

Improvement of the Sustain-driving Characteristics of AC PDP by Changing the Position of the Inductor

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Abstract

The characteristics of the sustain-driving circuit were examined in this paper. The sustain-driving circuit is in charge of the most important part of PDP driving because it manages most of the power consumption in the PDP. A couple of gate-driving circuits for the sustain-driving circuit were introduced in this paper, and a new driving circuit was also proposed. This new circuit is more cost-effective and has a simpler PCB layout compared to the conventional one. Some additional driving advantages were noted as well.

Keywords : energy recovery, driving, circuit, PDP

1. Introduction

The sustain circuit is a very important part of PDP driving because it manages much of the power that is needed in driving the PDP. Several kinds of driving circuits have been proposed, but the conventional circuit, known as "Weber's energy recovery circuit," is still being used at present.

The conventional sustain-driving circuit consists of several major electronic power devices, namely: the inductor, capacitor, and power switches [1]. The effects of a few devices on the clamping diode, however, are often neglected. Greater concern is usually shown about the output characteristics on the panel side of the inductor than about the output characteristics on the other side.

In the conventional method, the clamping diodes [Dc in Fig. 1] have to be designed on the other side of the inductor to remove the freewheeling [Fig. 2] that occurs at the V_L node shown in Fig. 1. Even though freewheeling does not influence the output characteristics, it still has a number of problems, such as the burden that it causes on heat generation and device reliability while it is driving. In the actual circuit, the number of clamping diodes is usually almost the same as that of the energy recovery diodes (D1, D2). This means that the clamping diodes are important devices for PDP driving.

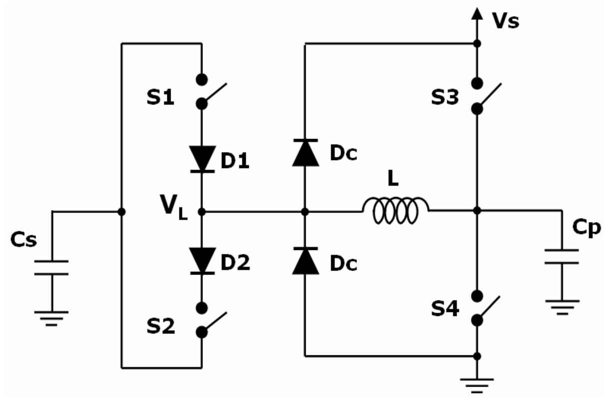

Fig. 1. Conventional energy recovery circuit.

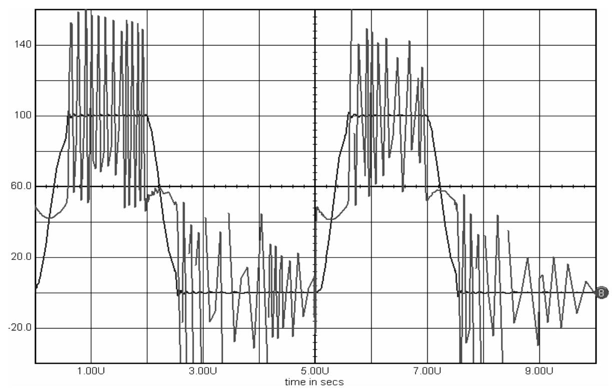

Fig. 2. Simulation result of the non-clamping waveform @ V_L with the output waveform @ C_P.

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2. Experiments

2.1 Examination of the Sustain-driving Circuit

Fig. 3 shows a conventional gate-driving circuit that has a coupling capacitor (Cp). The advantage of this method is that it uses only one gate voltage (V_G). Even though the gate voltages of the switches (S1, S2) have to be separated from their different base potentials on the source, the same gate voltage can be used for the different potential switches. The two different potentials can be separated due to the coupling capacitor. In rare situations, an irregular voltage variance on the drain can make the gate pulse unstable, which is a failure mode. Fig. 4 shows the operating status in detail. Nevertheless, this method may give rise to a major problem.

