Research on the Technology of Power Filter and Compensation System for High Speed Maglev System

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ABSTRACT: First, the paper analyzes the load characteristic of Shanghai Maglev. Next the paper points out those two ways are widely used to filter the harmonics: LC power filtering and active power filtering. The paper analyzes the two ways, and compare them by the aspect of technique and economic. In consideration of the characteristic of the IGCT power inverter which will be used in the maglev in the near future, the paper recommends that active filter (using cascaded H-bridge multilevel converter) be used.

1 INTRODUCTION

Maglev train is an inductive intermittent striking load with large capacity. When the propulsion condition and line slope change, the active power and reactive power consumed and the harmonics emitting also change frequently, which poses harmful influence on the power grid. Reactive power changing heavily makes Voltage fluctuation, and harmonics also make lots of hazard. To suppress these influences, power customers need make efforts to compensate reactive power and filter harmonics.

2 LOAD CHARACTERISTIC OF SHANGHAI MAGLEV

In Shanghai Maglev's case, as shown in figure 1, the busbar voltage is 20kV, the inverter's nominal capacity is 15MVA, and the SVG 6MVA. Additionally there are three LC filter and compensation circuit branches, namely 5^{th}, 7^{th},and 11^{th} high-pass filters. The capacity are 1MVA、1MVA and 4MVA respectively.

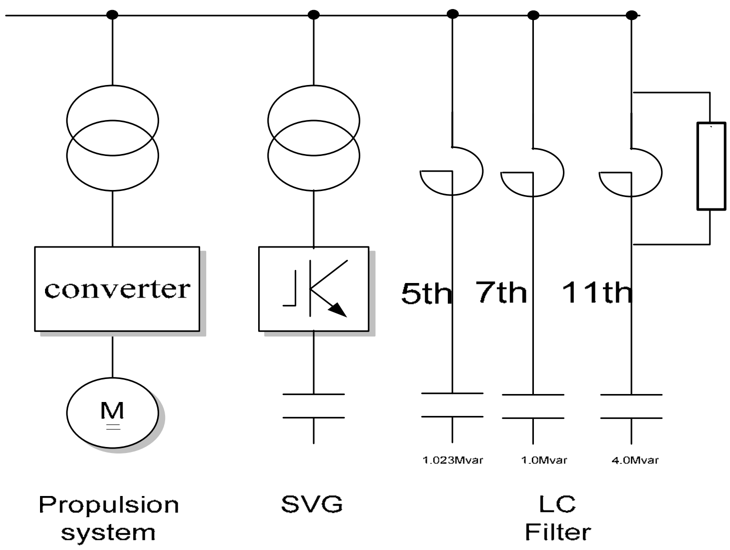

Figure 1 Sketch of power supply

2.1 Power Characteristic

There are 2 substations for Shanghai Maglev. Power consuming measurement for one normal shutter is made in one substation (the highest speed is 430km/h). The curves of measurement result are shown in Figure 2 and figure 3. When the vehicle accelerates, active and reactive power consumed rise rapidly. The peak appears when the vehicle still accelerates and almost reach its highest speed. At this moment, Maximum power is demanded. When the vehicle reaches its highest speed, power demand is decline rapidly because only wind resistance needs to be overcome. If there is no compensation equipment, such large power fluctuation will make large voltage fluctuation.

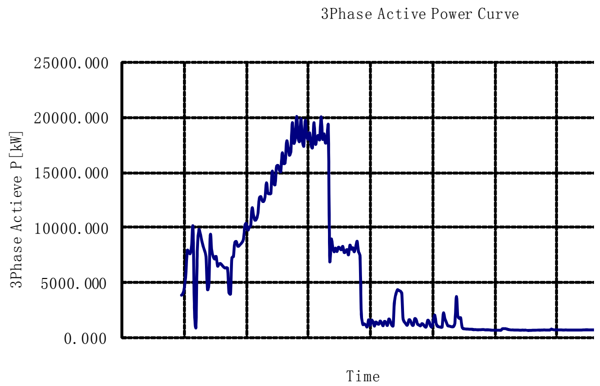

Figure 2 Three phase active power curve

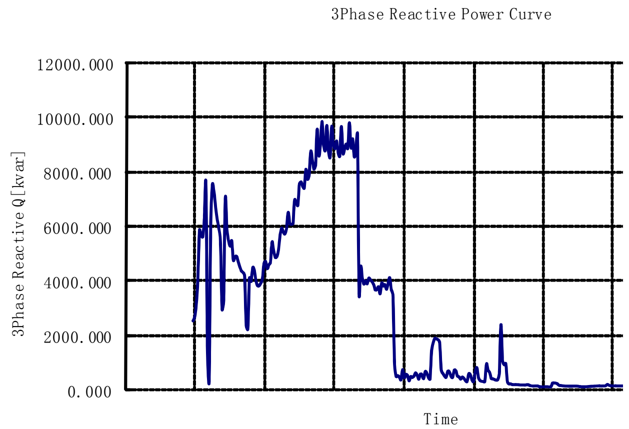

Figure 3 Three phase reactive power curve

2.2 Harmonic Characteristic

12 pulse phase rectifier is used in the converter. In theory, the rectifier emits only harmonics of 11th、13th、23th、25th …. But actually, it has also releases 5th and 7th harmonics. By measuring, the maximum harmonic content is obtained as shown in table 1. It cannot meet the Chinese Standard. Filtering measure must be taken.

