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멀티레벨 PWM ac/dc 컨버터의 향상된 단락보호기법 해석

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Analysis of An Improved Short-circuit Protection for Multilevel PWM ac/dc Converter

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ABSTRACT

This paper describes an improved short-circuit protection for a multilevel ac/dc power converter. The output dc power of the proposed converter can be disconnected from the load within several hundred microseconds at the instant of short-circuit fault. Once the fault has been cleared the dc power is reapplied to the load. The rising time of the dc load voltage is as small as several hundred microseconds, and there is no overshoot of the dc voltage because the dc output capacitors hold undischarged state. Therefore, the proposed converter can be used for a power supply, which requires a rapid disconnection of the load from the power supply in the case of a short circuit, as well as a rapid connection the load to the power supply after the clearance of the short circuit condition.

1. Introduction

An ac/dc power converter with special load such as an ion source requires excellent protective function at the time of load fault besides a precise regulation performance. The converter is different from the conventional power supply, its load - ion source will experience frequent spark downs. To protect both the ion source and the converter from the source short-circuit current, some methods of diverting current from the source and disconnecting the source from the accel power supply are necessary.

Many efforts have been made to satisfy the above requirements. At first, to obtain a high speed switching and protective function at the time of load fault, a tetrode was used as a switching element. GTO thyristors were used as a dc side switching element to overcome some problems of a tetrode. High voltage power supplies without dc side GTO switch were proposed to improve the performance [1,2].

Recently, multilevel PWM converters have been proposed as one of the practical solutions in high voltage and high power applications [3]. To obtain a high speed switching performance at the time of load fault, modified boost type multilevel converter was proposed [4,5].

This paper describes a new PWM rectifier suitable for a load with frequent short-circuit to improve the performance of the output short-circuit protection. The proposed circuit operation and characteristics are described, analysed, and simulated.

2. Operating Principle of the Proposed Circuit

2.1 Proposed circuit diagram

Fig. 1 shows the generalized multilevel ac/dc converter of the proposed scheme. The circuit diagram is basically similar to that of the conventional multilevel converter. Switches Sa, Sb, and Sc are inserted in the ac input side. Each filter capacitor of the conventional multilevel converter is replaced with a series connected switch (So1 ~ Son) and capacitor (C1 ~ Cn), and one switch Sdc is inserted in the positive dc side. A resistor Rdc is connected to the terminals of collector and emitter of the switches Sdc and Sol, respectively.

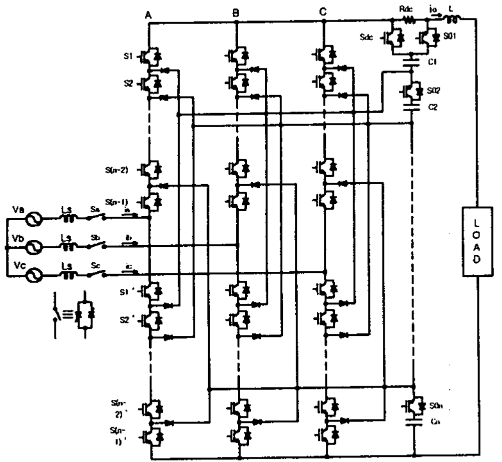


Fig. 1 Multilevel ac/dc converter of the proposed scheme

2.2 Operating principle

To simplify the explanation of the proposed circuit operation 2-level ac/dc converter is shown in Fig. 2. The basic operating principle of the converter in Fig. 2 is the same as that in Fig. 1. In normal operating mode, all the auxiliary switches of Sa, Sb, Sc, Sdc, and So keep on state while the main switches are turned on/off according to the generated PWM signals from a controller. The switching state of the switching devices following a sudden dc output short-circuit changes as shown in Fig. 3. The switching state of each device, load voltage, and output dc current waveform in each time interval are described as follows.

