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Circuit Design and Performance Analysis of CCFL Dimming Controller With Frequency Modulation

Cherl-Jin Kim†, Jae-Geun Ji* and Shin-Yong Yoon**

Abstract - The CCFL dimming control methods are generally used lamp current regulation or average current adjustment method feeding the CCFL inverter. Inverter operation frequency is higher than resonant frequency for safe operation. In this study, we design the half-bridge type series and parallel resonant converter circuit that switches at variable frequency modulation methods to control the output power. This method has advantages such as low EMI and reduced harmonics, and it is convenient for dimming control using a microprocessor. The validity of this study is confirmed from the simulation and experimental results.

Keywords: CCFL, dimming control, frequency modulation, resonant circuit, LCC, inverter, burst control, backlight

1. Introduction

Generally the CCFL is used as an illuminator and backlight of a LCD, requiring high electric field energy over 1200V when it initially drives, and needing to be supplied with a regular steady state voltage of nearly 400V~800V after ignition. The voltage gains ($G(jw)$) of the resonant inverter are decided by quality factor (Q), the parallel to series capacitance (C_P / C_S), and switching frequency to resonant frequency ratio (fn), etc. [1, 2]

The voltage gain is excessive because equivalent lamp impedance is infinitive prior to ignition. The high voltage is available for supply by Q value according to the high equivalent lamp impedance at starting instant. The LCC series-parallel resonant circuit acts on CCM mode when switching frequency moves toward higher than resonant frequency; also it is possible to adjust illumination over the resonant frequency region. [4, 5]

In this study, we invent a resonant inverter with a LCC series-parallel resonant feature for this experiment. This inverter uses the burst dimming control method by frequency variation.

The series-parallel voltage gain is analyzed by PSpice simulation, and the simulation results are verified by experimentation.

2. Operation Principle and Analysis

2.1 Operation of Resonant Inverter

The idealized LCC circuit is shown in Fig. 1. Through the analysis, it is assumed that the resonant circuit and any types of switching devices are ideal.

In the investigation, the operation mode is divided into categories of before and after CCFL ignition state. By operation condition, the quality factor (Q) is given as in the following equations (2) and (4).

The lamp resistance is extremely high before CCFL ignition, therefore the circuit is composed of a parallel resonant circuit with series connected C_S and C_P. Under this condition, the resonant frequency and quality factor (Q) are as in the following equations (1) and (2).

$$fr = \frac{1}{2\pi\sqrt{Lr \times (\frac{Cs \cdot Cp}{Cs + Cp})}} \tag{1}$$

$$Q \cong 0 \tag{2}$$

After lighting, the lamp quickly becomes of low resistance. As such, the effect of parallel capacitor C_P is reduced relatively, and the circuit is a form of series-parallel resonances by increased load effect.

Under this condition, the resonant frequency and quality factor are as presented in equations (3) and (4).

$$fr = \frac{1}{2\pi\sqrt{Lr \times Cs}} \tag{3}$$

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$$Q = \frac{\sqrt{Lr/Cs}}{R_{tot}} \tag{4}$$

Here, R_{tot} means equivalent total resistance, that is the winding resistances and the load resistance are added to the resonant circuit. Continuous Conduction Mode (CCM) is an available operation when the switching frequency is higher than resonant frequency as represented in equations (1) and (3). The selection of resonant capacitors C_S and C_P and resonant inductance Lr is possible by application of equations (1) and (3).

The fundamental component of voltage waveform is as depicted in equation (5) by Forier analysis when the source voltage V_{pulse} is supplied to the resonant circuit.

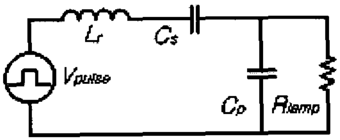


Fig. 1 Equivalent model

$$v_f = \frac{2V_{dc}}{\pi}\sin(2\pi f_s t) \tag{5}$$

Also, the voltage gain $G(jw)$ in the series-parallel resonant circuit is shown in equation (6).

$$|G(jw)| = \frac{1}{\sqrt{[1+(C_s/C_p)(1-f_n^2)]^2 + Q^2(f_n - 1/f_n)^2}} \tag{6}$$

Where, fn means normalized frequency $f_n(=f_s/f_r)$, and f_s and f_r are the switching and resonant frequency, respectively.

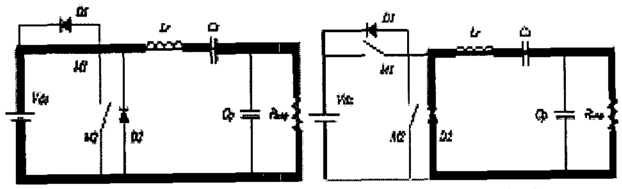
In the equation, the ratio C_P/C_S is an important parameter to determine the characteristics of the resonant circuit. The voltage gain $G(jw)$ is changed according to the C_P/C_S variation, and this relation is represented as equation (6).

