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Study on Power Quality Evaluation of Traction Power Supply System of High-speed Railway

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Abstract: *With the continuous development and progress of China's high-speed railway system, the power supply of high-speed railway has become an important load of the power system. The introduction of large load will bring certain voltage fluctuation, harmonic interference and other random problems to the power system. In this paper, the positive sequence, negative sequence and zero sequence component models of current and voltage are established to solve the problem of equivalent modeling for power quality assessment of high-speed railway power supply system. Firstly, the positive sequence, negative sequence and zero sequence component models of current and voltage based on symmetric component method are established. Through Fourier transform, the phase Angle of fundamental wave is solved, and the positive sequence, negative sequence, zero sequence component, sequence component diagram and current spectrum diagram of current and voltage under three actual working conditions are obtained Through the analysis of the whole train operation process, the amplitude graphs of the positive sequence, negative sequence and zero sequence components of the current and the curves of the third harmonic possession with time are obtained by using the above methods.*

Keywords: *High-speed railway, Power supply system, Each order component, Power quality assessment*

1. Introduction

With the rapid development of China's economy, the pace of high-speed railway construction continues to accelerate, and high-speed railway technology continues to progress. Therefore, China has become the country with the largest load of electrified railway operation in the world, and the annual electricity consumption of railway accounts for about 80% of the total annual power generation of the Three Gorges Dam. The traction power supply system of high-speed railway is the core of the normal operation of electric locomotives [1]. Its load has the characteristics of high power, high density, non-linearity and randomness, etc., which brings negative sequence, harmonics, voltage fluctuation and other power quality problems to the traction power supply system, and brings adverse effects to the power grid operation and regulation. Therefore, it is very important to evaluate the regional power grid with high-speed rail traction load, develop energy-saving and consumption reduction strategies, and accurately predict the traction load.

2. Positive, negative and zero sequence component model of current and voltage based on symmetric component method

2.1 Symmetric component method is used to solve the principles of positive, negative and zero order components

Any asymmetrical three-phase phasor, I_a, I_b, I_c, can be decomposed into three groups of symmetric components with different phase sequences [2]: The positive order components I_{a1}, I_{b1}, I_{c1}, the negative order components I_{a2}, I_{b2}, I_{c2}, and the zero order components I_{a3}, I_{b3}, I_{c3}, are shown in Figure 1.

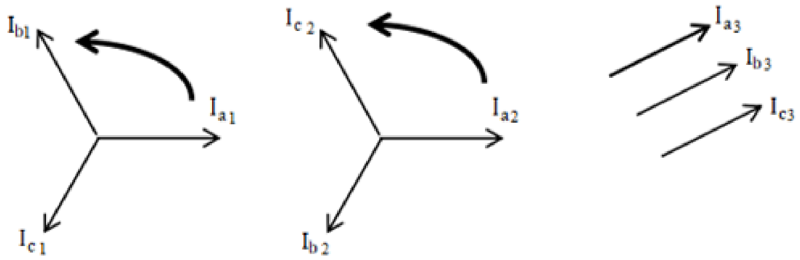

Figure 1: The positive, negative and zero sequence components of the current

When phase A is chosen as the reference phase, the relationship between the three-phase phasor and its symmetric components (e.g., the current) is:

$$\begin{cases} I_a = I_{a1} + I_{a2} + I_{a3} \\ I_b = a^2 * I_{b1} + a * I_{b2} + I_{b3} \\ I_c = a * I_{c1} + a^2 * I_{c2} + I_{c3} \end{cases} \tag{1}$$

a is operator $e^{120^\circ i}$。

According to the above equation, the positive sequence, negative sequence and zero sequence component equations of voltage or current can be calculated from three-phase voltage or current:

$$\begin{cases} I_P = \left(I_a + a * I_b + a^2 * I_c\right) / 3 \\ I_N = \left(I_a + a^2 * I_b + a * I_{b3}\right) / 3 \\ I_Z = \left(I_{c1} + I_{c2} + I_{c3}\right) / 3 \end{cases} \tag{2}$$

Taking its coefficient matrix as matrix operator, the following formula can be obtained:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{3}$$

2.2 In practice, positive, negative and zero order components are solved

Under ideal circumstances, the phase Angle of each of the three phases is 120°. However, since the actual phase Angle is unknown, it is necessary to calculate the actual phase Angle [3] [4].

