펄스 방전을 위한 고전압 스위치 설계

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Design of High Voltage Switch for Pulse Discharging

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ABSTRACT

Presented in this paper is the design of a high voltage switch module made up of MOSFETs, pulse transformers and their gate driver circuits compactly fitted onto a single PCB module. The ease by which the switch modules can be configured (series stacking and/or parallel stacking) to meet future load variations allows for flexible operation of this design. In addition, the detailed implementation of the gate driver circuit for reliable and easier switch synchronization is also described in this paper. The stored energy in the capacitor bank of a 15kV, 4.5kJ/s peak power capacitor charger was discharged using the developed high voltage switch, and by experimental results, the operation of the proposed circuit was verified to be effectively used as a switch for pulse discharging.

1. INTRODUCTION

Conventionally, thyratrons and other gaseous discharge switches have been utilized in pulsed power systems such as high voltage pulse generators, high voltage source inverters, etc. However, for pulsed power applications with low jitter and high repetition rates, these switches have the disadvantages of limited lifetime, limited repetition rate, and heavy driving circuitry. Recent studies have focused on the use of Semiconductor switches in pulsed power systems owing to their long life, simple driving circuitry and faster switching transient characteristics [1].

For higher voltage and current applications, series and/or parallel stacking of these switches are necessary in order to handle high voltages and current levels associated with the discharge energy. Parallel stacking operation of MOSFETs and IGBTs with the aim of increasing current rating is relatively easier due to their positive temperature coefficient. However, for series stacking operation, the voltage distribution across each switch during turn-off transition must be balanced. Secondly, the gate signals must be synchronized to turn each switch on/off simultaneously.

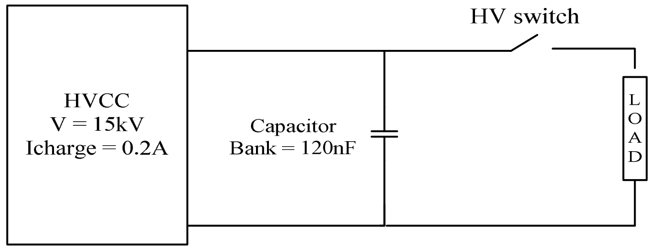

Fig 1. Block diagram of high voltage switch for pulse discharging

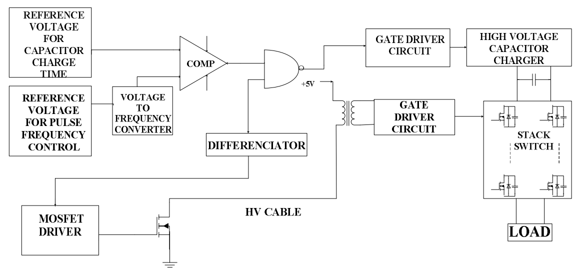

Fig 2. Control scheme of the high voltage switch

Synchronization failure would lead to the avalanche breakdown of all the switches in the stack.

Based on the aforementioned considerations, a simple switch module of MOSFET pair, consisting of pulse transformers and their gate driving circuitry is developed to discharge the energy stored in the capacitor bank of a capacitor charger.

2. ANALYSIS AND OPERATION OF THE PROPOSED DESIGN

The conceptual block diagram of the high voltage switch including the proposed multi-turn secondary LCC capacitor charger operating in above-resonant continuous conduction mode (CCM) is shown in Fig. 1.The capacitor bank is charged by an adjustable input voltage source, and a 20us pulse drives the gate of the switch connected between the load and the capacitor. Energy is discharged through the switch for a period set by adjusting parameters of the switch gate driver circuit.

