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Reducing Electromagnetic Influence (EMI) by Power MOS Switching Control

A. Rani Sangeetha*, Tamilarasu S*

**Research Scholar, Department of Electronics, Bharathiar University, Coimbatore, India*

Abstract *-In order to reduce size and weight of power supply unit, high frequency operation is required. However, this higher frequency operation significantly increases switching loss and leads to lower efficiency. Soft switching techniques are key technologies to overcome this problem. A number of soft switching technologies have been proposed. However, some switches in a resonant converter are subjected to voltage and current stresses significantly higher than those in their conventional pulse width-modulated (PWM) counterparts. Although the switching losses are eliminated, the conduction loss increases significantly. In order to solve the problem, edge resonance operation is proposed. The voltage or current of the switches on this operation resonates at a moment of switching terms. Therefore, the voltage and current waveforms of the switches are almost square-wave like a PWM converter. As a result, conduction loss reduces in comparison with resonant converter.*

1. Introduction

The reduction of switching losses is the basis for higher switching frequencies which lead to a reduction of the size and weight of the passive components. The limitations in high power applications are mainly parasitic effects as stray inductance and reverse recovery behavior of the diodes. The overvoltage spike caused by the parasitic inductance will limit the turn off switching speed. The losses and the increased electromagnetic influence (EMI) caused by the reverse recovery behavior of the freewheeling diode is the drawback for increased turn on switching speed. In a first step, the parasitic inductance is reduced to a minimum to solve the issue with turn-off. In a second step are the turn on losses reduced. This is achieved with the utilization of the parasitic inductance for turn-on by keeping the low inductive turn-off behavior.

The third activity for a switching loss reduction is the introduction of a neutral point clamped inverter topology. Finally a special topology for paralleling MOSFET with IGBT is introduced to show the advanced prospects of the idea. The feasibility of the new concept is proven with a power module concept incorporating all the discussed arrangements.

2. Switching Losses

The power dissipation in power electronics is caused by conductive losses and switching losses. The conductive losses are defined by the forward voltage drop in the semiconductor.

The switching losses are dependent on

- Switching speed of the transistor
- Reverse recovery behavior of the diode
- Serial inductance
- Additional parasitic effects

Turn-On

In a system with inductive load (see Fig 1) is the freewheeling diode conducting at turn on and the output voltage equals the negative DC-bus voltage (DC-).

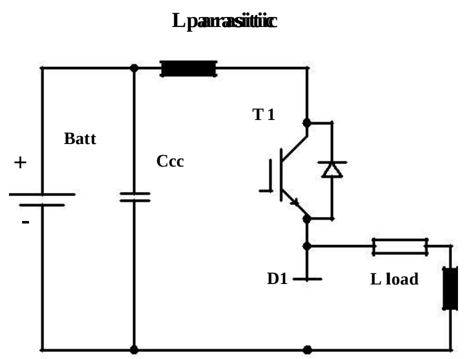

Fig 1 Switching circuit with inductive load

The transistor starts now to conduct. As soon the transistor takes over the complete output current, the output voltage will develop to the positive DC-bus voltage (DC+). The diode faces reverse voltage and will conduct in reverse direction. This will cause losses in the diode (EREC) and it will increase the current in the transistor. This current peak is often the root cause of EMI in the system. After the diode is completely recovered and blocking, the current in the transistor will fall back to the level of the output current. The turn-on process is now complete. An increased serial inductance with the transistor will reduce the turn on losses.

Turn-Off

At turn off will the voltage at the transistor develop up to the DC-bus voltage level and the diode will take over the output current. The overvoltage will cause additional losses and it endangers the transistor to be destroyed. The usage of fast transistors is limited on the inductance and the maximum current, as the voltage peak is dependent on the turn off speed. The stored energy in the serial inductance of the DC-input causes a voltage overshooting according.

3. Low Inductive Module Technology

With the new low inductive module technology we achieve:

- Fast and reliable turn-off of high current power modules
- Switching loss reduction (turn off)

The reduced voltage overshot at turn off allows the usage of fast components. The reduced inductance will not reduce the switching losses at turn-on. The turn-off losses will decrease but the turn-on losses of the transistor and the reverse recovery losses in the diode will increase even more. The efficiency of low inductive circuits will increase with the utilization of fast components. The goal of low turn on losses without increasing EMI requires ultra fast freewheeling diodes.

4. Unipolar Switching Modes

The switching operation of the unipolar circuit which uses the power MOSFET's as the switching device requires one switching device to be on continuously. While the other two switching devices are used to switch on and off in the switching period for controlling the value of load voltage. The unipolar switching mode has three disadvantages when compares with the limited unipolar switching mode. The unipolar circuit must to have introduced the blanking time between one switching device turn off and the other switching device turn on in the same leg to avoid cross-conduction. This will lead to be a problem of the reliability and the switching frequency is limited.