5th	7th	11th	13th
4.6%	3.2%	6.1%	4.9%

Table 1

3 FILTERING METHODS USED IN MAGLEV POWER SUPPLY SYSTEM

3.1 LC filter

LC filter is a common equipment to filter harmonics. It can not only suppress harmonics but also afford reactive compensation. It is widely used in high voltage and large power applications. It consists of reactor and capacitor in series, which tune in a particular frequency. At the tuned frequency, the filter expresses low impedance. In theory, at its tuned frequency the filter's impedance can be designed to zero. So the filter can absorb harmonics.

For the harmonics released by the converters, filters of the 5th, 7^{th,} and 11th high-pass filters are set in Shanghai Maglev. Basically, the filter system can suppress harmonics to meet the Chinese Standard. But there're two problems for such arrangement: On the one hand, when the vehicle is not running, the load is very small and large amount of reactive power produced by capacitors must be compensated by SVG, 6Mvar of reactive power is a heavy burden for the SVG; On the other hand, LC filter may have resonance with external power system. Filter impedance scan is shown in figure 4.

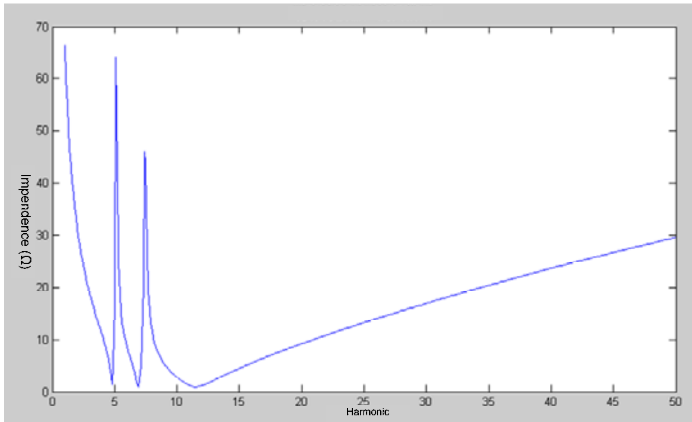

Figure 4 Filter impendence scan

As the figure shows, in the frequency of 4.8th, 6.9th, 11.5th harmonic, the filter series resonance occurs and impedance is low, and thus specific harmonics filtering effect is achieved; in the frequency of 5.1th and 7.4th harmonic, parallel resonance takes place and the impedance is greater.

With the existing filter, the equivalent impedance scan of 20kV side is shown in Figure 5.

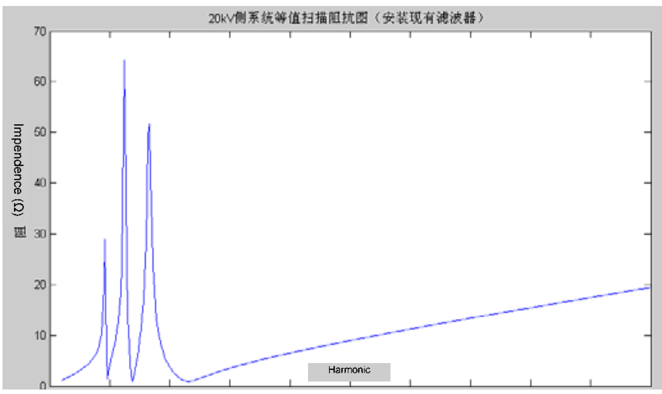

Figure 5 Impedance scan of 20kV side.

The frequencies of 4.6th, 6.2th, and 8.3th harmonic, are the parallel resonant points. In these frequencies, the system shows high impedance. If the harmonic current near the resonance point occurs, it will produce large harmonic voltage.

3.2 Active Filter

Different from the traditional passive LC filter, active filters have a totally new idea. Active filters inject harmonic current (with equal amplitude and opposite phase from the load harmonic current) to the grid, to cancel the load harmonic current, or to produce a large impedance for harmonic current to prevent the flow of harmonic current to the source. Active filters can filter different numbers of harmonic current simultaneously, they response fast, not limited to a few specific tuning frequency. Their filtering performance will not be influenced by power grid parameters. They can inhibit the grid shock and also effectively reduce the compensation system loss and improve the economy and reliability of compensation system. According to the way of connection with the load, they are divided into parallel and series form. Nowadays, lots of ways can achieve parallel active filter devices. With the actual situation on Shanghai Maglev Demonstration Line (its maximum capacity of harmonic currents is about 4MVA), the following content will focus on two commonly used active filter devices.