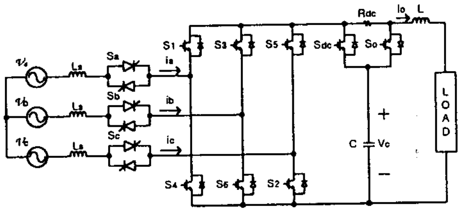


Fig. 2 2-level ac/dc converter of the proposed scheme

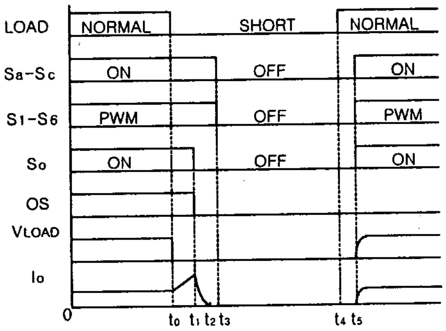


Fig. 3 Switching state, output voltage and current waveform

1) to≤t<t1

During this mode, the output dc current io increases linearly as follows.

$$i_o(t)=i_o(t_o)+\frac{V_c}{L}(t-t_o), \qquad t_o\le t\le t_1 \tag{1}$$

2) t1≤t<t2

At time t1, the dc current io reaches a previously set up output short-circuit current level of Ios. As soon as the OS signal becomes low gating signals for thyristors. Sa, Sb, and Sc are turned off and the power flow direction of the PWM converter is reversed. The magnitudes of ac line currents of ia, ib, and ic, under regeneration mode, decrease as follows.

$$i_a(t)=-(i_b(t)+i_c(t)) \tag{2}$$

$$i_b(t)=i_b(t_1)-\frac{1}{2Ls}\int_{t1}^{t}(V_c-v_{ab})dt \tag{3}$$

$$i_c(t)=i_c(t_1)-\frac{1}{2Ls}\int_{t1}^{t}(V_c-v_{ac})dt \tag{4}$$

During this mode the output current through inductor L decreases as follows.

$$i_o(t)=i_o(t_2)e^{-\frac{t-t_2}{\tau 1}}, \qquad t_2\le t\le t_3 \tag{5}$$

where $\tau 1=\frac{L}{R_{dc}}$ and the diode voltage drops of the main switches are neglected.

3) t2≤t<t3

In this mode, the decrease of the three phase ac line currents of ia, ib, and ic continues until the magnitudes of the currents become zero.

4) t3≤t<t4

There is no need of PWM switching in the main switches S1~S6. Thus, there is no current flow from ac or dc source to the load under the condition where the load keeps short-circuit.

5) t4≤t<t5

The short-circuit condition is cleared at time t4, and thus, the load becomes normal state. It is necessary to connect the dc source to the load again. The output dc current increases as follows after the dc source is applied to the load.

$$i_o(t)=\frac{V_c}{R_L}(1-e^{-\frac{t}{\tau 2}}) \qquad (6)$$

where $\tau 2=\frac{L}{R_L}$ and R_L is a load resistance.

3. Input and Ouput Current Analysis

3.1 AC input line current

The fundamental component of input current ia is

$$i_a(t)=\sqrt{2}I_a\sin(wt) \qquad (7)$$

The line current vanishing mechanism following an output short-circuit repeats with the same pattern every 60 degrees in one cycle of ia(t). The specific values of ia, ib, and ic are now introduced for 60 degrees.

1) $60^\circ \le wt < 90^\circ$

In (3) and (4), let

$$V_1=V_c-v_{ab} \qquad (8)$$

$$V_2=V_c-v_{ac} \qquad (9)$$

In this phase angle interval, V_1 and ic are smaller than V_2 and ib, respectively. As a result, the first line current to be vanished among three phase currents is ic. A required time for the ic to be zero can be calculated from (4). In (4),

$$v_{ac}(t)=\sqrt{2}V\sin(wt-\frac{\pi}{6}) \qquad (10)$$

Fig. 4 shows the required time tco with the variation of Ls under full load condition. AC input line voltage, line current, and output dc voltage are 220V, 10.5A, and 400V, respectively. As soon as the line current ic reduces to zero, the magnitude of the other two line currents ia and ib become equal as follows.

$$i_a(t)=-i_b(t)=-i_b(t'_{co})+\frac{1}{2Ls}\int_{t'_{co}}^{t}(V_c-v_{ab})dt \qquad (11)$$

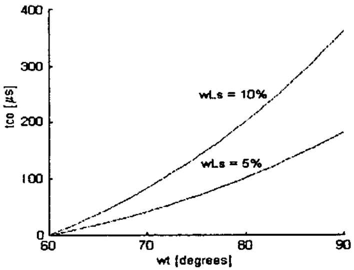


Fig. 4 Required time for ic to be vanished ($60^\circ \le wt < 90^\circ$)

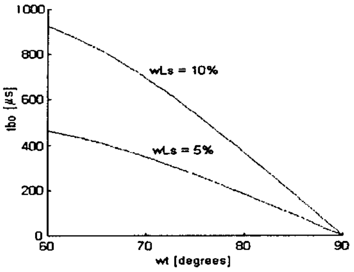


Fig. 5 Required time for ia and ib to be vanished after ic becomes zero ($60^\circ \le wt < 90^\circ$)

where a time instant of t'co corresponds to a time tco. Fig. 5 shows the time duration under the same condition as is used in Fig. 4.

