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Diode-Clamped 4-레벨 인버터 및 컨버터를 위한 Undeland 및 McMurray 스너버를 결합한 새로운 스너버 회로

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A New Snubber Circuit Combined Undeland and McMurray Snubber for Diode-Clamped Four-level Inverter and Converter

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ABSTRACT

지금까지 멀티레벨 컨버터 및 인버터에 적용되어온 기존의 스너버는 턴온 스너버로 RLD 스너버, 턴오프 스너버로 RCD 스너버를 사용하였으나, 이들 RCD/RLD는 많은 소자를 필요로 하며, 스위칭시의 overvoltage와 스너버 손실이 큰 단점을 지니고 있다. 이와 같은 문제점을 해결하기 위해 본 논문에서는 Diode-clamped 4-레벨 컨버터 및 인버터를 위한 새로운 스너버를 제안한다. 새로 제안하는 스너버는 Basic snubber unit로 특성이 좋은 Undeland 스너버와 수정된 RCD/RLD 스너버를 사용한다. 따라서 제안하는 스너버는, Undeland 스너버와 McMuray 스너버가 갖고 있는 특성, 즉 사용소자의 수의 감소, 과전압의 감소, 스너버 손실의 감소 등과 좋은 특성을 지니고 있다. 또한 본 논문에서 제안하는 4-레벨 컨버터 및 인버터를 위한 스너버 회로를 구성하는 방법은 다른 레벨의 멀티레벨 컨버터 및 인버터에도 적용 가능하다.

1. Introduction

Recently the multilevel inverter and converter have drawn tremendous interest for high voltage and high power applications.[1]-[7] The general structure of the multilevel inverter and converter is to synthesize sinusoidal voltage waveforms from several levels of voltages typically obtained from capacitor voltage sources. As the number of levels increase, the synthesized output waveform adds more steps, producing staircase waveform which approaches the sinusoidal wave with minimum harmonic distortion. More levels also mean that higher DC link voltage than voltage rating of device itself can be handled by series device without device voltage sharing problem and without the use of bulky and heavy transformer for multiple connections. Until now, for multilevel inverter and converter, conventional RCD and RLD snubber as turn-off snubber and turn-on snubber, respectively, have been used widely and exclusively

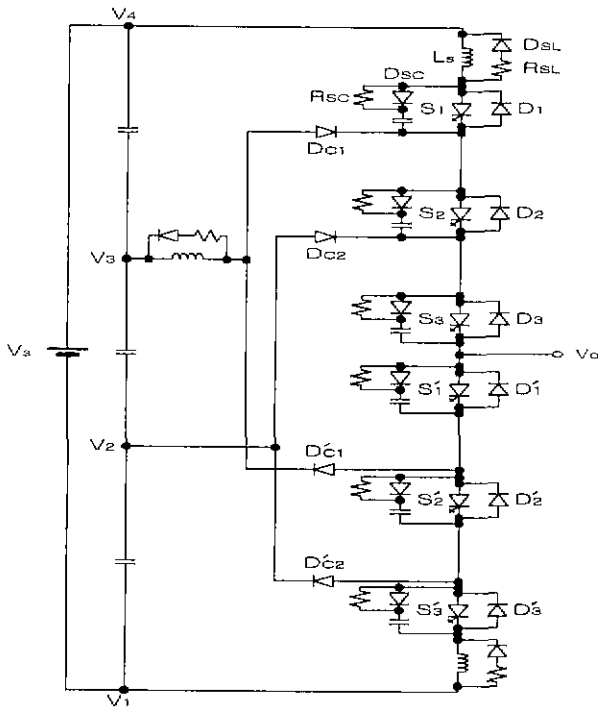

Fig. 1 4-level GTO inverter with conventional RCD and RLD snubber

because it is easy to apply to multilevel inverter and converter as shown in Fig. 1.[6]-[7] But this kind of snubbers need separate snubber circuit unit for each GTO which are composed of turn-off capacitor, turn-on inductor, resistors, and diodes. Thus the total number of snubber components become considerably high and the circuit becomes complex, thus resulting in high costly multilevel inverter and converter. And since the large amount of snubber energy is fully dissipated in snubber resistor, system power loss become high, which causes low system efficiency. Furthermore, during turn-off process, the overvoltage of GTO can be very high, usually about 1.8 times higher than DC link voltage because the turn-off capacitor is not large enough to absorb the stored

inductor energy In addition, unbalance problem of the overvoltage, which results from combination of multilevel structure and RCD/RLD snubbers, makes voltage stresses of the switching devices worse.[7]

To overcome the above-mentioned disadvantages of RCD/RLD snubber for multilevel inverter and converter, a new snubber topology suitable for multilevel inverter and converter, especially for 4-level inverter and converter, are proposed. The proposed snubber utilizes Undeland snubber and McMurray efficient snubber as basic snubber unit and can be regarded as a generalized combined Undeland and McMurray snubber for 4-level structure converter. Its good features include fewer number of component, improved efficiency due to low snubber loss, capability of clamping overvoltage across main switching device, and no unbalance problem of blocking voltage. This paper also explains in detail how to construct a snubber circuit for 4-level inverter and converter.

