Train Traction Systems for Passenger Comfort and Easier Maintenance

Satoru Inarida
Tetsuo Kojima
Motomi Shimada
Seikichi Masuda

OVERVIEW: Hitachi, Ltd. has been developing vector-control techniques, high-voltage insulated gate bipolar transistors (IGBTs), snubberless inverters[1), soft-gate circuits which can control switching behavior of IGBTs, airless line breakers, and electronic master controllers to make train traction systems smaller, lighter, more functional, and easier to maintain. Recently, however, the need for upgrading train traction systems has been growing due to changes in social conditions such as heightened environmental consciousness. In particular, train traction systems need to be even easier to maintain, more energy efficient, smaller and lighter (through simplification of cooling equipment by reducing refrigerant and blowers), and more functional (improved passenger comfort). To meet these new needs, Hitachi has developed (1) high-conductivity, high-voltage power devices to make cooling equipment smaller and lighter, (2) snubberless inverters using high-voltage power devices to reduce the number of components, (3) control systems to achieve advanced rolling-stock control and high functionality, (4) train power control using on-board data-transmission equipment, and (5) low-maintenance motors. Hitachi is enhancing these technologies to provide a train traction system that is smaller and lighter and easier to maintain while improving passenger comfort (Fig. 1).

INTRODUCTION

HITACHI has been applying vector-control techniques, high-voltage insulated gate bipolar transistors (IGBTs), snubberless inverters[1)], airless line breakers, electronic master controllers, and other devices to make train traction systems smaller, lighter, more functional, and easier to maintain. In the face of recent social changes, however, there is a growing need for train traction systems that are even easier to maintain, that incorporate smaller and lighter cooling equipment, and that feature advanced functions. To meet these new needs, Hitachi is developing inverter control technologies, new devices, and new electric motors, as described below.

NEEDS OF TRAIN TRACTION SYSTEMS

The needs of train traction systems and their corresponding technologies are shown in Fig. 2.

Hitachi has been working on the following technologies to reduce maintenance, improve passenger comfort, and raise energy efficiency.

(1) Reduce maintenance
- (a) Speed sensorless traction control using vector control to eliminate components requiring maintenance
- (b) Decreased brake-shoe maintenance by expanding regenerative braking region
- (c) Application of high-conductivity, high-voltage power devices to improve maintainability through simplification of cooling equipment
- (d) Electronic master controller
- (e) Airless line breaker
- (f) Low-maintenance motor

(2) Improve passenger comfort
- (a) Optimization of tractive force on motor-driven car and riding comfort through train-wide control of inverter equipment (control of distributed power converter system)
- (b) Improved reliability of on-board power supply through parallel operation of auxiliary power-supply converters

(3) Raise energy efficiency
- (a) Expansion of regenerative braking region
- (b) Snubberless inverter using high-conductivity, high-voltage power devices [1,3)]