The 4000 sampling unit Spaces A in A certain working condition are divided into 10 regions, and the secondary sampling space Q is obtained after the superposition of the above 10 regions.

$$Q = \sum_{i=1}^{10} A \tag{4}$$

Sample space $A = \begin{bmatrix} a_1 \\ \vdots \\ a_{4000} \end{bmatrix}_{4000\times1}$ $A = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_{10} \end{bmatrix}_{10\times1}$

2.3 Spectrum analysis using Fourier transform

Accordingly, Fourier transform is applied to the second-order sampling space Q to obtain the spectrum, where the Fourier transform formula is:

$$F(\omega)=F\left[Q(t)\right]=\int_{-\infty}^{+\infty}Q(t)e^{-j\omega t}dt \quad (5)$$

Then, the fundamental wave is separated from the k harmonic wave, and the phase Angle of the fundamental wave is taken as the phase Angle of the original three-phase signal. The fundamental wave is: $F(50)=a_0+b_0 j$ .K harmonic: $F(k*50)=\int_{-\infty}^{\infty}Q(t)e^{-50jkt}dt$. The phase Angle of the fundamental wave under each condition is obtained—— $\alpha=\arctan\frac{b_0}{a_0}$.

After this step, the current spectrum diagram and THD diagram can be obtained. According to the current spectrum diagram, the amplitudes and frequencies of the five harmonic components with the largest amplitudes are obtained [5].

2.4 Calculate negative sequence and zero sequence voltage unbalance degree.

The calculation formula of negative sequence voltage unbalance degree ε_{U2} and zero sequence voltage unbalance degree ε_{U0} is:

$$\begin{cases}\varepsilon_{U2}=\dfrac{U_2}{U_1}\times 100\% \\ \varepsilon_{U0}=\dfrac{U_0}{U_1}\times 100\%\end{cases} \quad (6)$$

2.5 Calculate the total harmonic distortion rate of current

The *h* harmonic current containing rate HRI_h Calculation formula:$HRI_h=\frac{I_h}{I_1}\times 100(\%)$

Harmonic current content I_H calculation formula:$I_H=\sqrt{\sum_{h=2}^{\infty}(I_h)^2}$

Total harmonic distortion rate of currentTHD_i:$THD_i=\frac{I_H}{I_1}\times 100(\%)$

Through the above steps, the following positive sequence, negative sequence and zero sequence component models of current and voltage can be established [6]:

3. Solving the current, voltage and sequence components under no-load, traction and braking conditions

Based on the above solution of the three-phase sequence component model, the three-sequence current and voltage under three operating conditions of no-load, traction and braking [7] are obtained. The results are shown in the table below.

Table 1: Voltage and current components under no-load conditions

	Voltage	Current
Positive sequence	9.4194×10^4 $+0.8375\times 10^4$i	0.0018 + 1.7600i
Negative sequence	-0.0651×10^4 $+0.0427\times 10^4$i	0.7863 - 0.3736i
Zero sequence	-0.0356×10^4 $+0.0127\times 10^4$i	-0.1720 + 0.0304i

Table 2: Voltage and current components under traction condition

	Voltage	Current
Positive sequence	-0.9037×10^4+9.4079×10^4i	0.7103 -11.1332i
Negative sequence	0.0532×10^4+ 0.0578×10^4i	-10.4011 - 5.2205i
Zero sequence	0.0189×10^4+ 0.0329×10^4i	0.0189 + 0.1497i

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Table 3: Voltage and current components under braking condition

	Voltage	Current
Positive sequence	$-4.2150\times 10^4 + 8.4764\times 10^4 i$	5.5451 - 8.7015i
Negative sequence	$-0.0286\times 10^4 - 0.0636\times 10^4 i$	-3.3579 - 9.4010i
Zero sequence	$-0.0002\times 10^4 - 0.0383\times 10^4 i$	-0.0111 - 0.1498i

The sequence components of current and voltage corresponding to the third working condition are shown in Figure 2 below:

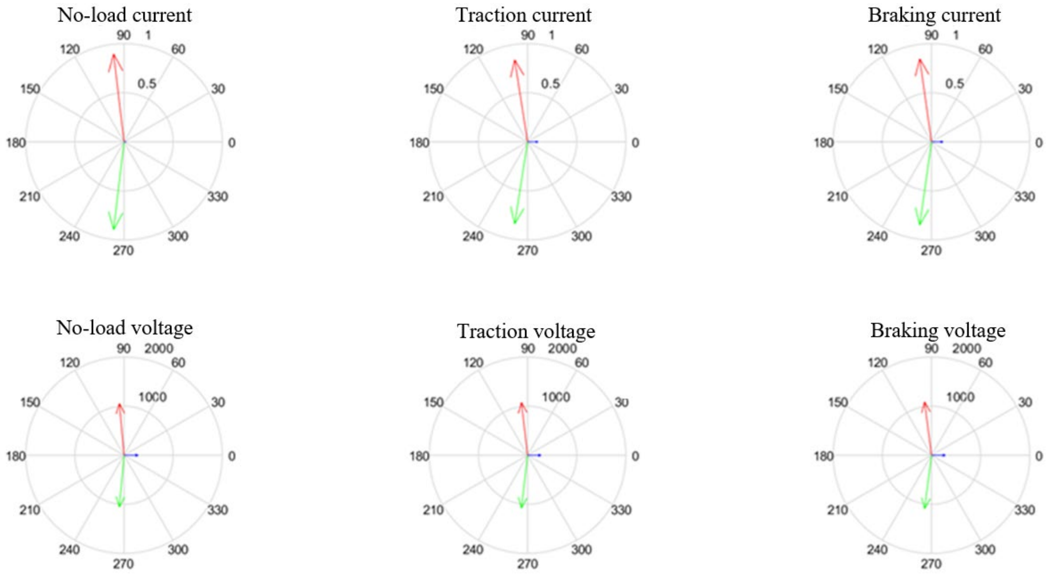

Figure 2: Current and voltage sequence component diagram under three working conditions

4. Current spectrum diagram

Based on the model, Fourier transform was carried out for the current under three working conditions to obtain the current spectrum diagram as shown in Figure 3.

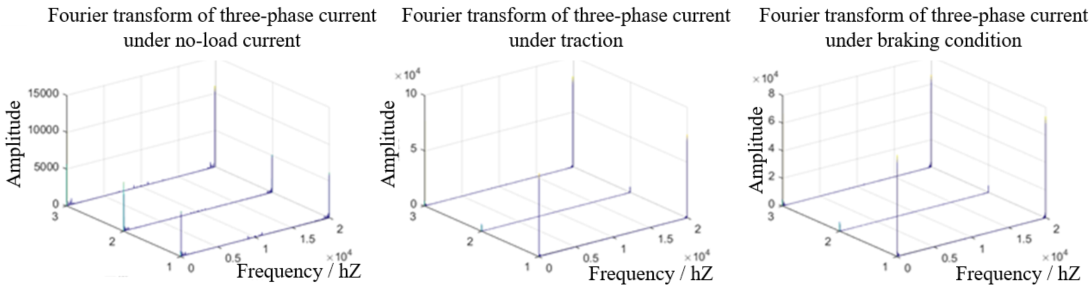

Figure 3: Current spectrum diagram of three working conditions

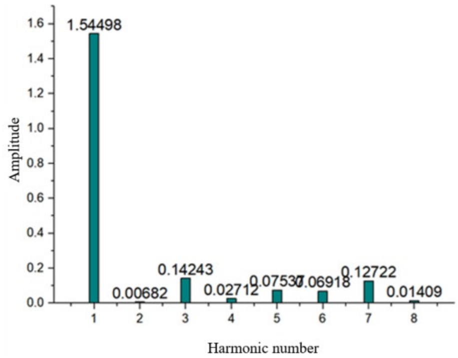

Figure 4: Harmonic histogram under no-load condition

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5. The amplitudes and frequencies of the five harmonic components with the largest amplitude

Table 4: Amplitude and frequency of harmonic components

The serial number	Amplitude (A)	Frequency //Hz
1	5.52	50
2	5.52	1.995×10^4
3	0.43	650
4	0.43	1.935×10^4
5	0.29	250

6. Conclusion

With the accelerating pace of high-speed railway construction in China and the continuous progress of high-speed railway technology, China has become the country with the largest operational load of electrified railway in the world. In order to ensure the normal operation of traction power supply system of high-speed railway and avoid adverse effects on power grid operation and regulation.

This paper evaluates the regional power grid with high speed rail traction load. The positive sequence, negative sequence and zero sequence component models of current and voltage are established by means of symmetric component method and Fourier transform method, and these problems are solved and analyzed. The data after model fitting is basically consistent with the actual data.

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