From Fig. 1, impedance Z of the resonant tank circuit is as shown in the following equation (7).

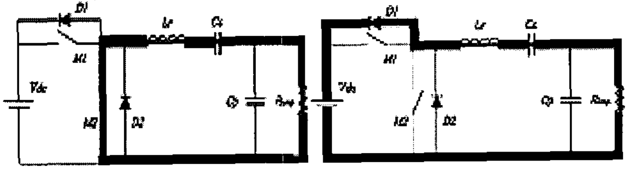
$$Z = jwL_r + \frac{1}{jwC_s} + \frac{R_{lamp}}{1+jwC_pR_{lamp}} \tag{7}$$

The current phase (θ_i) has the following relation in the resonant tank as depicted in equation (8), which is based on the fundamental component of the voltage.

$$\theta_i = \tan^{-1}\left(\frac{C_p \cdot f_n}{C_S \cdot Q_S}\right) - \tan^{-1}\left\{\frac{Q_S(f_n - 1/f_n)}{1 + C_p/C_S(1-f_n^2)}\right\} \tag{8}$$



(a) Mode 1 (b) Mode 2



(c) Mode 3 (d) Mode 4

(e) LCC inverter switching waveforms.

Fig. 2 Operating modes

Mode 1: Voltage source V_{dc} is supplied to the resonant circuit, then inductor current i_r is increased gradually according to the ratio of V_{dc}/L for M1 turn on. Here, C is equivalent capacitance of C_S and C_P.

Mode 2: When M1 becomes turn-off, the current loop is formed through diode D_2 by a phase delayed current.

Mode 3: M2 turns on after mode 2, and the stored energy in the resonant circuit releases through the current path as in Fig. 2 (c). In this mode, as inductor current i_L flows through diode D_1 to Voltage source V_{dc}, the regenerative circuit is formed when M2 is turned off.

As mentioned above, electrical power being supplied to the R_{lamp} is available according to the periodical repetition of the M1, M2 operation. Here, the supplied voltage to R_{lamp} is sinusoidal waveform by resonant tank circuit.

3. Circuit Design

3.1 Resonant Circuit Design

The voltage gain $G(jw)$ of the resonant inverter is decided by some parameters, such as quality factor (Q), the ratio of parallel to series capacitance $C_n(=C_P/C_S$, and the ratio of switching to resonant frequency $f_n(=f_s/f_r)$. Fig.

3 shows voltage gain $G(jw)$ according to the normalized frequency fn and quality factor Q variation in $C_P/C_S=1$ condition. At previous ignition state $Q \cong 1$, it represents high voltage gain, therefore an additional circuit is unnecessary.

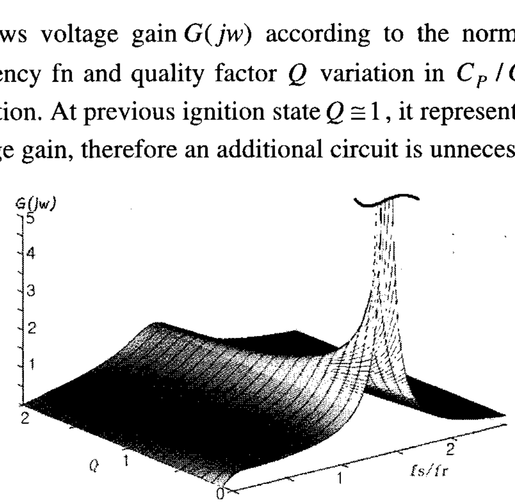


Fig. 3 Simulation waveform to the variation of Q and fn, when $C_P/C_S=1$.

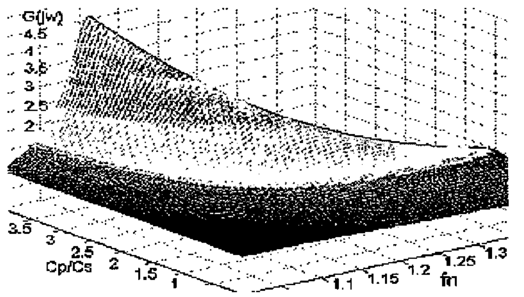


Fig. 4 Simulation waveform to the variation of C_P/C_S and fn, when $Q=1$.

Fig. 4 is the result of voltage gain $G(jw)$ in $Q=1$ case. We know that voltage gain $G(jw)$ is changed by capacitance ratio C_n and frequency ratio fn from this figure.

