HIGH FREQUENCY RESONANT INVERTER FOR GROUP DIMMING CONTROL OF FLUORESCENT LAMP LIGHTING SYSTEMS

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ABSTRACT

An electronic ballast for fluorescent lamp lighting using a new resonant inverter is proposed. The electronic ballast has high efficiency, light weight and small size because the resonant inverter operates at high frequencies with low switching losses. The inverter output power can be continuously controlled by regulating the L-C resonant tank energy of the resonant inverter with ease. The lighting system using this resonant inverter has the prominent features of high efficacy [lm/W], low flicker, low noise, wide dimming range, and soft starting. The basic operation principle of the proposed inverter and the dimming control scheme are described and the experimental results are presented.

I. INTRODUCTION

The fluorescent lamp has higher efficacy [lm/W], longer life than those of the incandescent lamp. Due to these advantages, the fluorescent lamp is widely used all over the world. A recent utility study has estimated that the fluorescent lighting constitutes 25 % of the total consumer load and often exceeds 30 % [1]. Therefore, more effective lighting of the fluorescent lamps is very important for energy savings.

The conventional core-coil ballast, however, has been usually used for lighting the fluorescent lamp. The fluorescent lamp using this ballast has 33 % of flicker and low efficacy because it operates at 50-60 Hz. Recently, high-frequency operations of fluorescent lamps have been studied to remedy the aforementioned drawbacks [2]. Furthermore new electronic ballasts with dimming controllers have been developed to attain further energy savings on the fluorescent lamp lighting systems [3-4].

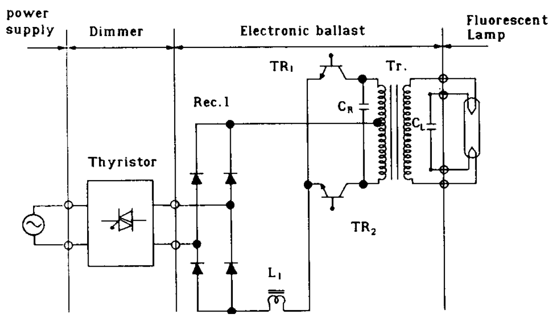


Fig.1 Electronic ballast using phase angle control dimming

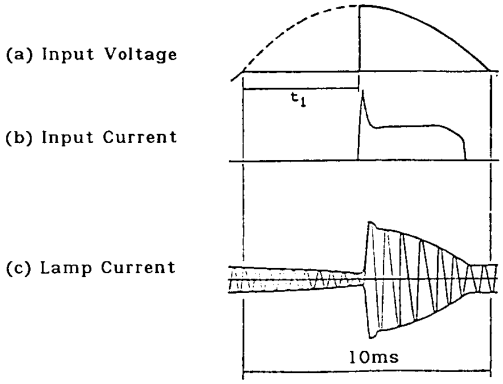


Fig.2 Voltage and current waveforms on 50% dimming codition for Fig.1

Fig. 1 shows the basic circuit configuration of electronic ballast proposed by Aoike, Yuhara and Nobuhara [3]. This ballast adopts a parallel resonant type push-pull transistor inverter and supplies high frequency power to the lamp. Lamp luminous flux can be continuously controlled from 50 % to 100 % of the maximum flux with TRIAC phase controlled dimmer. However, when the flux is below 50 %, the operation and the starting of the lamp are not reliable. Especially in dimming mode, it generates flickers and large harmonics at the input side because the supplied power to the load is modulated by phase angle as shown in Fig. 2.

These problems can be overcome by the proposed fluorescent lamp lighting system using a new resonant inverter. The resonant inverter is full-bridge type with two poles of switches as shown in Fig. 3(b). One pole performs zero voltage switching and the other pole performs zero current switching. Therefore, switching losess are very low. This fact enables high frequency operation with high efficiency. The high frequency operation results in improved efficacy and reduced flicker. The duty ratio control of the resonant inverter provides a continuous output power variation. Therefore, the luminous flux can be varied continuously from 0 % to 100 % of the maximum flux and reliable soft starting can be obtained also. The experiment is performed at the switching frequency of 20 KHz.

