The Design and Simulation of MMC Inverter Filter Device Based on SPWM Modulation

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Abstract

The modular multilevel converter(MMC) is a converter of new topology structure, with the advantages of low switching frequency, low loss, high voltage level. Based on the basic structure of the MMC and the modulation strategy, we established a MMC inverter model in the PSCAD environment. In order to make the harmonic content outputted meet the national standard, it is necessary to install filtering device at the outlet side. We choose two kinds of single turned filter: RLC filter and LC filter. The simulation results show that the validity of the selection and design of filter in this paper and the RLC filter has a better filtering effect.

Keywords

Modular multi level converter ,Harmonic control,Modulation strategy,Single tuned filter

1. Introduction

High-voltage direct current transmission technology (VSC-HVDC) based on voltage source inverter, namely flexible HVDC technology, is a hot spot in current research and application of power electronics industry. The voltage source converter for VSC-HVDC is mostly two or three level converter. There exist some defects, such as low voltage level and large loss, limiting its further application to some extent. Compared to traditional flexible HVDC technology, MMC has many advantages such as low switching frequency, low loss, and higher voltage grade.

The operation condition of MMC is nonlinear, it is inevitable to produce harmonics and pollute the power network. Therefore, it is necessary to design and install the MMC filter.

2. the Basic Structure and Modulation Strategy of MMC

Fig. 1 is the basic structure of the MMC. As shown, each bridge arm is composed of a valve reactor and more child modules in series and the upper and the lower bridge arm of each phase constitute a phase unit. A single child module has three different states. The output voltage of each module can be controlled by trigger. For the purpose of modularization, the rating value of child modules is the same and the reactance values of each bridge arm are equal. As the number of the child module in the output state of each phase is a fixed value, we can adjust the total ac voltage outputted through the distribution of the child module in the upper and lower bridge arm in phase unit.

Modulation strategy is one of the key technologies which influence the performance of MMC directly. MMC modulation strategy proposed currently has the following three: carrier phase-shifting modulation

(SPWM), space vector modulation (SVM), recent level approximation modulation (NLM). The SPWM is most widely applied in the field of MMC, for example, SPWM technology is used as MMC modulation strategy in literature [4]. In this case, we can gain high equivalent switching frequency under lower device switching frequency, which can reduce the output harmonic to a certain extent. Therefore, SPWM is used as the modulation strategy of MMC simulation in this article.

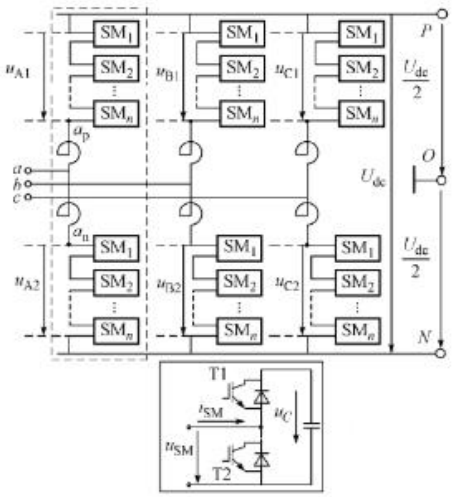

Fig. 1 The basic structure of MMC

3. The Simulation and Analysis of AC Harmonic of MMC Converter

In this paper, the simulation software PSCAD is used to establish the MMC inverter model of single loop PI control, as shown in figure 2. When the number of the bridge arm is large, the harmonic content outputted from MMC will be small. In order to know the filtering effect of design filter easier, the module number of single bridge arm is nine, which is less, and rated transportation capacity is 1.5 MW and the rated dc voltage is 1.0 kV in this paper. In the case of three-phase symmetrical operation, A phase is designed as the research object of simulation and analysis.