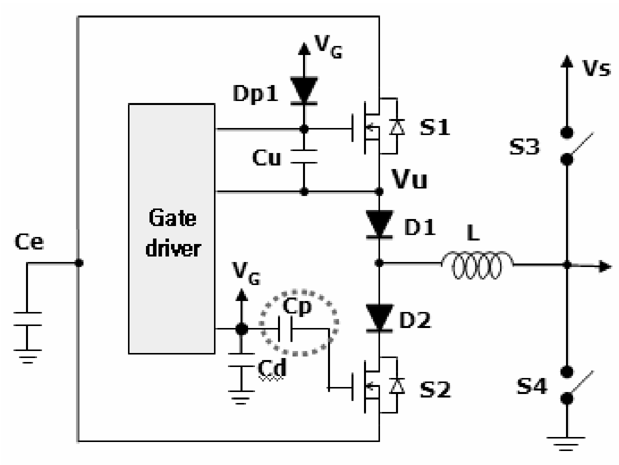


Fig. 3. The first case of the gate-driving circuit in the conventional method.

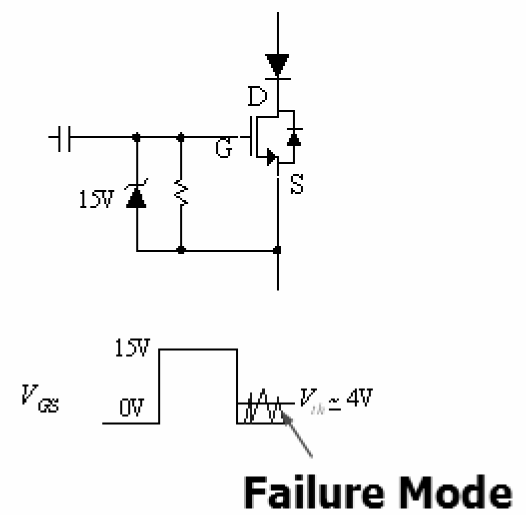


Fig. 4. The operating characteristics of the conventional circuit.

Fig. 5 shows another conventional gate-driving circuit, which has a bootstrap circuit. In such method, the bootstrap diodes (Dp1, Dp2) are needed to charge the bootstrap capacitor (Cu, Cd). This is due to the fact that the bottom capacitor (Cd) cannot charge up the voltage (V_G) itself. In particular, the upper capacitor (Cu) charges up to V_G while (S4) is switched on for ground potential. There is no time, however, to charge up for the bottom capacitor under normal conditions because the bottom capacitor is fixed on the recovery capacitor (Ce) with a Vs/2 potential. As such, the gate charge of the bottom capacitor has to be transferred from the upper capacitor. Moreover, this bootstrap circuit is processed in every sustain pulse period in a very short time.

The minimum capacitance (Cu, Cd) value can be calculated using the following equations:

$$C_{D,MIN} = \frac{Q_G + Q_{RR} + I_{BST} t_{ER\_DN,ON,MAX}}{V_{BST} - V_{UVLO}}, \quad \text{(a)}$$

$$C_{U,MIN} = C_{D,Min} + \frac{Q_G + Q_{RR} + I_{BST} t_{ER\_UP,ON,MAX}}{V_{BST} - V_{UVLO}}, \quad \text{(b)}$$

where Q_G : gate charge of IGBT;

Q_{RR} : reverse recovery of the bootstrap diode;

I_{BST} : $I_{LK,D} + I_{Q,LS} + I_{Q,DRV} + I_{GS}$;

$I_{LK,D}$: leakage current of the bootstrap diode;

$I_{Q,LS}$: quiescent current of the level shifter;

$I_{Q,DRV}$: gate driver;

I_{GS} : leakage current between the gate-source terminals;

V_{BST} : bias voltage; and

V_{UVLO} : under the voltage lockout threshold of the driver.

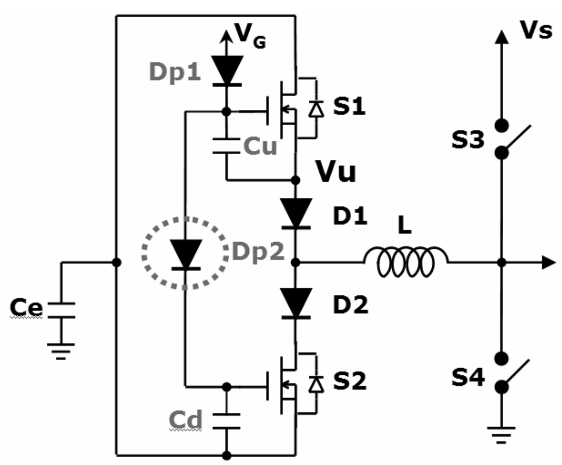


Fig. 5. The second case of the gate-driving circuit in the conventional method.