The following describes train-traction control

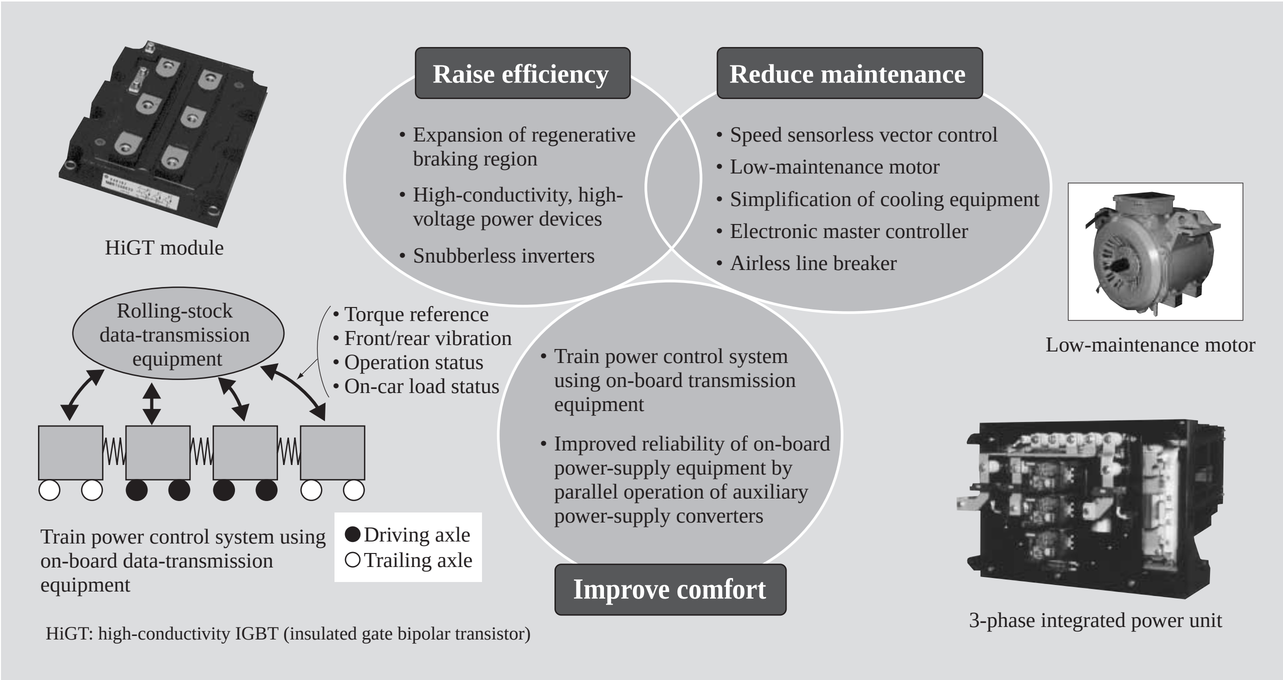

Fig. 1— Social Needs and Hitachi's Train Traction System.
Reflecting recent changes in social conditions, the need has been growing for train traction systems that are more efficient, easier to maintain, and more comfortable for passengers. Hitachi is developing a train traction system in response to these needs.

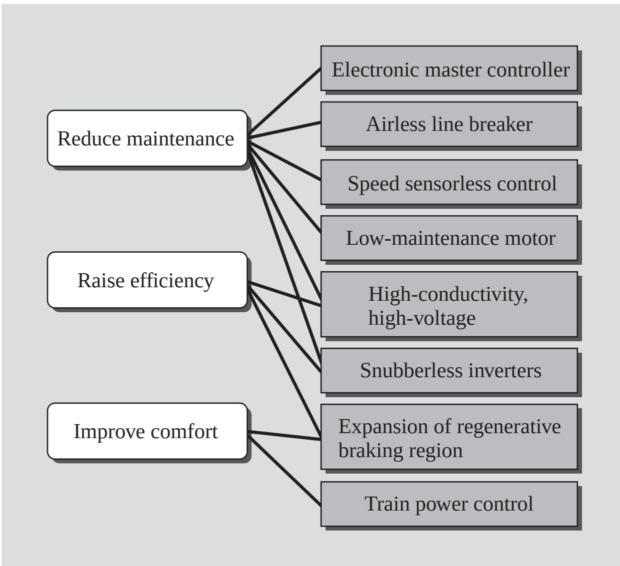

Fig. 2— Needs of Train Traction Systems and Corresponding Technologies.
Reflecting current social conditions, there is a growing need for train traction systems to require less maintenance, improve passenger comfort, and raise energy efficiency.

technologies and the power devices and low-maintenance motor used in the train traction system.

CONTROL TECHNOLOGIES FOR THE TRAIN TRACTION SYSTEM

Speed Sensorless Vector Control[2)]

Traction motor control with inverters used on railways is performed on the basis of rotor frequency detected by a speed sensor installed on the motor. Such a speed sensor, however, operates under severe conditions in terms of vibration, temperature, and other factors, and consequently requires periodic maintenance.

To solve this problem, Hitachi has developed speed sensorless vector control having a level of performance equivalent or greater than that of conventional vector control.

Speed sensorless vector control achieves high torque control performance without speed sensors by estimating rotor frequency from inverter voltage, motor current, etc. It can improve reliability and cut down on maintenance (Fig. 3).

