Analysis and Optimize Methods for the Output Waveform of the High Power Converter in Maglev

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Abstract--In this paper, the topological structure of a multilevel high power converter is presented. The output waveforms of the converter under different working conditions are analyzed. In order to eliminate the selected harmonic of the output voltage, the control methods of the converter is analyzed. Then an optimized control method is given in details. With this methods the output waveform of the converter is perfect. So this kind of converter is suitable for the heavy loads which are sensitive to the harmonics of the output of the converter.

I. Introduction

The high speed maglev is drived by the high power converter and sometimes there is a long distance (e. g. tens of kilometers) between the vehicle and the converter. If there is a big dv/dt with the converter output voltage, a voltage reflection may occur in the feed cable between the converter and the motor section. Then result in an over voltage and damage the cable. Also if there are abundant harmonics in the output waveform, a resonance may happen, then not only the cable but also the converters may be damaged. So the analysis and optimization of the converter output waveform is very important.

II. The structure of the converter

In order to provide big current when the vehicle starts and provide high enough voltage when the vehicle runs in high speed. A multilevel high power converter is applied. The topological structure of the converter is shown as Fig. 1.

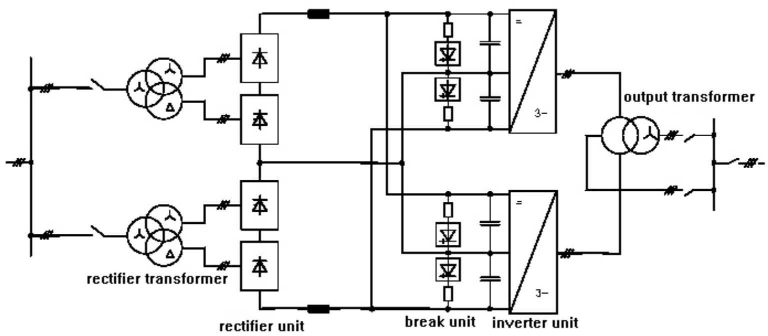

Fig.1 The topology structure of the system

The converter consists of two inverter modules, and each inverter module is based on three-level topological structure. See Fig. 2.

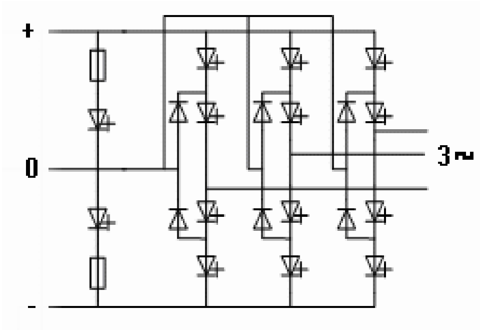

Fig.2 The structure of the inverter module

The two inverter modules are connected by an output transformer. In the primary winding of the transformer there is an additional center-tapped terminal, so the two inverter modules can be connected in series or parallel mode as desired. When the modules are connected in parallel mode, the center-tapped terminal is connected to the load by a switch and the secondary winding of the transformer doesn't work. In this way the output current of the converter is the sum of the two inverter modules. So it can provide big enough current for the load. When the load runs in high speed and needs high voltage to drive, the converter works in series mode. In this mode, the two inverter modules are in series connection and the secondary winding of the transformer is in star connection. So the converter can provide high enough voltage.

III. Analysis and optimization of the output waveform

When the vehicle runs in low speed, the output frequency of the converter is low. So we can apply the SHEPWM control method to eliminate the selected harmonic. Fig. 3 shows the three-level waveform.

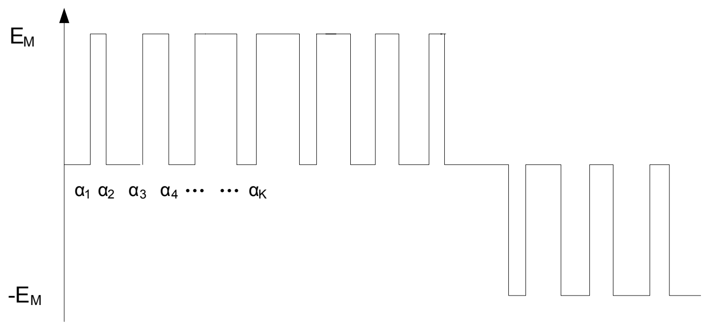

Fig. 3 The three-level PWM waveform

The $\alpha_1,\alpha_2,\ldots\alpha_N$ is the switching angle. Using FFT to the waveform we get the below equation:

$$\begin{cases} a_k = 0 \\ b_k = \frac{2}{\pi}\int_0^{\pi} f(\omega t)\sin k\omega t d(\omega t) = \frac{4}{k\pi}E_M\sum_{i=1}^{N}(-1)^{i+1}\cos k\alpha_i \end{cases}$$

Solve the equation b_k=0, we can get the switching angle $\alpha_1,\alpha_2,\ldots\alpha_N$. In this way the selected harmonics are eliminated. Fig.4 shows the output waveform measured in the laboratory.