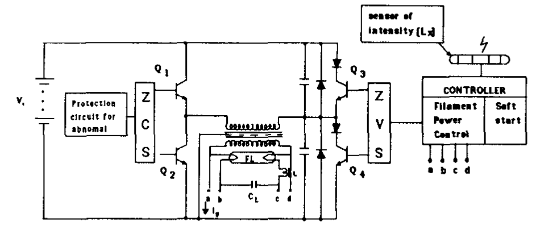
II. BASIC OPERATION OF THE PROPOSED RESONANT INVERTER

Fig. 3(a) shows the circuit configuration for efficient fluorescent lamp lighting using the proposed resonant inverter. Fig. 3(b) is the equivalent circuit of the resonant inverter of Fig. 3(a). The secondary load of the isolation transformer is reflected to the primary side with equivalent resistance R of the fluorescent lamp.

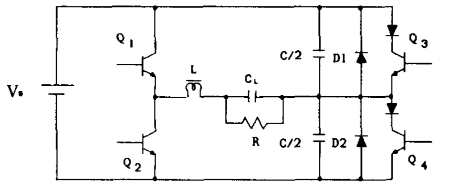
The operation of the proposed resonant inverter is described as follows. There are three switching modes in one switching cycle: energizing, resonance, and de-energizing modes as shown in Fig. 4.

A. Energizing mode

Initially, the inductor current i_L is zero and the voltage v_C of the capacitor which is connected in parallel with the diode D2 is zero. This mode initiates by turning on the two switches Q1 and Q4. Then the inductor current i_L begins to increase and power is transferred from the source to the load as shown in Fig. 5. The two switches Q1 and Q4 are turned on under the zero current and zero voltage switching condition, respectively. Therefore the turn on switching losses of the two switches are very low. The switch Q1 (Q2) is continuously turned on during one switching cycle and the conduction period of the switch Q4 (Q3) is determined by load demand. As load increases the conduction period of the switch Q4 (Q3) increases. Duty ratio is defined as the ratio of the conduction period of the switch Q4 (Q3) to that of the switch Q1 (Q2). At a proper time, the switch Q4 (Q3) is turned off with zero voltage switching condition and this mode ends.



(a) Overall Scheme



(b) Equivalent resonant inverter circuit

Fig.3 Proposed resonant inverter for fluorescent lamp lighting

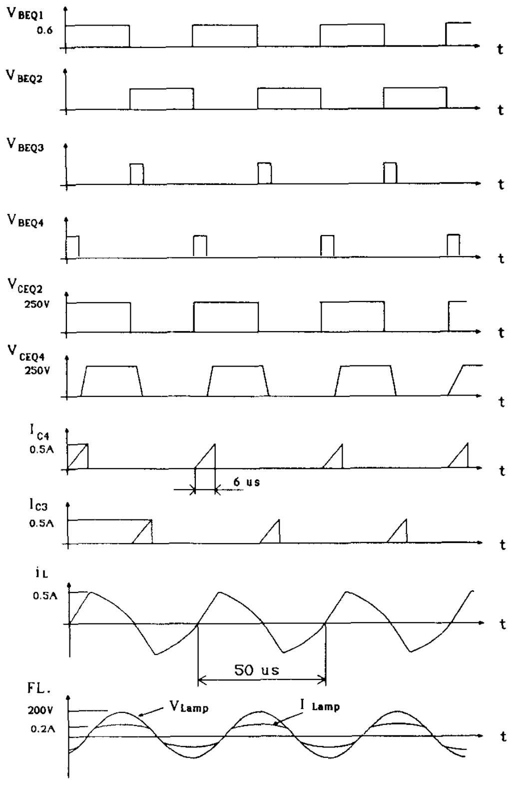
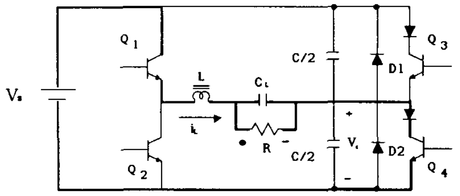
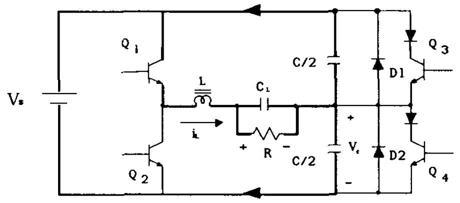


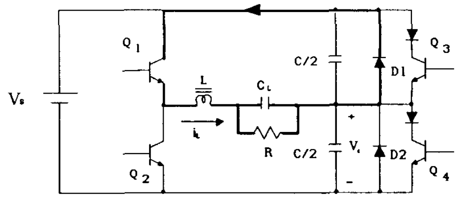
Fig.5 voltage and current waveforms of proposed inverer



(a) energizing mode



(b) resonant mode



(c) de-energizing mode

Fig.4 Three operation modes of proposed resonant inverter

B. Resonant mode

As the switch Q4 (Q3) is turned off, the current path is altered from switch Q4 to the capacitors as shown in Fig. 4(b). This resonant operation continues until the capacitor voltage v_C reaches to the supply voltage V_S. The resonant period is determined by the inductance L, capacitor C, inductor current i_L, supply voltage V_S, and output voltage.