2. Proposed Snubber for 4-level Inverter and Converter

An n-level multilevel inverter typically consists of n-1 capacitors on the DC bus and produces n-levels of the phase voltage. Fig. 2(a) shows one pole of four-level inverter in which the DC bus consists of three capacitors, C_1, C_2, and C_3. For a DC bus voltage V_S, the voltage across each capacitor is $V_S/3$ and each device voltage stress will be limited to one capacitor voltage level, $V_S/3$, through clamping diodes. Table 1 lists the voltage levels and their corresponding states. State condition 1 means the switch is on, and 0 is off. There exists three complementary switch pairs in each phase The complementary switch pair is defined such that turning on one of the pair switches excludes the other from being turned on. In case of four-level inverter, the three complementary pairs are (S_1, S_1'), (S_2, S_2'), and (S_3, S_3') which, respectively, correspond to each level change, that is, between V_4 and V_3, V_3 occur and V_2, and V_2 and V_1. Notice that the level changes only between adjacent levels. When investigating all level changes, we can find the operating part of circuit during each level change to converge to equivalent two level inverter, which is composed of complementary pair switches and corresponding clamping diodes.

Consider level changes between V_3 and V_2, as an example, shown in Fig. 2. The corresponding complementary pair is (S_2, S_2'). If S_2 is on and S_2' is off, output level is V_3. Conversely, If S_2 is off and S_2' is on, output level is V_2. During these level changes the operating components of four-level inverter can be drawn with thick line as shown in Fig. 2(a). The thick-lined part of the circuit can be transformed into Fig. 2(b) and can also be redrawn as Fig. 2(c) since switches S_3 and S_1' are always turned on irrespective of on/off condition of S_2 and S_2'. Fig. 2(c) shows that the operating part of circuit is equiv-

Table 1 Four-level inverter voltage levels and corresponding switch states

Output	Switch State (1 : ON, 0 : OFF)					
V_O	S_1	S_2	S_3	S_1'	S_2'	S_3'
$V_4=V_S$	1	1	1	0	0	0
$V_3=2V_S/3$	0	1	1	1	0	0
$V_2=V_S/3$	0	0	1	1	1	0
$V_1=0$	0	0	0	1	1	1

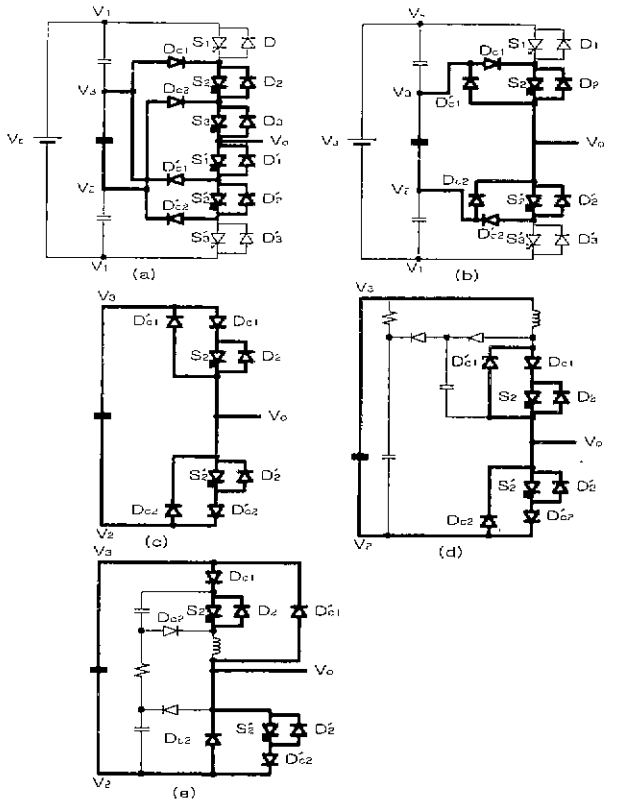

Fig. 2 Derivation of the proposed snubber for 4-level inverter (a)the operating part of circuit(thi-ck line) during level changes between V3 and V2 , (b) Redrawn circuit of (a), (c)Equivalent two-level inverter, (d)Equivalent circuit with Undeland basic snubber unit, (e)with McMurray basic snubber unit