Expansion of Regenerative Braking Region

Hitachi has been developing an all-speed regenerative-brake control system without pneumatic braking. In this system, the load of the braking force from a high-speed to 0 km/h is generated only by the regenerative brake. Greater efficiency in regenerative

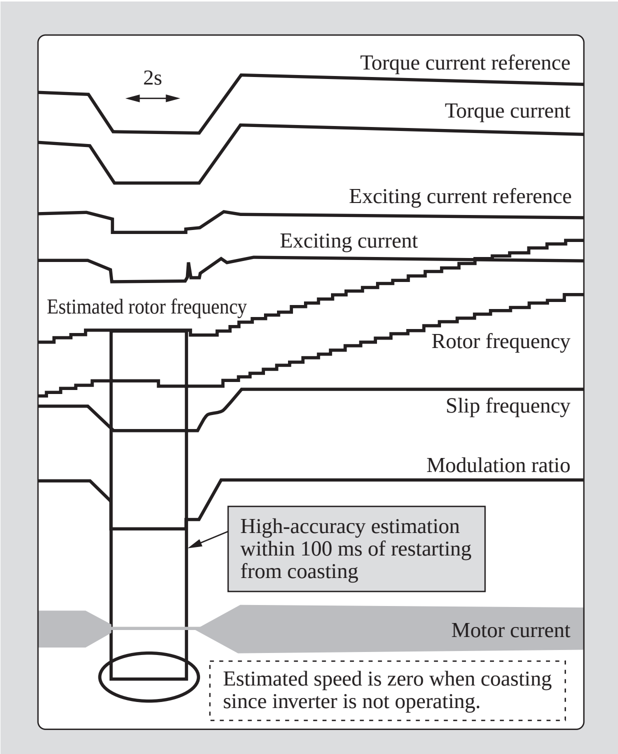

Fig. 3— Operation Waveforms When Restarting from Coasting Under Speed Sensorless Vector Control.
Speed sensorless vector control involves speed calculations based on current and voltage, which means that estimating speed when restarting from coasting (re-powering and initiating regeneration) becomes a problem. The developed system can estimate speed when restarting from coasting within 100 ms.

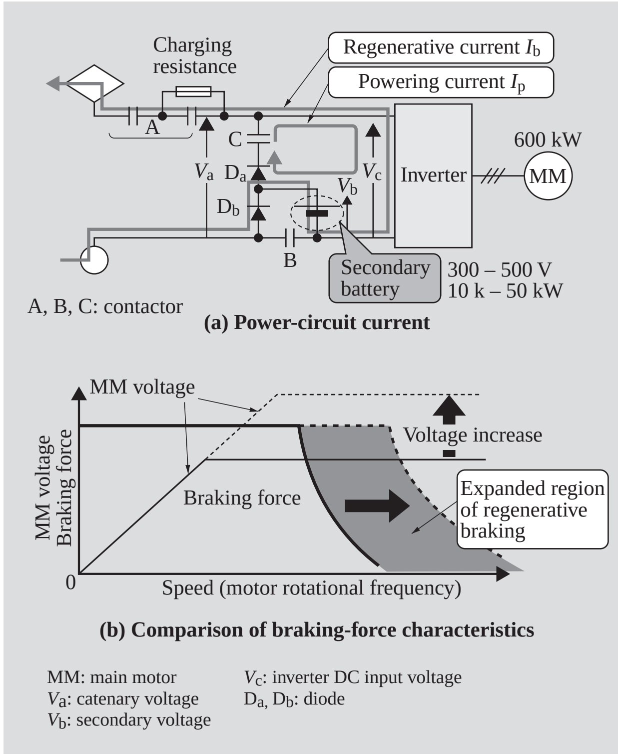

Fig. 4— Expansion of Regenerative Braking Region by a Secondary Battery.
In (a), DC voltage rises due to the secondary battery and voltage applied to the motor during regeneration increases. In (b), braking force expands into the high-speed region due to this rise in DC voltage. This raises energy efficiency and cuts down on brake-shoe maintenance.

energy and lower frequency of maintenance due to reduced load on the brake shoes can be expected by having only the regenerative brake in a high-speed region. Here, in order to have an all-speed regenerative brake bear regenerative braking force in a high-speed region, we can consider (1) increasing the motor's maximum output torque, and (2) raising the motor's terminal voltage (raising DC voltage).