C. De-energizing mode

As soon as the capacitor voltage v_C reaches to the supply voltage V_S, diode D1 begins to conduct and the current flows through the switch Q1, inductor L, load and diode D1 until the inductor current i_L is reduced to zero as shown in Fig. 4(c). When the current i_L reaches to zero, switch Q1 is turned off under zero current switching condition.

Through one switching cycle, the switches Q1 (Q2) and Q4 (Q3) are turned on and off under zero current and zero voltage switching condition, respectively. This results in very low switching losses in spite of controlling the power to the load at high frequencies. The output power can be continuously controlled because the conducting period of the switch Q4 (Q3) can be adjusted according to load demand. Therefore continuous luminous flux control is possible over wide variable range.

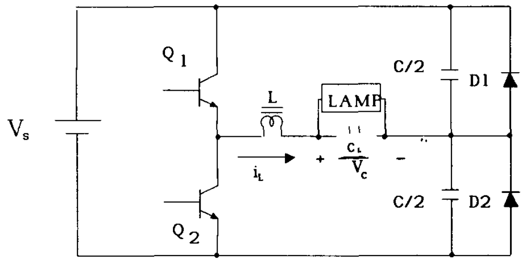


Fig.6 Equivalent circuit the lamp is started

III. LAMP STARTING AND DIMMING CONTROL

A. Lamp Starting

During the starting period, the maximum voltage across the lamp must be limited to proper value because high starting voltage rapidly reduces the operating life of the lamp. On the other hand, once the lamp is started, filament power of the lamp is another important factor for the life of the lamp at high frequency operation different from the 60 Hz operation [5,6].

The proposed converter can provide soft starting so that the voltage across the lamp is gradually increased as the lamp is started. Fig. 6 shows the equivalent circuit when the lamp is in starting mode. This figure shows that only switches Q1 and Q2 are turned on/off alternately in syncronization with current zero crossing points and the other two transistors Q3 and Q4 are kept off-states. Then the voltage across the lamp capacitor V_c is gradually increased because the energy is continuously delivered from input to the capacitor C_L and the lamp is simply in open state. The filaments are gradually heated and the lamp starts to discharge when the voltage across the lamp reaches to the starting voltage.

B. Dimming Control Scheme

After the lamp is turned on, the light output level is regulated by controlling the energizing interval which corresponds to the conduction period of the switches Q4 (Q3). As the energizing interval increases, the energy delivered to the lamp also increases and the light intensity grows to higher level. Therefore, the continuous dimming control of lamp can be obtained by adjusting the duty ratio of the switches Q3 and Q4 and can be set to a certain level according to the light environment. This control scheme can be used for group dimming control of lamps as shown in Fig. 8 as well.

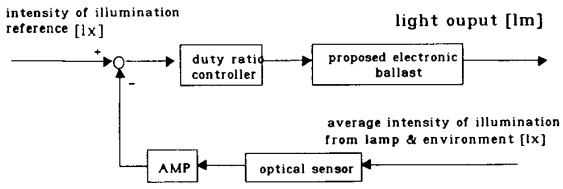


Fig.7 Control scheme for optimal intensity of illumination

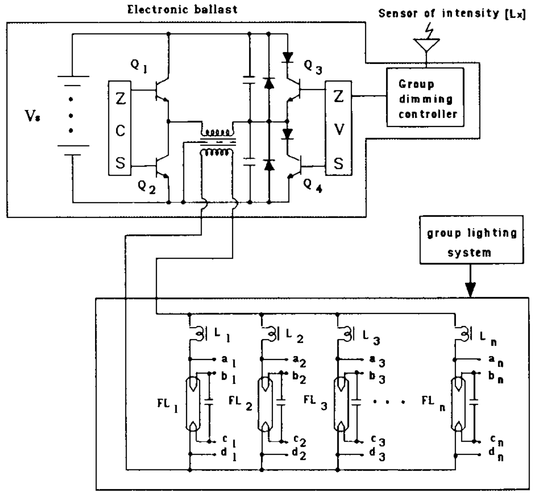


Fig.8 Overall system configulation for group dimming control

IV. EXPERIMENTAL RESULTS

Fig. 3(a) shows an overall system configuration for 40 W fluorescent lamp lighting used in this experiment. In this figure, ZCS (ZVS) block represents Zero Current (Zero Voltage) Switching control module. The values of passive elements used in the experiment are as follows :

$C/2$ = 1800 pF,
L = 3 mH,
C_L = 22 nF.

