PDP을 위한 새로운 저가형 에너지 회수 회로

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A new low-cost energy-recovery circuit for a plasma display panel

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ABSTRACT

A new low-cost energy-recovery circuit (ERC) for a plasma display panel (PDP) is proposed. It has two auxiliary switches clamped on a half sustain voltage, and inductor currents are built up before the PDP is charged and discharged. Therefore, it features a low cost, fully charged/discharged PDP, zero voltage switching (ZVS), low electromagnetic interference (EMI), low current stress, no severe voltage notch, and high energy-recovery capability.

1. Introduction

Since the PDP has advantages such as a wide view angle, lightness, thinness, high contrast, and large screen, it is one of the most leading candidates for large screen TVs. Generally, the PDP can be equivalently regarded as a capacitance load \( C_p \). Therefore, when a sustain voltage \( V_s \) is alternatively applied across the PDP using full bridge inverter, there are the considerable energy loss of \( 2C_pV_s^2 \) per each cycle, excessive surge current, and severe EMI noise.

To solve these problems, several approaches have been proposed. Among them, Weber's circuit shown in Fig. 1(a) features a low conduction loss and high performance [1]. However, it has several disadvantages. There is a severe voltage drop across a parasitic resistance, which results in the serious hard switching, excessive surge current, serious power dissipation, severe EMI noise, and poor energy-recovery capability. Also, a large gas-discharge current causes a serious voltage notch across the PDP. Above all, it uses four auxiliary switches having voltage stress of \( V_s/2 \), which results in high cost.

Sakai's circuit shown in Fig. 1(b) features a simple structure and good energy-recovery performance [2]. However, it still has disadvantage that voltage drop due to a parasitic resistance causes the serious hard switching, severe voltage notch, excessive surge current, serious power dissipation, severe EMI noise, and poor energy-recovery capability. Moreover, voltage stress of two auxiliary switches in ERC is \( V_s \), which results in high cost.

(a) Weber's circuit

(b) Sakai's circuit

Fig. 1 Prior circuits

To overcome these drawbacks of prior circuits, A new low-cost ERC for the PDP is proposed as shown in Fig. 2(a). Since the proposed circuit has two auxiliary switches clamped on \( V_s/2 \) instead of four auxiliary switches clamped on \( V_s \) for Weber's circuit and two auxiliary switches clamped on \( V_s \) for Sakai's
circuit, it features a lower cost of the production compared with prior circuits. Furthermore, the inductor currents are built up before the PDP is charged and discharged. These built-up inductor currents help to fully charge and discharge the PDP with fast transition time, achieve ZVS of main switches, and reduce the EMI noises. In particular, since these compensate for a large gas-discharge current, there is no severe voltage notch, and the current stress of main switches can be reduced effectively. Therefore, the proposed circuit features the high energy-recovery capability.

**Mode 2($t_1$-$t_2$):** When $M_5$ and $M_6$ are turned off at $t_1$, mode 2 begins. $L_1$ and $L_2$ begins to charge $C_5$ and $C_6$, and discharge $C_3$ and $C_4$ with initial conditions of $v_{C_5}(t_1)=-V_S$ and $i_{C_5}(t_1)=i_{C_6}(t_1)=V_S/(2L)$. The voltage $v_{C_3}$ decreases linearly with slope $-V_S/(2L)$ through $C_5$, $M_6$, $d_{C_5}$, and $D_1$. $i_{C_6}$ decreases linearly with slope $-V_S/(2L)$ through $D_2$, $d_{C_6}$, $M_5$, and $C_5$. Therefore, $M_1$ and $M_2$ can be turned on under ZVS, and $C_5$ is fully charged to $V_S$.

