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Simulation software for CRH2 and CRH3 traction driver systems based on SIMULINK and VC*

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Abstract: Simulation models of traction driver systems were established using SIMULINK, according to the actual structure and parameters of China Railway High-Speed 2 (CRH2) and China Railway High-Speed 3 (CRH3) trains. In these models, the traction motor adopts transient current control and an indirect rotor magnetic field orientation vector control strategy, and the traction converter uses sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) methods. After these models are transformed in VC++ program, and a friendly interface and data processing system are constructed, simulation software is obtained for CRH2 and CRH3 traction driver systems. On this basis, the operational performance of a traction converter was simulated and analyzed at different train speeds and in different conditions. The simulation results can provide a reference for the actual design and production of a traction converter.

Key words: High-speed train, Traction driver system, VC, China Railway High-Speed (CRH)
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1 Introduction

In recent years, the construction of high-speed trains has developed very quickly in China, especially the China Railway High-Speed 2 (CRH2) and China Railway High-Speed 3 (CRH3) models. Along with this development, the basic theories relative to CRH have been given more attention. Research on traction driver systems is particularly important because such systems transform the energy between the electric network and the train. They should not only supply enough energy to the train but also have high efficiency and high quality. To improve their performance, detailed simulation results are required. Thus, a suitable simulation method needs to be investigated (Song, 2009).

Normally, a simulation model of a traction driver system is developed using SIMULINK software. Due to strong computer power and the abundant components of SIMULINK, a model is easily established. But this kind of model cannot run without SIMULINK and also lacks a friendly interface to input parameters and output results. Moreover, users need to master the SIMULINK software and know the model well if they want to use it. These disadvantages limit its wide application. To overcome these disadvantages, a combined programming method using SIMULINK and VC++ is adopted because VC++ is popular software with object oriented. A strong simulation program with a friendly interface can then be obtained. Moreover, it can run on any computer and without SIMULINK (Zhang and Wang, 2008).

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2 Simulation model

The CRH2 and CRH3 are typical types of high-speed train and are becoming increasingly popular in China. Their traction driver systems consist of a traction transformer, a traction converter and traction motors. The function of the traction transformer is to change the 25 kV from the electric network to 1500 V. This single phase AC power is supplied to the traction converter, which adopts a popular AC-DC-AC transmission method. It includes a single phase pulse rectifier, a traction inverter and an intermediate DC link. Using this inverter, the 1500 V single phase AC voltage is rectified to 2600 V DC voltage, and then the DC power is inverted to three phase AC power with variable frequency and variable voltage, and supplied to four traction induction motors (Song, 2009).

For the CRH2, the topology of both the single phase pulse rectifier and the traction inverter is three-level, and has a controlled bridge for energy conversion. For the CRH3, the topology of both the single phase pulse rectifier and the traction inverter is two-level, with a controlled bridge. The controlled bridge operation principle can be illustrated based on their equivalent circuit (Carter *et al*., 1997; Lin and Lu, 2000). For example, Fig. 1 shows the equivalent circuit of a single phase pulse rectifier. Its voltage equation is

$$\dot{U}_s = \mathrm{j}\omega L\dot{I}_s + R\dot{I}_s + \dot{U}_{ab}, \quad (1)$$

where $\dot{U}_s$ is the input voltage, ω is the angular speed, R is the equivalent resistance, L is the equivalent inductance, $\dot{U}_{ab}$ is the output voltage of the single phase pulse rectifier, and $\dot{I}_s$ is the input current.

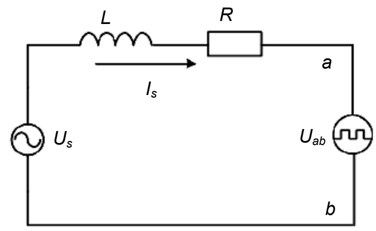

Fig. 1 Equivalent circuit of a single phase pulse rectifier

The traction motor adopts indirect rotor magnetic field orientation vector control strategy and space vector pulse width modulation (SVPWM) method. The position of the rotor flux need not be measured or directly calculated, but can be indirectly deduced from the slip frequency. The estimated value is taken as the position angle of stator current coordinate transformation. Comparing the measured motor speed with the given speed, the speed regulator obtains the given torque component of the stator current. The given rotor flux is deduced from the given curve of the rotor flux and speed. According to this flux, the excitation component of the stator current is calculated. By comparing these two given components of stator current to the corresponding current measured by the proportional-integral (PI) regulator, the given d*q* components of the voltage are obtained. These are then transformed in α-β coordinates with the estimated position of the rotor flux (Depenbrock, 1988; Lascu *et al*., 2000). Finally, the two voltage components are supplied to the SVPWM unit and output three phase variable voltage and variable frequency (VVVF) voltage.