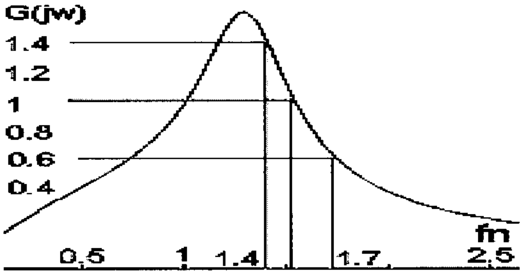


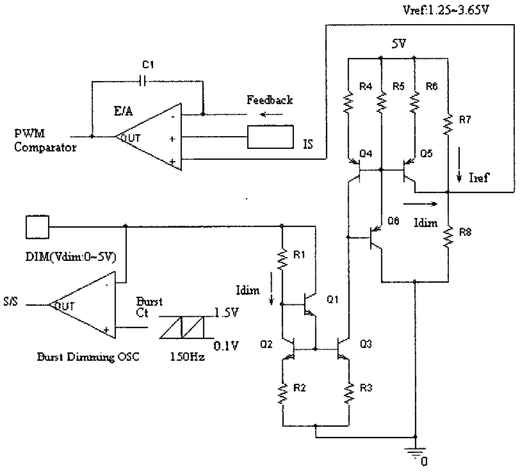
Fig. 5 Simulation waveform of $G(jw)$ versus f_n ($Q=1, C_P/C_S=1$).

Fig. 5 represents voltage gain $G(jw)$ to frequency ratio fn in the case of $Q=1$, and it is found that maximum voltage gain is occurred at $f_s \cong 1.3f_r$. The voltage gain becomes continuously decreased in accordance with controlled frequency being high frequency over the gain maximum frequency.

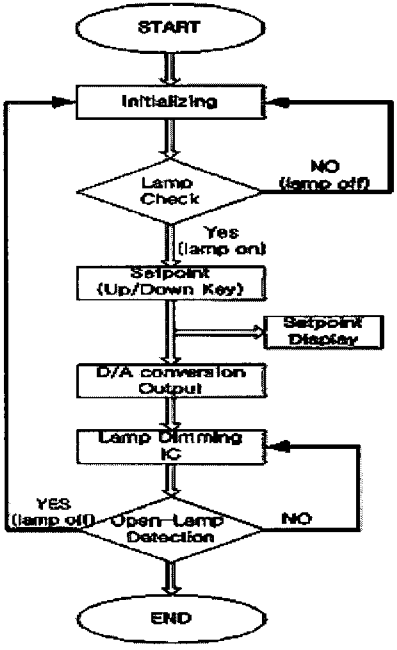
3.2 Dimming control

Dimming mode is divided by 2 types, burst dimming mode, which is composed of error amplifier and comparator and analog dimming mode. It is able to control the CCFL illuminations with relatively wide range when these kinds of dimming modes are combined together. The dimming control is realized by an external DC input signal, which is commanded by a microprocessor and D/A converter. The external DC signal of approximately 1.5V is compared with carrier wave by the comparator, and the compared output signal is used to burst the dimming signal.

Fig. 6 (a) shows the dimming control circuit, and Fig. 6 (b) represents the microprocessor control flowchart. Here, the control signal can perform adjustment of 256 steps by 8bit microprocessor application.



(a) Dimming control circuit



(b) Microprocessor control flowchart

Fig. 6 Lamp control stage diagram

4. Simulation and Experimental Results

4.1 Simulation results

The steady state analysis is carried out with the PSpice simulation program, and the equivalent model is as shown in Fig. 7. There are two resonant points depending on the primary inductor of the main transformer.

The $G(jw)$ for output determination uses resonant frequency formed by resonant components, and the current is stabilized by the equivalent resistance of the lamp when $G(jw)$ is stabilized. The analyzed output waveform by LCC tank circuit becomes the sinusoidal waveform as in Fig. 8.

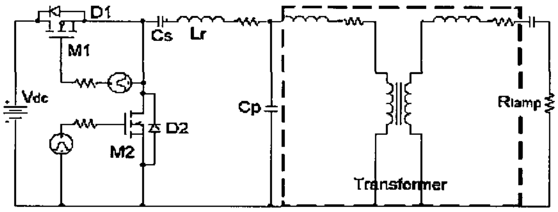


Fig. 7 Equivalent circuit using to the simulation

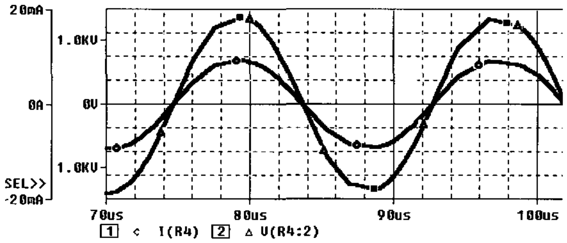


Fig. 8 Voltage and current simulation waveform of lamp

4.2 Experimental results

The component is selected by equivalent resistance of load and equation as indicated in (3) and (4). Voltage gain of the resonant circuit is determined by Cs and Cp, which are related to Q curve.

