Virtual development platform for Optimization and Design of High-speed Train Led by Top-level Technology Goals

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Abstract- 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. To support the improvement and development of these trains, a virtual platform for overall optimization and design of high-speed train is proposed in this paper. This paper studies the optimization and design process of high-speed train based on top-level goal as well. Function analysis, function design and framework building of the platform are described. Some simulation results are shown in the paper to display the platform functions. Availability of the simulation platform is ensured by improved continually with experimental data from the cooperative company.

Keywords- virtual platform; high-speed train; top-level technology goals; CRH

I. Introduction

China high-speed railway is developing rapidly since 2008. 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]. From August 2011, the China high-speed railway is slowed down temporarily. But the future of China high-speed railway is optimistic. The total length will grow to 18000km by 2020 according to *Mid/Long-Term Development Planning of China Railway* [2]. Improvement and innovation of CRH trains are imperative.

CRH380A is manufactured to meet the operation requirements of Beijing-Shanghai high-speed railway. CSR Qingdao Sifang Locomotive and Rolling Stock Co. Ltd. researched and developed CRH380A independently led by top-level technology goals. In this background，an assistant virtual development platform of high-speed train was planned to be built based on existing train data. It is to support improvement of CRH380A and design of the following CRH trains. Designing and verifying traction and braking ability of train are main functions of the platform currently and more functions will be gradually expanded.

Serving railway field evaluation, prediction, optimization and design is the motivation of railway simulation technology progress. Reference [3] sought to demonstrate the varying levels of simulation and their key role in the support of railway projects and the benefits from integrating simulation tools. Diversified simulation technology for railway industry was described in literatures. The virtual development platform proposed in this paper has an advantage that can assist in goal-based high-speed train subsystem design. In addition, it is a multifunction platform contains assistant software and experimental devices.

II. Design led by top-level technology goals

Accurate and complete expression of the demand for the virtual development platform is essential. How to design a high-speed train 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 [4].

The general system optimization idea proposed by relevant scholars is shown in fig.1. The optimization process can be divided into two stages which are "design of top-level goals" and "optimization design of subsystems". The top-level goals are a set of key technical indexes which reflect the technical characteristics and level of the whole system from the global. Each top-level goal will affect the design of multiple subsystems and has top-down rigid constraints and deployment function.

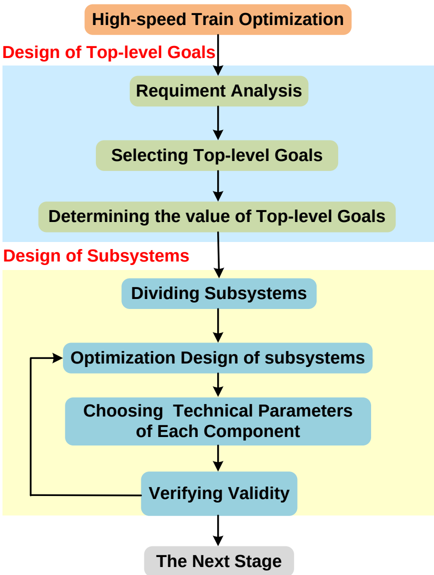

Fig.1. The general optimization idea.

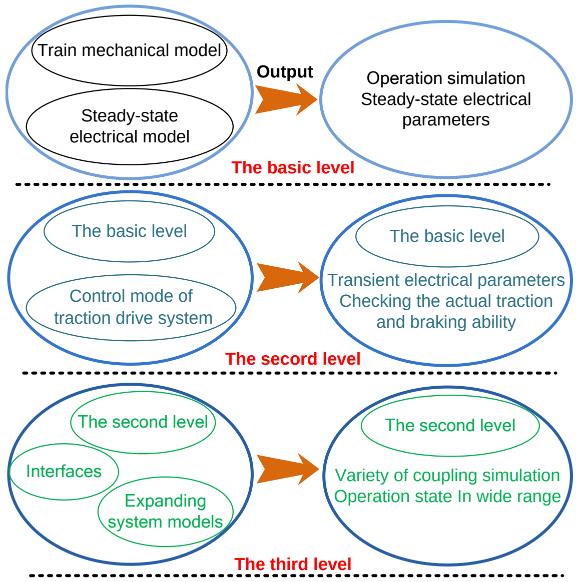

Fig.2. Function levels of the platform.

