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Pulse Density Modulated Zero Voltage Soft-Switching High-Frequency Inverter with Single Switch for Xenon Gas Dielectric Barrier Discharge Lamp Dimming

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Abstract- This paper presents soft switching zero voltage switching high frequency inverter for rare gas fluorescent lamp using dielectric-barrier discharge phenomenon. The simple high-frequency inverter can completely achieve stable zero voltage soft switching (ZVS) commutation for wide its output power regulation ranges and load variations under its constant high frequency pulse density modulation (PDM) scheme. Its transient and steady state operating principle is originally described and discussed for a constant high-frequency PDM control strategy under a stable ZVS operation commutation, together with its output effective power regulation characteristics-based on the high frequency PDM strategy. The experimental operating performances of this high frequency inverter are illustrated as compared with computer simulation results and experimental ones. Its light dimming characteristics due to power regulation scheme are evaluated and discussed on the basis of simulation and experimental results. The feasible effectiveness of this high frequency inverter appliance implemented here is proven from the practical point of view.
Index terms- Dielectric barrier discharge fluorescent lamp (DBD-FL), Pulse density modulation (PDM), Zero voltage switching (ZVS)

I. INTRODUCTION

At present, the cold cathode fluorescent lamp (CCFL) using mercury lamp has been generally used for liquid crystal backlight source of personal computer and car navigation and so on. This kind of lamp is more excellent on luminance performance and cost. However, the requirements of liquid crystal backlight due to a light source without mercury have been strongly increased from a viewpoint of the actual influence on environmental preservation and environmental recycling. As fluorescent lamp without mercury, a rare gas fluorescent lamp using Xe gas has been studied so far. This dielectric barrier discharge lamp has no influence on the human body and environmental recycle. Its operating life is long because electrode is out.

Two high frequency resonant inverters are more suitable for dielectric discharge lamp without mercury gas, which include the current source royer type class D parallel resonant high frequency inverter and voltage source class E type single ended inverter are discussed in this paper. The current source royer type center tapp push pull high frequency circuit is widely used for compact liquid crystal backlight. Its actual efficiency is relatively low. On the other hand, voltage source class E edge resonant inverter can achieve high efficiency and high quality. This class E inverter circuit topology is composed of a few parts and its power regulation can operate under zero voltage soft switching using the PDM control implementation. This PDM control method enables to maintain the discharge sustaining voltage and achieve zero soft switching commutation over wide dimming control ranges.

In this paper, the simulation and experimental results of the current-fed royer parallel resonant type high frequency inverter and voltage-fed class E edge resonant inverter as a high frequency power supply circuit for rare gas fluorescent lamp using Xe gas are comparatively evaluated and discussed from a practical point of view.

II. DIELECTRIC BARRIER DISCHARGE BASED RARE GAS FLUORESCENT LAMP

A rare gas fluorescent lamp based on dielectric barrier discharge principle is a kind of fluorescent lamp, which uses gas, and since it is not influenced upon temperature and constant actinography can be able to obtain. It is considered for light source in copy machine and scanner. Figure.1 shows a schematic structure of rare gas fluorescent lamp based on the dielectric barrier discharge principle. Two metal electrodes is set up around glass tube axis outside of the glass tube, phosphors are applied to inner surface of glass tube.

This electric discharge phenomenon can be described on the basis of dielectric barrier discharge. At first, a

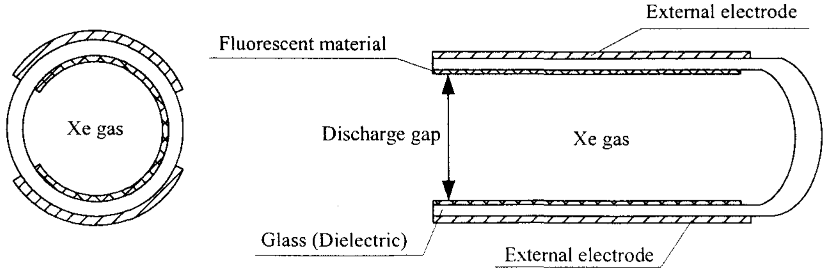

Fig.1 Schematic structure of rare gas fluorescent lamp

high frequency AC high voltage is applied between two metal electrodes. And the dielectric polarization occurs and high voltage is applied for driving lamp. The silent discharge starts to generate when the voltage across substrate glass reaches up to breakdown voltage without sound. This silent discharge is based on the dielectric barrier discharge or silent electric discharge.

