Featured Articles

Rolling Stock System Technologies Underpinning the Next Generation of Railways

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OVERVIEW: Hitachi is focusing on technological developments aimed at satisfying the diverse requirements for the next generation of railway systems. In the field of battery-based systems, Hitachi has developed a variety of systems such as a battery-powered drive system. For traction drive systems, Hitachi has been utilizing the characteristics of SiC hybrid modules to improve energy efficiency. Its work on rolling stock control systems includes the development of systems that assist train crew in order to drive trains with higher energy efficiency. Meanwhile, in the field of safety equipment, Hitachi is developing a millimeter-wave radar speed sensing module, a fixed-point stopping control system with an automatic learning function, and other safety devices intended to improve operational safety and reliability. Through the coordinated operation of these systems, Hitachi seeks to improve environmental value (energy efficiency), social value (reliable operation), and commercial value (maintenance).

INTRODUCTION

AMONG the circumstances surrounding the next generation of railway systems, three particular issues are: (1) energy problems, (2) an aging population and falling birth rate, and (3) the improvement of operational safety and reliability. Dealing with energy problems requires technologies for reducing electric power consumption to cope with major increases in the price of electric power, increasing scarcity of fossil fuels, and measures for preventing global warming. Dealing with the aging population involves the transfer of operation and maintenance techniques that utilize information and communication technology (ICT) in response to the anticipated loss of experienced staff and the fall in the number of people able to take their place. To improve operational safety and reliability, meanwhile, stations are installing safety barriers on platforms. This creates a need for trains to control accurately the point where they stop, even under different braking conditions (performance, weather, etc.).

Hitachi is developing a variety of technologies in response to these challenges.

BATTERY-BASED SYSTEMS

There has been growing interest in recent years in technologies that install high-capacity, high-output batteries in trains to improve the energy efficiency of diesel railcars, and to make further improvements in the energy efficiency of electric trains. Hitachi is working on the development of technology that can reduce energy use by using batteries to power electric drive systems when trains are running on non-electrified sections of track, and systems that reduce power consumption by incorporating batteries into the traction drive systems to recover excess regenerative electric power or increase the amount of regenerative electric power produced.

Hybrid Drive System

To reduce fuel consumption and toxic emissions by diesel railcars, East Japan Railway Company and Hitachi have jointly developed a hybrid engine system powered by a combination of a diesel engine and generator and lithium-ion batteries. The system reduces fuel consumption and noise by using electric power for both traction and auxiliary equipment, with

Fig. 1—Series HB-E300 Resort Train.
Lithium-ion batteries that can provide 15.2 kWh are installed on top of each car.

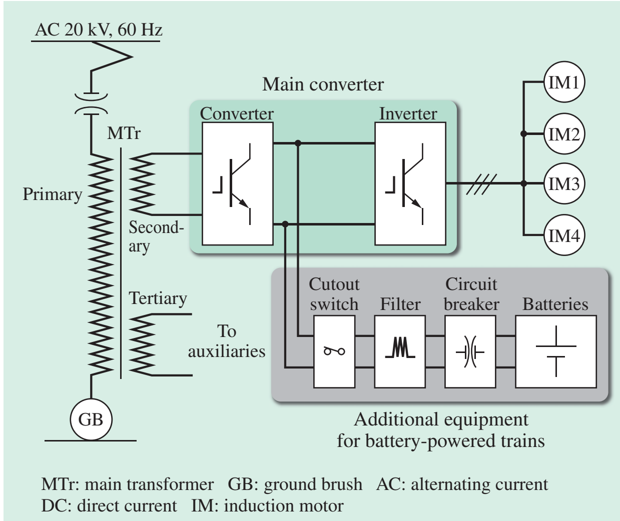

Fig. 2—Battery-based Traction Drive System for Lines with AC Power Supply.
A simple configuration for the traction drive circuit was achieved without the need for a dedicated battery charging system by using high-voltage batteries connected to the DC section of the main converter via a circuit breaker and other components.

high-output lithium-ion batteries designed for hybrid cars inserted into the traction drive circuit. This allows regenerative braking and idle-stopping, and constant-speed operation at a highly efficient operating point, functions not possible in conventional diesel hydraulic railcars. In July 2007, a kiha E200 train fitted with the system became the first hybrid train in the world to enter commercial operation. Additionally, the series HB-E300 resort train (see Fig. 1) commenced commercial operation in October 2010. The hybrid systems installed on these trains continue to operate reliably with the lithium-ion batteries achieving the expected level of reliability.