The following describes a system with additive inverter DC voltage using a secondary battery as a means of achieving an all-speed regenerative brake in a high-speed region.

Fig. 4 shows power-circuit configuration in this additive-DC-voltage system and a comparison of braking-force characteristics. In this circuit, the usual situation is that contactor B closes to cut off the battery from the power circuit. At the time of high-speed braking, however, contactor B opens with the result that catenary voltage V_a connects in series with secondary-battery voltage V_b making inverter DC input voltage V_c equal to $V_a + V_b$. This enables the voltage applied to the motor to rise and regenerative-braking force in the high-speed area to increase. Increased energy efficiency and reduced brake-shoe maintenance can therefore be expected.

At restart, circuit-breaker A opens and circuit-breaker C closes so that the inverter becomes supplied with only power from the secondary battery and restart occurs at low voltage. This enables a low-noise restart to be performed.

Train Power Control System

Hitachi has been developing a train power control system for sharing train data among multiple inverter equipment installed on the train. This is achieved through on-board data-transmission equipment that integrates control-, monitor-, and service-related information and transmits it at high speed over an on-board local area network (LAN). The use of this system (1) improves effective adhesion utilization over the

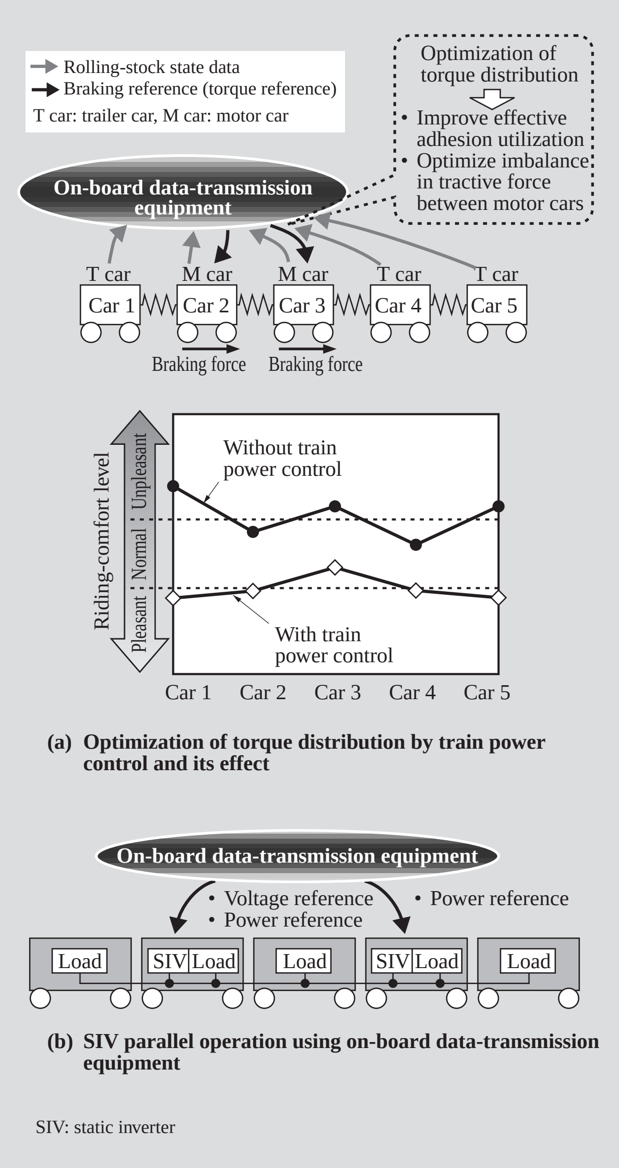

Fig. 5— Example of a Train Power Control System.
In (a)*, riding comfort and effective adhesion utilization over the entire train is improved by using on-board data-transmission equipment and optimizing the torque of motor cars. In* (b)*, the reliability of the train's power supply system is improved by operating auxiliary power supply converters in parallel.*