Moreover, the electric equivalent circuit represented by a nonlinear capacitive load and diode full bridge including the voltage source corresponding to the discharge sustaining voltage is shown in Fig.2. In this circuit model, the dielectric barrier discharge fluorescent lamp using rare gas can carry out the analysis of high frequency AC power supply circuit. C_a denotes capacitance between dielectric gaps with Xe gas, C_g denotes capacitance of substrate dielectric part of glass and V_z denotes dielectric sustaining voltage. C_a is connected in series with C_g during non-discharge, and the voltage across C_a is clamped to V_z during stable discharge.

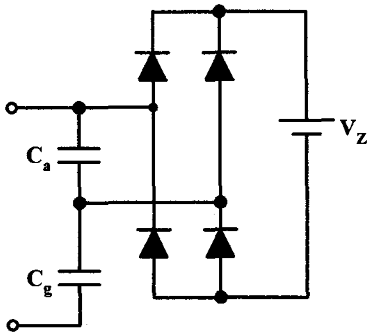

Fig.2 Equivalent circuit of rare gas fluorescent lamp as dielectric barrier discharge lamp

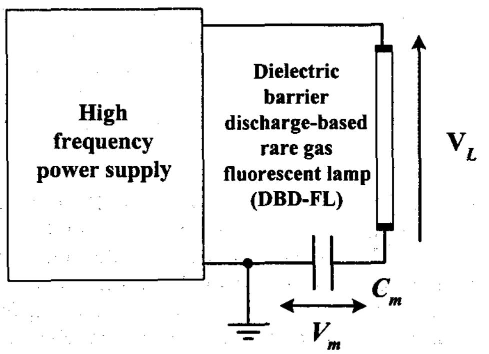

Fig.3 Circuit for measuring circuit parameters of DBD-FL

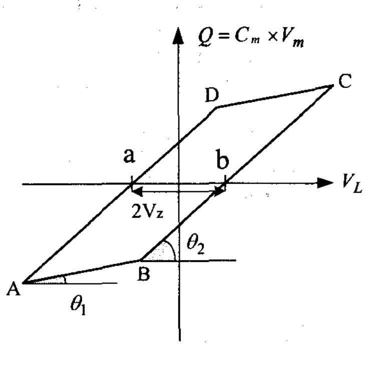

Fig.4 Q vs. V_L lissajous figure estimating circuit parameters of DBD-FL

Figure.3 shows the basic circuit for measuring circuit parameters of the equivalent circuit represented by a non-linear capacitive circuit. The auxiliary capacitor C_m is additionally connected in series with the dielectric barrier discharge- based rare gas fluorescent lamp (DBD-FL) and high frequency AC voltage is applied to a series circuit of DBD-FL and C_m. Then, the voltage V_L across the fluorescent lamp and V_m across C_m is respectively displayed as lissajous figure depicted in Fig.4 on oscilloscope. In this time, V_m multiplied by C_m given as electric charge Q. In Fig.4, the transition A-B denotes non-discharge period. Resultant capacitor C_{ag} series connected in series with C_a and C_g is obtained from eq.(1).

$$C_{ag} = \tan\theta_1 = \frac{\Delta Q_1}{\Delta V_{L1}} = \frac{C_m \Delta V_{C1}}{\Delta V_{L1}} \quad (1)$$

The transition B-C denotes discharge period. C_g is obtained from eq.(2).

$$C_g = \tan\theta_2 = \frac{\Delta Q_2}{\Delta V_{L2}} = \frac{C_m \Delta V_{C2}}{\Delta V_{L2}} \quad (2)$$

In addition, C_{ag} is represented by eq.(3), so that C_a is estimated by eq.(4).

$$C_{ag} = \frac{C_a C_g}{C_a + C_g} \quad (3)$$

$$C_a = \frac{C_{ag} C_g}{C_g - C_{ag}} \quad (4)$$

Moreover, V_z is equal to half of distance between a and b points on V_L axis.

