ISSN: 2664-9640

Operation Aata Analysis and Equivalent Modeling of High-speed Railway Traction power supply system

Shuo Zhang [1], Siyuan Yao[1] , Anqi Cai [1] , Kaiyuan Liu[2]

[1]School of Three Gorges University, Hubei 443000, China;

[2] School of North China University of Science and Technology, Tangsan 063210, China.

Abstract

Aiming at the problem of operation data analysis and equivalent modeling of high-speed railway traction power supply system, through a large number of data query, combined with the conditions given in this question, in the face of different requirements, different mathematical models were established for analysis and planning, and finally solved by programming software. Firstly, the study is carried out under different working conditions, and the sequence components of voltage and current are calculated by using symmetrical component method and the sequence component diagram is drawn. The amplitude and frequency of the five harmonic components with the largest amplitude were found by plotting the current spectrum of each operating condition. The uncertainty and the total harmonic distortion rate were calculated by the formula, so as to evaluate the influence of the degree of imbalance and current harmonics. When taking all the data as the object, the curves of the amplitude of positive sequence, negative sequence and zero sequence components of current and the third harmonic content with time as well as the curves of the instantaneous power of the train with time are drawn so as to obtain the relationship between the traction power, braking power and the three phase unbalance degree and harmonics. Firstly, the power consumption and feedback of high-speed EMUS are obtained by calculating the area of instantaneous power and time. The dynamic traction load model was established by linear regression. Finally, the grey prediction model is introduced to realize the simulation of dynamic traction load and accurate prediction of electric quantity of high-speed railway traction substation. In the traction power supply system, the single-phase traction transformer works in cooperation with the single-phase back-to-back converter PFC, and the traction transformer and PFC provide the continuous base frequency power supply for the locomotive with the same phase voltage. Thus the neutral section in substation is eliminated. In PFC, α -phase converter with single-phase traction transformer is used to realize unbalanced power compensation, and β -phase converter is used to realize basic frequency reactive power compensation. On the premise that reactive power filter can restrain harmonic current effectively and filter performance is good, the fundamental frequency operation of reactive power filter is discussed emphatically. Due to the operating voltage limitation of power electronic devices, PFC adopts step-down transformer on the power grid side and step-up transformer on the traction side. After calculating the test value through mathematical analysis and comparing it with the measured value, the error is only 1.6%, which verifies the validity of the model and improves and extends the model.

Keywords

Symmetric component method, correlation analysis, linear regression, grey prediction model.

1. Introduction

All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper. Use *italic* for emphasizing a word or phrase. Do not use boldface typing or capital letters except for section headings (cf. remarks on section headings, below).

Do not number your paper: All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question.

2. Symbol description

references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under a heading References, see Table 1.

Table 1: symbol description

symbol	implication
ε_{U_1}	Negative sequence voltage unbalance degree
ε_{U_0}	Zero sequence voltage unbalance degree
U_1	Square mean root of positive sequence component of three-phase voltage
U_2	Square mean root of negative sequence component of three-phase voltage
U_0	Square mean root of zero sequence component of three-phase voltage
HRU_h	The h times of harmonic voltage content degree
HRI_h	The h times of harmonic current content degree
U_H	Harmonic voltage content
I_H	Harmonic current content
THD_u	Total harmonic distortion rate of voltage
THD_i	Total harmonic distortion rate of current
$\dot{I}_A, \dot{I}_B, \dot{I}_C$	Three phase current

3. Problem analysis

3.1. Problem 1: Analysis of power quality assessment

The main operating conditions of high-speed EMUS can be divided into no-load, traction and braking. Different mathematical models are used to analyze different problems in these three operating conditions. The positive sequence, negative sequence and zero sequence components of voltage and current under each operating condition are obtained.

ISSN: 2664-9640

Function $A_{km}e^{j\phi_k}$ is the frequency spectrum function. According to it, the current spectrum of each operating condition can be drawn, and the amplitude and frequency of the 5 harmonic components with the maximum amplitude can be calculated according to the current spectrum.

According to the national power quality assessment standard in Appendix 1, the voltage and current unbalance degree and the total harmonic distortion rate of current under each operating condition are calculated according to the formula, and the influence of the unbalance degree and current harmonics can be evaluated accordingly.

3.2. Problem 2: Analysis of energy saving and consumption reduction schemes

Regenerative braking technology is widely used in high-speed EMUS, which converts kinetic energy into electric energy in braking conditions and feeds it back to the power system. The electric energy is the area of the curve of power change over time and the time axis. According to the instantaneous power calculation results in question 1, the consumption and feedback of high-speed EMUS are counted.

Design vehicle regenerative braking energy utilization system, from the system structure and function, energy utilization strategy and energy-saving effect and economic analysis. The regenerative braking energy utilization system of hub is designed and compared from the system structure and function, energy management scheme, energy saving effect, economic analysis and comprehensive income analysis.

3.3. Problem 3: Analysis of accurate prediction of dynamic traction load

To form the corresponding dynamic traction load database, the first response to the columns the emu in interval operation dynamic sequence active power demand in the process of extraction. On this basis, the application of correlation analysis methods, such as combination of appendix 3 to provide the information such as the emu running direction, models, the extracted dynamic traction load classification and identification. The dynamic traction load model was established by linear regression, and then the corresponding dynamic traction load model library was constructed. Finally, combining with the train schedule provided in Appendix 4, the grey prediction model is introduced to realize the simulation of dynamic traction load and accurate prediction of electric quantity of high-speed railway traction substation.

3.4. Problem 4: Analysis of equivalent modeling of traction load for high-speed railway traction substation

In the traction power supply system, the single-phase traction transformer and the single-phase back-to-back converter PFC work together. Traction transformers and PFC provide a continuous baseband power supply for locomotives with the same phase voltage. Thus the neutral section in substation is eliminated. In PFC, α -phase converter with single-phase traction transformer is used to realize unbalanced power compensation, and β -phase converter is used to realize basic frequency reactive power compensation. On the premise that reactive power filter can restrain harmonic current effectively and filter performance is good, the fundamental frequency operation of reactive power filter is discussed emphatically. Due to the operating voltage limitation of power electronic devices, PFC adopts step-down transformer on the power grid side and step-up transformer on the traction side. In order to verify the accuracy of the model, the voltage and current of the model should be calculated and analyzed. After the calculation formula is obtained, the same voltage value as before is selected to calculate the current value. Finally, the error of the model is obtained by comparing it with the measured current value.

