Evaluation of Capacitor Volume in Modular Multilevel Converter

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This paper discusses a volume evaluation of a step-down rectifier using Modular Multilevel Converter (MMC) for a utility gird of 6.6 kV in order to obtain the high power density. Especially, the volume of electrolytic capacitors is designed in terms of the lifetime and the withstand voltage of the capacitor. Moreover, this paper clarifies a relationship between an output voltage of the MMC and a volume of electrolytic capacitors. In conclusion, the conditions in order to reduce the volume of electrolytic capacitors are clarified in the proposed system at the power capacity of 200 kVA.

Keywords Modular Multilevel Converter, Step-down Rectifier, Volume of Electrolytic Capacitor, Ripple Current

1. Introduction

Recently, a DC micro-grid has been actively researched as next generation power grids [1]. The system is connected to a utility grid of 6.6 kV as one of power sources. Moreover, transformers are used between the utility grid and the DC micro-grid in order to convert from 6.6 kV into several hundred volts and obtain isolation between the utility grid and the DC micro-grid. However, a volume of the isolated transformer increases because the isolated transformer operates in a commercial frequency.

In order to avoid utilization of the bulky transformer, the step-down rectifier using Modular Multilevel Converter (MMC) has been proposed [2].

On the other hand, in terms of the realization of the high power density in the step-down rectifier using the MMC, it is necessary to consider the design method in order to reduce the volume of a capacitor with a large capacity. So far, the volume evaluation of capacitors based on the electrostatic energy has been reported [3]. However, it seems that the relationship between the capacitor volume and the number of cells has not been reported. Especially, it is important to consider a ripple current of the capacitors in terms of lifetime of the capacitor when the capacitor with the large capacity such as an electrolytic capacitor is applied.

This paper discusses the volume evaluation of capacitors in the MMC. Especially, the parallel connected number and the series connected number of capacitors are determined by the ripple current which flows to the electrolytic capacitor and the withstand voltage. Moreover, the relationship among the ripple current, the number of cells and the volume of electrolytic capacitors is clarified. In conclusion, the conditions in order to reduce the volume of electrolytic capacitors are clarified.

2. Configuration of proposed system

Fig. 1 shows the configuration of the step-down rectifier using the MMC. In the proposed system, H-bridge cells are applied. In the conventional MMC, chopper cells are applied. However, the MMC with chopper cells cannot achieve the step-down rectification because the chopper cell has a lower limit on its output voltage. The MMC with H-bridge cells converts the high AC voltage to the DC voltage of several hundred volts. After this step, the DC voltage of 400 V is supplied to the DC bus of the micro-grid by the isolated DC-DC converter. Therefore, the input side and the output side are isolated by the DC-DC converter. Moreover, the proposed system is constructed by two converters and can divide the step-down function in the MMC and the DC-DC converter. Thus, it is able to determine the optimal value of the output voltage of the MMC V_{mmc} in order to reduce the system volume.

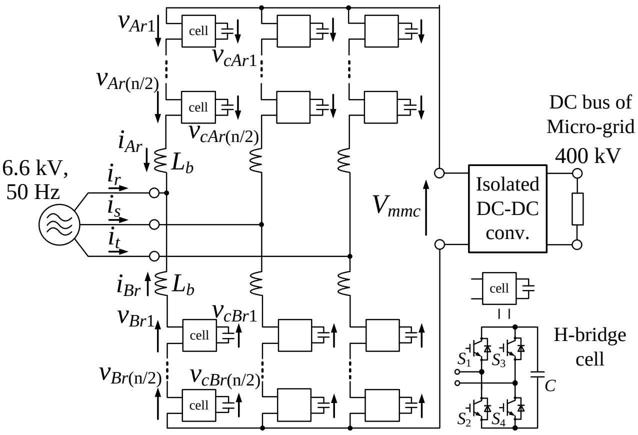

Fig. 1. Circuit configuration of step-down rectifier using MMC.

3. Operation of step-down rectifier using MMC

Fig. 2 shows waveforms of the input phase voltage, the input current and the MMC output voltage. Firstly, from the waveforms of the input phase voltage and the input current, it is confirmed that the unity power factor is obtained. Moreover, the total harmonic distortion (THD) of the input current is 3.1%. Second, the waveform of the MMC output voltage in lower side of Fig. 2 shows that the miniature model converts from the input voltage of 200 V into the MMC output voltage of 75 V. From this result, it is confirmed that the output voltage maintains constant. Therefore, the miniature model of the MMC achieves the step-down rectification.

Fig. 3 shows the waveforms of all capacitor voltages of H-bridge cells which are connected to the r-phase leg. As a result, the proposed system maintains all capacitor voltages. Besides, the error between the capacitor voltage command of 130 V and the measured voltage is 5% or less.

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4. Evaluation of capacitor volume

Fig. 4 shows the relationship between the allowable ripple current and the capacitor volume. The graph is drawn on datasheets of commonly-marketed electrolytic capacitors which are generally implemented into many products. Note that figures from 5 A to 30 A in Fig. 4 are the allowable ripple current of one capacitor. Therefore, the number of the capacitors which are connected in parallel on one cell increases with increasing the ripple current. Moreover, the start point of each line means the ripple current and the volume of one capacitor. As a result, the capacitor volume becomes small by connecting capacitors with the small allowable ripple current in parallel compared to utilization of the capacitors with the large allowable ripple current. Thus, the parallel connection of the capacitors with the small allowable ripple current is better than utilization of the capacitors with the large allowable ripple current in order to reduce the volume of the capacitors. Additionally, the ripple current does not change against the capacitance and the number of cells [2]. Thus, the minimum point of the capacitor volume against the number of cells achieves the minimum point of the overall volume.