3.2.1 Multiple Small-capacity Conventional Three-phase Inverters in Parallel.

Currently technology of inverter module around 500kVA is mature and its cooling technique is simple, multiple small-capacity IGBT modules in parallel via a transformer are connected to the power bus, as shown in Figure 6, the switching frequency can be around the 10 kHz, which can be able to meet the filtering switch frequency. Each module works independently, the total harmonic currents are averagely distributed. If one module failed, others will not be affected. Eight 500kVA modules are formed in parallel to form the capacity of 4MVA. In addition, as to the high-frequency harmonic current, a separate small-capacity high-frequency filter module can be designed.

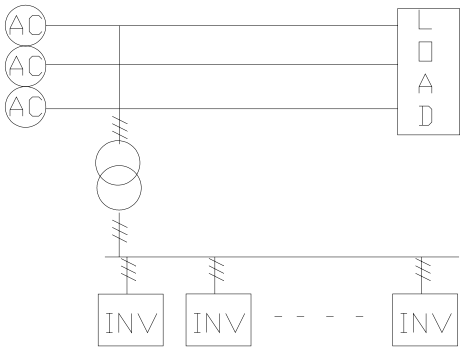

Figure 6 Multiple Three-phase Inverters in Parallel

3.2.2 Cascaded H-bridge (CHB) Multilevel Converter.

As shown in Figure 7, each module works at relatively low switching frequency, multi-modules cascade and the phase-shift control and phase staggers, so that the equivalent switching frequency can meet the requirement of active filter. This filter has several advantages: 1 low switching frequency, smaller loss; 2 chain structure can be independent phase controlled, which help to solve the problem of the balance between phases, and if the system is disturbed, it can provide voltage support better; 3 all the chains are the same, so it can be modularized designed and is easy for expansion and maintenance; 4 it eliminates the connecting transformer so that the losses and costs are reduced, and efficiency and response are improved.

However, as the level number increases, the circuit structure becomes complicated, control becomes difficult. Furthermore, all the modules work together, if one module fails, the others have to change the control to coordinate.

This way is more commonly used for large-capacity middle voltage active filter.

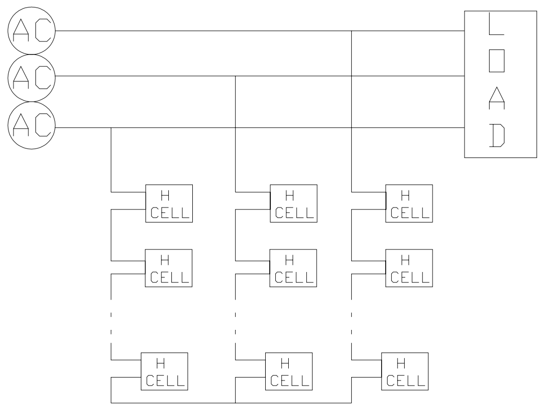

Figure 7 Cascaded H-bridge (CHB) Multilevel Converter

4 OUTPUT CHARACTERISTICS OF HIGH VOLTAGE-POWER CONVERTER BASED ON IGCT

Compared with GTO, IGCT have lots of advantages: large current level, high voltage level, high switching frequency (kHz range can be reached), low on-state losses and low turn-off losses; simple gate drive circuit, and easy series and parallel of devices. It has a great trend to replace the GTO.

Taking the converter (12-pulse phase-controlled high-voltage power converter based on IGCT) to be used on Shanghai Maglev Demonstration Line as an example, on one hand, its working power factor reaches 1, so no additional reactive power compensation equipment is needed; on the other hand, the converters emit lots of harmonics with high levels of high-order harmonic. So its major problem is to filter the harmonics.

According to the simulation data on the harmonic content provided by the converter manufacturer, the harmonic order concentrates on $12k \pm 1$, mainly in 11^{th}, 13^{th}, 23^{th}, 25^{th}, and there are some 5^{th} and 7^{th} harmonic. Figure 8 and 9 show the output voltage and current waveform and harmonic content for the converter with 3.5MVA inductive load. Figure 10 and 11 show no-load situation.