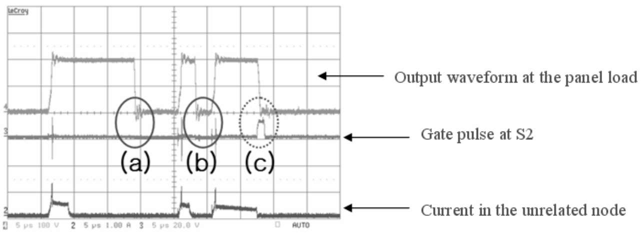


Fig. 6. Gate-driving failure in the conventional circuit. (a) and (b): failure mode. (c): normal.

If t_{ER} is less than at least 1 us, then:

$$2C_{D,MIN} \le C_{U,MIN} \;. \qquad \text{(c)} \qquad [2, 3]$$

For the actual circuit design, the aforementioned condition should be considered. Moreover, if the gate resistor is additionally used, the RC time constant should be considered more seriously in the circuit design. For example, Fig. 6 shows a failure mode of the gate pulse, which was omitted. Several tens of ohms values can make a difference in terms of failure. After all, the capacitances of these bootstrap capacitors (Cu, Cd) and resistor values have to be calculated accurately so they will not be too big or too small.

2.2 The Proposed Method (Free Resonance and Clamping)

Fig. 7 also shows a newer circuit design that is comparable to the design of the conventional circuit. The main difference is that in the new circuit design, the inductor (L) was moved next to the energy recovery capacitor (Cs). In spite of this modification, the new circuit's energy recovery driving is the same as that of the conventional one. The new circuit has some technical characteristics, however, that have to be examined.

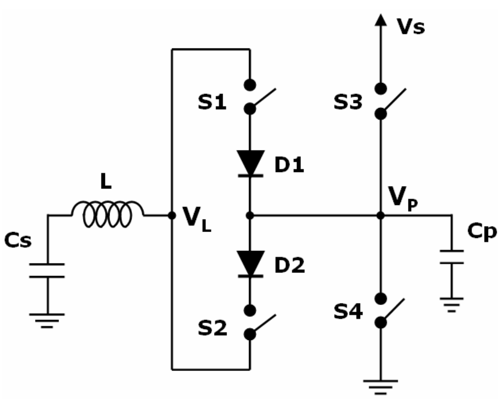


Fig. 7. Proposed circuit I.

Fig. 8 shows the driving characteristics of the proposed circuit. The free-resonant waveform level at V_L is located between Vs and the ground level. Since one side of the inductor is connected to the energy recovery capacitor (Cs), it is able to maintain the Vs/2 level. This is one difference between the two circuits. Accordingly, the proposed circuit does not need clamping diodes. As mentioned above, clamping diodes are needed only to protect the overshoot waveform when it exceeds the Vs or ground level. This method is thus named "RLC (resonant-level centering) driving."

There are some issues, however, that must be examined. One of these is the high resonant frequency for EMI, whose regulation range is usually between 30 MHz and 1 GHz. As shown in Fig. 8, the free-resonant frequency was about 8 MHz, which is out of the EMI range. Moreover, 8 MHz is a fundamental frequency, which does not have a harmonic frequency. Fig. 9 shows the results of the simulation of the conventional and proposed methods. The picture on the right (the proposed method) is shown to have better characteristics than the picture on the left (the conventional method). As such, it can be assumed that this freewheeling resonant frequency does not influence the EMI directly. Further, Fig. 10 shows the actual measurement results as well as the EMI level of the proposed circuit, which is lower and better than that of the conventional circuit.

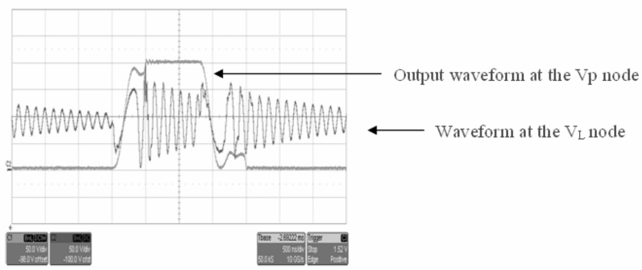


Fig. 8. Driving characteristics of the proposed circuit (output waveform @ V_P and V_L).

