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# Pulse Density Modulated ZVS High Frequency Inverter with Reverse Blocking Single Switch for Dielectric Barrier Discharge Lamp Dimming

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### *Abstract*

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, Dielectric Barrier Discharge based rare gas fluorescent lamp (DBD-FL) using xenon (Xe) gas has been studied so far. This DBD lamp has no influence on the human body and environmental recycle. Its operating life is long because electrode is out.

In this paper, the simulation and experimental results of soft switching high frequency inverter with reverse blocking single switch as a high frequency power supply circuit for DBD-FL using Xe gas are comparatively evaluated and discussed from a practical point of view.

*Index terms-* Dielectric barrier discharge fluorescent lamp (DBD-FL), Pulse density modulation (PDM), Zero voltage switching (ZVS)

## 1. 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.

## 2. 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 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

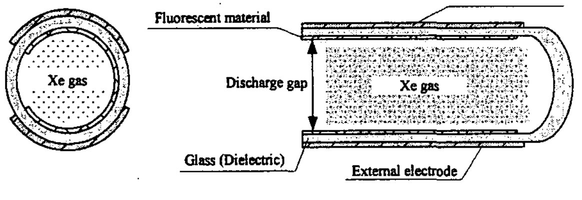


Fig. 1 Schematic structure of rare gas fluorescent lamp based on dielectric barrier discharge

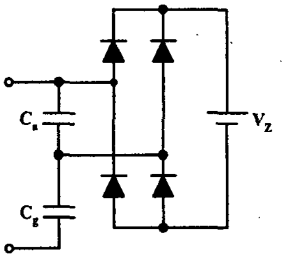


Fig.2 Equivalent circuit of rare gas fluorescent lamp based on dielectric barrier discharge lamp

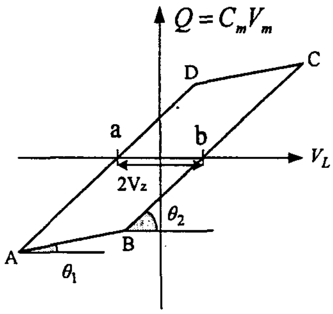


Fig.3 Q vs. VL lissajous figure identifying circuit parameters of DBD-FL

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.

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.3 on oscilloscope. In this time, $V_m$ multiplied by $C_m$ given as electric charge $Q$. In Fig.3, 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).

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

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

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

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

$$C_{ag}=\frac{C_aC_g}{C_a+C_g} \tag{3}$$

$$C_a=\frac{C_{ag}C_g}{C_g-C_{ag}} \tag{4}$$

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

## 3. Soft Switching PDM High Frequency Inverter Using Single Power MOSFET

### 3.1 Circuit Constructions

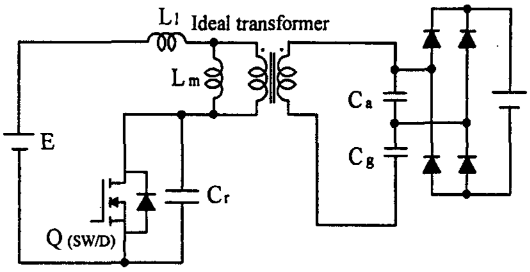


Fig.4 Voltage-fed ZVS-PDM high frequency inverter using single reverse conducting switch

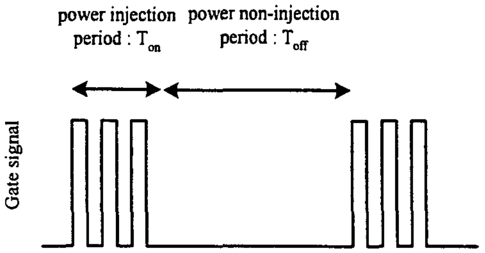


Fig.5 Gate signal pulse sequences of PDMcontrol

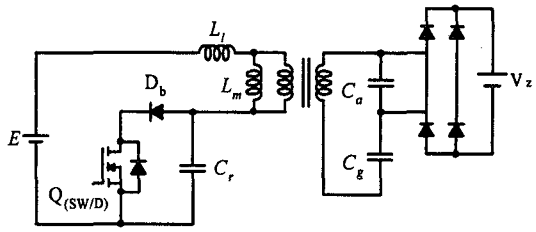


Fig.6 Soft switching high frequency inverter with single reverse blocking switch

Soft switching PDM high frequency inverter using single power MOSFET is illustrated Fig.4. This circuit is composed of the 12V input DC power supply, high frequency transformer (consisted of exciting inductance $L_m$, 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.

