet various space uses. Most effective method for reducing nominal output power related to light intensity, is voltage regulators also called AC-choppers. These electronic control systems reduce the RMS voltage to the load to reduce rated power down to 50% by chopping a part of each voltage cycle. They are used for control of both HID and fluorescent magnetic systems. They are compact and light controls, but can reduce power quality as well as lamp and ballast performance, causing harmonic distortions and active power losses. The main aim of research applications is to make these devices more effective, with high quality and low price. Some of these problems are discussed below in the text.

3. SWITCHING REGULATORS FOR LIGHT DIMMING SYSTEMS

Consider the requirements of HID lamp dimming systems, two main topologies of AC-AC regulators are shown. First uses thyristor switch, connected in diagonal of a Graetz bridge. (fig.1) Second is known as "AC-chopper" – using two bidirectional IGBT switches[3] (fig.2)

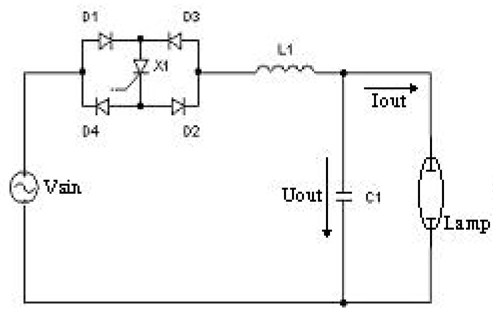


Fig.1: Thyristor regulator

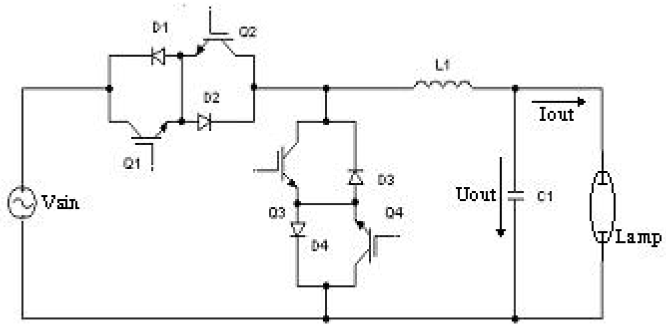
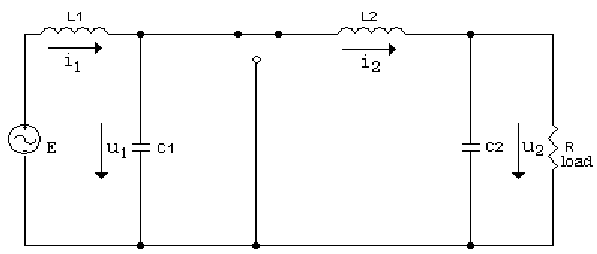


Fig.2: IGBT regulator

In terms of better performance characteristics and harmonic behavior second presented topology is most used in practical implementation and more interesting for this investigation. First topology is older and well known by some publications and it will be discussed only in brief and compare to AC chopper characteristics.

The equivalent circuit for IGBT regulator and the equations describe two basic functional conditions: 1.(fig.3)-storing energy in the ballast inductance and 2.(fig.4)-its dissipation. Unlike the thyristor regulator here we have two bi-directional fully controlled switches, which gives reliable and high quality circuit action.



Fig,.3: Equivalent circuit condition 1.

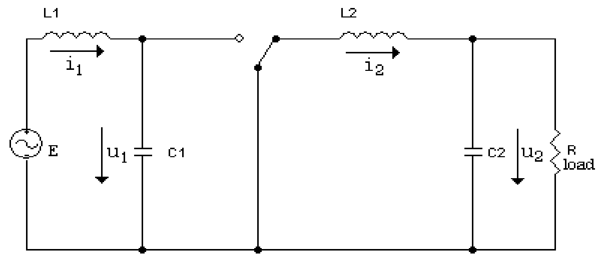


Fig.4:Equivalent circuit condition 2.

