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Research paper

Voltage Equalization Technique of Switch Series Circuit Using Clamp Circuit for High Pressure Switching

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Abstract

Background/Objectives: In recent years, in order to revitalize the energy conversion paradigm for energy efficiency, researches on large capacity energy transmission using DC have been actively carried out. In the DC power transmission system, LVDC, MVDC, and HVDC are applied according to the power transmission capacity.
Methods/Statistical analysis: The higher the power transmission capacity, the higher the transmission voltage becomes. Most of the DC voltage change is made by a static power converter using a semiconductor switch element. A power converter using a semiconductor switch element is difficult to increase in pressure due to the voltage strength of the semiconductor element.
Findings: In this paper, we propose a new topology that can switch high voltage by using a clamp circuit to each switching device connected in series to solve the balancing problem of voltage distribution when a switching device is configured in series for high voltage switching. The validity of the proposed high - pressure switching topology is verified by applying it to the reduced - pressure converter.
Improvements/Applications: The clamp circuit can limit the voltage in the transient state that occurs when the switch circuit is turned on and off, which is very helpful for stable switching operation. Therefore, this result is expected to be useful for the high voltage of DC / DC converter in the future.

Keywords: *High Voltage Switching, LVDC, Clamp Circuit, DC Power Transmission system, DC / DC converter*

1. Introduction

As global warming and environmental problems become global issues, there is a growing interest in renewable energy, which can generate DC power such as solar cells and fuel cells[1- 3]. In recent years, studies have been actively conducted on large capacity energy transmission using DC to efficiently transfer energy, and an important factor for efficient energy transmission is high voltage of transmission voltage[4, 5].Typical direct current energy transfer is classified into LVDC, MVDC, and HVDC depending on the voltage. The higher the power transmission capacity, the higher the transmission voltage is. Most of the direct current transmission is made by a static power converter using a semiconductor switch element. In order to increase the voltage, it is necessary to increase the voltage of the switch element. However, the dielectric strength of the switch elements currently on the market is much lower than the DC transmission voltage, which is a major obstacle to high voltage DC transmission. In order to solve the high - voltage switching problem, which is indispensable for the high - voltage DC transmission and distribution, a high voltage switching method using a switching device in series has been actively studied. However, in the high-voltage switching method using a switch series, the switching element voltage is not uniformly applied to the effect of the switching element parasitic capacitor, which causes a drawback that the switching voltage utilization rate is reduced[6, 7].Therefore, in this paper, we propose a new topology that uses a clamp circuit for each switching element to increase the switch voltage utilization in a series circuit of switching elements for high-voltage switching. The validity of the proposed high - pressure switching topology is verified by applying it to a reduced - pressure converter.

2. High-Voltage Switching Technique

2.1. Topology for High-Voltage Switching

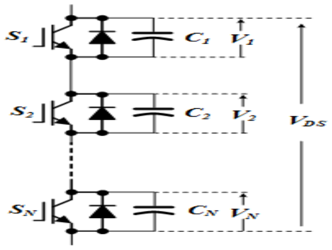

Figure 1: Switching device serial method for high voltage

Generally, as shown in figure 1, a low-voltage switch element is connected in series for high-voltage switching. The drain source voltage of each switch is determined by the gate signal and the drain-source capacitor capacitance of the IGBT. In this section, the gate signal is assumed to be the same, and the voltage due to the drain-source-side capacitor capacitance difference is analyzed[8-10]. As shown in figure 1, the parasitic capacitors are connected in series in a structure in which switching elements are connected in series. The total capacitance of each capacitor is given by equation (1).

$$C_T = \frac{1}{\sum_{k=1}^{N}\frac{1}{C_k}} \quad (1)$$

Therefore, the voltage applied to the switch when each switch-off is given by the parasitic capacitor capacity of each switch as follows.

$$V_k = \frac{1}{C_x} C_T V_{DS} \quad (2)$$

From the equation (2), the voltage applied at the time of switch-off becomes inversely proportional to the parasitic capacitance of each switch element. If the parasitic capacitor capacity of each switch element is equal to C_{ave}, the following equations (1) to (3) are given. When the switch is off, the voltage applied to each switch element becomes the same voltage as shown in equation (4), and the voltage is appropriately distributed.