**Mode 3($t_2$-$t_3$):** When $M_1$ and $M_2$ are turned on at $t_2$, mode 3 begins. $i_{C_1}$ fed back to an input voltage source through $C_{out}$, $M_3$, $d_{C_1}$, and $M_4$ compensates for a large part of the gas-discharge current through $M_4$, and $i_{C_2}$ fed back to an input voltage source through $M_5$, $d_{C_2}$, $M_5$, and $C_{out}$ compensates for a large part of the gas-discharge current through $M_5$. Therefore, the current stress of $M_1$ and $M_2$ can be considerably reduced as well as the voltage notch across the PDP can be effectively overcome. In this mode, when $i_{C_1}$ and $i_{C_2}$ decrease to zero, $M_5$ and $M_6$ are turned off. Voltages across $M_5$ and $M_6$ are clamped on $V_S/2$ due to $C_{out}$ and $C_{out}$ which results in a low cost. Therefore, the proposed circuit features the fully charged/discharged PDP, ZVS of main switches, no severe hard switching, less power dissipation, low surge current, and low EMI noise due to built-up inductor currents. Furthermore, it shows the high energy-recovery capability.

The circuit operation of $t_3$-$t_6$ is symmetric to that of $t_0$-$t_3$.

### 3. Design considerations

Since the brightness of a PDP depends on the operation frequency and transition time, the transition time $T_d=t_2-t_1$ is required to be as fast as possible. The built-up time, $\Delta t_L=t_1-t_0$ ($=t_3-t_3$), of $L_1=L_2$ can be determined from the equation (1) as follows:

$$\Delta t_L = \frac{\sqrt{2L(C_p+C_{out})}}{\tan[T_d/(2\sqrt{2L(C_p+C_{out}))}]}$$

Fig. 2 Proposed circuit and its key waveforms

Fig. 2(b) shows key waveforms of the proposed circuit. One cycle operation is divided into six modes. It is assumed that $C_1$, $C_2$, $C_3$, and $C_4$ are equal to $C_{out}$. $V_{C_1}$ and $V_{C_2}$ are equal to $V_S/2$, and $L_1$ and $L_2$ are equal to $L$. 

**Mode 1($t_0$-$t_1$):** When $M_3$ and $M_4$ are turned on at $t_0$, mode 1 begins. Since $V_S/2$ is applied across $L_1$ and $L_2$, $i_{C_1}$ and $i_{C_2}$ increase linearly with slope of $V_S/(2L)$. 

\[ v_{C_3}(t) = -V_S \cos(a(t-t_1)) + I_{th} \sqrt{\frac{2L}{C_p+C_{out}}} \sin(a(t-t_1)) \] (1)

where $\omega = 1/(2L(C_p+C_{out}))^{0.5}$. As shown in equation (1), $v_{C_3}$ increases from $-V_S$ by resonance between $2L$ and ($C_p+C_{out}$). And then, when $v_{C_3}$ is clamped on $V_S$, the gas-discharge begins to take place. $i_{C_1}$ decreases linearly with slope $-V_S/(2L)$ through $C_5$, $M_6$, $d_{C_5}$, and $D_1$. $i_{C_2}$ decreases linearly with slope $-V_S/(2L)$ through $D_2$, $d_{C_2}$, $M_5$, and $C_5$. Therefore, $M_1$ and $M_2$ can be turned on under ZVS, and $C_5$ is fully charged to $V_S$.
4. Experimental results

To verify the behavior and analysis of the proposed circuit, the prototype circuit is implemented with specifications of $f_s=50$ kHz, $C_p=2nF$ (6-inch PDP), $L=L_1+L_2=730\mu H$, transition time $\leq 800\mu s$, and $M_1=M_2=2SK2995$. Fig. 3 shows the experimental results of the proposed circuit. As shown in Fig. 3(a), $C_p$ is fully charged to $V_s$ or $-V_s$ without hard switching due to built-up inductor currents. Moreover, since $i_{L1}$ and $i_{L2}$ compensate for the large amount of the gas-discharge current, the current stress of main switches and voltage notch are effectively reduced. $M_2$ and $M_3$ are turned on under ZVS without severe hard switching due to built-up inductor currents as shown in Fig. 3(b).

5. Conclusions

A new low-cost ERC for the PDP has been proposed. The proposed circuit has two auxiliary switches clamped on $V_s/2$, which results in a lower cost of the production compared with prior circuits. Due to the built-up inductor currents, the PDP is fully charged and discharged without hard switching, the ZVS of main switches is achieved, and the EMI noises is reduced. Moreover, since these compensate for a large gas-discharge current, there is no severe voltage notch, and the current stress of main switches can be reduced effectively. The proposed circuit features the high energy-recovery capability. Therefore, it is expected to be suitable for the low-cost PDP.

References