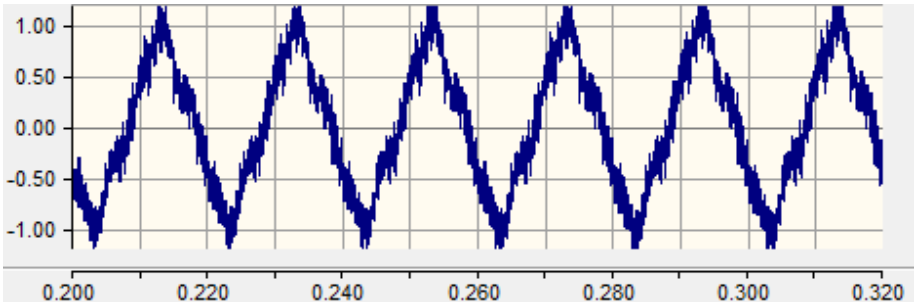

Fig. 3 the simulation waveform of MMC inverter export voltage

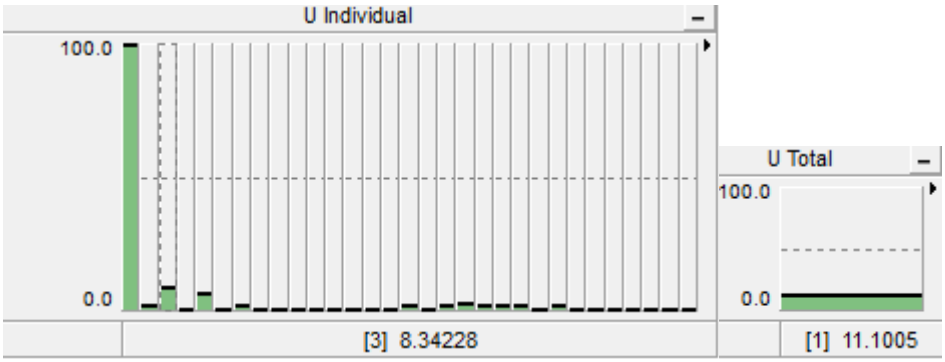

Fig. 4 every harmonic distortion rate of export voltage of inverter in A phase

As is shown in figure 3 and figure 4, due to the existence of the harmonic, voltage waveform has a serious distortion, and the content of third harmonic is the highest and the fifth harmonic is higher and

the seventh harmonic is the lowest. Therefore, we only need to filter out some low-order harmonics when choose and design filter.

4. The Selection and Calculation of MMC Converter Outlet Filter

According to the type of the components, filter can be divided into two kinds of active filter and passive filter. With the virtue of low cost and no capacity constraints, passive filter, although just can filter out a certain frequency range of harmonic, can improve the harmonic problem of system largely after carefully calculated design.

Passive filter can be divided into two main categories: tuned filter and high-pass filter. For the carrier phase shift modulation, the switching frequency of device is low, so the proportion of the low-order harmonic component is large and we should adopt tuned filter in stand of high-pass filter. Single tuned filter has a relatively simple structure and can filter out important single harmonic filter. In addition, that the cost on loss and maintenance is low makes this kind of filter has a strong advantage. Therefore, we choose single tuned filter as the MMC export filter.

4.1 LC filter

LC filter is a kind of single tuned filter with simple structure.It consists of one capacitor and one inductance. There are some assumptions as follows:(1) DC voltage is the ideal voltage source; (2) the switch of inverter is ideal switch; (3) ignore the parasitic parameters of inductance and capacitance; (4) the load are linear load.

Firstly, calculate the load impedance according to the output power and the output voltage of interver:

$$R_L = \frac{U_0^2}{P} \tag{1}$$

The nominal characteristic impedance of filter:

$$R = (0.5 \sim 0.8)R_L \tag{2}$$

The angular frequency of filter:

$$\omega_L = 2\pi f_L = \frac{1}{\sqrt{LC}} \tag{3}$$

The filter inductance of filter:

$$L = \frac{R}{2\pi f_L} \tag{4}$$

The filter capacitor of filter:

$$C = \frac{L}{R^2} = \frac{L}{2\pi f_L LR} = \frac{1}{2\pi f_L R} \tag{5}$$

Among them, f_L is the cutoff frequency. On the basis of reference [7-8], f_L is usually chose between 100~400Hz when the fundamental wave frequency of output voltage is power frequency 50 Hz.

4.2 RLC filter

As MMC HVDC system does not need to filter for reactive power compensation, the reactive compensation capacity should be as small as possible in order not to affect the operating performance. Therefore, the installed capacity of filter capacitor can be designed according to the minimum capacity. The minimum installed capacity of the NTH filter capacitor:

$$C = \frac{I_F(n)}{U\omega_0}\frac{n^2-1}{\sqrt{n}n^2} \tag{6}$$

Among them, $I_F(n)$ is the harmonic current of the NTH filter branch which can be obtained by simulation. U is the fundamental component of ac bus voltage. ω_0 is the fundamental wave frequency.

Single tuned filter resonates at the NTH harmonic frequency. Then we can calculate the reactor value:

$$L = \frac{1}{(n\omega_0)^2 C} \tag{7}$$

Thus the resistance of filter is:

$$R = \frac{\sqrt{L/C}}{\mathrm{Q}} \tag{8}$$

Among them, Q is quality factor of filter, and the best value range is 30~60.