III. CURRENT-FED ROYER TYPE RESONANT HIGH FREQUENCY INVERTER

The circuit topology the Royer type resonant high frequency inverter is shown Fig.5. This circuit is composed of 12V DC power supply, choke coil L_1, resonant capacitor C_r, and high frequency transformer *TR*. Bipolar transistor S1 and S2 are used for the switching devices. A rare gas fluorescent lamp of the load is shown by the equivalent circuit model which is a capacitive load. As for the feature of royer type inverter, the base signal of the transistors to switch is taken directly from the circuit. In general, the switching pulse signal generating circuit is necessary for the power conversion circuit in addition a main circuit. However, the Royer type resonant high frequency inverter is a method supplied the switching signal directly by the main circuit that is called the self-excited type. Therefore, because the number of circuit components decreases, low-cost can be achieved. In addition, it has the advantage of miniaturizing the circuit easily because the switching pulse signal generating circuit is unnecessary. The power regulation of this high frequency inverter, that is, the dimming control of the lamp is pulse amplitude modulation (PAM) control method. In general, the output is regulated with the DC-DC converter connected with the foreside of Royer type high frequency inverter shown Fig.6.

IV. SOFT SWITCHING PDM HIGH FREQUENCY INVERTER USING SINGLE POWER MOSFET

A. Circuit Constructions

Soft switching PDM high frequency inverter using single power MOSFET is illustrated Fig.7. This circuit is composed of the 12V input DC power supply, high frequency transformer (consisted of exciting inductance Lm, leakage inductance L_l and ideal transformer), semiconductor power switching device Q(SW/D) (MOSFET: manufactured by IR, IRFP264), resonant capacitor C_r, and DBD-FL load.

B. Pulse Density Modulation Control

It proposes the PDM control for the power regulation of reverse conducting type high frequency inverter for driving rare gas fluorescent lamp. The principle of PDM

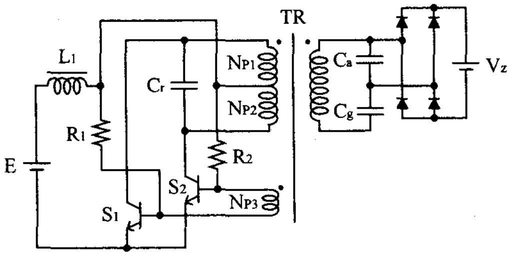

Fig.5 Royer type resonant high frequency inverter

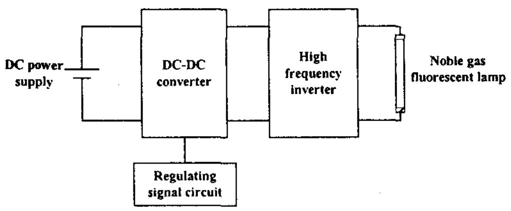

Fig.6 Power regulating system of Royer type inverter

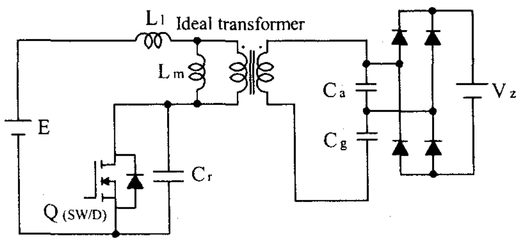

Fig.7 ZVS-PDM high frequency inverter using single switch

Control is shown in Fig.8. The PDM control is a power regulating method changing the ratio at power injection period and idle period with constant frequency of the high frequency inverter. The PDM control variable D is defined in the eq.(5).

$$D = \frac{T_{on}}{T_{on} + T_{off}} = \frac{T_{on}}{T} \tag{5}$$

The variable is a ratio to one PDM signal cycle T (T_{on} $+T_{off}$) for the power injection period T_{on}. By controlling this variable D, the inverter output power can be regulated. Because the discharge sustaining voltage V_z doesn't decrease when the high frequency inverter is controlled with PDM, the lamp can be discharged stably in a wide output power regulating range.

C. Simulation and Experimental Results

Design specifications and circuit parameters are shown in Table1. Simulation and experimental waveforms of switch Q in case of D=0.5 are depicted in Fig.9. As can be seen in this figure, the switch is achieved a ZVS & ZCS turn on and ZVS turnoff commutation. The typical voltage and current operation waveforms of simulation and experimental ones have a good agreement within the slight error.

Lamp luminance vs. PDM control variable characteristics are illustrated Fig.10. The output power can be controlled linearly with PDM variable different from the Royer type resonant high frequency inverter. In this figure, it can be considered that the controllability of soft switching PDM high frequency inverter using single power MOSFET is higher than the royer type inverter.

