Basic Investigation of Three-Phase to Single–Phase Power Converter using Modular Multilevel Converter Topology

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Abstract:- In this paper, an AC-AC direct type power converter that uses a Modular Multilevel Converter (MMC) topology is proposed for medium voltage application. The proposed system can convert a three-phase AC power supply into a high frequency AC voltage without DC link stage. Moreover, the proposed system can control the input current and capacitor voltage in each cell which is consisting of a DC capacitor and a H-bridge converter. The simulation results show that the proposed system can directly convert a three-phase AC power supply of 200 V, 50 Hz into a high frequency AC voltage of 360 V, 1-kHz. In addition, the proposed system can obtain low harmonic components of sinusoidal input current and maintain the cell capacitor voltage at constant closed to the capacitor voltage command 200 V.

Keywords : Direct Power Conversion , Modular Multilevel Converter , Capacitor voltage control , High frequency output

1. Introduction

Recently, the modular multilevel converters (MMCs) are actively being researched in order to apply a power converter to medium voltage such as 3.3 kV or 6.6 kV without huge transformers. Besides, the MMCs can reduce the harmonic distortions in the output voltage due to use of many voltage level. Therefore, the MMCs topology can be applied in the high power converters; such as STATCOM and medium adjustable speed drive systems [1]. However, three-phase to single-phase AC-AC direct converters with the MMC topology has not so many reported. This converter can be used as front stage of an isolated AC-DC converter.

This paper proposes a novel three-phase to single-phase AC-AC direct power conversion system using MMC which can convert commercial frequency AC voltage into high frequency voltage. This paper will show the simulation results of the proposed system with the output voltage of 360 V, 1-kHz AC. Moreover, the proposed system evaluates the harmonics of the input current waveform and the fluctuation of the cell capacitor voltages.

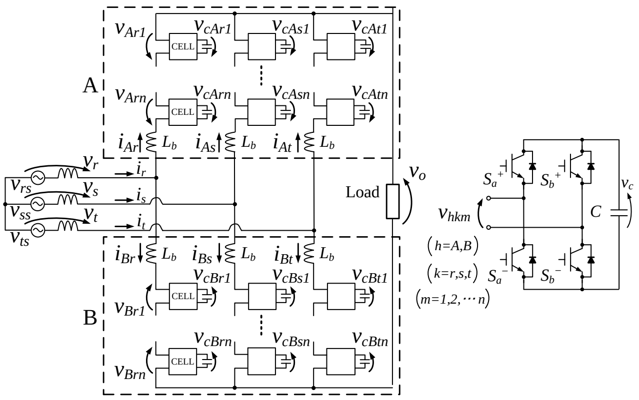
2. Circuit configuration

2.1 Main Circuit Fig. 1(a) shows the main circuit configuration of the proposed three-phase to single-phase direct power converter using MMC. Each leg consists of two interconnection reactors L_b and H-bridge cells. Then, each of the leg is connected to a load in parallel. Due to cascade connection of cells, the proposed converter can achieve a multi-level voltage waveform and also reduce the rated voltage of each cell. Thus, many cascaded cells are used in practical because it can reduce harmonic distortion and utilize with a low voltage rating devices.

2.2 H-bridge Cell Fig. 1(b) shows a configuration of H-bridge cell. Each cell consists of four IGBTs and a DC capacitor. Furthermore, the output voltage of the cell and capacitor voltage are controlled by a pulse width modulation (PWM).

3. Control Strategy

Fig. 2 shows the control block of the proposed converter. One



(a) Main circuit (b) H-bridge cell

Fig. 1. Circuit configuration of three-phase to single-phase direct power converter using MMC.

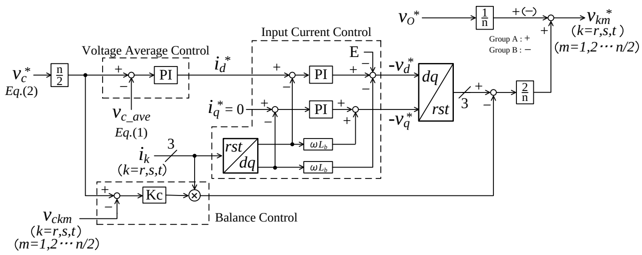


Fig. 2. Control block diagram of three-phase to single-phase direct power converter using MMC applied to each arm group

of the features in the proposed system is to control each arm group of A and B as shown in Fig. 1(a). The control block diagram is separated to the capacitor voltage control block and the input current control block. Moreover, the capacitor voltage control block uses two controls, namely an average control and a balance control. [2]

3.1 Average Control The average control corrects the error between the average value of the capacitors voltage on each arm group and the command voltage with a PI control. The average value of the capacitors voltage v_{c_ave} is given by (1)

$$v_{c\_ave} = \frac{1}{3}\sum_{m=1}^{n/2}\left(v_{crm} + v_{csm} + v_{ctm}\right) \cdots\cdots (1)$$

The output of the PI controller is connected to the active current controller in the input current control block because the capacitor voltages are adjusted by active current i_d.

3.2 Balance control The balance control is used to keep the voltage in each capacitor voltage at constant and same value. The average value of all capacitor voltage is controlled to be constant by the average control. However, unbalance voltage which occurs among the capacitors cannot be controlled by the average control only because the average control corrects only the error between the average value of the capacitors voltage on each arm group and the command voltage. Therefore, the balance control is used to correct the error between each capacitors voltage and the command voltage.

