Virtual Development Platform of High-Speed Train Traction Drive System in View of Top-level Goals

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***Abstract*—To support the improvement and development of CRH (China Railways High-Speed) trains, a virtual development platform is set up for high-speed train traction drive system. The traction drive system of CRH2 EMU (electric multiple unit) is described. A design idea based on top-level goals is proposed in this paper and has been used in the platform. Aiming at CRH380A, traction drive system design around the maximum operation speed is shown with some simulation results.**

Keywords—virtual platform; traction drive system; high-speed train; CRH

I. INTRODUCTION

The development of high-speed railway in China is optimistic. According to the statistics from UIC (International Union of Railways), high-speed lines with length of 9356km has been opened up in China by the end of 2012 [1].With continueing development of high-speed railway in China, 18000km high-speed lines will be opened up by 2020 according to Mid/Long-Term Development Planning of China Railway [2]. The rapid development of high-speed railway in China leads to increasing demand for CRH (China Railways High-Speed) trains, both in quantity and types. Different performances of high-speed trains are required due to the variety of line conditions and operation environment. Therefore, improving and redesigning the traction system of existing CRH trains are inevitable. The study of high-speed train traction drive system needs a lot of simulation, real train experiment and practical operation. Some unreasonable design of transformers' and motors' allowance and performance hasn't usually been discovered until testing the real train. In this way, it wastes a lot of time and increase the costs. Furthermore, it's really hard for the real train experiment to change operation conditions. Therefore, establishment of an effective and credible high-speed train traction drive system virtual development platform is urgent.

Nowadays, computer simulation technology has been widely used in the railway industry. Diversified simulation technology for railway industry was described in [3]-[9] and lots of other references. Even though many types of simulation software and platform have been established for railway industry, a virtual development platform that has enough multifunction and can support the target based design and optimization of an entire traction drive system effectively is necessary. The virtual development platform is studied for CRH2 EMU (electric multiple unit) in this paper.

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II. THE TRACTION DRIVE SYSTEM OF CRH2 EMU

CRH2 EMUs consist mainly of three speed levels. They are CRH2A running 200~250km/h, CRH2C running 300~350km/h and CRH380A running 380km/h. This platform is developed based on CRH380A and can be used for other types of CRH2 EMUs. A CRH380A EMU have 14 motor cars and 2 trail cars. Two head cars are trail car, and others are motor car. Two adjacent motor cars as a basic power unit, each power unit has a separate traction drive system.

The traction drive system main circuit structure of a power unit is shown in fig. 1. Other types of CRH2 EMUs have the similar main circuit structure. It contains high voltage electrical equipment in the network side, a traction transformer, two traction converters, eight three-phase AC induction traction motors and other components.

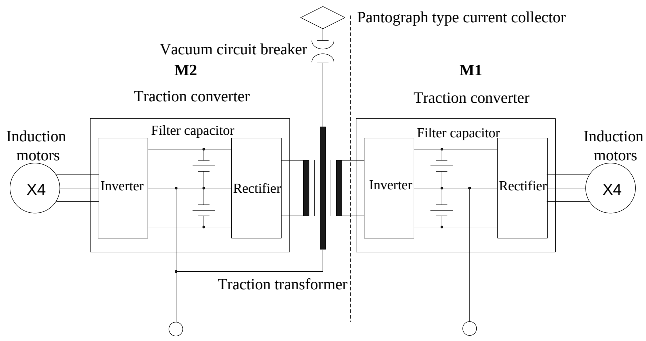

Fig. 1. Main circuit structure of CRH2 EMUs.

Pantograph accepts 25kV, 50 Hz single-phase AC power from the power supply grid and connected to the traction transformer by vacuum circuit breaker in traction mode. Traction winding of the transformer vice edge will supply 1650V, 50 Hz single-phase AC power to the four-quadrant pulse rectifier in the converter. Converter of CRH2 EMUs is three- level, which is a feature, compared to other CRH EMUs. Four-quadrant rectifier output DC power. DC voltage is maintained between 2600V and 3000V by intermediate DC link, which consists mainly of DC support capacitor and discharge circuit. Without filter circuit in intermediate DC link is another feature of CRH2 EMUs, therefore it is required to remedy in modulation strategy of converter. Three-phase variable voltage variable frequency AC power is supplied to traction motors by inverter. Traction motors drive the train through gear box. The electrical energy is eventually converted into mechanical energy.