ISSN: 2664-9640

4. Establishment and answer of Model 1

4.1. Model establishment

As the main load of traction power supply system, high-speed EMU has the characteristics of non-linear, single phase and impact, Due to the electric energy quality problems such as the harmonics of the regional power grids and Power such as negative order, different mathematical models should be used to evaluate the electric energy quality of the high-speed EMU.

4.1.1. Analysis of the three operating conditions

The main operating conditions of the high-speed EMU can be divided into no-live load traction and braking, and different mathematical models are chosen to analyze the different problems under these three working conditions.

Firstly, the positive sequence ,negative sequence and zero sequence components of voltage and current under each operation conditions are selected to introduce the symmetric component method to analyze the asymmetric three-phase voltage and three-phase current, and regard a set of asymmetric three-phase voltage and current as the superposition of three symmetrical voltage or current of the same frequency, which is called the symmetric component of the former.

In the vector graph, $\dot{I}_A^+$, $\dot{I}_B^+$ and $\dot{I}_C^+$ lags behind in turn 120°,it is called positive sequence,in the top right corner is marked "+"; $\dot{I}_A^-$, $\dot{I}_B^-$ and $\dot{I}_C^-$ take 120°in advance,known as negative order,in the top right corner is marked "-"; $\dot{I}_A^0=\dot{I}_B^0=\dot{I}_C^0$,three-phase current is in the same phase order,become zero sequence.Three sets of uncorrelated symmetric currents in positive sequence ,negative sequence and zero sequence components were superimposed,an asymmetric set of three-term currents is obtained $\dot{I}_A$、 $\dot{I}_B$、 $\dot{I}_C$,there is①:

$$\left.\begin{aligned}\dot{I}_A&=\dot{I}_A^++\dot{I}_A^-+\dot{I}_A^0\\\dot{I}_B&=\dot{I}_B^++\dot{I}_B^-+\dot{I}_B^0\\\dot{I}_C&=\dot{I}_C^++\dot{I}_C^-+\dot{I}_C^0\end{aligned}\right\}$$

In turn, any set of asymmetric three-phase currents can also break down the unique three sets of symmetric components.The relationship between the currents in the phase order components can be described as②:

$$\left.\begin{aligned}&\dot{I}_B^+=\alpha^2\dot{I}_A^+,\ \dot{I}_C^+=\alpha\dot{I}_A^+\\&\dot{I}_B^-=\alpha\dot{I}_A^-,\ \dot{I}_C^-=\alpha^2\dot{I}_A^-\\&\dot{I}_A^0=\dot{I}_B^0=\dot{I}_C^0\end{aligned}\right\}$$

In the equation,The plural computing symbol $\alpha=e^{j\frac{2\pi}{3}}=-\frac{1}{2}+j\frac{\sqrt{3}}{2}$, the effect is to make a phase quantity in positive rotation120°.

Substitute formula ② into formula①,can be obtained③:

$$\left.\begin{aligned}\dot{I}_A&=\dot{I}_A^++\dot{I}_A^-+\dot{I}_A^0\\\dot{I}_B&=\alpha^2\dot{I}_A^++\dot{I}_A^-+\dot{I}_A^0\\\dot{I}_C&=\alpha\dot{I}_A^++\alpha^2\dot{I}_A^-+\dot{I}_A^0\end{aligned}\right\}$$

From the persimmon formula, the components of each phase sequence of a can be obtained fr om the asymmetric three-phase current $\dot{I}_A$、 $\dot{I}_B$、 $\dot{I}_C$.Which is:

$$\left.\begin{aligned} \dot{I}_A^{+} &= \frac{1}{3}\left(\dot{I}_A + \alpha \dot{I}_B + \alpha^2 \dot{I}_C\right) \\ \dot{I}_A^{-} &= \frac{1}{3}\left(\dot{I}_A + \alpha^2 \dot{I}_B + \alpha \dot{I}_C\right) \\ \dot{I}_A^{0} &= \frac{1}{3}\left(\dot{I}_A + \dot{I}_B + \dot{I}_C\right) \end{aligned}\right\}$$

Because all the various phase-order components are symmetric,After finding the A phase component, the B, C phase component can be determined.And the The order component diagram can be drawn according to this.Finally, the degree of imbalance is calculated by the following formula,negative-order voltage disequilibrium ε_{U_1} ,zero-order voltage imbalance degree ε_{U_0} ,It is calculated as the following formula:

$$\left.\begin{aligned} \varepsilon_{U_2} &= \frac{U_2}{U_1}\times 100\% \\ \varepsilon_{U_0} &= \frac{U_0}{U_1}\times 100\% \end{aligned}\right\}$$

In this formula: U_1 is the root mean square value of the positive order component of the three-phase voltage,the unit is volt(V); U_2 is the root mean square value of the negative order component of the three-phase voltage,the unit is volt(V); U_0 is the root mean square value of the zero order component of the three-phase voltage,the unit is volt(V).

Replace U_1 , U_2 , U_0 in the equation with $\dot{I}_1$、$\dot{I}_2$、$\dot{I}_0$.

Is the expression of the corresponding current imbalance ε_{12} and ε_{10} .