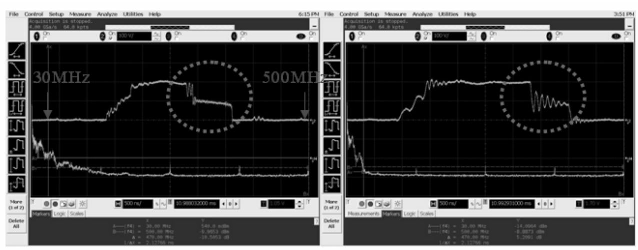
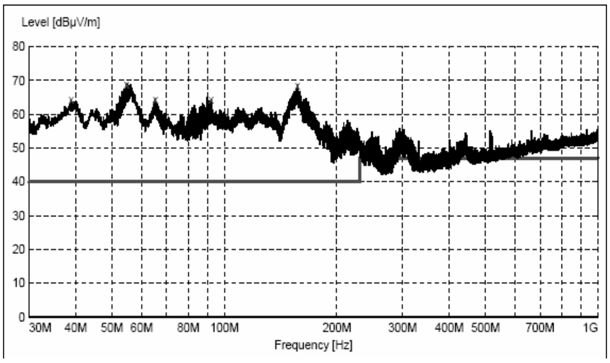
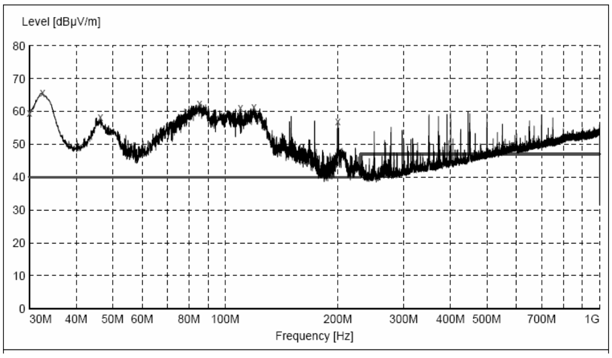


Fig. 9. Result of the simulation of the proposed method (100 V/div, 500 ns/div, 20 dBm/div).



(a) Conventional method



(b) Proposed method

Fig. 10. Result of the measurement of the proposed method.

The other issue is about the reliability of the device. Either way, the freewheeling current in the inductor can influence the other devices (S1, S2). This can cause heat problems or other kinds of problems. As such, a filtering circuit can be designed as a snubber. Fig. 11 shows an RC filtering circuit that absorbs the influencing frequency [Fig. 12]. The RC filter is actually for specific-frequency absorbing.

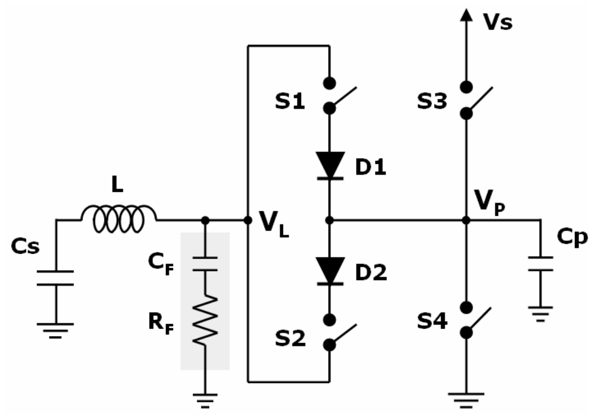


Fig. 11. Proposed circuit II.

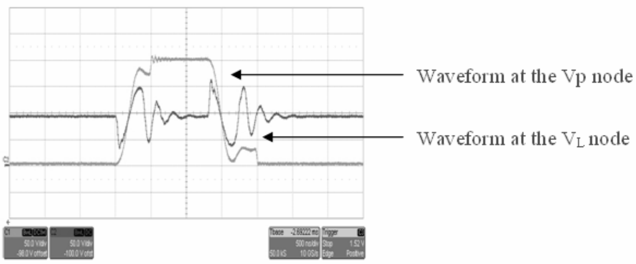


Fig. 12. Driving characteristics of the circuit with an RC filter (output waveform @ V_P and V_L).