III. Analysis and design of the platform

3.1 Function analysis

In this paper, the virtual platform for optimization and design will go through the entire high-speed train design process based on top-level goals. So the platform should integrate design, validation and display platform as a whole. It should be able to support the technology study as a research platform as well.

1. Design platform. It can assist the overall performance design of a train, such as traction performance, braking performance. And it can also assist to design subsystems.
2. Verification platform. To carry out a series of train internal subsystem status simulations and external environment coupled simulations. Such as converter temperature simulation, train operation simulation, wheel-rail interaction simulation and so on.
3. Display platform. To summarize and display the design result in various forms. For example, produces a design report, or performs 3D (three-dimensional) visual simulation.
4. Research platform. Based on modeling a high-speed train and providing virtual operation environment, it can exchange simulation data with experiment devices or other commercial simulation software to research high-speed train correlative technical problems. Such as coordination and control between high-speed train and traction power supply system, estimation of traction motor service life, etc.

Constrained by complexity of high-speed train system, the virtual platform must have good scalability and compatibility.

3.2 Function design

Complete platform will have diverse functions. The emulator will bear large computing work. However, not all users are interested in for all functions. So functions of the virtual platform are divided into three levels shown in fig. 2: the basic level, the second level and the third level. This structure also facilitates functional expansion.

1. The basic level: To build train mechanical model and traction drive system steady-state electrical model. Mechanical calculation results such as train's speed, acceleration, distance and time can be obtained by running the train on certain conditions in a particular virtual line. Steady-state electrical parameters such as electric capacity of main components of traction drive system can also be determined.
2. The second level: Control models of traction transformer, rectifier and inverter will be increased based on the basic level. Transient electrical parameters can be calculated. The influence of the wheel set differences on the drive system can be reflected by simulating operation state of the train under real train formation and power arrangement. The platform can also be used to analyze the harmonic of drive system, calculate the traction motor torque ripple and study the control strategy of train drive system components.
3. The third level: Based on the second level, internal subsystem models are increased, such as the bogie model and control network model; external subsystem models are built, such as track spectrum and traction power supply network model; interfaces to other simulation software are built, such as the interface to dynamics simulation software SIMPACK and the interface to limited element analysis software ANSYS; interface to experiment devices is built. Therefore, the internal and external operation state of the train can be simulated in a wide range, and a variety of coupling simulation can be carried out to study multidisciplinary technical problems.

3.3 Platform building

Platform framework

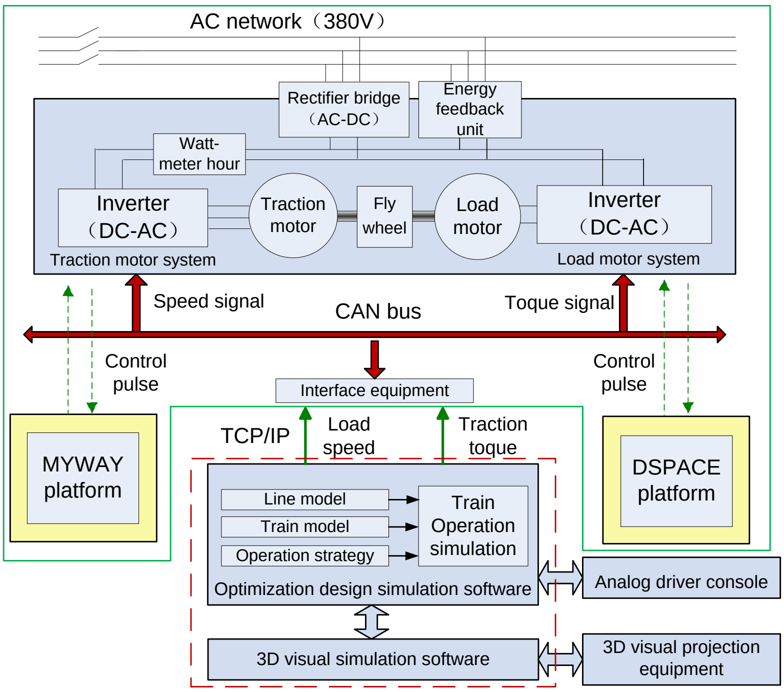

Fig.3. The platform has been set up.