To complete the current spectrum map of each operating condition,The non-sinusoidal periodic current function shall be decomposed into Fourier series,Non-sinusoidal periodic ,it is:

$$f(t) = f(t + nT)$$

Where the T is the cycle of the periodic function $f(t)$,after inspection,this cycle function meets the Dilligley conditions,Thus it can unfold into a convergent Fourier series,

$$\begin{aligned} f(t) &= \frac{a_0}{2} + \left[a_1 \cos(\omega_1 t) + b_1 \sin(\omega_1 t)\right] + \\ &\left[a_2 \cos(2\omega_1 t) + b_2 \sin(2\omega_1 t)\right] \\ &+ \ldots + \left[a_k \cos(2\omega_k t) + b_k \sin(2\omega_k t)\right] + \ldots \\ &= \frac{a_0}{2} + \sum_{k=1}^{\infty}\left[a_k \cos(2\omega_k t) + b_k \sin(2\omega_k t)\right] \end{aligned}$$

Coefficients in the upper equation,You can be obtained by the integration.

$$\frac{1}{T}\int_0^T f(t)\cos(n\omega_1 t)dt = \frac{1}{T}\int_0^T \left\{\frac{a_0}{2} + \sum\left[a_k \cos(k\omega_1 t) + b_k \sin(k\omega_1 t)\right]\right\}\cos(n\omega_1 t)dt$$

$$\frac{1}{T}\int_0^T f(t)\sin(n\omega_1 t)dt = \frac{1}{T}\int_0^T \left\{\frac{a_0}{2} + \sum\left[a_k \sin(k\omega_1 t) + b_k \sin(k\omega_1 t)\right]\right\}\sin(n\omega_1 t)dt$$

As $n \neq k$,The above integration are all zero; As $n = k$, in the first integral formula, only the integral of term a_k is not zero.in the second integral form ula, only the integral of term b_k is not zero.The following integral formula for solving a_k, b_k can therefore be obtained:

$$\left.\begin{aligned}
a_k &= \frac{2}{T}t\int_0^T f(t)\cos(k\omega_1 t)\,dt = \frac{2}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\cos(k\omega_1 t)\,dt \\
&= \frac{1}{\pi}\int_0^{2\pi} f(t)\cos(k\omega_1 t)\,d(\omega_1 t) = \frac{1}{\pi}\int_{-\pi}^{\pi} f(t)\cos(k\omega_1 t)\,d(\omega_1 t) \\
b_k &= \frac{2}{T}t\int_0^T f(t)\sin(k\omega_1 t)\,dt = \frac{2}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\sin(k\omega_1 t)\,dt \\
&= \frac{1}{\pi}\int_0^{2\pi} f(t)\sin(k\omega_1 t)\,d(\omega_1 t) = \frac{1}{\pi}\int_{-\pi}^{\pi} f(t)\sin(k\omega_1 t)\,d(\omega_1 t) \\
A_{km}e^{j\phi_k} &= a_k - jb_k = \frac{2}{T}\int_0^T f(t)e^{-jk\omega_1 t}\,dt
\end{aligned}\right\}$$

The function $A_{km}e^{j\phi_k}$ is also the spectral function,draw the current spectrum of each operating condition,

According to the current spectrum, the amplitude and frequency of the five harmonic compon ents with the largest amplitude can be calculated.

Combined with the National Electric Energy Quality Assessment Standards contained in Appendix 1 ,the voltage,current imbalance and current total harmonic distortion rate are calculated according to the following formula:

Calculation formula of the first harmonic voltage content rate HRU_h :

$$HRU_h = \frac{U_h}{U_1} \times 100\%$$

Calculation formula of the first harmonic voltage content rate HRI_h :

$$HRI_h = \frac{I_h}{I_1} \times 100\%$$

Calculation formula of the harmonic voltage content U_H:

$$U_H = \sqrt{\sum_{h=2}^{\infty} (U_h)^2}$$

Calculation formula of the harmonic current content I_H :

$$I_H = \sqrt{\sum_{h=2}^{\infty} (I_h)^2}$$

Calculation formula for total voltage harmonic distortion rate THD_u :

$$THD_u = \frac{U_H}{U_1} \times 100\%$$

ISSN: 2664-9640

Calculation formula of the total current harmonic distortion rate THD_i :

$$THD_i = \frac{I_H}{I_1} \times 100\%$$

Calculation formula of negative sequence voltage unbalance ε_{U2} and zero sequence voltage unbalance ε_{U0}:

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

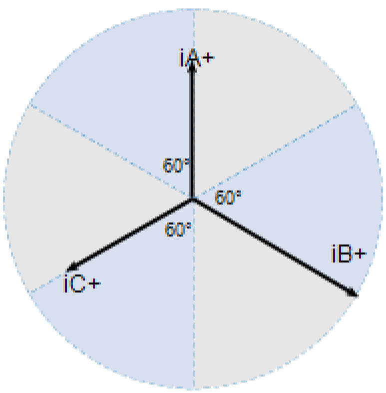
According to the above formula, the voltage, the current imbalance degree and the current total harmonic distortion rate can be calculated under each operating condition, from which the influence of the imbalance degree and the current harmonic wave can be evaluated.

4.2. Solutions to the model

The positive sequence, negative sequence and zero sequence of voltage and current under various operating conditions were calculated by using symmetric vector method and solved by MATLAB programming. Partial results are as follows (see appendix for detailed results) :

Table 1: components of voltage under braking conditions

Positive sequence			Negative sequence			Zero sequence		
$\vec{I}_A^{+}$	$\vec{I}_B^{+}$	$\vec{I}_C^{+}$	$\vec{I}_A^{-}$	$\vec{I}_B^{-}$	$\vec{I}_C^{-}$	$\vec{I}_A^{0}$	$\vec{I}_B^{0}$	$\vec{I}_C^{0}$
0.153	0.202	0.153	5.286	5.286	6.993	15.858	15.858	15.858
0.242	0.320	0.242	5.749	5.749	7.606	17.248	17.248	17.248



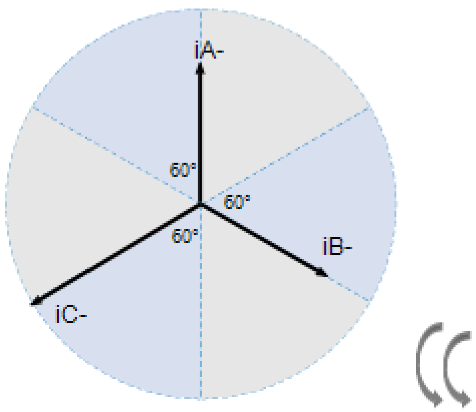


Figure 1: Positive sequence component diagram Figure 2: negative sequence component diagram