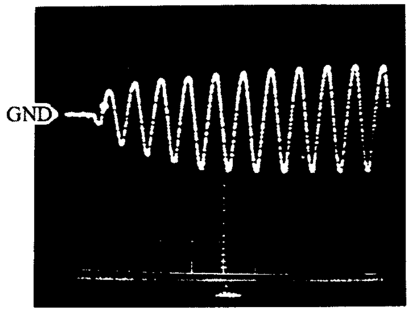
The turn ratio of the isolation transformer is one to one.

The soft starting characteristic of the lamp is shown in Fig. 9, where the lamp voltage gradually increases until the lamp is turned on. Fig. 10 and 11 show the switching waveforms of the proposed inverter at 100 % and 50 % light levels, respectively. The conduction period of switch Q4 and the peak value of the collector current in Fig. 10(b) are about two times those in Fig. 11.

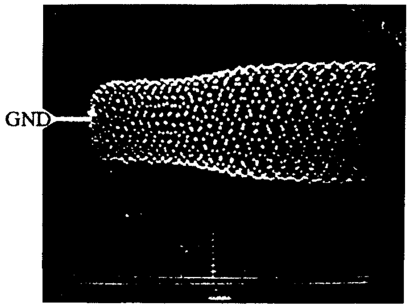
Fig. 12 shows the lamp voltage and current waveforms at different light levels. Note that the two lamp voltage and current waveforms in Fig. 12 are all in phase, which means that the lamp can be approximately modelled as the equivalent resistor. Fig. 12 shows that lamp current is uniform and not modulated with low frequency component for varying light level condition unlike the case shown in Fig. 2. Therefore the flicker of the lamp can be significantly reduced in this case.

Fig. 13 shows the current waveform flowing through the shorted line from the isolation transformer shield to ground. This figure shows that large current spikes are generated when the primary voltage changes rapidly.

Fig. 14 shows the frequency spectrum of EMI noise radiated from the ballast-lamp system with and without shielding cases between the primary and secondary windings of the isolation transformer. This shows that the shielded system does not interfere with currently used remote control systems.

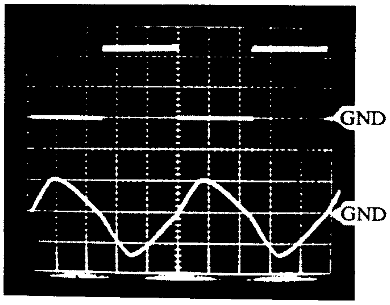


(a) initial build-up (50μS/div)



(b) until steady state (0.5mS/div)

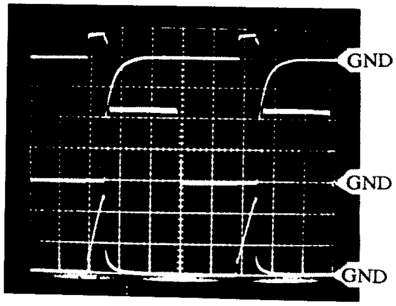
Fig.9 Lamp starting voltage waveforms (100V/div)



(a)

upper : collector-emitter voltage of switch Q_2 (100V/div)

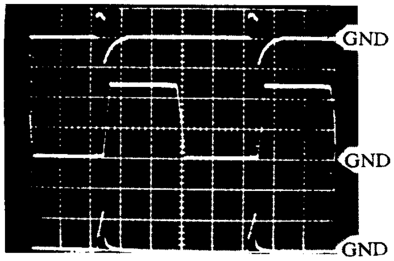
lower : inductor current i_L (0.5A/div)



(b)

