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ANALYSIS AND DESIGN OF A NEW FREQUENCY CONVERTER FOR DIMMING OF DISCHARGE LAMPS

M.Vijayasanthi[1], Dr.M.sushama[2]

[1]EEE, CMRCET, Secunderabad, (India)

[2]EEE, JNTUH, Hyderabad, (India)

ABSTRACT

Around 19% of global power consumption and around 3% of global oil demand is attributable to lighting. After the first incandescent lamp was invented in 1879, more and more energy efficient lighting devices, such as gas discharge lamps, and Light-Emitting Diodes (LED), have been developed during the last century. It is estimated that over 38% of future global lighting energy demand could be avoided by the use of more efficient lamps and ballasts. High Intensity Discharge (HID) lamps, one category of gas discharge lamp, have been widely used in both commercial and residential lighting applications due to their merits of high efficacy, long life, compact size and good color rendition . However, HID lamps require a well designed ballast to stabilize the negative voltage current characteristics. It is well-known high frequency electronic ballasts can greatly save energy, improve lamp performance, and reduce the ballast size and weight compared with the conventional magnetic ballast. However, a unique phenomenon called acoustic resonance could occur in HID lamps under high-frequency operation. A typical electronic HID ballast consist of three stages: power factor correction (PFC), DC/DC power regulation and low frequency DC/AC inverter. This paper discusses applications of a magnetic energy recovery switch (MERS) to lighting control, the work presented here is a new type of converter for lamp application. Main advantage of new converter circuit is High power factor , High efficiency and intrinsic dimming function. Proposed design is based on the operation concept of Magnetic Energy Recovery switch (MERS) , turn-on and turn–off intervals are under soft switching regimes, allowing minimum stress and power losses on switches.

Keywords: HID Lamps, Magnetic Energy Recovery Switch (MERS), Electronic Ballast, Dimming of Lamps, Magnetic Ballast.

I. INTRODUCTION

Although gas-discharge lamps have tremendous advantages over incandescent lamps, Discharge lamps require an auxiliary apparatus called a ballast to run . It is a well-known fact that gas discharge lamps have negative incremental impedance [8], as shown in Figure 1. If an HID lamp is directly connected to a voltage source, a small variation of the current may lead to the extinguishment or bursting of the lamp. As a result, a ballast with a positive impedance is needed to compensate the negative incremental impedance, and stabilize the lamp current. This is the first requirement for the HID lamp ballast

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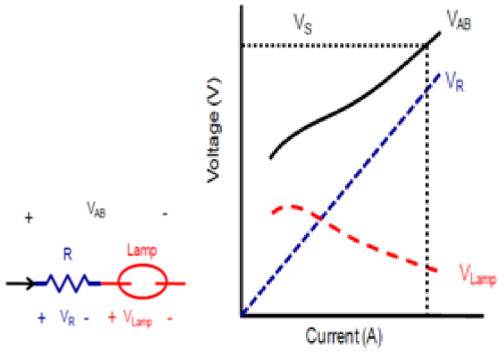

Figure 1. Negative Incremental Impedance of Gas Discharge Lamp.

Obviously, the resistive ballast incurs large power loss and significantly reduces the system efficiency. Fortunately, most discharge lamps are operated in alternating-current (AC) circuits, so inductive or capacitive impedance can be used to provide current limitation. The inductor(lag) and the inductor-capacitor (lead) ballast represent the conventional ballasting approaches, and are known as magnetic ballasts.

Magnetic ballasts are operated at 50/60Hz line frequency. Every half cycle, Magnetic ballast reignite the lamp and limit the lamp current. Although magnetic ballasts have the advantages of low cost and high reliability, Magnetic ballast have several fundamental performance limitations due to low frequency operation. First of all, the ballast is bulky and heavy. Second, the arc is reignited twice each cycle, which causes two big problems: significant lamp electrode wear and annoying audible line frequency flickering [9]. Finally, not efficient and cost-effective way to regulate the lamp power.