Based on the CRH2 traction driver system, the simulation model is constructed based on SIMULINK (Fig. 2).

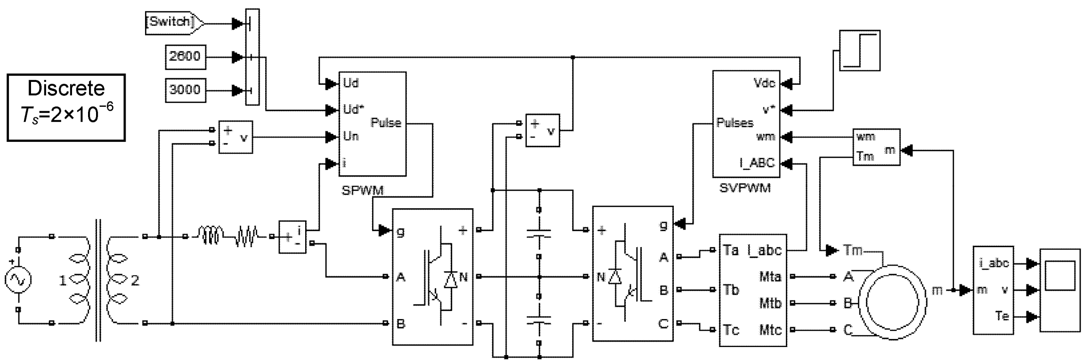

Fig. 2 Simulated model of the traction driver system of CRH2

Based on the CRH3 traction driver system, the simulation model is constructed based on SIMULINK (Fig. 3). Compared to CRH2, there are two secondary windings and two single phase pulse rectifiers. The two output DC powers are in parallel connection, and supply an inverter. The inverter is easier to control due to the two-level topology, but the LC filter is needed in the DC link. In addition, the power of the traction system is much greater than that of CRH2.

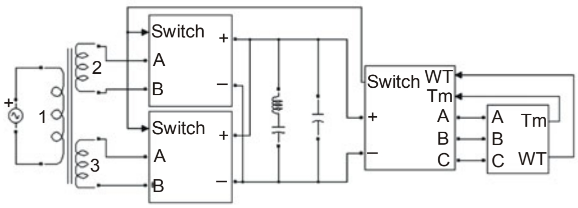

Fig. 3 Simulated model of the traction driver system of CRH3

3 Developed simulation software

The simulation software of the CRH2 traction driver system consists of a main program, an input and output interface program and a simulation core program. All programs are developed using VC++. The main program supplies a friendly interface to accept the simulation parameters and shows the output results. The input and output interface program can not only exchange more data between the main program and the simulation model, but also deals with the input parameters and output results as required. The diagram of this simulation software is shown in Fig. 4.

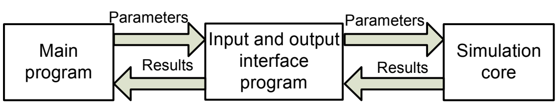

Fig. 4 Diagram of simulation software

The simulation core program of VC++ is changed from that model shown in Fig. 2 by real-time workshop (RTW), which includes the main code file (*.cpp), data file (*-data.cpp) and three basic files (Grt_main. c, rt_logging. c, and rt_sim. c). The main code file describes the simulation model in C code, initials the program, sets up the sample time and outputs the results. The input and output interface function is also added to this file. The data file gives values to every module such as the motor, inverter and transformer. Because the other basic three files are the same in all models, they do not have any detailed information within this simulation structure. Although it can not add any detailed code, the adding input and output interface function should declare for call. Fig. 5 shows the simulation software.

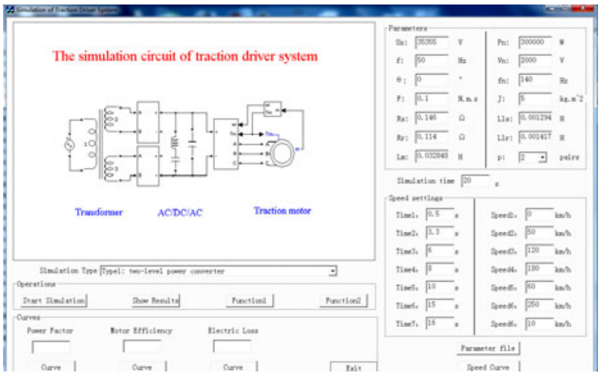

Fig. 5 Simulation software

For the CRH2 and CRH3, each has two simulation models, such as a two-level one motor model, a two-level four motor model or a three-level four motor model. To every model, the parameters of the motor, power supply and given train speed can be input. The simulation results are read in real time and displayed dynamically. At the same time, the results are analyzed and calculated, and then the fundamental component, harmonic component, efficiency, power factor and heating power of every link are obtained.