$$C_T = \frac{C_{ave}}{N} \quad (3)$$

$$V_k = \frac{V_{DS}}{N} \quad (4)$$

However, the capacitance of the parasitic capacitors of the switch element is different for each switch. In this case, the voltage applied to the capacitor is different as shown in equation (2). Figure 2 shows the voltage ratio applied when switching off according to the parasitic capacitance difference based on equation (2).As shown in figure 2, when the parasitic capacitor capacity is large, there is no problem in the switch operation because the applied voltage is small. However, when the parasitic capacitor capacity is small, the applied voltage is large, and the switch may be burned out due to the over -voltage during the switch operation. Therefore, in general, it is designed to be about 70[%] of the switch voltage strength, which causes a disadvantage that the number of serial switches increases for high voltage switching[11-13].

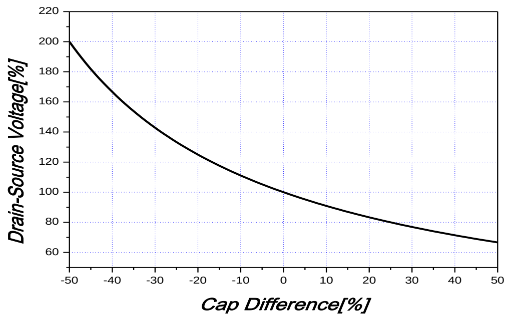

Figure 2: Applied voltage according to parasitic capacitance difference

2.2. The Proposed High-Voltage Switching Topology

For high-voltage switching, when a low-voltage switching device is connected in series, the voltage applied when switching off is determined by the parasitic capacitance of the switching device. However, it is very difficult to make the same value in the semiconductor manufacturing process. In addition, the method of adding a capacitor to the outside in the case of the series circuit configuration is also different from each other when the switching device is implemented, and the reality is not enough. In this paper, the proposed topology that can limit the voltage applied to each switching element by the clamp circuit when switch off is shown in figure 3.

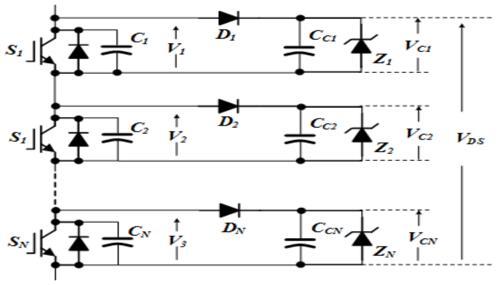

Figure 3: The Proposed high-pressure switching topology

When the clamp circuit is constructed as shown in figure 3, the voltage determining element becomes the breakdown voltage of the Zener diode. In this paper, this voltage is set to about 120 [%] of the voltage at the equipotential voltage distribution shown in equation (4). Therefore, the voltage of each switch element connected in series cannot exceed the voltage of equation (5).

$$V_Z \neq \frac{V_{DS}}{N} * 1.2 \quad (5)$$

In addition, since the voltage is limited in the clamp circuit, there is an advantage that the voltage of other switches connected in series can be reduced. Therefore, it is possible to perform stable switching due to voltage equalization of each switch. In this paper, the proposed switching circuit is applied to the buck converter by the proposed clamp circuit to verify its validity. Figure 4 shows a reduced-pressure converter with a series switching structure. Figure 4(a) shows a conventional buck converter circuit and figure 4(b) shows a buck converter circuit with the clamp circuit proposed in this paper. The number of series switching elements is determined by the driving voltage and the insulation strength of the switching element.