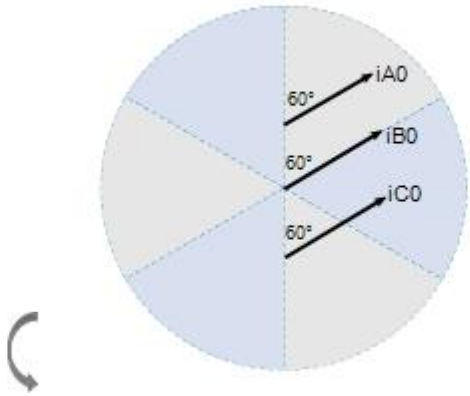


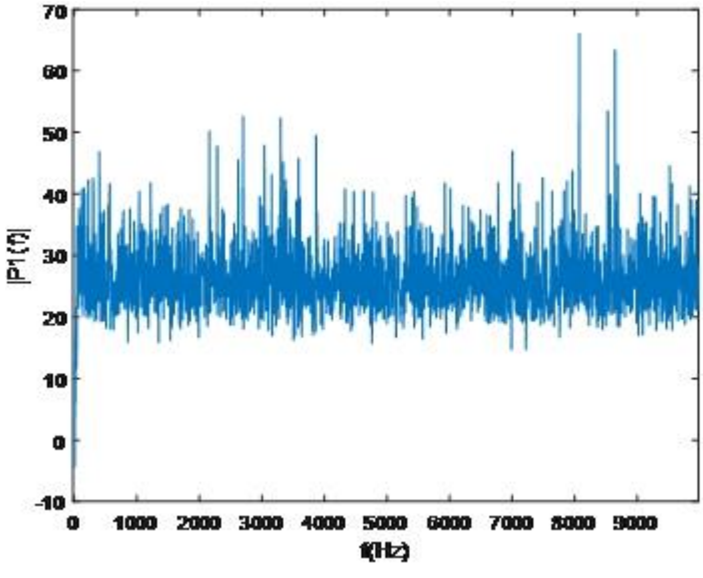
Figure 3:Zero-order component graph

The imbalance degree of voltage and current is analyzed by calculating the imbalance degree of voltage and current in this section. The greater the imbalance degree is, the greater the imbalance degree is. Some results are as follows (see appendix for detailed results) :

Table 2: The imbalance of voltage under brake conditions

Negative order	Zero order
34.54902	103.6471
21.84298	65.5289
15.57995	46.74255

Then the current spectrum of each operating condition is plotted as follows:



As shown in the figure above, the five harmonic components with the maximum amplitude and their frequencies can be obtained as follows:

Table 3: the five harmonic components with the largest amplitude and their frequencies

A phase no-load		A phase traction		A phase brake	
Amplitude	frequency	amplitude	frequency	amplitude	frequency
6179.9	0.1375	75484.	20000.125	73526.58	50000.13
762.2528	0.0125	2158.1	20000.025	3709.185	50000.25

ISSN: 2664-9640

649.7155	0.3875	1677.6	20000.375	2141.602	50000.38
508.8634	0.8875	1630.2	20000.625	2027.802	50000.63
499.6594	1.6375	1011.2	20000. 5	1676.874	50000.5
B phase no-load		B phase traction		B phase brake	
Amplitude	frequency	amplitude	frequency	amplitude	frequency
6708.8	0.0125	6735.344	20000	6817.436	50000
5127.3	0.1375	5285.318	20000.13	5166.11	50000.13
620.8361	0.3875	609.8959	20000.38	568.2037	50000.38
426.1789	0.8875	481.4511	20001.63	469.3039	50001.63
389.5157	1.3875	446.5826	20001.38	360.0662	50000.88
C phase no-load		C phase traction		C phase brake	
amplitude	frequency	amplitude	frequency	amplitude	frequency
11047.3	0.1375	82157.65	20000.13	66798.09	50000.13
5693.7	0.0125	4840.202	20000	4918.098	50000
866.9028	1.6375	2258.382	20000.25	3762.456	50000.25
598.9810	0.6375	1552.166	20000.63	2386.833	50000.63
530.4713	1.3875	1502.766	20000.38	1582.038	50000.5

Through data query, combined with the national power quality assessment standard in the appendix, the voltage and current imbalance degree under each operating condition was calculated,Partial results are as follows (see appendix for detailed results) :

Table 4: Voltage unbalance under braking condition

Negative sequence	Zero sequence
15.05993	45.17978
32.66667	97.99625
22.13706	66.41117

The total harmonic distortion rate of the current is shown in the figure below:

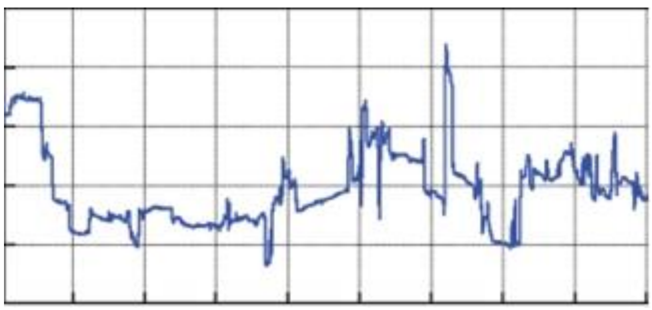


Figure 4: Total harmonic distortion rate of a-phase current

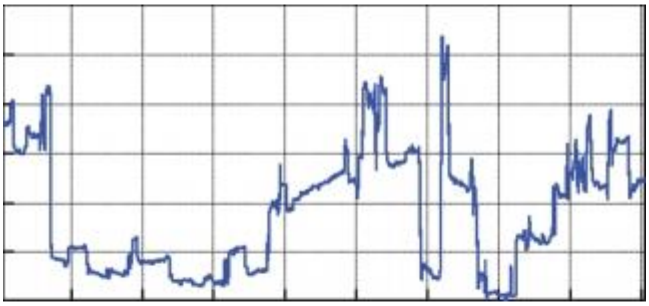


Figure 5: Total harmonic distortion rate of b-phase current

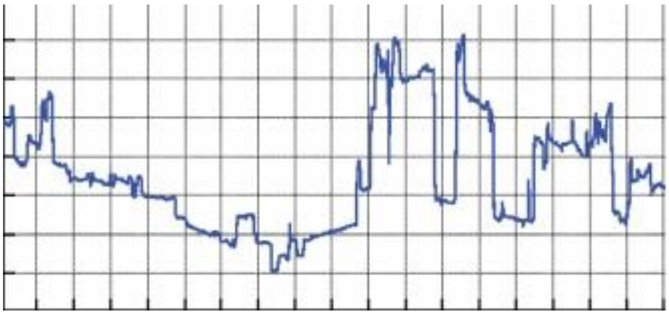


Figure 6: Total harmonic distortion rate of C-phase current

When all data are taken as the analysis object, the amplitude of positive sequence, negative sequence and zero sequence components of current and the variation curve of the third harmonic content are shown as follows:

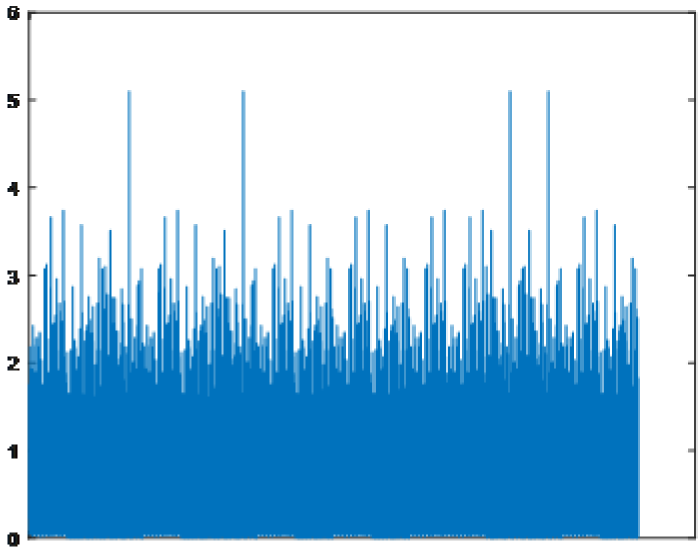


Figure 7: Current positive sequence changes with time

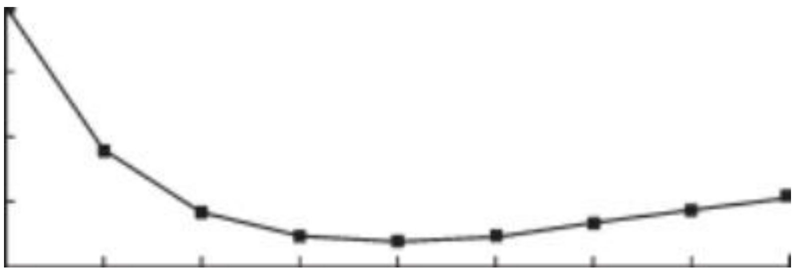


Figure 8: Variation of 3rd harmonic content over time

It can be seen from the above curve that the highest period of the curve is the period of the most serious imbalance.

ISSN: 2664-9640

The instantaneous speed of the train is calculated by the formula as 699098.512874683 watts, 508098.230751231 watts, 608657.230186975 watts, etc. (see appendix for detailed results). According to it, its change curve with time is shown as follows:

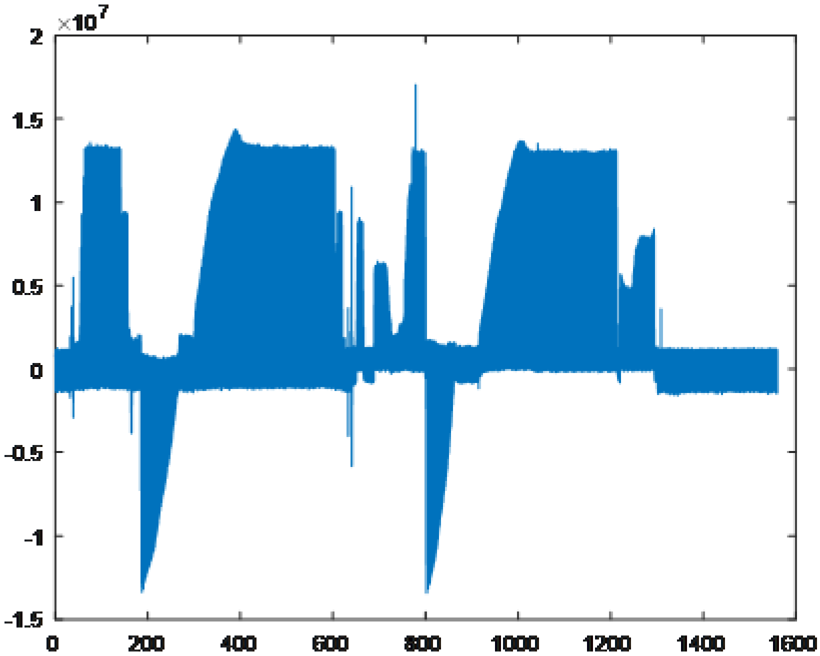


Figure 9: Instantaneous power diagram

According to the above curves, the moment of maximum traction power and braking power can be found out,The maximum moment of traction power is 8.007685 seconds, and the maximum moment of braking power is 20.0155 seconds.

According to the diagram above, we can find the relationship between traction power, braking power and three-phase unbalance degree and harmonics.