Battery-powered Trains

Battery-powered trains (trains that do not require overhead power lines) are attracting growing attention as another way for trains that run on non-electrified sections of track to save energy. High-capacity batteries installed on the trains are charged on electrified sections and then used as the sole energy source when running on non-electrified sections. In addition to significantly reducing maintenance and energy costs by eliminating the need for combustion engine, the successful implementation of battery-powered trains will also improve passenger convenience and rolling stock utilization by allowing services that travel along both electrified and non-electrified sections, thereby helping revitalize places served by non-electrified lines.

Hitachi, Kyushu Railway Company, Railway Technical Research Institute, and GS Yuasa Corporation have jointly developed a traction drive system for battery-powered trains that operate on lines with alternating current (AC) electrification, and installed the system on a prototype train(1) (2).

Fig. 2 shows a diagram of the traction drive system. To allow the installation of as many batteries on the train as possible, the amount of peripheral battery equipment was minimized and maximum use was made of the existing AC traction drive system.

The prototype train was tested on an actual line to assess its basic performance. Note that this project was undertaken through railway technology development funding received by the Kyushu Railway Company from the Ministry of Land, Infrastructure, Transport and Tourism. Fig. 3 shows a photograph of the prototype train.

Fig. 3—Prototype Battery-powered Train.
The 83 kWh of high-capacity lithium-ion batteries installed under the floor store energy when traveling on electrified sections of track and provide the energy to run on non-electrified sections.

Battery-based Technologies for Trains

Hitachi is also developing a new generation of drive systems that use battery technology in rolling stock, having already developed a technique that helps ensure stable regeneration at high speeds[(3)].

Although progress has been made in recent years on improving rolling stock energy efficiency by reducing weight and utilizing regenerative braking, problems remain in cases where the generated energy cannot be returned to the overhead lines, or when full use cannot be made of the regenerative energy because it is consumed by the resistive load of the overhead lines.

To overcome these problems, Hitachi has since 2007 been developing systems that utilize battery technology in trains. The following section describes some of the solutions being worked on in preparation for commercialization in relation to (1) underfloor installation of batteries and (2) passenger and crew safety.

To allow underfloor installation, Hitachi has achieved a high installation density by drastically revising the cooling technique used to remove the heat generated during charging and discharging. Hitachi has also reduced the component count and system size by combining the existing inverter and the chopper used for charging and discharging control into a single integrated power unit. Fig. 4 shows the circuit design for the traction drive system. Meanwhile, the design takes account of passenger and crew safety by satisfying the relevant standards and government safety rules.

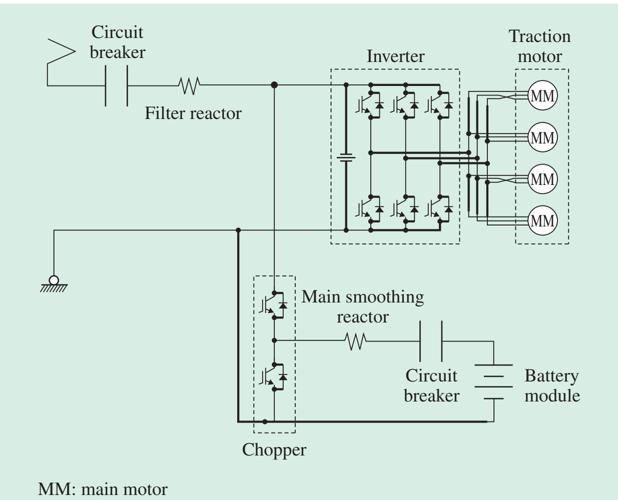

Fig. 4—Circuit Design for Battery-based Traction Drive System.
The battery system is installed under the floor. The system complies with the relevant standards and government safety rules, and testing has been conducted during commercial operation.

The new system was installed on Series 20000 rolling stock (20105 Series trains) belonging to Seibu Railway Co., Ltd. in 2013 to evaluate their performance in commercial operation. Based on the data and feedback from this trial, Hitachi is now working on further development in anticipation of commercialization.