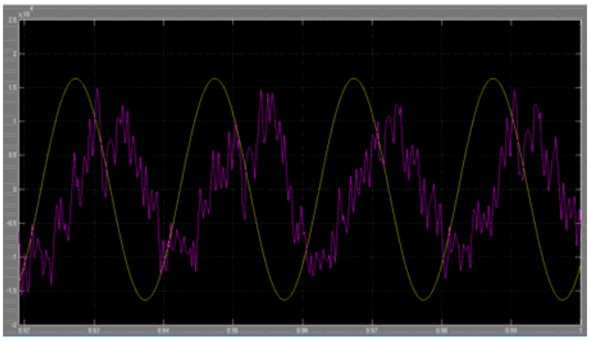

Figure 8 Output voltage and current when 3.5MVA inductive load

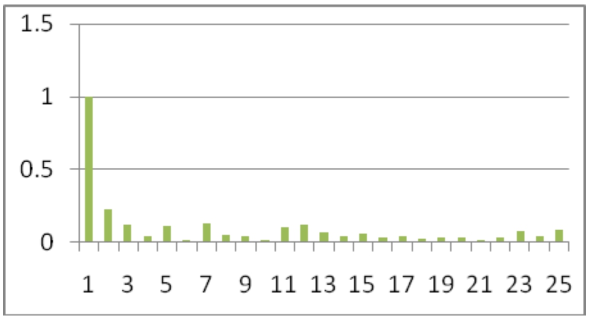

Figure 9 Harmonic content when 3.5MVA inductive load

No-load current is messy. The harmonic is more complicated, its distribution is lack of rules and its content level is very high.

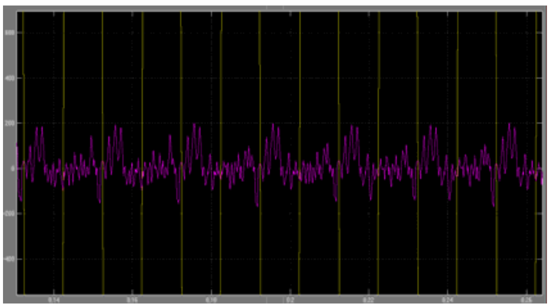

Figure 10 Output current when no-load

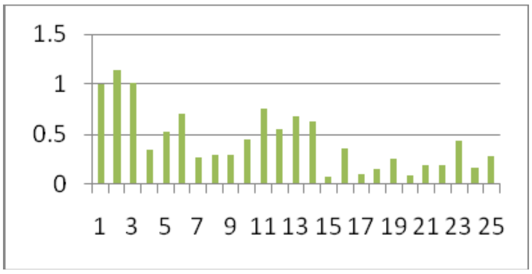

Figure 11 Harmonic content when no-load

5 CONCLUSIONS

The bus voltage of power supply system for Maglev usually uses 20KV or 35KV, harmonic current capacity is generally around a few MVar. It belongs to high-power medium voltage applications. Because the power factor of the inverter based on IGCT discussed in this paper reaches 1, no additional equipments are needed to compensate reactive power. So the main problem is to filter out harmonics. Under such conditions, the advantages and disadvantages of above-mentioned filters will be discussed in the following:

LC harmonic filter can filter out harmonics of specific orders, but there are two problems: first, with the capacitance and inductance component aging, the resistance will change, which may make the parallel resonant frequency point to integer, so the system has much possibility of parallel resonance. The inverter is very rich in harmonic content without load. Secondly, large amount of reactive power produced by LC filter needs to be absorbed by the converter, which increases the burden of converter.

Active filters (using multiple small-capacity conventional three-phase inverters in parallel form). The connecting transformer not only increases cost, and space requirement but also brings response delay and phase shift, which makes control more difficult. Furthermore, current in the transformer low voltage side is far larger than that in high voltage side and IGBTs are working at high switching frequency, both of which will increase heat losses. Last but not least, because of high content of 23^{th} and 25^{th} harmonics, high-frequency harmonics filter has to be installed, which increases the cost also.

Active filters (using cascaded H-bridge multilevel converter) can effectively overcome the above problems. Cascading in the high voltage side directly not only makes the current greatly reduced but also improves the response. Because of a large number of modules in series, devices are allowed to operate at lower switching frequencies to filter high-frequency harmonics. In engineering, the application of filter (using cascaded H-bridge multilevel converter) has been developed. For each phase N+2 modules are used, such redundancy approach ensures reliability.

Medium voltage power electronics technology is well established. Cascaded H-bridge multilevel converters based on medium voltage power electronic devices, which are suitable for medium-voltage high-power applications, develop very fast [2]. Considering the features of the high-power IGCT inverter, I recommend that active filter (using cascaded H-bridge multilevel converter) to be used in Maglev power supply system in the near future.

6 REFERENCE

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[2]LEOPOLDO G. FRANQUELO,JOSE RODRÍGUEZ, JOSE I. LEON,SAMIR KOURO, RAMON PORTILLO,and MARIA A.M. PRATS,“The Age of Multilevel Converters Arrives”,IEEE INDUSTRIAL ELECTRONICS MAGAZINE JUNE 2008