5. Establishment and solution of model 2

5.1. Statistics of power consumption of high-speed EMU

Regenerative braking technology is widely used in high-speed EMUs, which converts kinetic energy into electric energy under braking conditions and feeds it back to the power system. In the first question, the variation curve of instantaneous power with time has been obtained. In the three operating conditions of EMUs, only braking conditions play a role of feedback, and other conditions play a role of consumption. The relationship between electric quantity and power and time is as follows:

$w = P \times t$

It can be seen that the electric quantity is the area surrounded by the power change curve with time and the time axis.

According to the instantaneous power calculation results in question 1, count the power consumption and feedback of high-speed EMU. The feedback power is $0.1804 \times 10^2 KW \cdot h$, The power consumption is $1.3667 \times 10^2 KW \cdot h$.

ISSN: 2664-9640

5.2. Regenerative braking energy utilization scheme placed on vehicle energy storage On board regenerative braking energy utilization system.

5.2.1. System structure and function

The topology of regenerative braking energy utilization system with on-board energy storage is shown in the figure below, including isolation transformer, btbc, energy storage converter and supercapacitor

The functions of each part are as follows: the ESS and TPS are connected by isolation transformer. Specifically, the primary side of the isolation transformer is connected to t bus and track, and the secondary side is connected to btbc. The btbc is connected to an isolated transformer to transfer energy between the two power phases and the supercapacitor. In addition, an energy storage converter is connected between the DC bus and the super capacitor to transfer energy between the DC bus and the super capacitor. This structure can improve the utilization of RBE and reduce the imbalance between the two power phases. In addition, the proposed topology provides a DC interface to integrate renewable resources along the railway.

5.2.2. Energy utilization strategy

1) Converter main mode control strategy: the left converter of btbc works in main mode. According to the control objective, the classical double loop control mode of current inner loop and voltage outer loop is used to control the DC bus voltage and reference current, and the proportional integral control is used to stabilize the DC bus voltage .

2) Control strategy of the slave converter: according to the control objectives of the slave converter, the btbc and the right converter of the energy storage converter are required to adjust the current equal to the reference current. Therefore, both slave stations only use the current control.

3) State machine logic strategy: adjust the state machine to meet the following objectives: (1) determine the operation mode of ESS and generate reference power and current for the converter; (2) Realize seamless transition between different operation modes.

5.2.3. Energy saving effect and economic analysis

(1) Energy saving analysis

When the energy-saving regenerative braking scheme is not adopted, the 24h power consumption of EMU is 124.58mw · h, and the maximum demand is 16.11mw. The charging and discharging power threshold of the energy storage system is 10MW and the capacity threshold is 100kW · h. The measured data are analyzed. After setting the energy storage system, the maximum daily demand of the traction substation is reduced by 948.31kw and 5.89%. In terms of power saving, the traction substation can save 5.51mwh power every day. Compared with before energy storage, the power saving ratio is 4.42%. The daily power saving of energy-saving regeneration system is as follows:

Table 4: Daily power saving of energy saving regeneration system

Parameter	Numerical Value	Proportion
Reduce maximum demand /KW	948.31kW	5.89%
Saved power /(MWh)	5.51MWh	4.42%

(2) Cost analysis

The scheme cost mainly considers the cost of system integration (container, air conditioner, etc.) and the cost of system hardware (isolation transformer, converter, super capacitor). The specific cost is shown in the table:

ISSN: 2664-9640

Table 5: Cost of energy storage scheme

Name	Unit / 10000 yuan	Total price / 10000 yuan
System integration /MW	5	50
Isolation transformer /MW	3	60
Four quadrant converter /MW	20	400
Bidirectional DC /DC/MW	15	150
Supercapacitor/MW	60	600
Total Cost	-	1310

The super capacitor in the table is composed of standard modules connected in series and parallel. The super capacitor selected in this paper can store about 10kW electric energy per MW. According to the cost unit prices listed in the table, the total cost of 10MW and 100kW · h energy storage system set in this case is 13.1 million yuan, of which the highest single cost is super capacitor, which reaches 6 million yuan, followed by converter cost, which reaches 5.5 million yuan.

(3)Comprehensive income analysis

The scheme benefits include direct economic benefits (saved electricity charges) and indirect economic benefits (such as improving power supply reliability and stability, improving power quality, etc., and prolonging the service life of traction power supply system equipment). Because it is difficult to evaluate indirect economic benefits, this paper only considers direct economic benefits.

According to the daily power saving data of the substation in the table, calculate the annual electricity saving. It can be seen from the annex that the electricity price of high-speed EMU is 0.63 yuan / kWh, so the calculation of annual electricity charge can be calculated accordingly. The comparison results of annual electricity charge before and after on-board regenerative braking energy utilization system are shown in the figure below

It can be seen from the figure that after the energy storage is set, the basic electricity charge and electricity charge will be reduced by 5.89% and 4.42% respectively, and the annual total electricity charge saving ratio will be 4.59%, saving a total of 1.7309 million yuan.

5.3. Hub regenerative braking energy utilization system

5.3.1. System structure and function

The topology of regenerative braking energy utilization system in electrified railway hub is shown in the figure, including btbc, energy feed system and energy storage system

The functions of each part are as follows :

(1)BTBC. Connecting the isolation transformer and the traction power supply arm can balance the power of the two power supply arms and provide stable DC voltage for the external power flow device.

(2) Energy feed system. The three-phase grid connected inverter inverts the direct current into three-phase power frequency alternating current, which is connected to the energy feedback point of railway 10kV power system through step-up transformer to feed back electric energy.

(3) Energy storage system. The charge / discharge working mode can be switched to absorb the remaining regenerative braking energy after feedback or provide electric energy for the load of the power supply arm.

The coordinated control of the above three parts can make the regenerative braking energy flow in two directions between the energy storage system and the traction power supply system or supply power according to the power demand of 10kV load. At the same time, in

ISSN: 2664-9640

order to ensure the reliability of railway 10kV power system for power supply to primary load, the energy feedback point will only be set on the comprehensive load power through line.