These drawbacks led to study the Application of high-frequency AC current to drive the discharge lamps. High-frequency operation not only results in significant ballast volume and weight reduction, but also improves the properties of the gas discharge lamp, such as improved circuit efficiency, improved luminous efficacy of lamps, improved lamp lifetime, absence of flickering, and the elimination of audible noise.

II. DIMMING OF DISCHARGE LAMPS

The discharge lamps dimming face three difficulties:

1)Lamp current has to be continuous; once the current flowing through becomes zero, the lamp blacks out. 2) The ballast inductance influences the possibility of dimming by power supply voltage control. In the case of fluorescent lamps, they operate at glow discharge in steady state, the glow voltage is much lower than the power supply voltage therefore a large ballast inductance is inserted to balance this difference. On the other side, HID lamps start at glow discharge and shift to arc discharge in normal operating state. Therefore, a small ballast inductance is usually used to balance the high arc voltage and power supply voltage. That results in a high starting current flowing through which is almost twice of the rated current. Also, once the small voltage difference reduces to zero, for example, when dimming the discharge lamps by changing the power supply voltage, the lamps may black out. 3) The lamp temperature changes under different dimming states especially for the HID lamps. The time delay for the temperature change may influence the electric transient state waveforms, even causes lamp black out. This paper proposes a new dimming method which is suitable for not only fluorescent lamps but also the HID lamps. In the proposed method, the power supply voltage is kept constant; the lamp current is controlled by changing the applied electric frequency. It is applicable because the ballast impedance increases with the applied electric frequency. The proposed dimming configuration is illustrated in Fig. 2.

The lamps group are expected to be dimmed by inserting one frequency converter between the power supply and the loads. This dimming control has the following characteristics: 1) The operating frequency varies in a range close to the rated frequency (eg: from 50 Hz to 150 Hz).

The acoustic resonance problems do not happen in this range.

2) The power supply voltage is kept constant during dimming. It decreases the possibility of lamp voltage running over the power supply voltage, thus decreases the possibility of going out. It indicates a wide dimming range for the HID lamps.

3) The proposed method suits for all kinds of discharge lamps only if the magnetic ballast is installed. Collective dimming is possible for the lamp groups. Therefore, fluorescent lamps, mercury lamp, high pressure sodium, metal halide lamps or combination of different types are possible to be dimmed by one frequency control device.

III. THE PROPOSED CONFIGURATION OF THE FREQUENCY CONVERTER:

To conclude, the proposed frequency converter should meet the following demands: rectangle wave output; frequency variable. With regard to the harmonics influence on the power grid, an improved input power factor is desirable for the frequency converter so that the electromagnetic compatibility standard on the home appliances is satisfied. A boost converter configuration is widely used as a traditional power factor correction.

As a general Circuit configuration: The basic configuration of single phase AC circuit with MERS is shown in below fig2

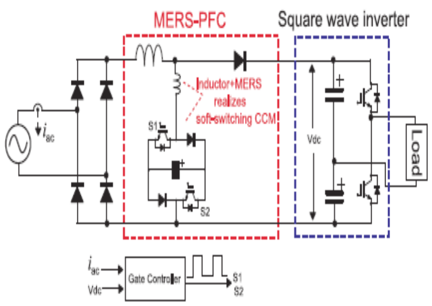

Fig. 2: Proposed Configuration Using MERS-PFC Circuit

Two IGBT'S (or MOSFET'S) and two diodes connected into two parallel arms each arm consists of one IGBT and one diode connected in series . the middle points are connected to a capacitor. When it is hooked up with an external Inductor, one of the use of the device is to adjust circuit power factor. The MERS is inserted in series between ac power source and load. The switch absorbs magnetic energy which has been stored in the inductance of the circuit and recovers it to the load. MERS circuit consists of 2 forced commutated switches and a dc capacitor, By inserting a small inductor in the MERS branch, a zero current turn on is expected for the IGBT'S .

The operation of MERS is divided into four modes:

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1. Discharging mode: In this mode there was no current flowing through the MERS circuit . When IGBT turn on, capacitor discharges and current flows through the IGBT'S and then backs to the power supply.