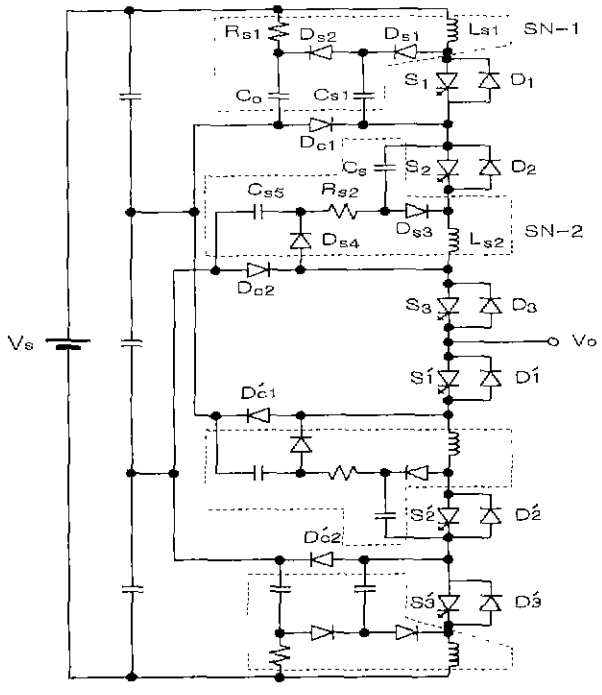

Fig. 3 4-level inverter with the proposed snubber(within the dotted line)

alent to the conventional two-level voltage source inverter. It follows that for the equivalent two-level inverter related to switching devices (S_2, S_2'), the basic snubber unit which have been used in two-level inverter can be applied as shown in Fig. 2(d) and 2(e) in case of Undeland snubber and McMurray snubber as a basic snubber, respectively.

In the same way, all the equivalent-two-level inverter corresponding to each level change, that is, each complementary pair in multilevel inverter can be derived, and the same basic snubber units can apply to them. So, we can obtain the proposed snubber circuit for four-level inverter as shown in Fig. 3. When using the same principle, a generalized snubber circuit for any multilevel inverter and converter can be achieved. The generalized snubber has the same good features as the basic snubber unit. In this paper since we use the Undeland snubber and McMurray efficient snubber as the basic snubber unit, the characteristics of the generalized snubber are such as fewer number of component, improved efficiency due to low loss snubber, capability of clamping overvoltage across main switching device and easy arrangements and mounting of snubber circuit. Furthermore thanks to the snubber structure, the generalized snubber has no unbalance problem of overvoltage unlike RCD/RLD snubber, thus resulting in equal voltage stress to all main switching devices except clamping diodes.

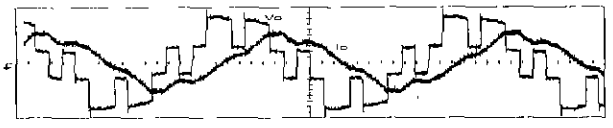

Fig. 4 overall output voltage v_o and current i_o waveforms [100v/div, 50A/div, 5msec/div]

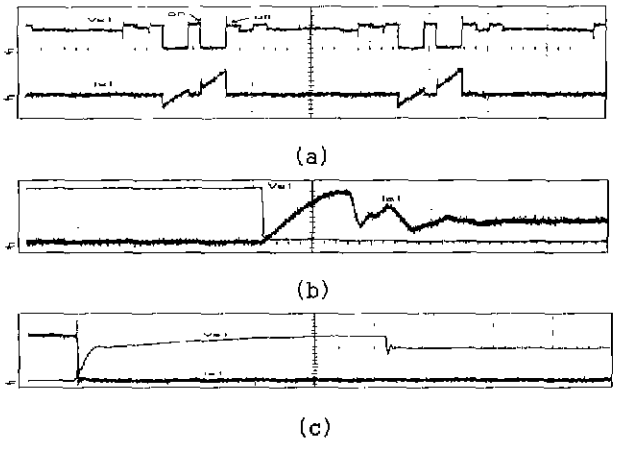

Fig. 5 (a) measured voltage v_{S_1} and current i_{S_1} of switches S_1[100v/div, 50A/div, 5msec/div] (b) their zoomed waveforms during turn-on inter-val and (c) during turn-off interval [50v/div, 20A/div, 10μsec/div]

3. Experimental Results

In order to verify the operation of the proposed snubber circuit, one pole of 4-level inverter was properly implemented with rated power 7.5[kw] and output current 50[A]. The prototype inverter is controlled through triangular waveform carrier-based PWM operation with carrier frequency 250[Hz]. The inverter with the proposed snubber circuit utilizes IXYS IGBT MII(MID, MDI)100-12A3 of current rating 135[A] for main switches S_1-S'_3 and clamp diodes D_{C1}-D'_{C2}, IXYS DSEI 2×61 for snubber diodes, ferrite core inductor of 25[μH] for snubber inductor L_S, and polypropylene capacitor of 1[μF], 400[v] for snubber capacitor C_S, polypropylene capacitor of 40[μF], 400[v] for snubber capacitor C_O, snubber resistors R_{S1} 4.7[Ω] and R_{S2} 0.5[Ω]. The switching devices IGBT as main switches are used to check only the operation of the proposed snubber circuit.