2) $90^\circ \le wt < 120^\circ$

In this interval, the magnitude of V2 and ib is smaller than that of V1 and ic, respectively. Accordingly, the ib becomes zero first. Through a similar calculating procedure that used in the interval of $60^\circ \le wt < 90^\circ$ tco and tbo are calculated.

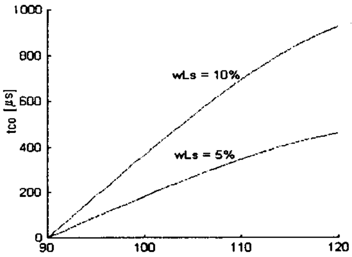


Fig. 6 Required vanishing time of ib ($90^\circ \le wt < 120^\circ$)

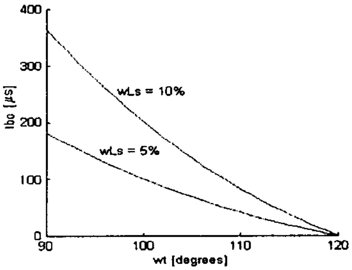


Fig. 7 Required time for ia and ic to be vanished after ib becomes zero ($90^\circ \le wt < 120^\circ$)

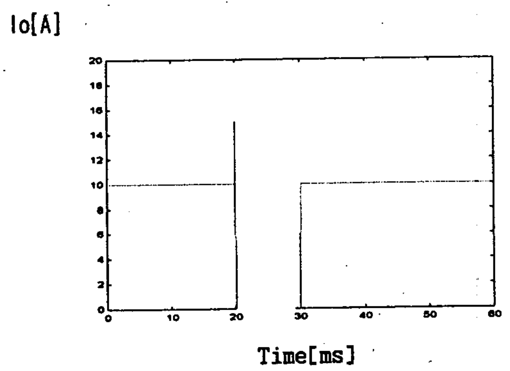
Fig. 6 and 7 show the resulting values.

3.2 DC output current

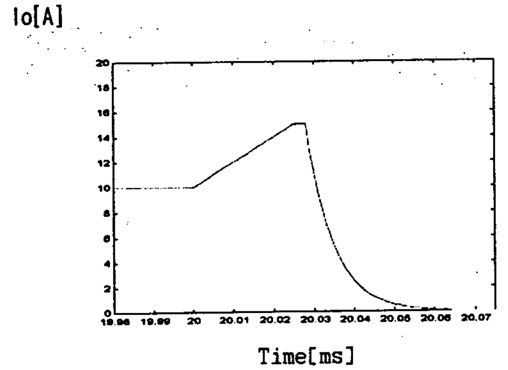
The dc output current begins to increase after the instant of a short-circuit as in (1). As soon as the switch So is turned off, the output current begins to decrease through an altered path, which comprises L, load, diodes which are anti-parallel connected to the IGBTs, and Rdc.

4. Simulation Results

The output switching characteristic of the proposed power converter is simulated with the following parameters. The ac input line-to-line voltage = 220 V, Ls = 2 mH, Rdc = 300 Ω, C1, C2 = 2,200 μF, L = 2 mH, output dc voltage = 400 V, and load resistance = 40 Ω. Fig. 8(a) shows the load current Io. Fig. 8(b) shows the detailed output current waveform around 20ms. The increasing time interval is 25 μs and the discharging time interval is almost 30 μs.



(a) Waveform of Io



(b) Detailed waveform of Io

Fig. 8 Waveforms of Io in the case of a load short-circuit

5. Conclusion

A new multilevel ac/dc converter suitable for a short-circuit protection is described. The major features of the proposed scheme are summarized as follows:

1) Simplified structure compared with the conventional inverter type power supply.
2) High speed disconnection a dc source from a short-circuit load without damage.
3) Rapid connection of a dc source to a normal load with reduced load voltage build up time.
4) Negligible switching losses of the auxiliary switches.
5) Reasonable input and output current magnitude.

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