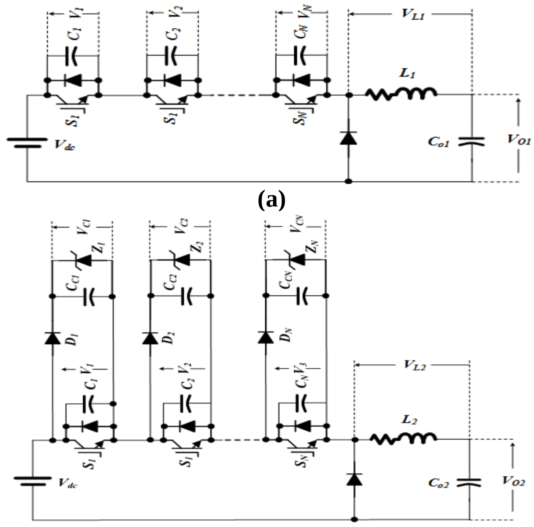

Figure 4: Buck converter with serial switching structure

2.3. Feasibility Analysis of the Proposed Topology

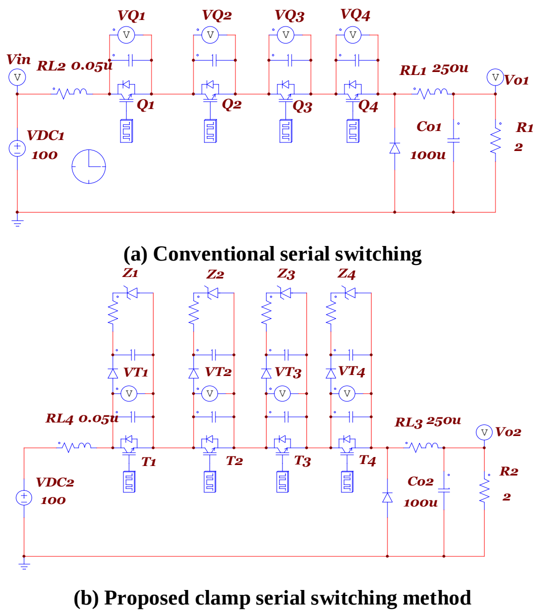

Figure 5: Circuit serial switching scheme

In order to analyze the validity of the proposed clamping circuit, the conventional method and the proposed method buck converter circuit using the four switching serials circuits are constructed as shown in figure 5. Figure 6 shows the waveforms of the power circuit of figure 5 when input voltage 100 [V] is used and parasitic capacitor capacitances of the switching elements are set to 100, 150, 200, 250 [nF] and the duty ratio is 0.5.

