32인치 LCD TV의 EEFL 인버터 백라이트에 적합한 풀브리지 RLC 직렬 공진 인버터의 분석 및 설계

† 오원식, † 조규민, † 문건우, ‡ 이상길, ‡ 박문수
† 한국과학기술원 디스플레이 센터, ‡ 삼성전자

Analysis and Design of Full-Bridge RLC Series-Resonant Inverter for EEFL Backlight of 32-inch LCD TV

† Won-Sik Oh, † Kyoo-Min Cho, † Gun-Woo Moon, ‡ Sang-Gil Lee, and ‡ Mun-Soo Park
† Display Center of KAIST,and ‡ Samsung Electronics Co., Ltd.

Abstract

As the screen size of LCD TV increases, an external electrode fluorescent lamp (EEFL) has been suggested to be applicable as backlight source for LCD TV. Since the EEFL has non-linear characteristics, which makes the analysis and design complicated. In this paper, the characteristics of the EEFL are investigated and a full-bridge RLC series-resonant inverter is analyzed and designed for EEFL backlight of 32-inch LCD TV. Finally, the experimental results are shown to validate the analysis and design.

I. Introduction

Recently, as the demand of flat panel display (FPD) has dramatically increased by the expansion of the digital TV market, the large sized LCD TV has been replacing CRT TV and competing with PDP TVs in the over 40-inch ranges. As the screen size of LCD increases, the backlight inverter become more important since the most power is consumed in backlight.

Up to now, cold cathode fluorescent lamp (CCFL) is widely used as the backlight source, due to the slim size, high optical efficiency and so on. Fig. 1 (a) shows the structure of CCFL. Since the electrodes of CCFL are located through the tube as shown in Fig. 1 (a), the current can be increased abruptly when the voltage is applied to the lamp[1]. For a stable operation, a ballast capacitor should be attached to the electrode of the CCFL.

On the other hand, since the electrodes of EEFL are insulated by the tube as shown in Fig. 1 (b), EEFL has many advantages such that the life time of the EEFL is longer than that of the CCFL, and the structure of EEFL inverter is simple as shown Fig. 2. Especially,in large sized LCD TV applications, compact design can be realized. Since a single inverter can drive multiple EEFL tubes, the cost of EEFL inverter would be much lower than that of CCFL inverter[2]. EEFL inverter is relatively simple and small comparing to CCFL inverter. Therefore, it is one of the reasons that EEFL has been suggested to be a cost effective backlight source for applied for LCD TV[3-4].

In this paper, the characteristics of full-bridge RLC series-resonant inverter for the EEFL backlight are analyzed and sinusoidal driving method is adapted to the complementary full-bridge EEFL inverter. From the characteristics of EEFL and the analysis of the driving system, the optimal design can be obtained in 120V input voltage specifications. The validity of this study is verified by the experimental results.

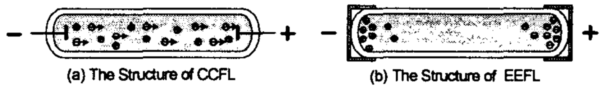


Fig. 1 The structure of fluorescent lamp (a) CCFL,(b) EEFL

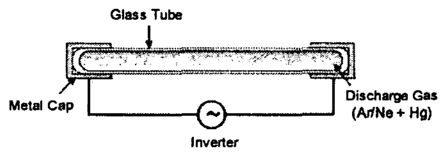


Fig. 2 The structure of EEFL inverter

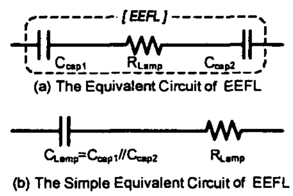


Fig. 3 Equivalent model of the EEFL

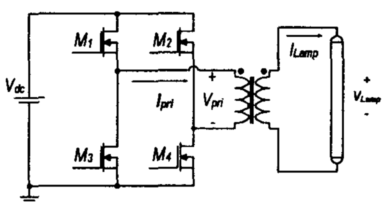
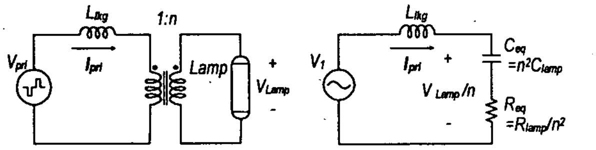