Controlling traction inverter allows traction motor in the power generation state in regenerative braking mode. Mechanical energy is converted into electrical energy back to power supply grid through traction drive system.

III. Design in View of Top-Level Goals

Accurate and complete expression of the demand for the virtual development platform is essential. How to design the traction drive system determines the composition of the platform.

Combining with system theory and the idea of top-level design, the concept of top-level goal is proposed by some scholars in the process to explore the optimization methods of Beijing-Shanghai high-speed railway system. Five optimization top-level goals of high-speed train are selected according to the conclusions. They are travel time and the maximum operation speed, comfort, energy saving and environmental protection, safety and disaster prevention, operation principles and plan [10].

The general system optimization idea is shown in fig. 2 proposed by relevant scholars. The optimization process can be divided into two stages which are “design of top-level goals” and “optimization design of subsystems”.

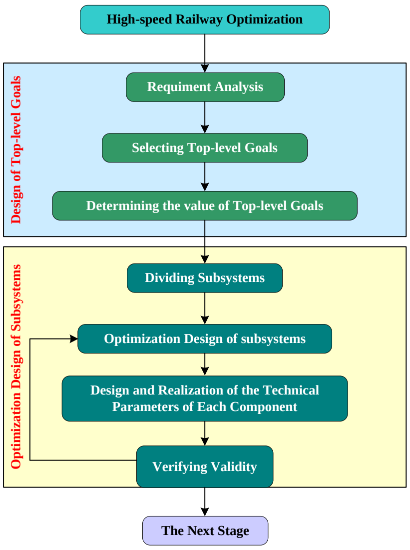

Fig. 2. The general system optimization idea based on top-level goals.

The optimization process shown in fig.2 can be used for high-speed train, which is a key subsystem of high-speed railway. In the general system optimization idea, to optimize subsystems based on the selection of the top-level goals, the determination of the value of top-level goals, the quantization of the top-level indexes, is to do systemic technology integration with definite optimization goals. Traction drive system is the power source of a train. The design of it should follow the above optimization process.

IV. Analysis and Design of The Platform

In this paper, the virtual platform will go through the entire design process of high-speed train traction drive system. The platform should integrate design, validation and display as a whole. It should be able to support study as a research platform as well.

- Design platform. It can assist the overall performance design of the train, such as traction performance curve, braking performance curve. And it can also assist the optimization of traction and braking components.
- Verification platform. To carry out a series of train internal subsystem status simulation, train operation simulation and the external environment coupled simulation. Such as the converter temperature simulation, train fixed-time operation simulation and the wheel-rail interaction simulation.
- Display platform. To summarize and display the design result in various forms. For example, produces a design report, or performs three-dimensional visual simulation.
- Study platform. It can exchange data with hardware experiment platform or other commercial simulation software to study high-speed train correlative technical problems. Such as coordination and control between high-speed train and traction power supply systems, the relationship between contact-loss of pantograph and the performance of traction drive system, estimation of traction motor service life, etc.

Constrained by the complexity of high-speed train system, the virtual platform must have good scalability and compatibility. Based on function analysis, the simulation platform includes the host computer, hardware experiment platform, analog driver console and three-dimensional visual projection equipment. The optimization supporting software and 3D visual simulation software is built-in host computer. Structural relationship among the platform modules is shown in fig. 3.

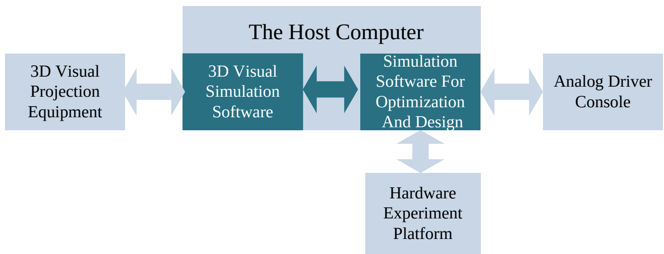

Fig. 3. Structural relationship among the platform modules.