The luminance vs. input power characteristics is shown in Fig.11. As can be seen, soft switching PDM high frequency inverter using single power MOSFET can not be output compared with the royer type inverter. In this inverter, the resonance period achieved high

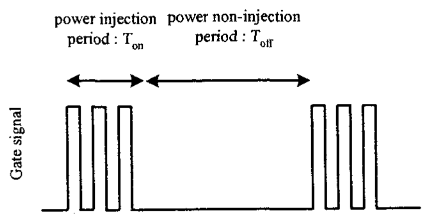

Fig.8 PDM pulse signal sequences

Table 1 Design specifications and circuit parameters

Item	Symbol	Value
Input DC Voltage	E	12.0V
Leakage inductance	L_l	2.45μH
Magnetizing inductance	L_m	32.38μH
Turn ratio	-	1:25
Resonant capacitor	C_r	120nH
Gap capacitance	C_a	517pF
Dielectric capacitance	C_g	671pF
Discharge sustaining voltage	V_z	237.9V
Switching frequency	f_{sw}	25.0kHz
PDM frequency	f_{PDM}	100Hz

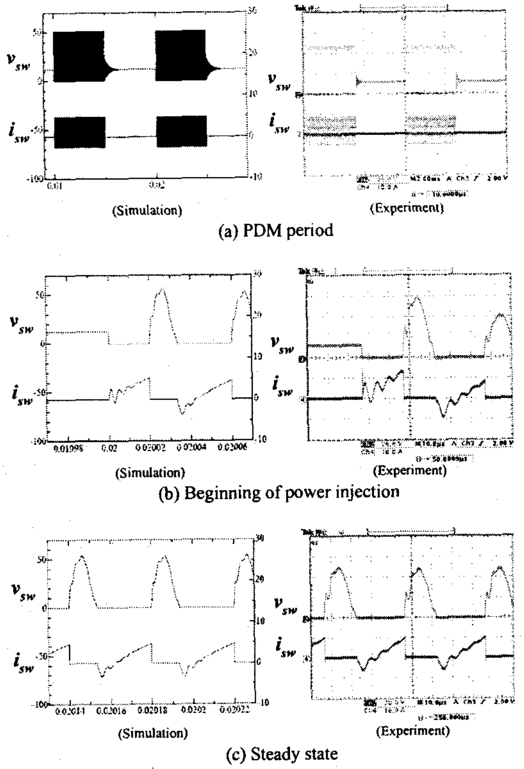

Fig.9 Simulation and experimental waveforms of switch Q in case of D=0.5

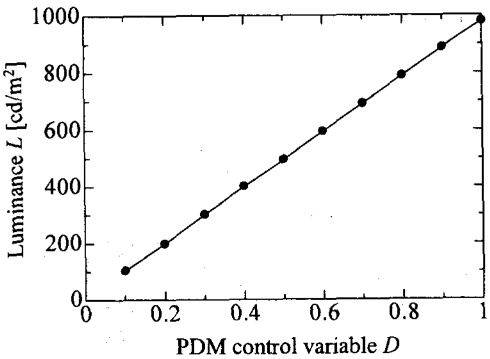

Fig.10 Lamp luminance vs. PDM control variable characteristics

power output ends commutating from capacitor C_r to a reverse conducting diode of the switch Q. It is complicated to shorten the resonance period by this commutation operation.

In the above, it is considered soft switching PDM high frequency inverter using single power MOSFET has high controllability and can be lighted without flicker in the low luminance control range however the inverter can not output high luminance.

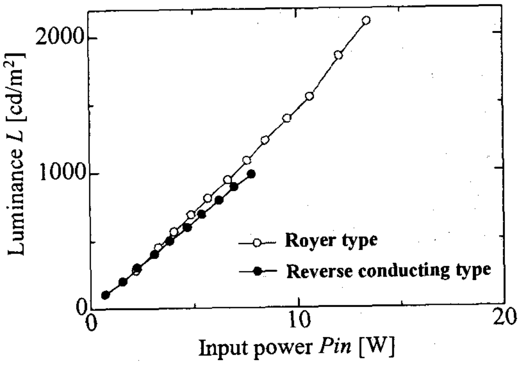

Fig.11 Luminance vs. input power characteristics

V. CONCLUSIONS

This paper presented the Royer type resonant high frequency inverter and soft switching PDM high frequency inverter using single power MOSFET. Moreover, these operation principles, circuit topologies and circuit characteristics were described here. In addition, characteristics of these circuits were compared the simulation with the experimental results. The Royer type resonant high frequency inverter could output high luminance. However, the rare gas fluorescent lamp flickered in case of regulating low luminance, and the controllability of the inverter was not so high.

In the future, it will be discussed that the new circuit topology with high controllability and high luminance.

ACKNOWLEDGMENT

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