An inductance and a capacitor can constitute a first-order low-pass filter, and an inductance and a capacitor and a resistor can constitute a second-order low-pass filter. The attenuation stop band of second-order low-pass filter is about twice of that of first-order low-pass filter. Therefore, theoretically, The filtering effect of RLC filter will be better than that of the LC filter.

5. The Simulation and Analysis of MMC Export Filter Based on PSCAD

As for the existing power quality standards regulations, total harmonic distortion rate of low voltage power grid is not more than 5% of the fundamental wave. Calculating filter parameters after filtering out three harmonic using the above method, then analyzing and comparing the filtering effect.

f_L is 350Hz in (3) .According to the formula(1)~ (5), parameters of LC filter are as follows.

$$L = 0.07mH, C = 11410\mu F$$

Q is 60 in (8). According to the formula (6)~(8), parameters of RLC filter are as follows.

$$C = 3500\mu F, R = 0.05\Omega, L = 8.8mH$$

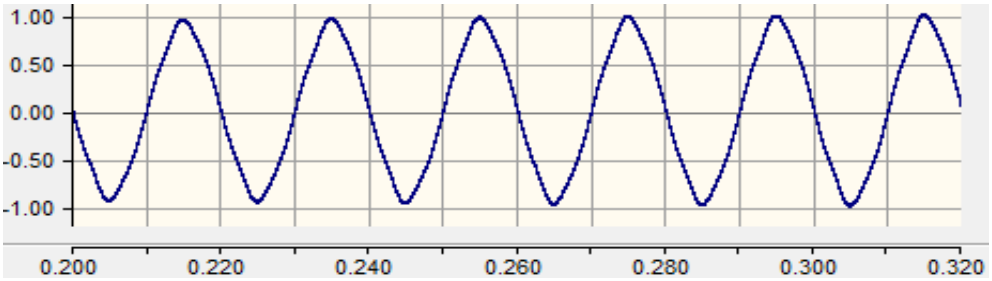

Fig. 8 the output voltage waveform after filtering of LC filter

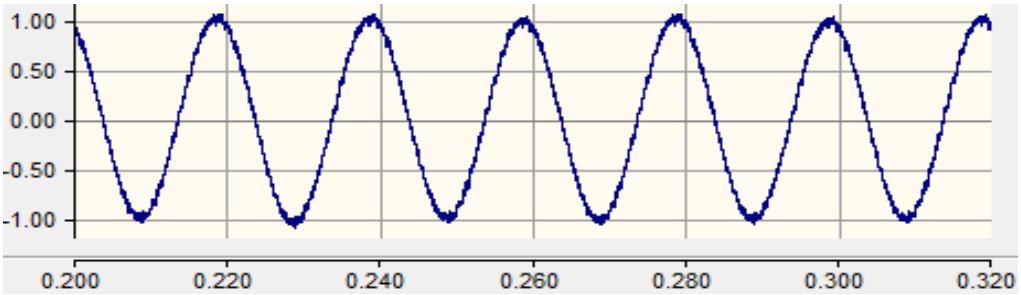

Fig. 9 the output voltage waveform after filtering of RLC filter

We design filters according to the above parameters ignoring the high harmonic. Assuming that the total number of harmonic current in PCC point is 31, the waveform of output voltage and the distortion rate of every harmonic voltage are as shown in Fig.8 and Fig.9.

Table 1 the comparison of filtering effect between RLC filter and LC filter

Harmonics	3	5	7	9	THD
LC filter	2.83138	2.89692	0.55534	0.00699	3.01242
RLC ilter	0.03231	0.22647	0.06167	0.05119	1.83996

As is shown in the figure 8 and figure 9, the waveform of output voltage is relatively smooth, the distortion is greatly reduced, and the output voltage filtered by RLC filter is basically a standard sine wave, thus we can verify the correctness of the method of MMC filtering device designed. The data in table 1 shows that both low-order harmonic content and total voltage distortion rate are lower after being filtered by RLC filter. Through theoretical analysis and experimental verification, we can get the conclusion that the filtering effect of RLC filter is better than that of LC filter.

6. Conclusion

In order to suppress the harmonic pollution of MMC inverter, according to the topology of the MMC and modulation strategy, we designed single turned filter in the export side of the inverter and the simulation results show that under the action of the filtering device, harmonic voltage content can meet the requirements of power quality standard regulations, and compared with the LC filter, RLC filter filtering effect is better.

Acknowledgments

Basic scientific research service in the Central University: Research on the operation control technology of UPQC based on MMC (serial number: 13MS70)

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