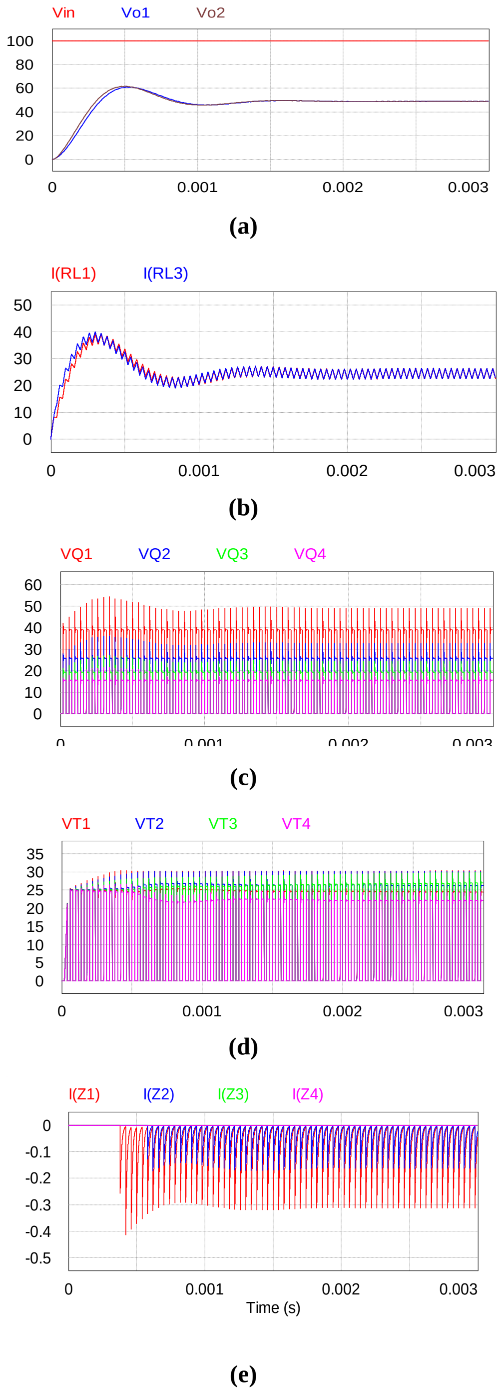

Figure 6: Dynamic characteristics results of serial switching method

3. Simulation

As shown in figure 6(a), it can be seen that the two converters output the same voltage at an output voltage of 50[V]. In the initial stage of the output voltage, the voltage rise rate of the proposed converter is fast due to the charging effect of the clamp circuit. When the switch-off, it can be seen that the voltage applied to each switch is different from that of the conventional scheme figure 6(b) by applying a maximum of 55 [V]. However, in the proposed scheme figure 6(c), it can be seen that a similar voltage is applied while the voltage of the switching device having a parasitic capacitance of 100 and 150 [uF] is limited to a maximum voltage of 30 [V].Figure 6(d) shows the current of the zener diode. It shows that the current is zero at the switching element side 200, 250 [uF] which is not clamped, and it forms low current at the switching element of 100, 150 [uF]. Figure 7 shows waveforms for analyzing the voltage uniformity results of serial switching method. Figure 7(a) shows that the overvoltage voltage of the switch with 100, 150, 200, and 250 [nF] capacitors is 48[V], the steady-state voltages were 39, 26, 19, and 16, respectively. Figure 7(b) shows that the transient state voltage of the switch of 100, 150, 200, 250 [nF] switch is 30 [V] maximum and the steady-state voltages were 25, 26, 27, and 22, respectively. Since the transient state voltage is affected by the line inductors of the buck converter, it is different according to the configuration of the power supply. Therefore, in the case of considering the steady state only, the switching system having the internal voltage of 39[V], Since the proposed method can use a switching device with a breakdown voltage of 27[V], the conventional method requires a switching device having a high breakdown voltage of 144 [%]. Figure 7(c) shows the waveform of the voltage reduction effect when the proposed method is used for the switching element voltage of 100 [nF], which is the maximum voltage applied in the conventional method, and it is changed from the original 39 [V] to 25 [V]. It can be seen that the voltage applied to the switch is greatly reduced.

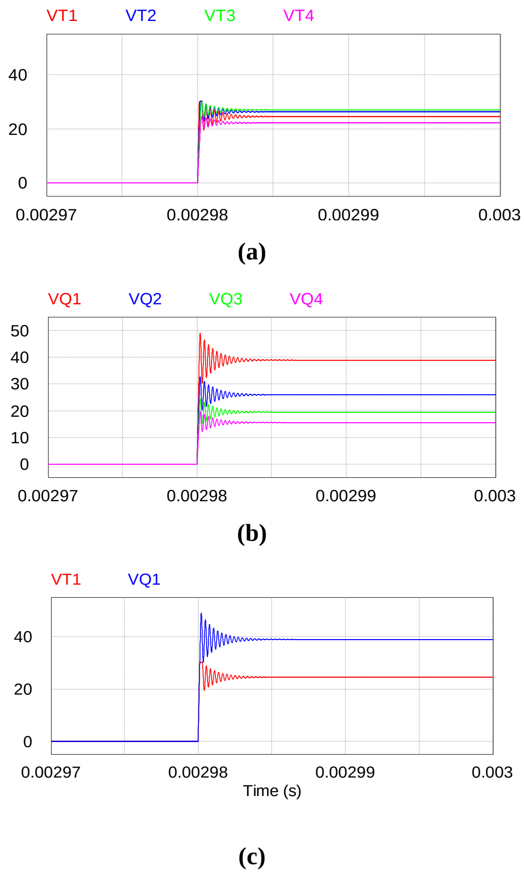

Figure 7: Voltage uniformity result of serial switching method

4. Conclusion

This paper is proposed serial switch architecture with clamp circuit capable of high voltage switching for efficient power transmission of DC power transmission system. In the proposed method, since the switch voltage does not exceed the set voltage of the clamp circuit, the stability against the switch insulation voltage during the switch operation is ensured. Therefore, it is verified that high voltage switching is possible with a small number of series because the voltage utilization rate of the switch series circuit for high voltage can be higher than that of the conventional method. As a result of applying the proposed method to 4 - series decompression converter, the voltage reduction effect is 30% compared to the conventional method. In addition, the clamp circuit can limit the voltage in the transient state that occurs when the switch circuit is turned on and off, which is very helpful for stable switching operation. Therefore, this result is expected to be useful for the high voltage of DC / DC converter in the future.

Acknowledgment

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