3.3 Input Current Control The input current control is implemented by PI controllers to correct the error between input current command and detected value, and the compensators for cross terms of i_d and i_q which are provided by the transformation to the rotating frame. The input current control is separated into the active current control given by the average control and the balance control, and the reactive current control. Then, the reactive current i_q^* is set to zero because the reactive current does not contribute to the control over capacitor voltage.

3.4 Capacitor Voltage The output voltage command v_o^* that uses to obtain the high frequency output voltage is added to the output of the input current control block. The change of voltage value in each cell depends on the number of cells at each leg since the cells are connected to the load in series. In addition, each capacitor voltage also depends on the input and output voltage. The capacitor voltage command $v_c^*$is given by (2)

$$v_c^* \geq \frac{1}{n}\left(2\sqrt{\frac{2}{3}}E + V_O\right) \quad \cdots\cdots (2)$$

where E is an effective value of the input line to line voltage, V_o is a maximum value of output voltage command and n is the number of cells at each leg. From (2), the output voltage of each cell becomes smaller as the numbers of cells. Therefore, the capacitor voltage command can be set lower.

4. Simulation Results

Table. 1 shows the simulation parameters. Switching devices are defined as ideal elements. The output voltage command is square wave.

Fig. 3 shows the simulation results that demonstrates the input voltage and input current. From Fig. 3, it is confirmed that the unity power factor can obtain in the input stage. Moreover, the total harmonic distortion (THD) of input current is about 1%.

Fig. 4 shows the waveform of the capacitor voltage. From Fig. 4, the error of capacitors voltage within a same arm occurs. However, a ratio of maximum error against command voltage is about 0.31%. Thus, the error does not affect the circuit operation. Moreover, the maximum ripple factor of each capacitor voltage is obtained 0.47 %.

Fig. 5 shows the waveform of the output voltage. From the result, it is confirmed that the high frequency AC voltage can be obtained. The time constant of the rising and falling of output voltage depends on the inductance of the interconnection reactors and load resistance. In particular, the equivalent inductance is 2/3 times as large as the interconnection reactor L_b because each leg is connected to the load in parallel. In addition, the ripple of the output voltage is caused by switching. The ripple can be reduced by applying larger interconnection reactor L_b and increasing the carrier frequency.

Table.1. Simulation parameters

Input voltage (line to line)	$200V_{rms}$	Cell (per one leg)	4
Input voltage frequency	50 Hz	DC Capacitor	2 mF
Output maximum voltage	360 V	R load	100 Ω
Output voltage frequency	1 kHz	Interconnection reactor	2 mH
Carrier frequency	9 kHz		

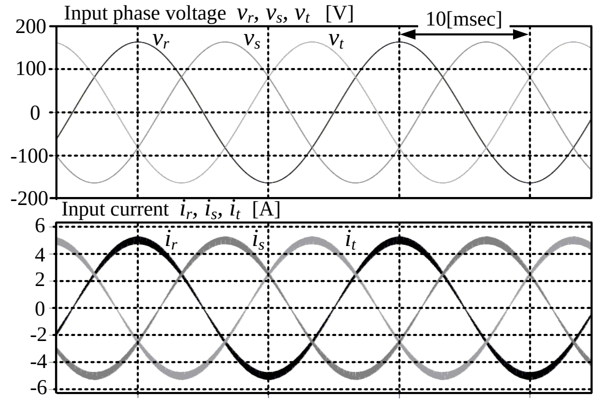


Fig. 3. Waveforms of input voltage and input current

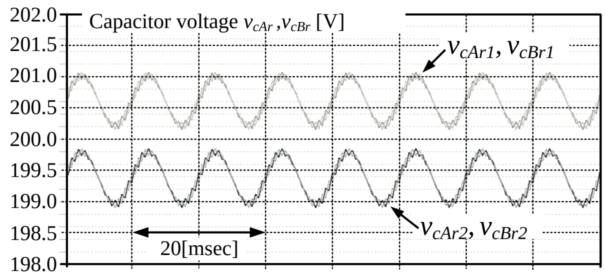


Fig. 4. Waveform of capacitor voltage

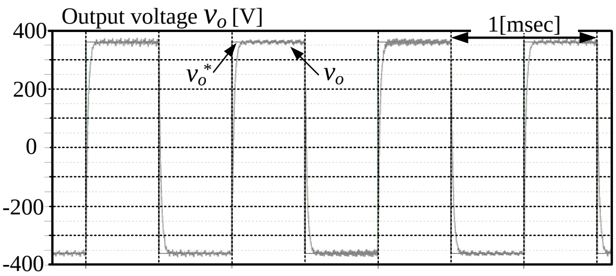


Fig. 5. Waveform of output voltage

5. Conclusion

The proposed direct power converter using a modular multilevel converter topology can directly convert a three-phase AC power supply into 360 V, 1-kHz AC voltage. Moreover, the proposed system can achieve that the THD of input current is about 1% and the maximum ripple factor of each capacitor voltage is 0.47 %. In the future work, the control method to correct the error of capacitors voltage within a same arm with a larger numbers of cells will be discussed.

References

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