Software framework and functions in detail has been described in [11].

V. Traction Drive System Design Around the Maximum Operation Speed

A. *Target Speed of The Railway*

Target speed of railway has three layers of meanings.

- Infrastructure design speed: That is speed of civil engineering. Infrastructure design speed should be leeway for follow develop.

- Train design speed: It gradually increases with the high-speed train technology upgrading.
- Commercial operation speed: The speed target value of the actual operation of the railway sector.

Has the train itself, train speed is mainly affected by traction ability and mechanical strength. As the source of power, the design of traction drive system should be around train design speed. Operation speed of the train is limited by infrastructure design speed as well. In the simulation platform, the validation of train operation ability, infrastructure design speed is show as the line limit speed. Commercial operation status is the daily status of the train. Commercial operation speed is reflected in fixed time operation simulation, which is used to validate train traction performance.

B. The Design Process

Based on technical requirements of the train and the line condition the train will be applied, some models as train dynamics model, traction drive system model, converter loss calculation model and motor temperature model were built. Electrical parameters of main components of traction drive system can be calculated according to the designed train traction and braking performance curves. Train's speed, acceleration, distance and time can be obtained by running the train on certain conditions in a particular virtual line. Basic electrical parameters, converter temperature rise and motor temperature rise in the train's virtual operation process can be calculated by loading the basic models built. The basic design process by the virtual platform is shown in fig. 4.

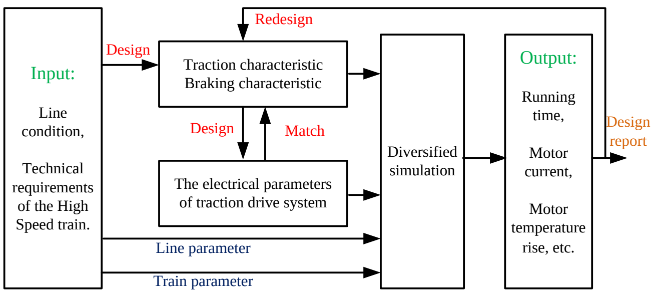

Fig. 4. Basic design process by the virtual platform.

C. Traction Performance Curve

Traction power pk (kW) of the train can be estimated by:

$$p_k = \frac{[M\cdot\omega_0 + (1+\gamma)\cdot M\cdot\Delta a\cdot 10^3](v_{\max}+\Delta v)\cdot 10^{-3}}{3.6} \quad (1)$$

Where M (t) is vehicle weight, ω_0 (N/t) is the basic operation resistance, γ is inertia coefficient, Δa (m/s^2) is residual acceleration at maximum speed, $v_{\max}$ (km/h) is maximum speed, Δv (km/h) is the wind speed be considered.

Low-speed segment traction force F_{v0} (kN) can be estimated by:

$$F_{v0} = [M\cdot\omega_q + (1+\gamma)\cdot M\cdot a_0\cdot 10^3]\cdot 10^{-3} + M\cdot g\cdot\theta_0 \quad (2)$$

Where ω_q (N/t) is the starting resistance taken into account, a_0 (m/s^2) is low-speed segment acceleration, g (m/s^2) is gravitational acceleration, θ_0 (‰) the ramp taken into account.

Traction force is limited by the adhesion. According to the adhesion formula (wet rail) of the Japanese high-speed railway, the adhesion coefficient μ is related to the speed:

$$\mu = 13.6/(85+v) \quad (3)$$

The formation of CRH380A is 14M2T. The personnel quota is 1065. Every passenger and his baggage are estimated to be 80 kg. And the gross weight is 900.5t. To achieve the speed target, designed top-level indexes are shown in Table 1.

TABLE I. TOP-LEVEL INDEXES OF CRH380A.