Fig. 5 shows the relationship among the number of cells, the overall volume of the capacitor and a withstand voltage ratio. Note that the number of series connection capacitors increases when the required withstand voltage is larger than the withstand voltage of one capacitor. Thus, it is necessary to meet the conditions of the required withstand voltage by series connection of capacitors. Besides, the required withstand voltage is set 30% more than the value which is calculated by (1).

$$v_c^* \ge \frac{1}{n\lambda}\left(2\sqrt{\frac{2}{3}}E + V_{mmc}^*\right) \quad \cdots\cdots\cdots\cdots (1)$$

where E is an effective value of an input line-to-line voltage, n is the number of cells at each leg, the MMC output voltage is V_{mmc} and λ is an modulation index. In this evaluation, λ is set 0.9.

Moreover, the capacitor volume is determined by the multiplied value of the number of series connection capacitors and the number of cells under the same condition for the ripple current. In addition, the withstand voltage ratio is defined as the ratio of the required withstand voltage to the actual withstand voltage when capacitors are connected in series. From Fig. 5, the capacitor volume becomes small when the withstand voltage ratio is close to 1.0. In other words, it is possible to achieve the volume reduction by closing the withstand voltage ratio to 1.0. As a conclusion, it is necessary to meet following conditions in order to reduce the volume of the capacitors.

(1) Applying the capacitor with the small ripple current

(2) Maximizing withstand voltage ratio (Approaching to 1.0)

5. Conclusion

This paper clarified the relationship among the capacitor volume, the allowable ripple current which flows to the capacitor and the number of cells. Especially, the connection number of capacitors is determined by the allowable ripple current and the capacitor voltage in terms of the lifetime and the withstand voltage of the capacitor. In conclusion, it is necessary to meet following conditions in order to reduce the volume of capacitors.

1) Applying the capacitor with the small ripple current

2) Maximizing the withstand voltage ratio

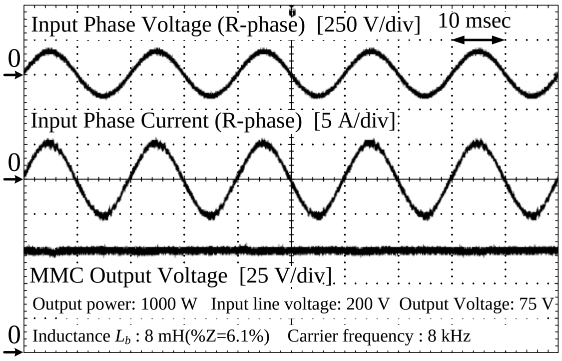

Fig. 2. Waveforms of input voltage, input current and MMC output voltage.

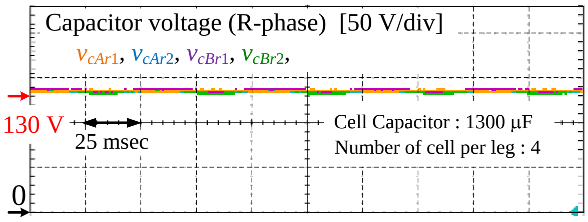

Fig. 3. Waveforms of capacitor voltage in r-phase leg.

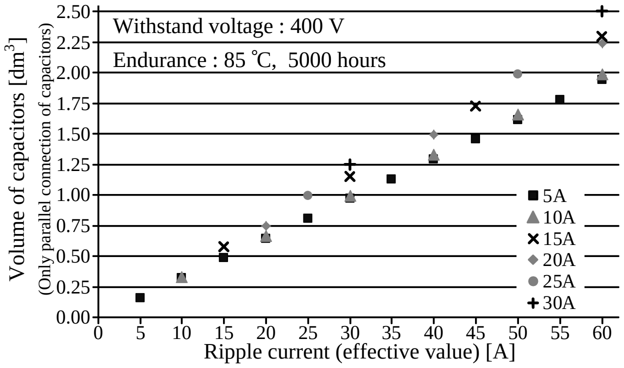

Fig. 4. Relationship between ripple current and capacitor volume.

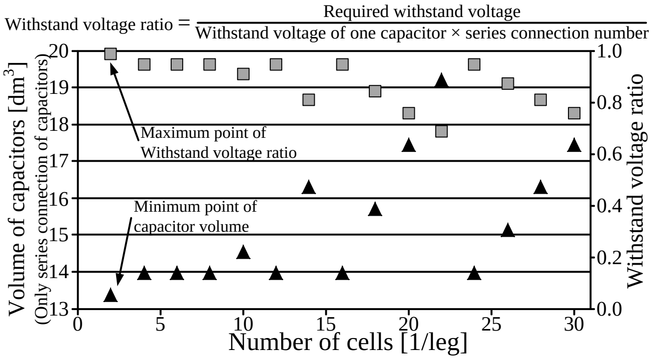

Fig. 5. Relationship between number of cells and capacitor volume.

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