Based on function analysis and design, it is determined that the platform should include a host computer, some experiment devices, an analog driver console and a 3D visual projection equipment. The optimization supporting software and 3D visual simulation software is built-in host computer. A specific platform has been set up and shown in fig.3. Its functions are being expanded.

The experiment devices mainly consist of a traction motor load torque simulation system. The load simulation system is built in order to study the operation characteristics of traction motor and control method of AC drive system in laboratory condition. The toque command and speed command are provided for the traction motor and the load motor from the optimization supporting software respectively. Reference [5] provides the control method of the load simulation system in detail.

Connected with the simulation software for optimization and design, the analog driver console can control the train operation simulation and 3D simulation. The 3D simulation system is able to simulate the variety of weather, view, terrain, day and night etc. Especially, the acoustic data in 3D simulation is picked on the line from Wuhan to Guangzhou and varies with the train speed. A uniqueness of this 3D simulation system is the availability to simulate the effects of whether conditions on speed limitation and train operation simulation.

Software component

The optimization supporting software is the key module of the virtual platform. It provides virtual operation environment for the experiment devices, and a background control for the 3D visual simulation. The components of the optimization supporting software are shown in fig.4. It consists of five main parts.

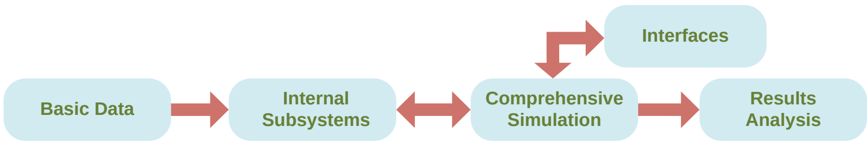

Fig.4. The components of optimization supporting software.

1. Basic data setting: To define basic information of a train, and set top-level goals of the train.
2. Internal subsystems: Models of train's subsystems are built by parameters design. Traction drive subsystem and the braking system have been completed and other subsystems will be gradually built with the in-depth development of the simulation.
3. Comprehensive simulation: Diversified simulation can be carried out to validate the performance of a train. Some simulation as train operation simulation and temperature rise simulation for drive system has been set up. With improvement of the platform, more simulations will be carried out. Such as dynamic simulation for wheel-rail interaction, fluid-structure coupling between car-body and air simulation etc.
4. Interfaces: To achieve the data interaction with experiment devices, 3D visual simulation, driver analog console, external system models and other software, a series of interfaces were reserved in comprehensive simulation part.
5. Results analysis: With various forms such as real-time display and design reports, simulation results are analyzed and the design results can be summarized.

IV. Function display

Some typical simulation and experiment results are shown to verify that the platform has functions of supporting design, verification, display and research.

4.1 Traction ability design

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. There are some speed top-Level Indexes of CRH380A. Two of them are very important: 1. Maximum operation speed is 380 km/h. 2. 380 km/h residual acceleration is greater than or equal to 0.01 m/s^2.

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. 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 0.5m/s^2 at range from 0 to 200km/h calculated by the platform which is acceptable.

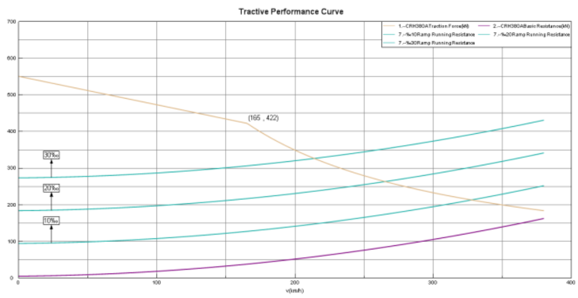

Fig.5. Caculated traction performance curve.

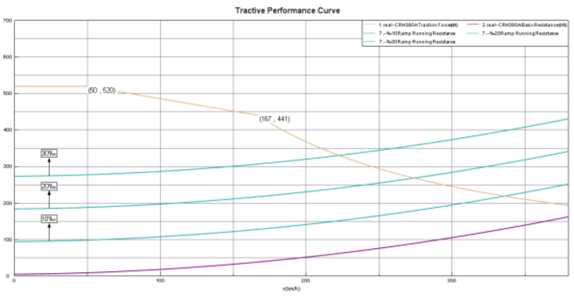

Fig.6. Optimized traction performance curve

4.2 Temperature rise verification

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. The platform has a database for IGBTs usually be used in train. The following figures are based on parameters and cooling parameters of IGBT used in CRH2A. Temperature of the IGBT is about 90℃ under the rated conditions shown in the fig.7 is reasonable and acceptable.