4 Simulation results

In the developed simulation software, the traction performance can be simulated. The parameters were as follows: power supply voltage U_s=25 000 V, transformer ratio k=25 000/1500, carrier frequency of pulse rectifier f_c=1250 Hz, DC voltage U_{DC}=2600 V (traction)/3000 V(brake), DC capacitance C_1=C_2=16 mF, motor rated power P_N=300 kW, rated voltage U_N=2000 V, rated frequency f_N=140 Hz, stator resistance R_s=0.114 Ω, stator leakage inductance L_s=1.417 mH, rotor resistance R_r=0.146 Ω, rotor leakage inductance L_r=1.294 mH, mutual inductance L_{rm}=32.8 mH, and pole pair p=2.

4.1 Traction and brake performance of CRH2

The simulation assumes the train accelerates to 200 km/h during 2.2 s, keeps this speed for 1.3 s and decreases speed to zero during 1.3 s. Fig. 6 shows the simulation results of traction and brake conditions.

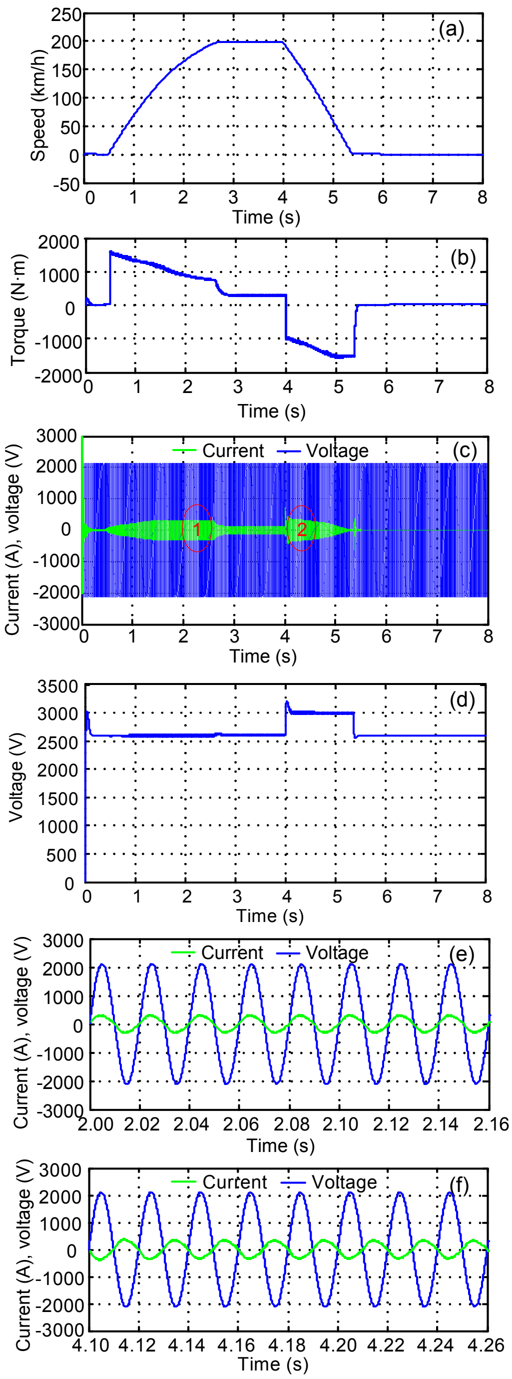

Fig. 6 Simulated traction and brake performance results of CRH2. (a) Simulated value of train speed; (b) Electromagnetic torque; (c) Output of transformer in the secondary winding; (d) DC voltage; (e) Traction condition (circle 1 in (c)); (f) Brake condition (circle 2 in (c))

The simulated value of the train speed coincides with the given value. The traction driver system has a large torque only when the train accelerates or decelerates. The voltage of the DC link remains at 2600 V in traction condition and at 3000 V in brake condition, which meets the requirements of CRH2. In traction condition, the current and voltage of the transformer secondary winding are almost in the same phase, i.e., the power factor is almost one. In brake condition, the current and voltage of the transformer secondary winding are in positive phase.