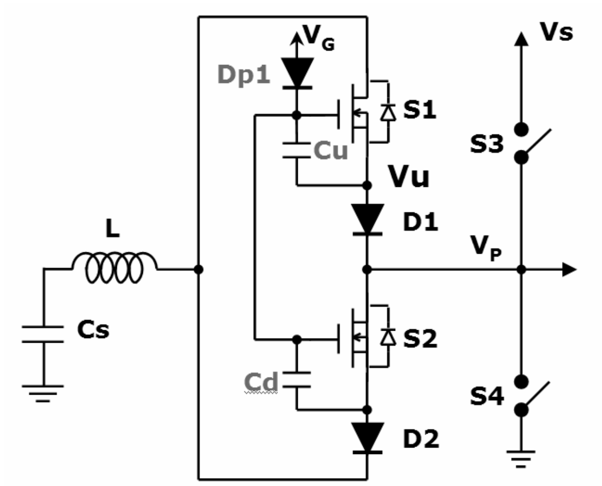


Fig. 13. Gate-driving in the proposed circuit.

As the inductor was moved in the proposed circuit, its gate driving is more reliable than that of the conventional circuit. Fig. 13 shows the new gate-driving circuit, which is more reliable than the conventional one. The bootstrap capacitors (Cu, Cd) were charged up at the same time (with S4 on), under the same conditions. The positions of the devices (S2, D2) were changed reciprocally, which is not possible in the conventional circuit without clamping. The proposed circuit has no problem with wider margins, however, so it can be said that it is more reliable.

2.3 Other Issues

Another advantage of the proposed circuit is its easy PCB layout and patterning. As the inductor was moved, the current pattern of the four major switches can be laid out on the same node (Vp). No difference was found in the simulation, and no difference can be seen in the block diagram. In the actual circuit design, however, there is a big advantage. If all of the switching devices will be designed on a chip or a module, the proposed circuit structure will be inevitable.

3. Results

A new, simpler circuit is proposed in this paper, whose inductor has been relocated and whose clamping diodes can be removed. The following are its other driving advantages:

1. Cost-effective design: The clamping diodes were removed.
2. It has safer gate-driving on the ER switching.
3. It is easier to get to the PCB layout design.

The clamping diodes were removed because the inductor was moved towards the energy recovery capacitor. If there were no clamping diodes in the conventional circuit, the freewheeling peak voltage of the inductor would surpass the sustain voltage and would proceed to go below the ground. In the proposed circuit, however, the peak voltage of the inductor always remains within a certain voltage range (0 V~Vs) because the other side of the inductor is bound to Vs/2 on the ER capacitor (Cs). Table 1 shows the results of the measurement of the voltage range of each device. No major differences were found between them.

As the inductor was moved in the proposed circuit, it will be easier to design the PCB on the output node. The four switches, which consists of the sustain/ER circuits, are combined at the same singular node. This has a profound effect on the PCB design for actual engineering and not for simulation. As such, the PCB area can be reduced and can be expected to be capable of more efficient driving.

The driving characteristics of the proposed circuit are the same as those of the conventional one. An RC filter has been installed on one side of the inductor to absorb the free resonance of the inductor. There is actually no need to absorb all the frequency ranges. This resonant frequency can be appropriately reduced with just a C filter.

Table 1. Voltage Ranges of the Devices.

	Conventional (V)	**Proposed (V)**
ER_UP Diode	207	205
ER_UP SW	119	125
ER_DN Diode	202	210
ER_DN SW	140	130

The efficiency and heat dissipation of the devices in the proposed circuit are not different from those in the conventional circuit as there were no changes in the current for the current path.

4. Conclusions

Theoretical energy recovery circuits have often been discussed rather than viewing them from the viewpoint of actual engineering. In this paper, some issues related to the conventional sustain-driving circuit were dealt with from the point of view of actual engineering. Consequently, a new circuit was suggested. Attempts to utilize such circuit and to deal with other issues from the point of view of actual engineering are expected.

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※ Parts of this work were presented in Proceedings of IMID 2008