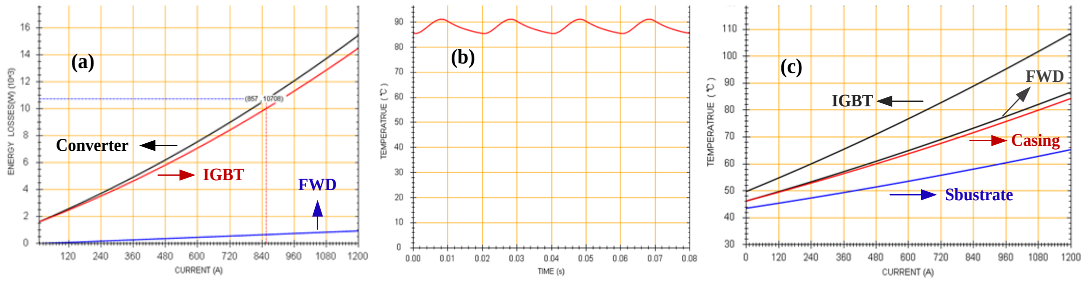

Fig.7. (a) Loss calculation of rectifier devices, (b) transient junction temperature calculation of IGBT and (c) steady temperature rise calculation of rectifier devices.

4.3 3D visual display

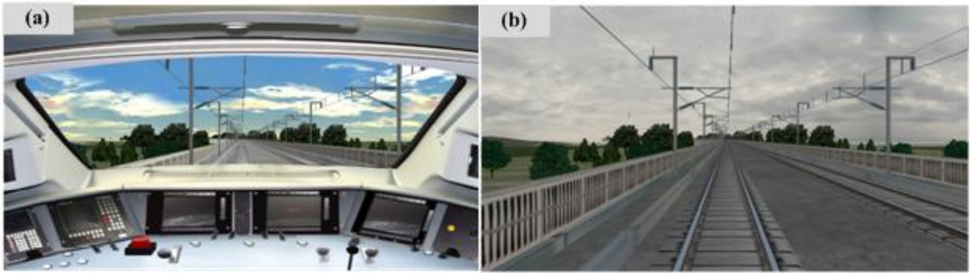

Fig.8. Various interfaces of 3D visual simulation. (a) View of driver, (d) rainy day.

Fig.8 shows the interface of 3D visual simulation includes the views of the driver and rainy day in the view without t driver console.

4.4 Cooperation between optimization supporting software and load simulation system

A result about co-simulation combining the load simulation system with the optimization supporting software is shown in the fig. 9, with the distance as abscissa and the train speed and motor speed as ordinate. The motor speed follows the train speed well. Therefore, the co-simulation can be used to study academic problems about high-speed train with train real running condition within-laboratory.

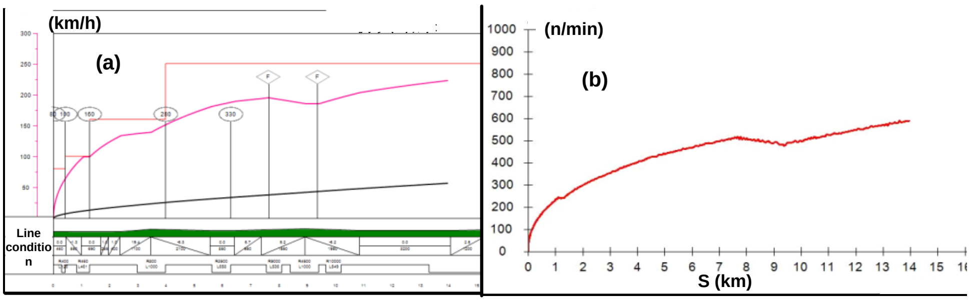

Fig.9. Traction motor's rotational speed follows the command of speed calculated by the optimization supporting. (a) Speed of train, (b) rotational speed of traction motor.

V. 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. Part functions of the platform are shown in this paper with some meaningful simulation results. This platform can support the design of high-speed train led by top-level goals powerfully. Function of the platform will be more comprehensive with the following research and development.

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