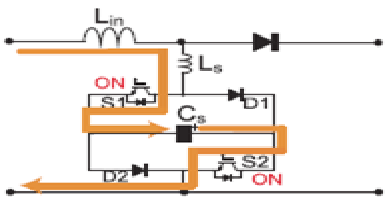

Fig. 3: Operation State One of the Proposed MERS-PFC

2. Parallel conduction mode: After the capacitor discharges to zero voltage, it shifts to parallel conduction mode current paths are S_1-D_2 and D_1-S_2 respectively.

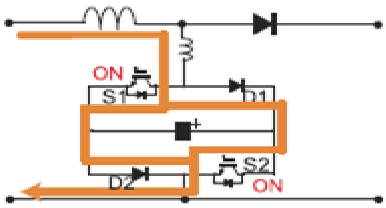

Fig. 4: Operation State Two of the Proposed MERS-PFC

3. Charging mode: once IGBT'S turn off, the current flows through the diodes and charges the capacitor. When capacitor voltage is over the output voltage the output diode conducts and the current flowing through MERS starts to decreases

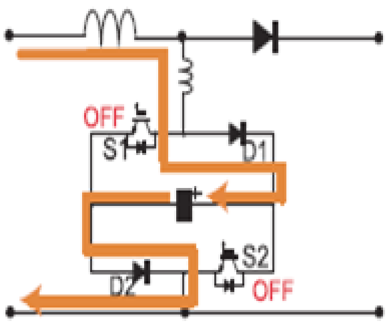

Fig. 5: Operation State Three of the Proposed MERS-PFC

4. Bypass mode: The current flows through the output diode and MERS is Bypassed. This mode keeps on until the next switching cycle.

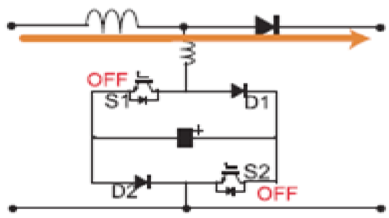

Fig. 6: Operation State Four of the Proposed MERS-PFC

IV. POWER FACTOR CORRECTION

The input current and input voltage of MERS is shown in below fig The current waveforms are distorted The power factor of the fundamental component of $\boldsymbol{V_1}$ and $\boldsymbol{I_1}$ is nearly 1. The power factor of input is improved. Efficiency does not decreases, although the current waveform is distorted. MERS improve the power factor while it does not affect the load side. MERS with PWM control also achieves the power factor correction.

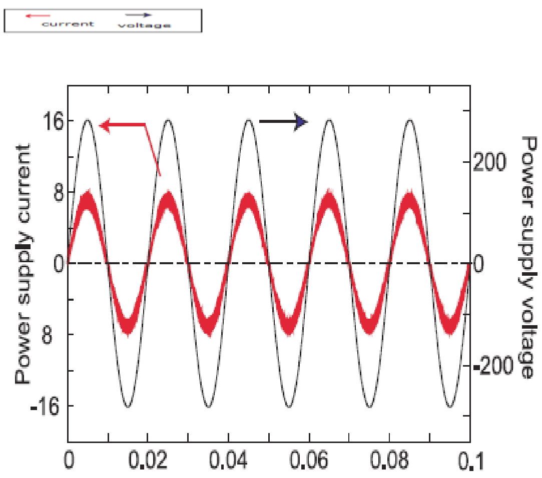

Fig. 7: Input voltage and current waves of the power supply

V. DUTY RATIO OF THE MERS-PFC

In order to realizes a certain step-up ratio, the duty ratio is investigated for the proposed MERS-PFC configuration, MERS-PFC without the small inductor L_s, and the traditional one switch PFC configuration. Simulation conditions are as follows: load power P_{load} = 1 kW when output DC voltage is 400 V.

Power supply voltage amplitude is 200 V; the input inductor L_{in} is 2.5mH; switching frequency f_{sw} is 40 kHz, for a certain step-up ratio, the duty ratio decreases in the case of MERS-PFC configuration and decreases further when the small inductor L_s is inserted. The reason is that both the capacitor C_s and inductor L_s store energy when current flowing through the MERS branch and energy transfers to the input inductor L_{in} in the next switching cycle. With a same output voltage demand, the duty ratio is therefore decreased. As a result, the voltage peak of capacitor C_s and IGBT reaches to a higher value. The duty ratio decreases with the C_s increasing for a certain step-up ratio. It proves the capacitor stored energy would turn into the output DC voltage eventually.