NEXT-GENERATION TRACTION DRIVE SYSTEM

Along with reducing the losses by individual items of equipment such as the inverter and traction motor, work by Hitachi on traction drive systems aimed at responding to energy concerns also includes developments that use system control to reduce power consumption. Hitachi has also reduced power consumption by (1) using magnetic field analysis tools with improved accuracy to determine the situations in which losses occur in the traction motor and (2) developing a new pulse-width modulation (PWM) control pattern for the inverter to reduce harmonic losses[(4)]. This development is aimed at achieving step-by-step growth by applying these techniques to the battery-based systems described above. Fig. 5 lists work being undertaken on the next generation of traction drive systems.

Next-generation Inverter

For inverters, Hitachi has been improving the efficiency of individual components by, for example, developing silicon carbide (SiC) hybrid modules, which succeeded in reducing inverter size and weight by 40% and power loss by 35% compared with the silicon (Si) components typically used in past inverters.

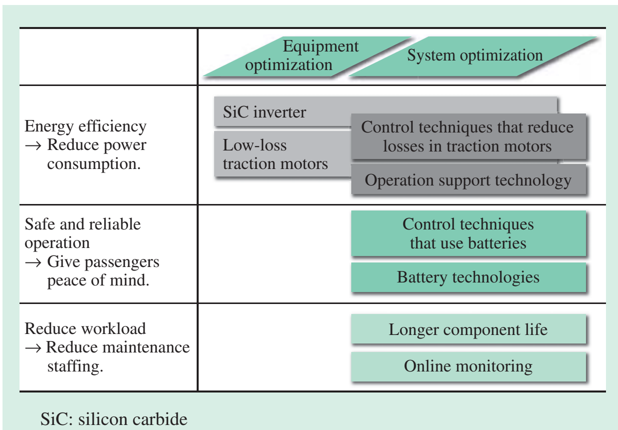

Fig. 5—Work on Next Generation of Traction Drive Systems.
System optimization is being performed by optimizing individual items of equipment.

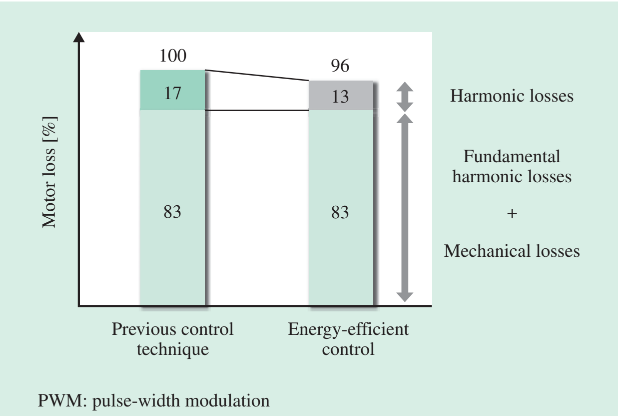

Fig. 6—Reductions in Motor Losses Resulting from Energy-efficient PWM Control.
The reductions in motor losses resulting from energy-efficient PWM control are assessed by measuring the cumulative power required to reach maximum speed from a standing start. Here, 100% represents the losses when using the previous control technique.

To improve energy efficiency further, Hitachi has developed a technique that uses PWM control to reduce motor losses by 4%. Fig. 6 shows a comparison of losses in a traction motor [one main motor (MM)].

Reducing maintenance work is also necessary for responding to the aging of the population. This includes adopting designs that allow anyone to replace components, without requiring specialist skills, and allowing longer maintenance intervals by extending the operating life of components. For operational parts such as contactors, Hitachi has developed a system that integrates with rolling stock control systems to monitor operating times and notify maintenance staff to replace the parts when something changes.