The unipolar circuit uses the two driver circuit for the turn on-off of the switching device that introduces the high cost and complexity. In addition, characteristic of this operating mode, there are two switching devices to be switched in the one switching period which causes to generate the conducted EMI and the switching loss more than the limited unipolar switching mode.

5. Limited Unipolar Switching Modes

The operating mode of the limited unipolar is one switching device to be on continuously, but only one switching device is operated on and off in the switching period to control the motor's voltage; that does not require the provision of the blanking time and it is more reliable. Due to the limited unipolar circuit it needs only one driver circuit which is simpler and lower cost. Otherwise in this circuit the number of the switching times in the switching period is 1/2 decrease so that the both conducted EMI and the switching loss will decrease.

6. Current Transient Circuit

Fig. 2 shows the schematic of the buck converter with transient current circuit. Fig. 3 shows the key waveforms of this converter. It differs from a conventional buck converter by possessing a transient current circuit consisting of two auxiliary switches (S_{a1}, S_{a2}), two diodes (D_{a1}, D_{a2}), an inductor (L_a), and a capacitor (C_a). Transient current circuit operate at two periods which auxiliary capacitor (C_a) is charged or discharge. Other operation is same as conventional buck converter.

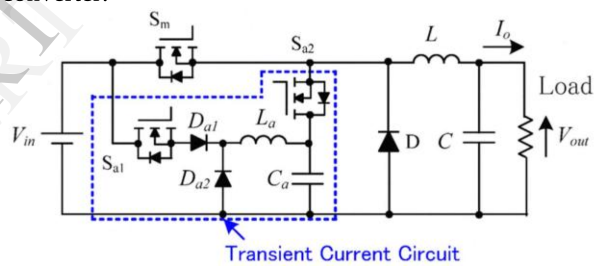

Fig. 2 Buck converter with transient current circuit

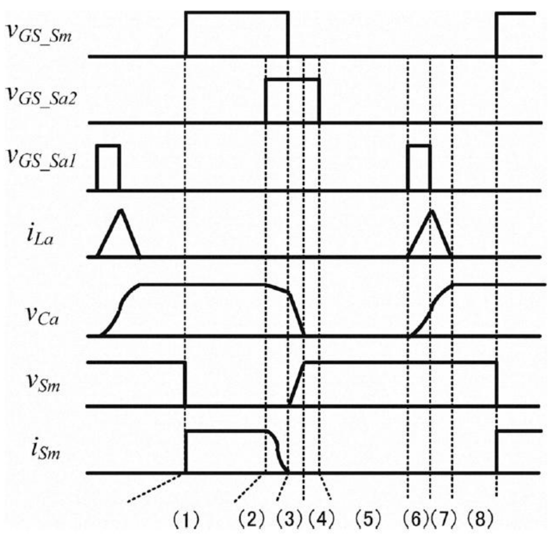

Fig. 3 Waveforms

From Fig. 3, the proposed circuit has eight peration states.

(l): S_m is turned on, and D is turned off. During this state, S_m is turned on. This state is same as conventional buck converter. Because S_{al} and S_{a2} are turned off, voltage of C_a, charged in advance is held.

(2), (3), (4): At these states, S_{a2} is turned on. Transient current circuit operates originally. This operation achieves zero-current switching, and reduces switching loss. Besides, suppresses turn off surge voltage of S_m.

(5): S_{a2} is turned off. Transient current circuit is separated. This state is same as conventional buck converter.

(6), (7): S_{al} or D_{a2} is turned on. Transient current circuit operates originally. This operation aims at having charged Ca until required voltage

(8): Operation of transient current circuit finishes, and circuit is separated. Operation state becomes same as state 5. From Fig. 3, D is turned on between state 5 and state 8. Therefore, load current have no effect even if transient current circuit operates at state 6 or 7. Thereby, if the period between state 2 and state 4 is enough short compared with switching pitch, input-output characteristic of converter is almost same as conventional.

7. Conclusion

The experimental result of the improved limited unipolar circuit comparing with the unipolar circuit, the conducted EMI and the switching loss are greatly improved by using the appreciated gate driver and the auxiliary current circuits. The low inductive module concept ensures the fast and reliable turn-off in high current power modules and reduces the voltage overshot. The power module setup with very low internal parasitic elements it is able to utilize the external stray inductance for a reduction of switching losses without investing in expensive high-speed semiconductor technology. The asymmetrical inductance leads to lower switching losses, reduced EMC (Electromagnetic Compatibility) and minimized effort for the inverter mechanics. Low inductive bus bars are not needed anymore. A flexible low cost cable connection in the DC link can be used. The increased serial inductance will just cause additional reduction of the turn-on losses.

8. Reference

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