VI. SIZING OF THE LS AND CS

Sizing of the L_s and C_s should meet the requirement of soft-switching. Therefore,

1) C_s should be small enough to discharge to zero voltage during the discharging mode in order to realize zero voltage turn off.

2) L_s realizes zero current turn on. Larger L_s results in a higher switch voltage peak, but it also bring in low duty ratio and slowly current increase when turning on the IGBT. Weather the C_s can discharge to zero voltage or not is determined by

$$C_s \times V_{cs}^2/2 = i_{in} \times V_{cs} \times t_{dis}, \quad \text{------ --} \quad (1)$$

$$t_{dis} \le t_{on} = D \times T \text{ ------ -------} \quad (2)$$

Here, V_{cs} is the voltage peak of C_s; i_{in} is the current flowing through the input inductor L_{in}. t_{dis} is the necessary discharging time to zero voltage; t_{on} is the switch on time determined by the duty D and switching cycle T.

The current rising time t_r when switching on the IGBTs is defined as the time for the MERS current increasing from 0 to i_{in}. It is calculated by

$$t_r = L_s \times i_{in} / V_{cs} + V_{out} \quad \text{-------------} \quad (3)$$

Furthermore, sizing of Ls and Cs should be a trade off of the duty ratio and the increased switch voltage capacity.

VII. CONCLUSIONS

Discharge lamps are difficult to dim by traditional reduced voltage control due to its negative impedance characteristics. Taking the present being installed magnetic ballast type discharge lamps as research object, this paper proposes a simple dimming method by controlling the frequency

The advantages of the proposed dimming control are summarized as

1) A good compatibility with the present installed discharge lamps.

2) Possible collective control for discharge lamp groups, even mixed composition of different type of discharge lamps.

3) Simple control and a wide dimming range.

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	**M.VIJAYASANTHI**[1] *is presently working as Assistant Professor in the department of Electrical & Electronics Engineering at CMR College of Engineering and technology, Hyderabad. She has 8 years of teaching experience. She obtained master of technology in Power Electronics from VNRVJIET Hyderabad, Andhra Pradesh, India. Presently doing research in Jawaharlal Nehru Technological University, Hyderabad, area of interest is power electronic applications in power systems she is a life member of ISTE.*
	***Dr.MALAJI SUSHAMA***[2] *Professor Electrical & Electronics Engineering Areas of Interest: Power Quality, Wavelets Dr. M.Sushama, born on 8th Feb 1973, in Nalgonda , a small town near Nagarjuna Sagar, A.P., India .Obtained her B.Tech degree in 1993 and M.Tech degree in 2003 with a specialization in Electrical Power Systems from JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY , INDIA. She obtained her Ph.D. from JNTU Hyderabad, India in 2009 in the area of "Power Quality" using Wavelet Transforms. She started her career as Assistant Professor in the Department of EEE, JNTU College of Egg. Anantapur, in the year 1995. She worked as Associate Professor for 8 years in the Department of Electrical & Electronics Engineering, JNTUH College of Engg. Hyderabad. Presently she is working as Professor & Head in Electrical & Electronics Engineering in the Department of EEE, JNTUH College of Engineering, Kukatpally, Hyderabad. She had 20 years of teaching & 7 years of research experience. During her teaching career she taught various subjects like C-language & Data Structures, Microprocessors and Micro controllers, Artificial Neural Networks & Fuzzy systems, etc. apart from almost all Electrical Engineering related subjects which includes Electrical Machines and Power systems. She has published 17 international conference papers in various IEEE sponsored conferences, 15 International journal papers and one article in "Electrical INDIA". Her research interests include Power Quality, Wavelet Transforms, Neural & Fuzzy expert Systems. She is currently guiding 5 PhD students. She is a life member of ISTE, Systems Society of India (SSI) & IETE.*