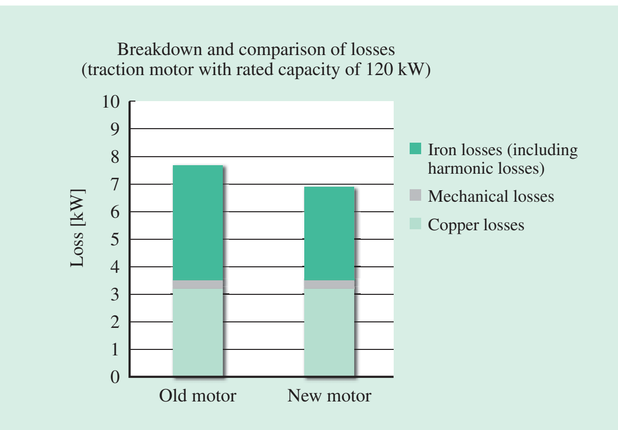

Fig. 7—Comparison of Losses on Old and New Traction Motors.
Total losses have been reduced by combining inverter control with traction motor built using low-loss materials.

Highly Efficient Traction Motors

Hitachi is also improving the efficiency of traction motors by developing techniques that reduce their losses, which can be categorized into iron losses, copper losses, mechanical losses, and harmonic losses. To reduce iron and copper losses, Hitachi is increasingly utilizing the low-loss materials used in main motors for the Shinkansen in commuter trains also. Hitachi has also succeeded in reducing total losses by approximately 11% compared with previous models by using detailed analysis of magnetic fields to determine the harmonic flux distribution in traction motors and develop inverter control to reduce harmonic losses, as well as by developing traction motors that use low-loss materials. Fig. 7 shows a comparison of losses in the new and old traction motors. Development is also proceeding on incorporating variable-voltage, variable-frequency (VVVF) inverters to maximize the performance of these highly efficient traction motors.

ROLLING STOCK CONTROL SYSTEMS

The next generation of railway systems will be built using standardized open networks to provide an architecture that facilitates the exchange of information with traffic management, power system supervisory control and data acquisition (SCADA), and other systems. Accordingly, the incorporation of open networks into rolling stock control systems can improve convenience and service. By linking rolling stock control systems and on-board equipment to enhance the realtime characteristics of the information required for operation and maintenance, and other status information, it is possible to improve the productivity of train crew and engineering staff while also providing detailed information to passengers.

Next-generation Rolling Stock Control Systems

To work with the next generation of railway systems, rolling stock control systems need to be built using standardized open networks. Fig. 8 illustrates the concepts behind the next generation of rolling stock control systems and Fig. 9 shows a system block diagram.

The three main features are (1) simple system configuration using a standardized open network, with processing and communications functions kept separate (2) a refined graphical user interface (GUI) design, and (3) plug-in unit configuration for better maintenance.

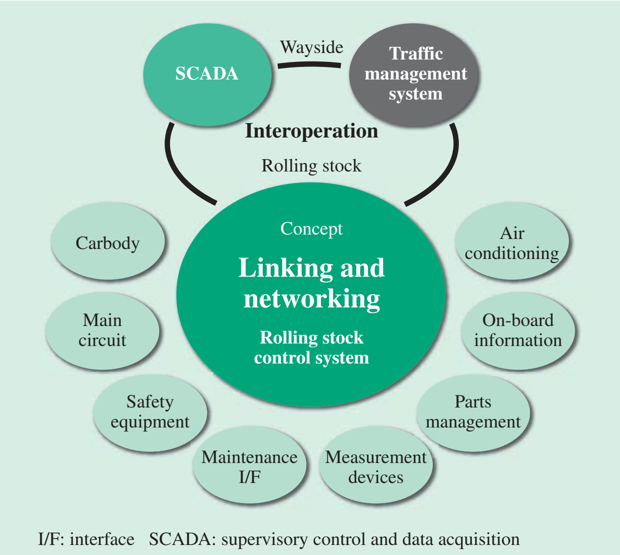

Fig. 8—Concepts Behind Next-generation Rolling Stock Control System.
The rolling stock control system was developed to overcome problems faced by railway operators based on the concepts of linking and networking.