The equations, which describe the electrical process in both circuit conditions are shown on eq.1:

$$L_1.\frac{di_1}{dt} = \sqrt{2}.E.\sin\omega t - u_1 - r_1.i_1 \qquad L_1.\frac{di_1}{dt} = \sqrt{2}.E.\sin\omega t - u_1 - r_1.i_1$$

$$L_2.\frac{di_2}{dt} = u_1 - u_2 - r_2.i_2 \qquad L_2.\frac{di_2}{dt} = - u_2 - r_2.i_2$$

$$C_1.\frac{du_1}{dt} = i_1 - i_2 \qquad C_1.\frac{du_1}{dt} = i_1 \qquad (1)$$

$$C_2.\frac{du_2}{dt} = i_2 - \frac{u_2}{r_{load}} \qquad C_2.\frac{du_2}{dt} = i_2 - \frac{u_2}{r_{load}}$$

Using a commutation function k, we can determinate both equivalent circuits, which can be described by one equation system and coefficients as follows (eq.2):

$$k = \begin{bmatrix} 0\ ,\ \text{if}\ N.T_S + D < t < (N+1).T_S \\ 1\ ,\ \text{if}\ N.T_S < t < N.T_S + D \end{bmatrix}$$

$$L_1.\frac{di_1}{dt} = \sqrt{2}.E.\sin\omega t - u_1(1-k) - r_1.i_1$$

$$L_2.\frac{di_2}{dt} = u_1.k - u_2 \qquad (2)$$

$$C_1.\frac{du_1}{dt} = i_1.(1-k) - i_2.k$$

$$C_2.\frac{du_2}{dt} = i_2 - \frac{u_2}{r_{load}}$$

These two basic equivalent circuits and differential equations describe the behavior of an AC-choppers. We can calculate practical implementation element values using substitutions by different coefficients, which shows relationship between some output parameters, switching frequency and values of used elements in the circuit. The main advance of chopper circuit is possibility of stored inductive energy dissipation by second used (parallel) switch. Beside of that, IGBT switches are fully controllable devices and points of commutation are independent from current direction, reactance of the load and etc. These advantages allow using of various commutation strategies, which helps to avoid harmonic distortions, achieve near to unity power factor capability and other[7]. Simulation and experimental results shows the advances of IGBT-choppers, compared to thyristor regulators.

4. SWITCHING REGULATOR SIMULATION RESULTS

In this investigation two of most used circuit topology are shown. First is well known AC regulator with thyristor switch. Second is AC regulator with two bi-directional IGBT switches. PSpice simulation analysis is used to determinate harmonic behaviour of these converter circuits. Results were given for steady-state condition of 400 watts HID-lamp with proper ballast inductor value (165mH).

First example circuit is thyristor regulator with phase angle control (fig.1) This is simple way of line voltage regulation, but suffers from low power factor, poor harmonic behaviour, discontinuous current mode, consumed by the mains. Results are shown in fig.5 and table 1. Second example shows IGBT switch regulator (fig.2) with modified phase angle control. The transistors Q1 and Q2 are switched on from the beginning of half-period and turned off at phase angle (π-α). This is a way to obtain better power factor, consuming current from the mains with minimum phase lag (depending from the load inductance), but harmonic spectrum is still poor. Results are shown in fig.6 and table 2:

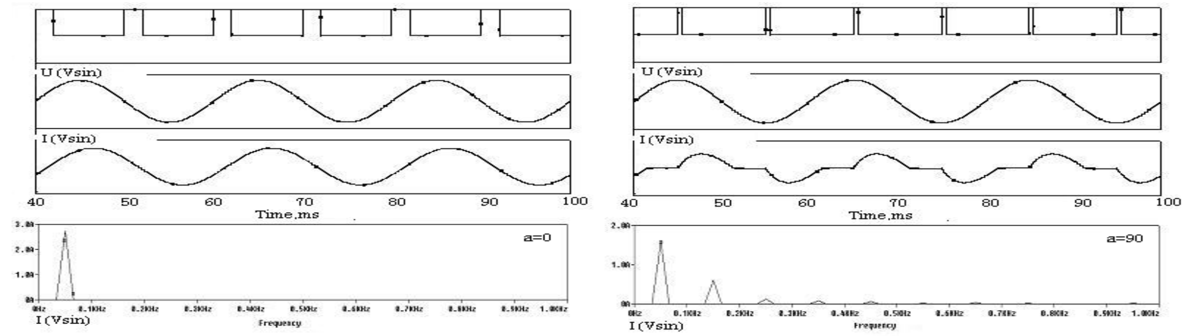


Fig.5: Thyristor regulator waveforms

TABLE I
HARMONIC ANALYSIS RESULTS

a , deg	0	18	36	54	72	90
I(Vsin) , THD%	0,18	0,18	4,4	15,1	26,6	39,6

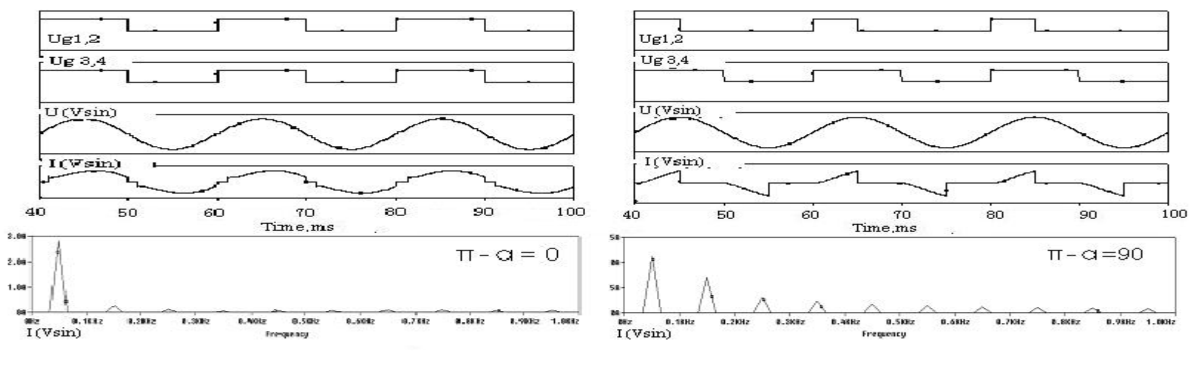


Fig.6: IGBT regulator waveforms

TABLE II
HARMONIC ANALYSIS RESULTS

π-a , deg	180	162	144	126	108	90
I(Vsin) , THD%	10,2	17,1	28,9	42,9	58,1	74

Second half of AC regulators investigation is based on IGBT-regulator with bi-directional switches (fig.2) and two different types of PWM control. We assume that use of higher switching frequency and pulse width modulation can improve power factor, seeing by the mains, can reduce harmonic distortion and active power losses, due to sharp commutation of large amount of currents. First example utilize linear PWM, and second-sinusoidal PWM. The results shows that these techniques improve quality of input and output variables and reduce harmonic distortion. Beside of that we can any further get better performance by optimized LC-filters and low switching loss devices. Experimental results for linear PWM are shown on fig.7 and table 3 and for sinusoidal PWM on fig.8 and table 4:

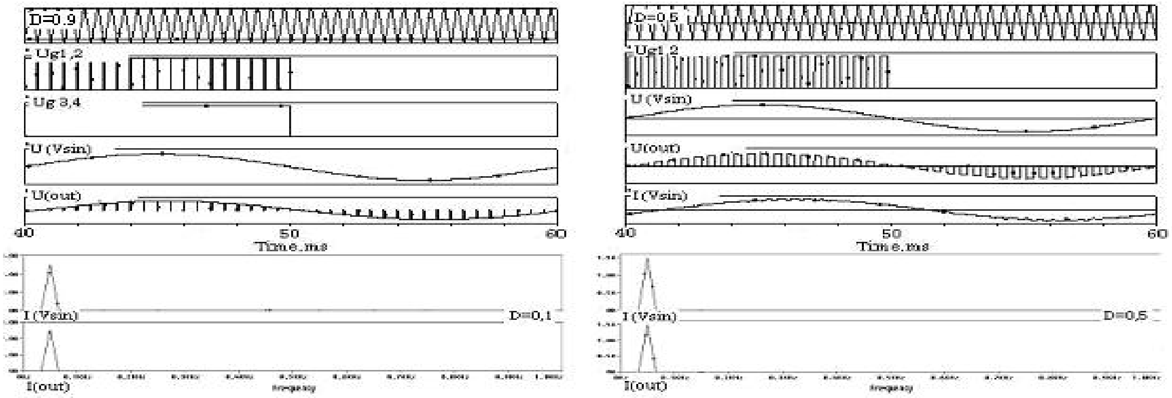


Fig.7:IGBT regulator waveforms

TABLE III
HARMONIC ANALYSIS RESULTS

D	0,9	0,8	0,7	0,6	0,5
I(Vsin) , THD%	0,54	0,81	0,94	0,97	1,1
I(out) , THD%	0,36	0,37	0,54	0,63	0,93

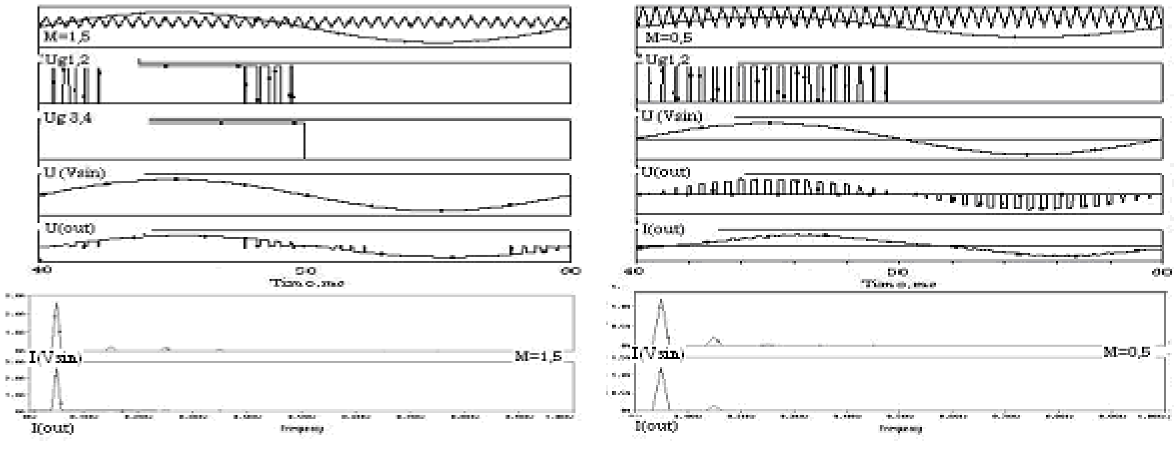


Fig.8:IGBT regulator waveforms

TABLE IV
HARMONIC ANALYSIS RESULTS

M	1,5	1,2	0,9	0,7	0,5
I(Vsin) , THD%	11,9	15,4	18,4	18,2	18,9
I(out) , THD%	5,2	8,2	10,7	10,6	10,8

5. CONCLUSION

HID lamp dimming reduces energy costs by reducing the input power to the lighting systems. It offers greater flexibility to adapt spaces to different uses. Most effective method for reducing nominal output power related to light intensity, is voltage regulators with two bi-directional switches (AC-choppers). Experimental results shows that they have improved quality characteristics, compared to regular thyristor line voltage regulators. Other advantages are possibility of different types of commutation strategy for reduce harmonic distortion and power losses. With proper circuit topology they can meet the requirements of HID lamp operation conditions and successfully may be used as dimming regulators in public and industrial lighting system as saving energy and cost solutions.

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