Speed index	***Sustainable operation speed(km/h)***	350
	Maximum operation speed(km/h)	380
	Test speed(km/h)	≥400
Traction ability index	***0~200km/h average acceleration(m/s^2)***	≥0.4
	350km/h residual acceleration (m/s^2)	≥0.05
	380km/h residual acceleration (m/s^2)	≥0.01

Referenced traction performance curve can be obtained by the platform. In fig. 5, the yellow line stands for the maximum traction force, the purple one is for the basic operation resistance, and the green ones are for the operation resistance on a certain slope line. It is with the speed in km/h as abscissa and the force in kN as ordinate.

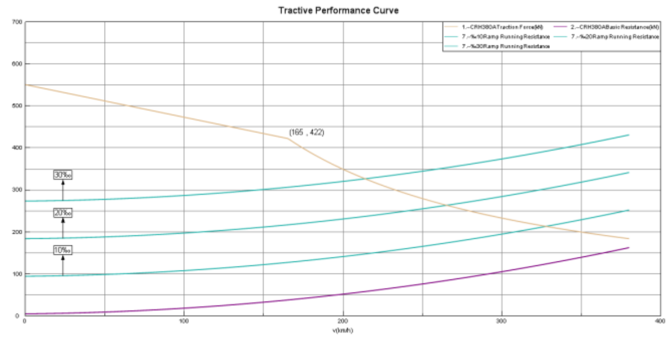

Fig. 5. The traction performance curve of CRH380A obtained.

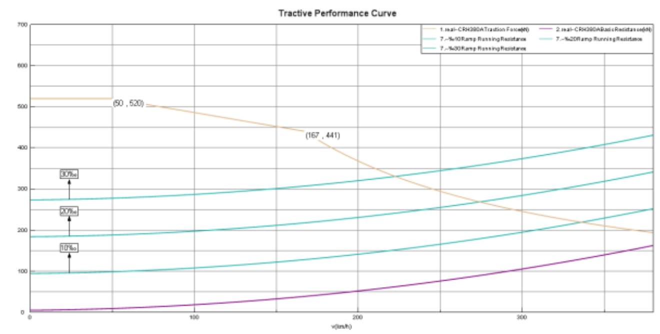

Fig. 6. Optimized traction performance curve of CRH380A.

Optimized traction performance curve could be directly input or obtained by modifying relative parameters. Fig. 6 shows the optimized maximum traction force curve of CRH380A.

Average acceleration of the optimized maximum traction force of CRH380A is $0.5 m/s^2$ at range from 0 to 200km/h calculated by the platform which is acceptable.

D. *Unit Capacity Estimation*

Traction transformers, main converters, traction motors capacity calculation is very important to design basis. Capacity of traction units should be estimated in turn following energy flows, traction mode and regenerative braking mode separately. Power factor and efficiency of the train is closely associated with the operating modes, and changes with speed change. Efficiency characteristic is difficult to describe in precise mathematical model. Power factor and efficiency is assumed to be constant, often using rating, when estimating unit capacity.

According to the optimization results, unit capacity of CRH380A traction drive system is obtained by the platform and shown in Table 2.

TABLE II. UNIT CAPACITY OBTAINED BY THE PLATFORM

Parameter		**Value**
Secondary side winding of transformer	***Capacity (kVA)***	1667.5
	Voltage (V)	1658
	Current (A)	1006
Output parameter of converter	***Voltage (V)***	2400
	Current (A)	448
Rated parameter of motor	***Power (kW)***	365
	Voltage (V)	2000
	Current (A)	130

E. *Temperature Rise Characteristic*

Temperature rise characteristic of traction units is an important index. It is directly affected by the change of traction characteristics. Steady and dynamic temperature rise characteristic can be calculated by this platform. Temperature rise model of converter is built in the platform, and models of transformer and motor are built in ANSYS and called by the platform.

There is database for IGBTs usually be used in train traction in the platform. The following figures are based on parameters and cooling parameters of IGBT used in CRH2A. Fig. 7 shows the results including loss calculation of rectifier devices. Fig. 8 shows transient junction temperature calculation of IGBT under the rated conditions. Fig. 9 shows steady temperature rise calculation of rectifier devices. Temperature of the IGBT is about 90℃ under the rated conditions shown in the fig.8 and fig.9 is reasonable and acceptable.