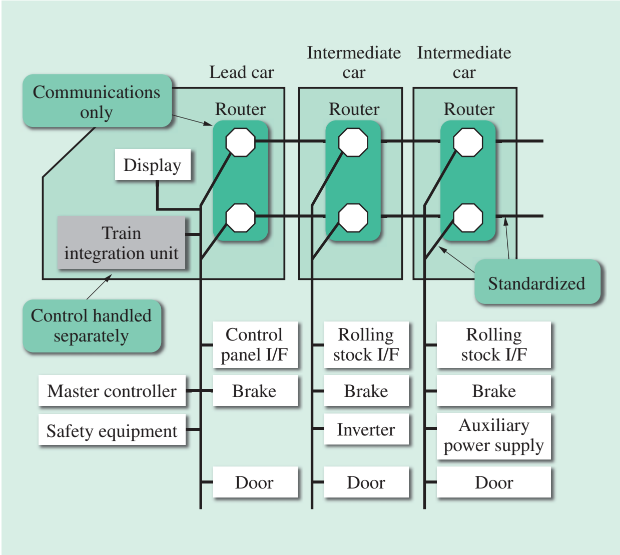

Fig. 9—Block Diagram of Next-generation Rolling Stock Control System.
A simple system configuration is achieved using a standardized open network, with processing and communications functions kept separate.

Fig. 10 shows some of the hardware and the control panel displays. The display units use pop-up menus to make it easier to call up information for display. To improve equipment maintenance and make it easy for anyone to replace parts, an easy-to-use unit-based hardware configuration is adopted in place of the tray-based configuration used in the past.

The reliability and expandability of the system have been improved by utilizing a simple design concept in which basic functional blocks are combined to provide the required functions. Since rolling stock built in recent years are expected to remain in service for 30 to 40 years, this approach was adopted with the aim of minimizing the cost of a complete upgrade to the rolling stock control system when new functions are added to enhance the value of the rolling stock over this lifetime.

New technology is also incorporated in the form of additional functions, including the ability to implement energy-efficient operation support functions and online monitoring to minimize maintenance.

Hitachi has undertaken development and on-rail trials using a prototype train in collaboration with the East Japan Railway Company to confirm control stability and other considerations[5].

Hitachi recently built a rolling stock control system for the Tokyo Monorail's Series 10000 that uses this basic configuration. Fig. 11 shows the control panel for the Series 10000[6].

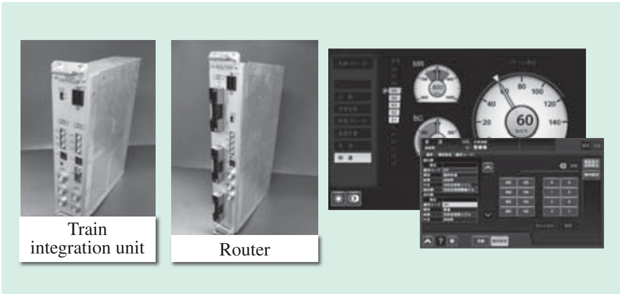

Fig. 10—Hardware and Control Panel Displays.
The workload for train crew and engineering staff is reduced by the use of a plug-in hardware configuration and enhanced-visibility displays.

Fig. 11—Control Panel for Tokyo Monorail Series 10000.
The control panel has two monitors. A pop-up display format is used to improve operation.

SAFETY EQUIPMENT, OPERATION SUPPORT SYSTEM

To improve the safety and reliability of train operations, there is a growing trend toward the installation of train control systems based on on-board systems that are capable of future expansion while providing the same or better level of reliability and safety as existing equipment. Meanwhile, platform barriers are also being installed to prevent accidents such as people falling from platforms or coming into contact with trains. The platform barrier system requires a high level of stopping accuracy in order to align the positions of the barriers and train doors. Hitachi is developing technology to meet these needs.

Safety Equipment

Hitachi is working with the West Japan Railway Company on a new safety system to replace existing automatic train stop (ATS) equipment. The new safety system is an on-board mechanism for continuous speed limit control based on predefined line information that is implemented using an on-board system that incorporates a train positioning function and is preloaded with a database of information on signals, curves, and other wayside equipment (on-board control).

The on-board equipment is divided into a communication and database unit and a controller, with Hitachi being responsible for the development, design, and manufacture of the controller. The central processing unit (CPU) board that handles control is from the latest series of control boards and has 10 times the processing performance of previous models. It is capable of performing control functions for both the new safety system (on-board control) and the existing automatic train stop-pattern (ATS-P) system. It incorporates a wide range of operation support functions that relate to driving the train. The system will be fitted to new rolling stock that is being progressively deployed in the Hiroshima region by the West Japan Railway Company.

Millimeter-wave Radar Speed Sensing Module[7]

When a train control system is based on on-board control, the on-board speed and position measurement sensors play an important role. While speed measurement and cumulative distance travelled have typically been obtained using a tacho-generator driven by the train wheels, improving the accuracy of this method in the presence of wheel slip or skidding is a problem.