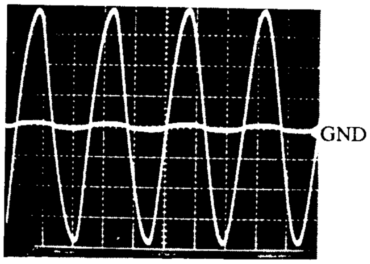
upper : base-emitter voltage of switch Q_4 (1V/div)
middle : capacitor voltage v_c (100V/div)
lower : collector current of switch Q_4 (0.2A/div)

Fig.10 Voltage and current waveforms of inverter for 100% light level (10 μs/div)

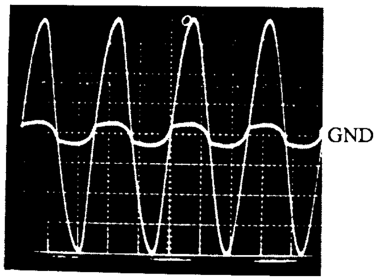


upper : base-emitter voltage of switch Q_4 (1V/div)
middle : capacitor voltage v_c (100V/div)
lower : collector current of switch Q_4 (0.2A/div)

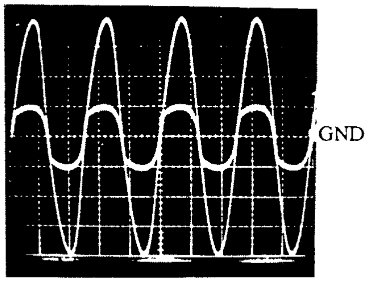
Fig.11 Voltage and current waveforms of inverter for 50% light level (10 μs/div)



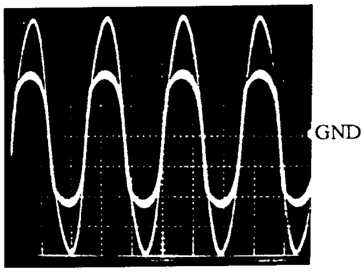
(a) 0.5%



(b) 10%



(c) 50%



(d) 100%

Fig.12 Lamp voltage and current waveforms for different light levels (each 20μS/div, 50V/div, 100mA/div except (e))

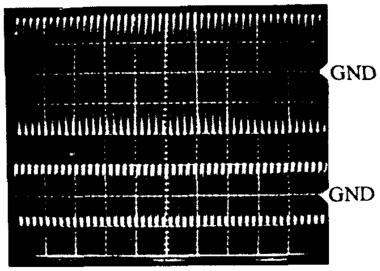


Fig.12(e) 50% (200μS/div)

upper : lamp voltage (100V/div)
lower : lamp current (100mA/div)

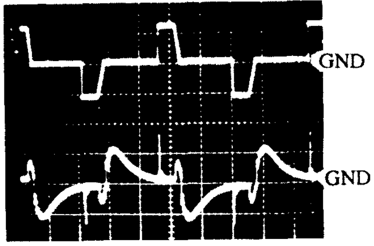
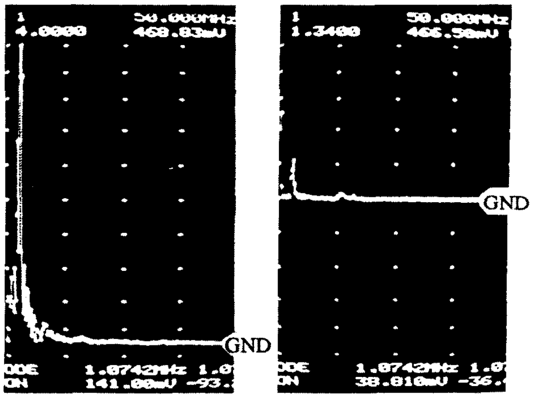


Fig.13 Effect of stray capacitance between the primary and secondary windings of isolation transformer (10μs/div)

upper : primary voltage of transformer (200V/div)
lower : current waveform from transformer shield to ground (5mA/div)



(a) without shielding (b) with shielding

Fig.14 Freguency spectrum of EMI noise radiated from the ballast-lamp system

V. SUMMARY

An efficient fluorescent lamp lighting system using the soft switching resonant inverter is proposed. The resonant inverter circuit operation, principle of dimming control and soft starting method are described. The features of the proposed high frequency resonant inverter for the fluorescent lamp lighting can be summarized as follows :

1) high efficacy (lm/W),
2) high efficiency due to the soft switching,
3) low EMI,
4) continuous dimming control by varying duty ratio,
5) wide dimming range (200:1),
6) longer lamp life due to the soft starting and proper filament heating,
7) no flicker on dimming condition,
8) capability of group dimming control of lamps.

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