After understanding of the resonant frequency and resonant parameters is achieved, we are able to decide the range of operating frequency and $G(jw)$ with Figs. (3), (4) and (5). The voltage gain $G(jw)$ is appreciated easily from the simulated result in Fig. 5. The following parameters are applied to the experimental inverter, as represented in Tables 1, 2 and II I.

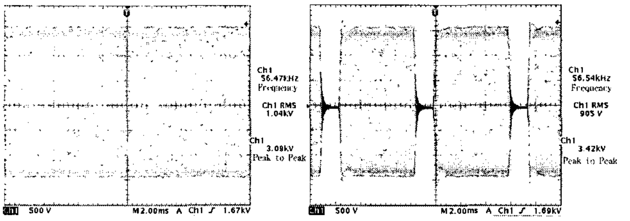
Table 1 Input Data

Specification	
Input Voltage	DC 12 V
Output Power	5 W
Switching Frequency	55kHz
Lamp Resistance	150 kΩ

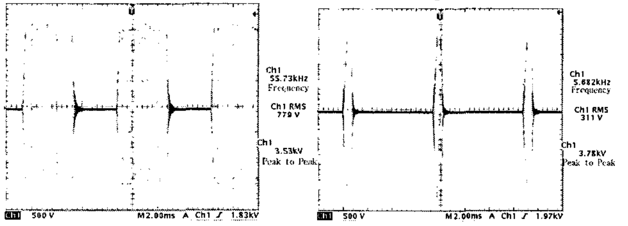
Table 2 Parameters Used On The Experiment

Resonant Tank Parameter and Transformer Specification	
Lr	15.5 uH
Cs	1 uF
Cp	1 uF
Transformer turn ratio	Secondary 15 / Primary 170

Fig. 9 (a) represents the CCFL output waveform that is generated in accordance with commanded dimming value of the microprocessor and proper operation of the resonant circuit. Figs. 9 (b), (c) and (d) indicate the results of CCFL output waveforms in each of the illuminations by stages.



(a) Dimming level: 100% (b) Dimming level: 80%.



(c) Dimming level: 50% (d) Dimming level: 10%

Switching frequency 55 kHz, dimming frequency 120Hz

Fig. 9 Experimental results (Burst dimming control)

5. Conclusions

The CCFL inverter demands low input and high output voltage performance for LCD backlight application. When it applies for LCC series-parallel resonant circuits in CCFL power supply, it has certain advantages such as driving the lamp at high voltage gain and low switching losses. The LCC series-parallel resonant circuit has the ability to adjust the lamp illumination by output gain control to switching frequency. This performance is able to result in not only energy saving, but miniaturization of the unit in the CCFL application devices.

It is presented that the design method of the resonant inverter is applicable to lamp dimming in this study.

The voltage to frequency control method using a microprocessor and D/A converter is applied to this inverter. The designed burst dimming circuit is able to adjust smoothly, dimming also at low illumination state.

We have confirmed the suitability of the proposed design method through comparison of the simulation and experimental results, which have good agreement. The

CCFL dimming method of burst control is widely applicable to many related industrial fields.

References

[1] Joel A. Donahue, P.E. and Milan M. Jovanovic, "The LCC Inverter as a Cold Cathode Fluorescent Lamp Driver", APEC 1994, pp.427-433.

[2] Louis Robert Nerone, "Design of a 2.5-MHz, Soft-Switching, Class-D Converter for Electrodeless Lighting", IEEE Trans, On Power Electronics. Vol 12, No 3, May 1997.

[3] M.Jordan, J.O'conner, "Resonant Fluorescent Lamp Converter Provides Efficient and Compact Solution", Unitrode application note U-141.

[4] S.W.Lee, D.Y.Ko, D.Y.Huh and Y.I.Yoo "Simplified Control Technique for LCD Backlight Inverter System Using the Mixed Dimming Method" IEEE Trans, On Power Electronics.

[5] S.A.El-Hamamsy, "Design of High-Efficiency RF Class-D Power Amplifier," IEEE Trans, On Power Electronics. Vol 9, No3, pp. 297-308, May 1994.

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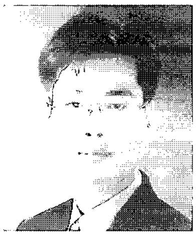

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