Fig. 4 Full-bridge inverter for EEFL

II. Operational Principles

CCFL shows a highly nonlinear load to the inverter[1]. In steady-state operation, CCFL can be simply operated as resistive load. The structure of EEFL is similar to the CCFL except its external electrodes: As can be seen in Fig. 2 (b), glass barrier is located between a metal cap (an external electrode) and EEFL tube, it can be modeled as series connected capacitors and a resistor as shown in Fig. 3.

To drive parallel connected 20 EEFLs for a 32-inch LCD TV, a full-bridge inverter can be adapted as shown in Fig. 4, since it can change the duty of the powering and handle high power. An equivalent circuit for full-bridge EEFL inverter can be expressed as a simple RLC series-resonant circuit as shown in Fig. 5. The inductor represents a transformer leakage inductance due to a separated bobbin used.



(a) EEFL Inverter (b) Equivalent Circuit

Fig. 5 The EEFL inverter and the equivalent circuit

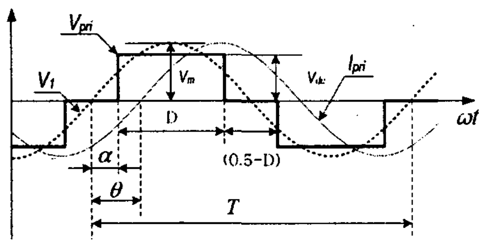


Fig. 6 Voltage waveforms of the transformer primary side

In a RLC resonant circuit, its resonant frequency, fr, is determined by Llkg and Ceq. the resonant frequency and quality factor, Q, are expressed as following equations (1), (2).

$$f_r = \frac{1}{2\pi\sqrt{L_{llkg} \times C_{eq}}} \tag{1}$$

$$Q = \frac{1}{R_{eq}}\sqrt{\frac{L_{llkg}}{C_{eq}}} \tag{2}$$

Fig. 6 shows the voltage waveform of transformer primary side, Vpri, and its fundamental component, V1, with the amplitude of Vm. From Fourier series, the amplitude of V1, can be expressed as

$$V_m = \frac{4}{\pi} V_{dc} \cos(D\pi) \tag{3}$$

where, D is duty ratio (0~0.5).

Therefore, V_1 can be expressed as

$$\begin{aligned} V_1 &= \frac{V_m}{\sqrt{2}} \sin(\omega t - \psi) \\ &= \frac{2\sqrt{2}}{\pi} V_{dc} \cos(D\pi) \sin(\omega t - \psi) \end{aligned} \tag{4}$$

where, Ψ is the phase angle.

The phase angle between the fundamental component of the primary voltage and resonant current is θ and can be calculated as

$$\begin{aligned} \theta &= \angle \frac{V_1}{I_{pri}} = \angle R_{eq} + j\left(\omega L_{llkg} - \frac{1}{\omega C_{eq}}\right) \\ &= \angle 1 + jQ\left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}\right) \end{aligned} \tag{5}$$

where, $\omega = 2\pi f$ and $\omega_r = 2\pi f_r$, respectively

Obviously, θ should be greater than $\alpha = 2\pi(0.5-D)/2$ so that switches M1 and M3 turns on negative current, i.e., ZVS of switches M1 and M3.