5.3.2. Energy management scheme

The regenerative braking power of the electrified railway hub fluctuates greatly, and the constant power feedback is easy to cause excessive or insufficient feedback of the system. By judging the working conditions (working or idle) of the energy feedback system and the energy storage system, the operation modes of the regenerative braking energy utilization system can be divided into four types: ① idle mode; ② Energy storage mode; ③ Energy feed mode; ④ Energy feed + energy storage mode. The four operation modes and corresponding transition conditions are shown in the figure below. The characteristics of each operation mode are as follows:

(1) Idle mode. In this mode, the energy feed system and energy storage system are idle, and there is no energy connection between the traction power supply system and the railway 10kV power system.

(2) Energy storage mode. In this mode, the energy feed system is idle, and the energy storage system stores or releases regenerative braking energy.

(3) Energy feed mode. In this mode, the energy storage system is idle, and the energy feed system will feed back the regenerative braking energy to the railway 10kV power system for 10kV load.

(4) Energy feed + energy storage mode. In this mode, both the energy feed system and the energy storage system work. The energy feed system feeds back the regenerative braking energy to the railway 10kV power system, and the energy storage system stores or releases the regenerative braking energy.

5.3.3. Energy saving effect and economic analysis

When the energy-saving regenerative braking scheme is not adopted, the 24h power consumption of the motor car is 124.58mw · h, and the maximum demand is 16.11mw. The charging and discharging power threshold of the energy storage system is 10MW and the capacity threshold is 100kW · h. The measured data are analyzed. After setting the energy storage system, the maximum daily demand of the traction substation is reduced by 968.25kw and 6.01%. In terms of power saving, the traction substation can save 5.78mwh power every day. Compared with before energy storage, the power saving ratio is 4.64%. The daily power saving of energy-saving regeneration system is as follows:

Table 6: daily power saving of energy saving regeneration system

Parameter	Numerical Value	Proportion
Reduce maximum demand /KW	968.25kW	6.01%
Saved power /(MWh)	5.78MWh	4.64%.

5.3.4. Comprehensive income analysis

The scheme benefits include direct economic benefits (saved electricity charges) and indirect economic benefits (such as improving power supply reliability and stability, improving power quality, etc., and prolonging the service life of traction power supply system equipment). Because it is difficult to evaluate indirect economic benefits, this paper only considers direct economic benefits.

According to the daily power saving data of the substation in the table, calculate the annual electricity saving. It can be seen from the annex that the electricity price of high-speed EMU is 0.63 yuan / kWh, so the calculation of annual electricity charge can be calculated accordingly. The comparison results of annual electricity charge before and after on-board regenerative braking energy utilization system are shown in the figure below.

ISSN: 2664-9640

It can be seen from the figure that after the energy storage is set, the basic electricity charge and electricity charge will be reduced by 6.01% and 4.64% respectively, and the annual total electricity charge saving ratio will be 4.80%, saving a total of 1.18101 million yuan.

5.4. Comparison of two schemes

Finally, by comparing schemes B and C, it can be found that under the condition of similar cost, scheme C saves more electricity than scheme B, so the electricity charge of scheme C will be lower than that of scheme B. at the same time, the security of both schemes is very reliable. Therefore, scheme C is better than scheme B.

6. Problem three: establishment and solution of model

6.1. Establishment of model

6.1.1. Extraction of dynamic active power demand

After a large amount of data inquiry and collection, the traction power obtained by the EMU passes through the traction transformer, pulse rectifier, traction inverter and traction motor in turn, and finally is converted to the wheel circumference output power of the wheels of the EMU.

Therefore, under different operating conditions, the active power at the networking side of the motor car can be expressed as

$$p_{net}(t)=\begin{cases}\dfrac{p(t)}{\eta}+p_{aux},p(t)<0\\ p_{aux},p(t)=0\\ p(t)\cdot\eta+p_{aux},p(t)>0\end{cases}$$

Through the above formula, $p(t)=\dfrac{1000F_D(t)v(t)}{3.6}$ combined with the data in Annex III, the dynamic active power demand sequence can be obtained.

After obtaining the active power, draw it into a curve as follows:

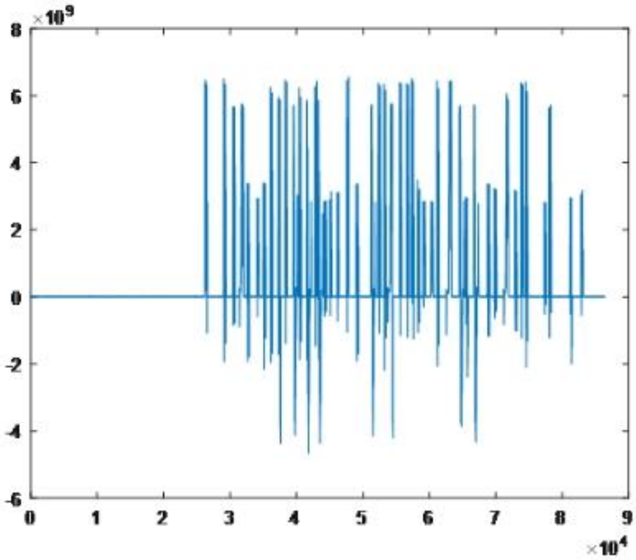


Figure 10: Active power

ISSN: 2664-9640

Under the condition of obtaining the active power, the correlation analysis is selected to classify and identify the EMUs in the appendix in combination with the operation direction, vehicle type and other information of EMUs provided in Appendix 3.

Combined with the line data and the dynamic load calculation model of multiple units of each train number, the dynamic traction load calculation model of the line throughout the day can be constructed.

In order to realize the simulation of dynamic traction load and accurate prediction of electric quantity in high-speed railway traction substation [3], the grey prediction model is selected to be introduced. Firstly, the first-order cumulative new data sequence $x(1)$ is obtained respectively according to the original load sample data sequenÎ$x(2)$

$$x_i^{(1)} = \sum_{k=1}^{i} x_k^{(0)}, i = 1, 2, 3 \ldots, n$$

The new sequence is used to generate the nearest mean generation order.