One way to overcome this problem is to use a non-contact sensor that can measure speed relative to the ground, such as a millimeter-wave radar speed sensing module. This sensor provides reliable speed measurements that are unaffected by wheel slip and skidding, with other advantages including not needing to specify the wheel diameter.

Hitachi has collaborated with the West Japan Railway Company on the development of a new millimeter-wave radar speed sensing module that is small and lightweight. Fig. 12 shows a prototype. When tested in operational trials on a West Japan Railway Company line, the speed sensor produced accurate measurements. Fig. 13 shows a chart of the trial results.

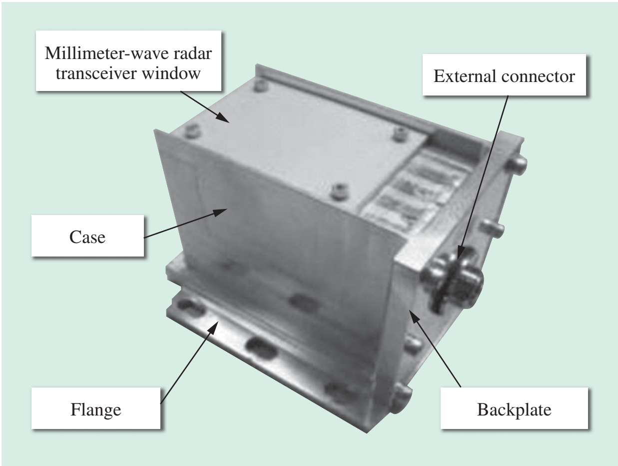

Fig. 12—Prototype of Millimeter-wave Radar Speed Sensing Module.
Hitachi has developed and prototyped a small and lightweight millimeter-wave radar speed sensing module with the aim of commercializing it for railway applications.

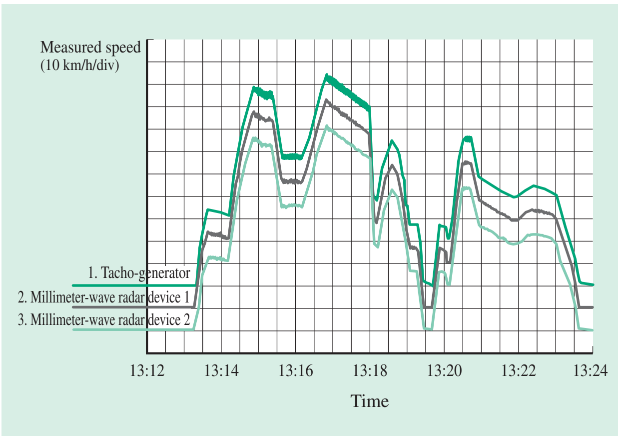

Fig. 13—Chart of Operational Trials (on Operating Line).
The millimeter-wave radar speed sensing module and tacho-generator give largely similar speed measurements.

Operation Support System (Fixed-point Stopping Control System)

The installation of platform barriers is driving growing demand for automatic train operation/train automatic stop control (ATO/TASC) operation support systems to ensure trains stop at the correct position at a station. The past practice in ATO/TASC commissioning has been to tune control parameters by trial and error based on the difference between the actual and design values for rolling stock performance during operational trials. This is both time-consuming and requires the railway operator to provide time for testing and deal with any resulting disruption.

Hitachi is developing an automatic tuning function for ATO/TASC control. This function involves collecting data from routine operation and the use of online statistical processing to determine the rolling stock performance. The results are then used as a basis for outputting brake commands to rolling stock at the appropriate timing. Use of this automatic tuning function is expected to reduce the amount of commissioning work (less time required for operational testing) and help maintain stopping accuracy by continuing to use automatic tuning (learning) on rolling stock after it enters commercial operation.

CONCLUSIONS

Hitachi supplies systems that are each being progressively improved, and is developing technology for the next generation of railway systems in response to increasingly diverse needs.

In the future, this development will utilize advances in ICT to implement interoperation with other systems, and will extend to control as well as to providing information. Hitachi intends to continue working on further technical innovations by connecting systems together so as to achieve synergies that improve economic performance for users.

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