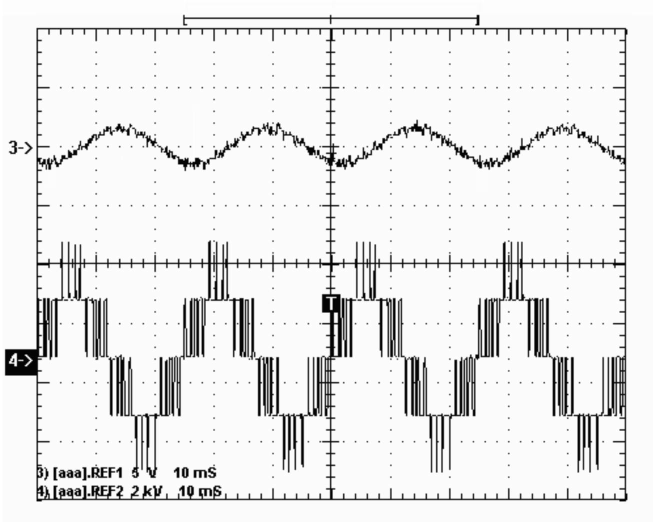

Fig.4 The waveforms of the output voltage and current measured in lab.

When the vehicle runs in high speed, The output frequency of the converter is required up to 300 HZ. Under this condition it is not suitable for the switching devices working in multi-pulse mode, such as PWM, for the switching frequency will be very high. We have to use the single pulse mode to reduce the switching losses and control the temperature. On the other hand, the load is sensitive to the harmonics of the converter, so we have to apply an optimized control method to eliminate the selected harmonic. Let's study the voltage waveform of the primary winding of the transformer. See Fig. 5.

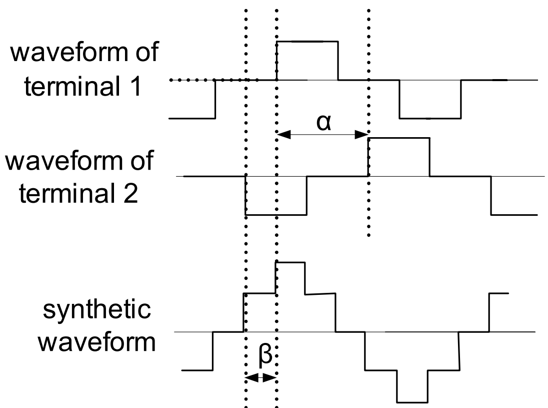

Fig.5 The waveforms of the primary winding of the output transformer

Now the converter works in series mode. We can change the RMS of the output voltage by change the angle α. (α is the phase difference of the three-level waveform of the two inverter modules). So the angle β is a freedom we can use to eliminate the selected harmonic. We get the below equation by using FFT to the synthetic waveform.

$$\begin{cases} a_k = 0 \\ b_k = \dfrac{2}{\pi}\int_0^{\pi} E_M \sin k\omega t d(\omega t) = \dfrac{2}{k\pi} E_M \left[1 - \cos k\pi + 2\sin\dfrac{k\pi}{2}\sin(\dfrac{k\pi}{2} - k\beta) \right] \end{cases}$$

From the equation we can find that no even harmonics in the output waveform. By change the angle β we can eliminate the selected odd harmonics. For example ,when $\beta = \frac{\pi}{7}$, we can eliminate 7th harmonic; When $\beta = \frac{\pi}{13}$,we can eliminate 13th harmonic.

Fig.6 shows the line voltage measured on-site. The measuring spot is after the output transformer. Fig.7 is the FFT result of the output voltage. It shows the harmonics are effectively suppressed.

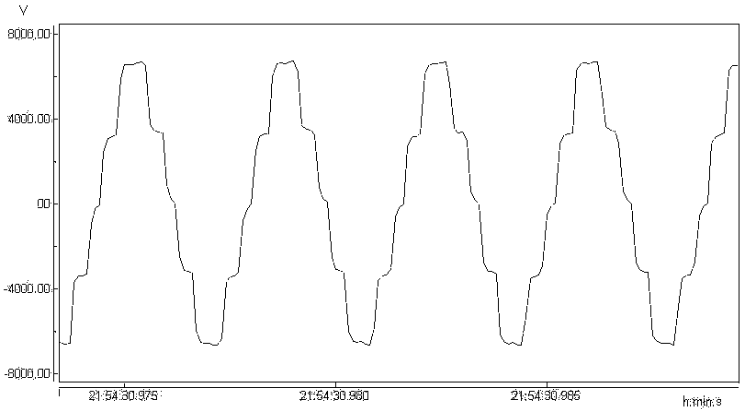

Fig.6 The line voltage waveform measured on-site

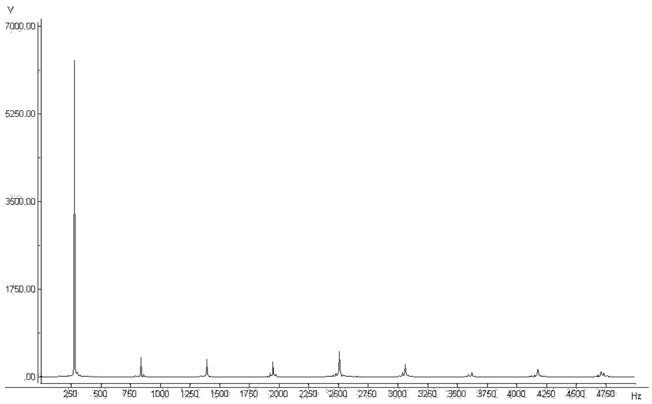

Fig.7 The spectrum of the FFT of the output voltage

IV. Conclusion

This kind of converter can provide high voltage and big current to the load. Especially with the optimized control methods, it can eliminate the selected harmonics. So this kind of converter is suitable for the heavy loads which are sensitive to the harmonics of the output of the converter.

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