7. Establishment and solution of model 4

7.1. Buildup of model

In order to deeply study the influence of high-speed EMU operation on power grid, a mathematical model reflecting high-speed EMU operation was established to analyze voltage and current.

In the traction power supply system, the single-phase traction transformer works in cooperation with the single-phase back-to-back converter PFC.

Traction transformers and PFC provide a continuous baseband power supply for locomotives with the same phase voltage. Thus the neutral section in substation is eliminated. In PFC, α -phase converter with single-phase traction transformer is used to realize unbalanced power compensation, and β -phase converter is used to realize basic frequency reactive power compensation. On the premise that reactive power filter can restrain harmonic current effectively and filter performance is good, the fundamental frequency operation of reactive power filter is discussed emphatically. Due to the operating voltage limitation of power electronic devices, PFC adopts step-down transformer on the power grid side and step-up transformer on the traction side.

To verify the accuracy of the model, the voltage and current of the model should be calculated and analyzed. Firstly, the active power balance equation is composed as follows:

$$\begin{cases} U_T I_{TP} + U_\alpha I_{\alpha P} = U_T I_{LP} \\ U_T I_{TP} + U_\beta I_{\beta P} = U_T I_{LP} \end{cases}$$

The second is the reactive power balance equation:

$$\begin{cases} I_{TP} = I_{\alpha P} = 0 \\ U_\beta I_{\beta P} = U_T I_{LP} \end{cases}$$

The modified unbalanced current equation is composed of active and reactive power components:

$$\begin{cases} \dfrac{1}{2\sqrt{3}N_1} I_{TP} - \dfrac{1}{6N_2} I_{\alpha P} = 0 \\ -\dfrac{1}{2N_1} I_{TP} + \dfrac{C}{2\sqrt{3}N_2} I_{\alpha P} = 0 \end{cases}$$

Finally, the operating current of single-phase traction transformer and the compensation current of PFC are obtained, and written as:

$$\begin{cases} I_{TP} = \dfrac{1}{2} I_{LP} \\ I_{TP} = 0 \\ I_{\alpha P} = \dfrac{\sqrt{3}N_2}{2N_1} I_{LP} \\ I_{\alpha q} = 0 \\ I_{\beta P} = \dfrac{N_3}{2} I_{LP} \\ I_{\beta q} = N_3 I_{LP} \end{cases}$$

7.2. Solution of model

After obtaining the calculation formula, select the same voltage value as before to calculate the current value, and finally compare it with the measured current value, so as to get the error of the model. Draw the model current and the measured current into the same figure for comparison, as shown below:

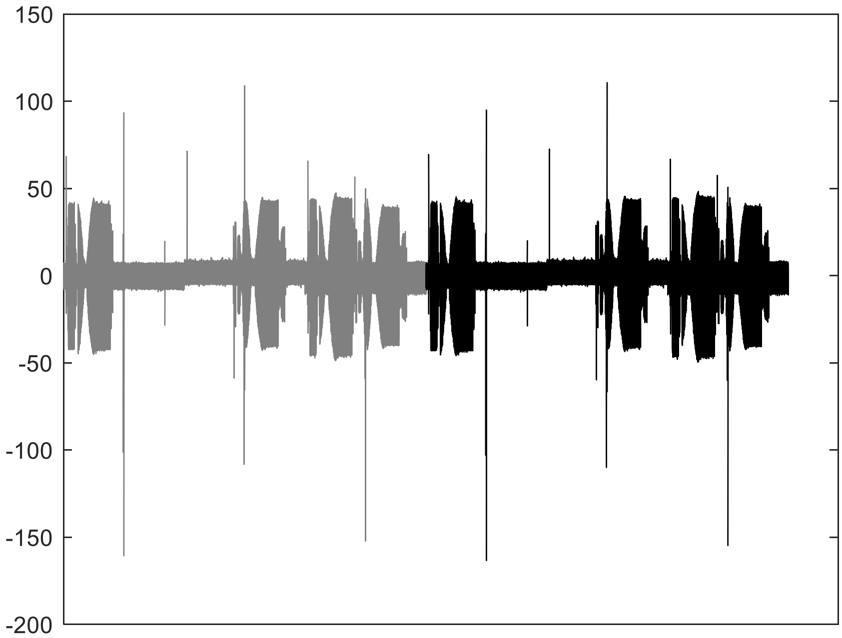


Figure 11: Comparison of model current with measured current

It can be seen from the figure above that the current value of the model is basically the same as the measured current value. After comparing and calculating its amplitude, it is found that the current value of the model is 1.016 times of the measured current value, that is to say, the error between the model value and the measured value is 1.6%. It can be seen that the difference between the model value and the measured value is very small, which verifies the validity of the model. On this basis, the model can be further improved to make it not only applicable to EMU, but also applicable to other vehicles such as cars, so that it can play a greater role.

References

[1] Xia Yankun. A photovoltaic power generation access method to reduce the negative sequence current of high-speed rail traction power supply system [J]. Sichuan electric power technology, 2021,44 (04): 62-66.

[2] Cheng Caihong. Study on Optimization of relay protection scheme for traction substation of high-speed railway [J]. China Railway, 2021 (04): 85-91.
[3] Chen Jinqiang, Zhao Liping, Xie Shaofeng, Chen Weirong. Teaching design and practice of virtual simulation experiment of high speed railway traction power supply system [J]. Research on higher engineering education, 2021 (01): 67-71 + 107.
[4] Wang pan. Research on self-healing reconstruction scheme of intelligent traction power supply system of Beijing Zhangjiakou high speed railway [J]. Electrified railway, 2020,31 (S2): 126-131
[5] Lang Bing, sun Jianxin, Wang Yajie. Research on simulation system of traction power supply dispatching operation and fault handling of high speed railway [J]. Electrified railway, 2020,31 (06): 7-13.
[6] Xia Yan. Research and development prospect of Railway Intelligent traction power supply system technology [J]. Electrified railway, 2020,31 (04): 1-5 + 14.