The ac-to-ac voltage transfer function from the input of inverter to the lamp is

$$\begin{aligned} G(j\omega) &= \frac{\mathbf{V}_{Req}}{\mathbf{V}_1} = \frac{R_{eq} - j\frac{1}{\omega C_{eq}}}{R_{eq} + j\left(\omega L_{llkg} - \frac{1}{\omega C_{eq}}\right)} \\ &= \frac{1 - jQ\frac{\omega_r}{\omega}}{1 + jQ\left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}\right)} \end{aligned} \tag{6}$$

from which, the voltage gain can be expressed as

$$|G(j\omega)| = \frac{V_{Req}}{V_1} = \frac{\sqrt{1 + Q^2\left(\frac{\omega_r}{\omega}\right)^2}}{\sqrt{1 + Q^2\left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}\right)^2}} \tag{7}$$

Using equation (7) calculated voltage gains with various Q values are shown in Fig. 7.

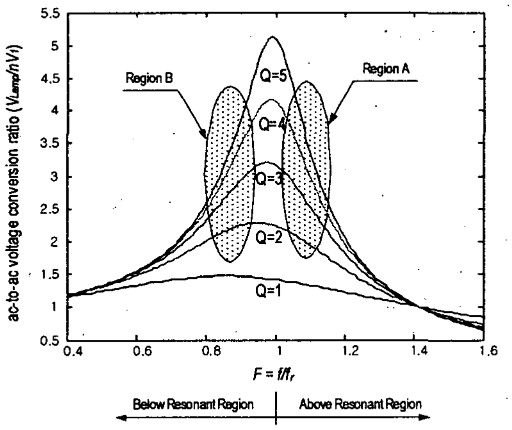


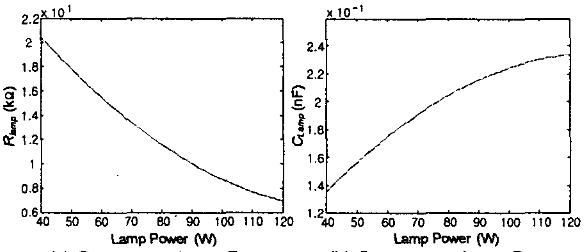
Fig. 7 Voltage gain of the SRC series-resonant inverter

From (4) and (7), the magnitude of the dc-to-ac voltage transfer function for the full-bridge series-resonant inverter can be expressed as

$$\frac{V_{Lamp}}{V_{dc}} = n \cdot \frac{2\sqrt{2}}{\pi} \cdot \cos(D\pi) \cdot \frac{\sqrt{1 + Q^2\left(\frac{\omega_r}{\omega}\right)^2}}{\sqrt{1 + Q^2\left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}\right)^2}} \tag{8}$$

III. Design of EEFL Inverter

The EEFL is inherently a nonlinear load. However, it can be assumed that the lamp impedance is constant at steady-state. Fig. 8 shows the resistance and capacitance characteristics of an EEFL at steady-state which is obtained by the experiments. Table 1 shows the specifications of an EEFL. The typical lamp current is 5mA, the rated power is 5W, and its maximum allowable power is 6W. Typical operating lamp voltage is about 1470~1670V and its starting up voltage (firing voltage) is 1360Vrms at 25℃and 1650Vrms at 0℃, respectively. For a 32-inch LCD TV backlight system, 20 EEFLs are used and the inverter delivers 120W of maximum output power.



(a) R_{lamp} versus Lamp Power (b) C_{Lamp} versus Lamp Power

Fig. 8 EEFL impedance characteristics for the lamp power

Table 1 Specifications of EEFL

Items	Symbol	Unit		Requirement		
				MIN.	TYP.	MAX.
Lamp current	I_{LTYP}	mArms		3.0	5.0	6.0
Lamp Voltage	V_{Lamp}	Vrms		1370±7% (IL:3.0mA) 1470±7% (IL:4.0mA) 1570±7% (IL:5.0mA) 1670±7% (IL:6.0mA)		
Starting Up Voltage	V_{start}	Vrms	25℃	-	-	1360
			0℃	-	-	1650

Since the resistance is very high before EEFL is excited, the lamp voltage can be decided from the transformer turns ratio and the input voltage. Therefore, in order to ensure that the EEFL can be started, the transformer turnsratio, n, determined by the lowest input voltage Vdc,min and the starting up voltage Vstart should be satisfied with the following equation:

$$n = \frac{N_s}{N_p} \ge \frac{\sqrt{2}V_{start}}{\pi V_{dc,min}} \tag{9}$$

where, Np and Ns are the number of turns of primary side and secondary side of transformer, respectively. $V_{dc,min}$ is the lowest input voltage and V_{start} is the starting up voltage.