Fig. 4 shows overall output voltage v_o and current i_o waveforms. Fig. 5 shows the measured voltage v_{S_1} and current i_{S_1} of switches S_1, their

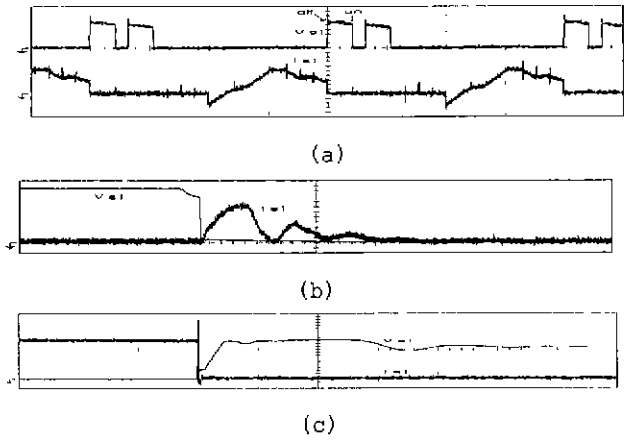

Fig. 6 (a) measured voltage v_{S_1} and i_{S_1} current of switches S_1 [100v/div, 50A/div, 5msec/div] (b) their zoomed waveforms during turn-on interval [50v/div, 10A/div, 10μsec/div] and (c) during turn-off interval [50v/div, 10A/div, 20μsec/div]

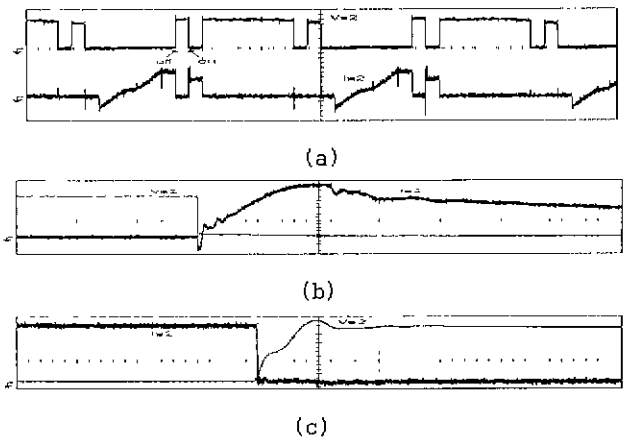

Fig. 7 (a) measured voltage v_{S_2}, and current i_{S_2} of switches S_2[100v/div, 50A/div, 5msec/div], (b) their zoomed waveforms during turn-on interval and (c) during turn-off interval [50v/div, 20A/div, 10μsec/div]

zoomed waveforms during turn-on interval and turn-off interval. Fig. 6 shows the measured voltage v_{S_1} and i_{S_1} current of switches S_1 and their zoomed waveforms during turn-on and turn-off intervals. It shows that the proposed snubber results in the good waveforms around the main switches S_1 and S_1 in terms of limiting the di/dt and dv/dt values and reducing switching losses. Since the snubber for the main switches S_1 and S_1 is similar to Undeland snubber, the measured results are as good as those of Undeland snubber.

Fig. 7 shows the measured voltage v_{S_2} and current i_{S_2} of switches S_2, and their zoomed waveform during turn-on and turn-off intervals. It proves that the proposed snubber provides S_2 and D_{C2} the good di/dt and dv/dt protections, reducing switching losses. Since the snubber for the main switches S_1 and S_1 is similar to McMurray snubber, the measured results are as good as those of McMurray snubber.

4. Conclusion

This paper proposes a new efficient snubber circuit for 4-level inverter and converter. The snubber circuit makes use of Undeland snubber and McMurray snubber as basic snubber unit and can be regarded as a generalized combined Undeland snubber and McMurray snubber. The proposed snubber keeps such good features as fewer number of component, improved efficiency due to low snubber loss, capability of clamping overvoltage across main switching device and no unbalance problem of blocking voltage. Furthermore, the proposed concept of constructing a snubber circuit for 4-level inverter and converter can apply to any level of multilevel converters easily.

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