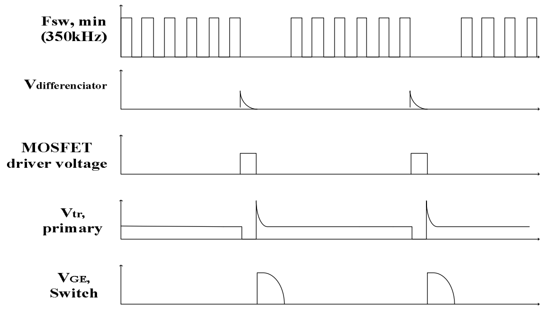

Fig 3. Control signals of high voltage switch

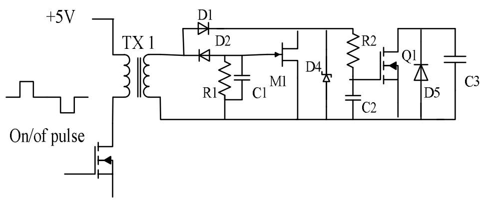

Fig 4. Circuit drawing of Gate driver

2.1 Control of High Voltage Switches and Capacitor Charger

Shown in Fig 2 is the control scheme of the high voltage switches as well as the capacitor charger. Turn-on voltage spike of the MOSFET is transferred through a power loop, serving as the primary side of the gate driver for operation of the switches [2]. The associated control signals are depicted in Fig 3.

2.2 Gate Driver Circuit

The circuit diagram of the gate driver for driving the stack switches is show in Fig 4. The operational principle can be explained as follow.

Mode 1: Turn on pulse is applied to the transformer, and D2 blocks current flow thereby turning M1 off. D1 conducts current to charge capacitor C2 through R2. The charged voltage level is clamped by zener D4 even if the turn on pulse voltage level is different for each driver circuit.

Mode 2: There is no pulse applied to the transformer, and the capacitor C2 maintains its charged voltage level (hold on mode)

Mode 3: Negative pulse is applied to TX1 in the turn off mode. M1 is turned on through R1 and C1, thus providing a discharging path for C2.

Regulating R1 and C1 values effectively ensure the full discharge of the capacitor bank energy before the next capacitor bank charging cycle begins

3. EXPERIMENTAL RESULTS

The controller circuits of the designed stack switch was first operated without any input voltage to the capacitor charger, and the control signals were recorded. As shown in Fig 5., the pulse repetitive function of the designed system can be verified. The IGBT switches are turned on after a

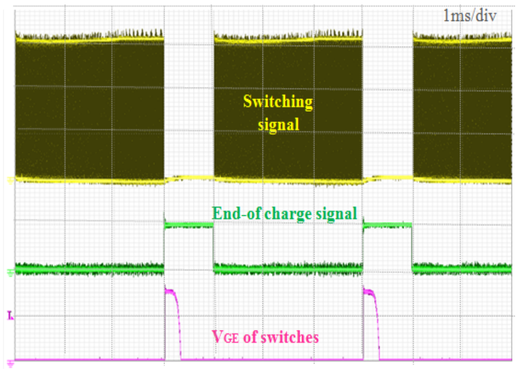

Fig 5. Experimental waveforms showing pulse repetitive function

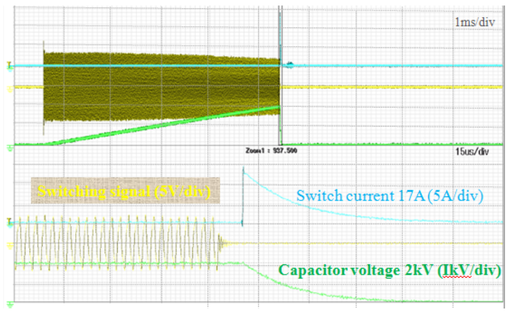

Fig 6. Experimental waveforms at 130Ω load operation (Vin = 50V)

20us pulse from the MOSFET driver. Also the gate-emitter voltage of the switches shows the conduction of current by the stacked switches after every switching period..

4. CONCLUSION

In this paper, the design and implementation of a high voltage switch used to discharge stored energy in the capacitor bank of a capacitor charger are described. The experimental result of the operation of the gate driver circuit in ensuring complete discharge of the capacitor bank energy through the switch proves the reliability and superiority of the design. Future work would focus on additional stacking of the switches to operate the capacitor charger at its rated conditions.

REFERENCES

[1] Millan J.; Godigon P.; Perpina X.; Perez-Tomas A.; Rebollo J., “A survey of wide bandgap power semiconductor devices,” IEEE Transactions on Power Electronics, 2014, pp 2155-2163.

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