IV. Experimental Results

For validity verification, a full-bridge resonant inverter with 120V input voltage is designed and investigated. Two transformers are connected in series to reduce the number of turns on the transformer's primary side. Table 2 shows the system parameters as results of manufactured transformers. The resonant frequencies is 85.6kHz.

Table 2 System parameters of EEFL Inverter

V_{dc}	L_{lkg}	C_{Lamp}	n	L_{eq}	C_{eq}	f_r
120V	75uH	230pF	10	150uH	23nF	85.6kH

From the equation (5), the phase angles, θ, between V1 and Ipri is 0.94 rad. From the ZVS condition, θ>α=2π (0.5-D)/2, the minimum duty ratio is 0.2. Therefore, the inverter has wide rang of ZVS for the variation of duty ratio, D.

Fig. 9 shows the experimental results. The inverter was operated with a driving frequency f=97kHz, duty ratio D=0.3125, phase angel θ=0.133(0.82rad), and α =0.09375(0.59rad). As a result of all switch's ZVS, the inverter is achieved high efficiency over 7,000cd/m of the luminance.

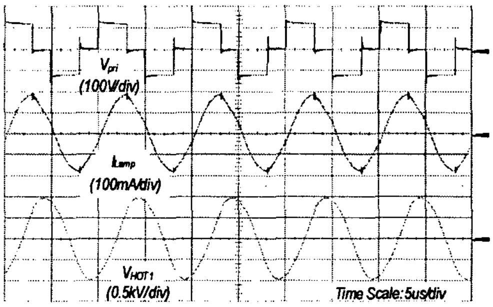


Fig. 9 Experimental results

V. Conclusions

In this paper, the characteristics of the EEFL are investigated and the complementary full-bridge RLC series-resonant inverter is analyzed for EEFL backlight of 32-inch LCD TV. From the characteristics of EEFL and the analysis of the driving system, the optimal design can be obtained in 120V input voltage specifications. The validity of this study is confirmed from the experimental results.

Acknowledgement

This work is supported by LCD Business of Samsung Electronics Co., LTD, Korea, under Display Research Center Program.

References

[1] Jordan, M and O'Connor, J. A., "Resonant Fluorescent Lamp Converter Provides Efficient and Compact Solution", Proceeding of Applied Power Electronics Conference and Exposition, pp424-431, 1993.

[2] Y. Takeda, M. Takagi, T. Kurita, Y. Watanabe, M. Amano, and H. Nakano, "The characteristics of the external-electrode mercury fluorescent lamp for backlighting liquid-crystal-television displays", Journal of the SID, 11/4, 2003.

[3] Won-Sik Oh, Kyu-Min Cho, Gun-Woo Moou, Sook-Kyu Min, Hyun-Jin Kim, Hyoung-Jun Jeon, Jong-Sun Kim, and Byoung-Woon Min, "Study on High Efficiency EEFL Backlight inverter for 32-inch LCD TV", Proceedings of 10th KIPE Power Electronics Annual Conference, pp.405~407, 2005.

[4] Yeon-Jae Lee, Won-Sik Oh, Sung-Sae Lee, Gun-Woo Moon, "Comparative Study on Sinusoidal and Square Wave Driving Meghods of EEFL (External Electrode Fluorescent Lamp) for LCD TV Backlight", Proceedings of 10th KIPE Power Electronics Annual Conference, pp.325~328, 2005.