### 3.2 Pulse Density Modulation Control

It proposes the PDM control for the power regulation of reverse conducting type high frequency inverter for driving DBD-FL. The principle of PDM Control is shown in Fig.5. The PDM control is a power regulating method changing the ratio at power injection period and power non-injection period with constant frequency of the high frequency inverter. The PDM control variable $D$ is defined in the eq(5).

$$D=\frac{T_{on}}{T_{on}+T_{off}}=\frac{T_{on}}{T} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(5)$$

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 $D$, output power of the high frequency inverter can be regulated. Because the discharge sustaining voltage $V_z$ does not decrease when the high frequency inverter is controlled with PDM, the lamp can be discharged stably in a wide output power regulating range.

## 4. Soft Switching High Frequency Inverter with Reverse Blocking Single Switch

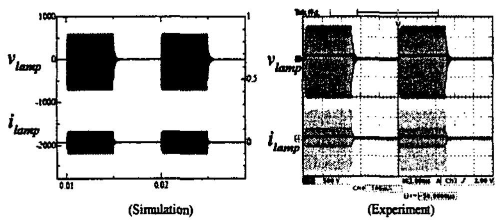
### *4.1 Circuit Constructions*

In chapter 3, soft switching PDM high frequency inverter using single power MOSFET is shown that a high luminance output is more difficult than the conventional royer type inverter. Therefore, this chapter describes soft switching high frequency inverter with reverse blocking single switch that can output higher luminance.

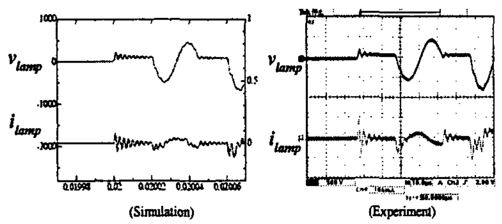
Soft switching high frequency inverter with reverse blocking single switch is illustrated Fig.6. The circuit topology of the high frequency inverter is the same as the inverter shown in Fig.4 excluding reverse blocking diode. The power regulation of the proposed inverter can be achieved by PDM control.

Table II Design Specifications and Circuit Parameters

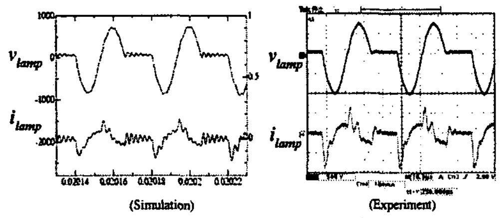
| Item | Symbol | Value |
|---|---|---|
| Input DC Voltage | E | 12.0V |
| Leakage inductance | Ll | 4.94 H |
| Magnetizing inductance | Lm | 72.26 H |
| Turn ratio | - | 1:10 |
| Resonant capacitor | Cr | 180nH |
| Gap capacitance | Ca | 517pF |
| Dielectric capacitance | Cg | 671pF |
| Discharge sustaining voltage | Vz | 237.9V |
| Switching frequency | fsw | 25.0kHz |
| PDM frequency | fPDM | 100Hz |



(a) On PDM period



(b) Beginning of power injection period



(c) On power injection period

Fig.7 Simulation and experimental waveforms of DBD-FL in case of D=0.5

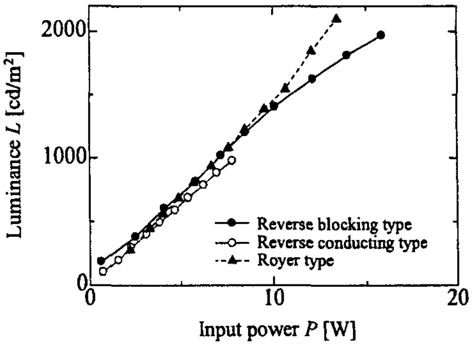


Fig.8 Luminance vs. input power characteristics

### *4.2 Simulation and Experimental Results*

Design specifications and circuit parameters are shown in Table 2. Simulation and experimental waveforms of switch Q and DBD-FL in case of $D$=0.5 are depicted in Fig.7. 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. However, switching serge current is flowed through the switch in case of beginning of power injection period. Because, the serge current is flowed by the discharge of the charge accumulated in the capacitor $C_r$ on non-power injection period when the switch turns on.

The luminance vs. input power characteristics is shown in Fig.8. As can be seen, it is shown that the proposed circuit has higher luminance equal with the royer type inverter and linear controllability of the reverse conducting switch type inverter.

## 5. Conclusions

This paper presented the Royer type resonant high frequency inverter, soft switching PDM high frequency inverter using single power MOSFET and soft switching high frequency inverter with reverse blocking single switch. 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. Soft switching high frequency inverter with reverse blocking single switch can be achieved higher luminance and linear controllability.

## Acknowledgment

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