As all simulation results met the actual work conditions, it can be concluded that the developed simulation software is useful and of benefit to system optimization.

4.2 Speed regulation performance simulation

This simulation assumed the train runs at 200, 120, 180, 60 and 250 km/h, in turn (Fig. 7). The electromagnetic torque and motor current not only increase quickly as the train accelerates or decelerates, but also increase with the train speed. But the effect of acceleration is much greater than that of speed. Thus, the speed regulation performance of this traction system is fine.

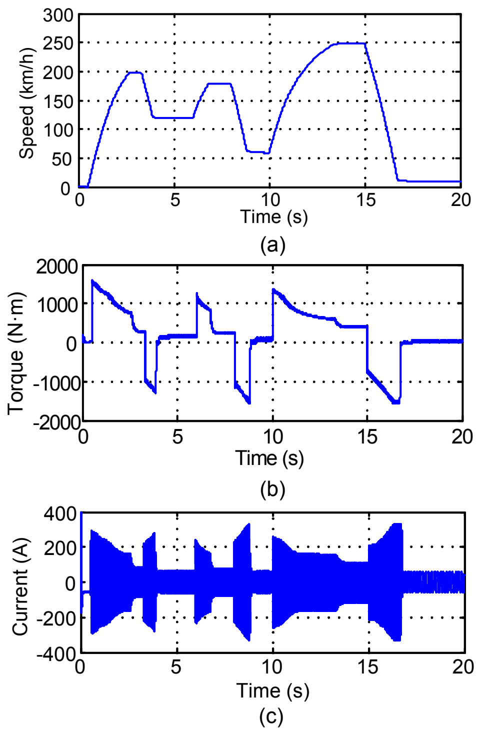

Fig. 7 Simulated speed regulation performance results of CRH2. (a) Simulated value of train speed; (b) Electromagnetic torque; (c) Motor current

4.3 Transient performance of fault condition

Apart from normal operation, the simulation software can also be used to simulate the transient performance of a fault condition such as the pantograph temporarily disconnecting to the grid, four wheels with different radii, or motors with small differences in parameters. Fig. 8a shows the transient train speed when the pantograph temporarily disconnects from the grid at speeds of 50, 100, and 150 km/h. The time for which the speed is maintained is 1.2, 0.5, and 0.13 s, respectively. Thus, the time decreases rapidly as the speed increases. Fig. 8b shows the voltage of the DC link. It decreases firstly due to the lost power supply, and then increases after a short time when the motor acts as a generator. But the increase is very short-lived. Both the value and duration of the increase depend on the train speed.

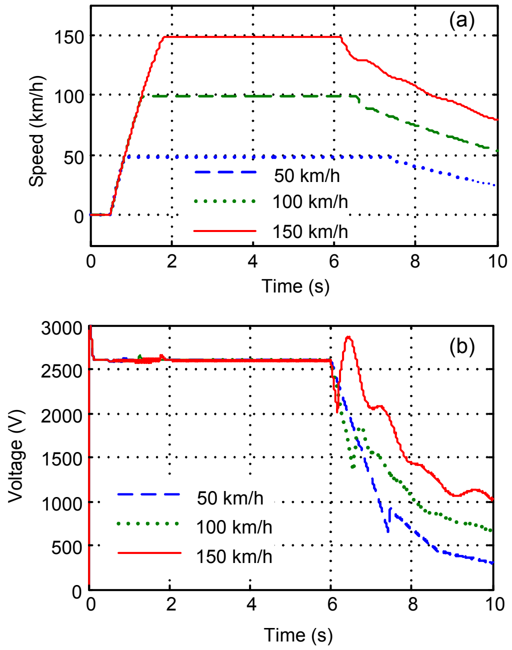

Fig. 8 Transient performance of a fault condition of CRH2
(a) Transient train speed; (b) Voltage of DC links

5 Conclusions

This paper describes the development of simulation software in VC++ which can simulate operation performance and fault diagnosis. After the simulation, the cores of the CRH2 and CRH3 traction driver system differ from the corresponding models established by SIMULINK. The developed simulation software combines a friendly interface and data processing. In the software, the traction motor adopts transient current control and an indirect rotor magnetic field orientation vector control strategy, and the traction converter uses SPWM and SVPWM methods. On this basis, the typical operation performance and fault condition of a traction converter were simulated and analyzed at different train speeds. The simulation software has proved useful and can provide a reference for the actual design and production of traction converters.

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