F. *Verification with Operation Simulation*

Most of the performance verification will need data supporting from operation simulation. Tow operation strategies has been established in the platform. They are the minimum time and the fixed time operation mode. The best performance of the traction drive system can be vivificated by the operation simulation with the minimum time operation strategy.

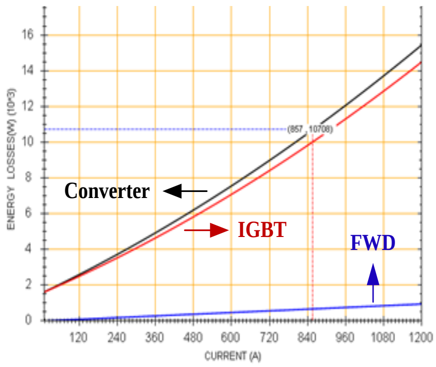

Fig. 7. Loss calculation of rectifier devices.

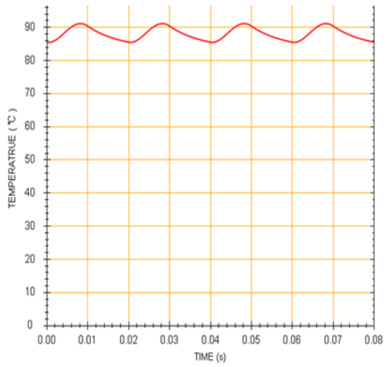

Fig. 8. Transient junction temperature of IGBT.

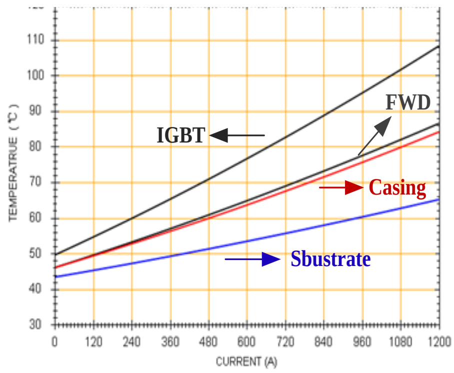

Fig. 9. Steady temperature rise calculation of rectifier devices

There are two important targets about travel time and energy saving in the design of CRH380A:

- The through running time in Beijing-Shanghai high-speed railway should be within about 4 hours.
- The power consumption per passenger should be less than 80 kWh.

Fig. 10 shows part of the operation simulation result with the minimum time operation strategy. The simulation result shows that the through running time in Beijing-Shanghai high-speed railway is 236.9 minutes which is close to 4 hours and shorter than 4 hours. The total energy consumption is 71255 kWh, and the consumption of the auxiliary system is 7920 kWh. As mentioned above, the personnel quota is 1065. So power consumption per passenger is 75kWh, which is less than 80kWh.

Simulation results prove that the traction ability worked out by the platform of CRH380A can match the technical requirements of the train.

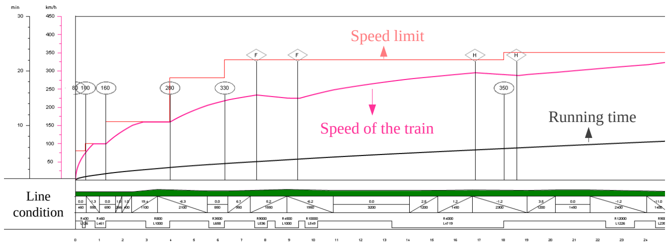

Fig. 10. Part result of the minimum time operation mode

VI. CONCLUSIONS

Development of this virtual platform is necessary. Based on design and optimization idea in view top-level goals, the integrated virtual platform has been set up. A basic design process aiming at CRH380A is shown in this paper with some meaningful simulation results. Simulation function of the platform is diversified. Just part of them has shown in this paper. Dynamic simulation functions and research capabilities are not shown. This platform can support the design of high-speed train traction drive system in view top-level goals powerfully. Function of the platform will be more comprehensive with the following research and development.

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