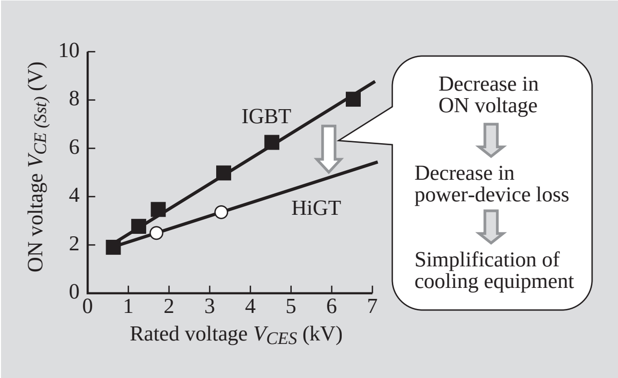

Fig. 6— High-conductivity, High-voltage Power Devices (HiGT).
An enhanced device structure makes it possible to achieve the same switching characteristics as IGBT and reduce ON (conducting) voltage with the end result of decreasing power-device loss.

Fig. 7— Low-maintenance Motor.
A dust-separation structure in a forced-draft fan decreases the amount of accumulated dust in the motor's ventilation paths.

entire train by optimizing torque distribution; (2) improves riding comfort; and (3) improves reliability of the train's power supply system through parallel operation of auxiliary power supply converters. Fig. 5 shows an example of a train power control system.

A train power control system as described here raises the level of riding comfort over the entire train. Parallel auxiliary-power-supply-converter operation, moreover, can improve the reliability of the train's power supply system.

COMPONENTS OF THE TRAIN TRACTION SYSTEM

High-conductivity, High-voltage Power Device (HiGT)[3)]

Fig. 6 compares the ON (conducting) voltage characteristics of high-conductivity insulated gate bipolar transistor (HiGT) and IGBT power devices. As shown, the use of HiGT reduces ON voltage by about 25% compared to IGBT while achieving switching characteristics equivalent to those of IGBT because of an enhanced device structure. The use of HiGT devices can reduce loss in power-switching devices and therefore simplify cooling equipment.

Low-maintenance Motor [4)]

Hitachi has developed a low-maintenance motor featuring a dust separating structure for reducing the amount of accumulated dust in the motor's ventilation paths (Fig. 7).

This low-maintenance motor adopts a forced-draft fan system to force cooling air into the motor. The system features a pocket-shaped space on the periphery of the fan and a dust exhaust outlet on that periphery. This makes it possible to expel dust mixed in with the cooling air by a dust-separation effect produced by the fan.

We have been conducting long-term verification experiments with this low-maintenance motor on actual trains and have been obtaining favorable results as expected. We have also found that combining this motor with bearing equipment having new long-life synthesized lubricating grease can significantly reduce maintenance work[5].

CONCLUSIONS

In this report, we have described control technologies, high-conductivity, high-voltage power devices, and a low-maintenance motor for meeting the new needs of train traction systems.

For the future, Hitachi intends to continue its efforts in accumulating such technologies and promoting new technologies with the aim of developing train traction systems that are smaller and lighter while providing greater passenger comfort and requiring less maintenance.

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ABOUT THE AUTHORS

Satoru Inarida

Joined Hitachi, Ltd. in 1992, and now works at the Rolling Stock Development Center at the Mito Transportation Systems Product Division. He is currently engaged in the development of power converter systems for electric cars. Mr. Inarida is a member of the Institute of Electrical Engineers of Japan.

Tetsuo Kojima

Joined Hitachi, Ltd. in 1994, and now works at the Rolling Stock Development Center at the Mito Transportation Systems Product Division. He is currently engaged in the development of power converter system for electric cars. Mr. Kojima is a member of the Institute of Electrical Engineers of Japan.

Motomi Shimada

Joined Hitachi, Ltd. in 1995, and now works at the Rolling Stock Development Center at the Mito Transportation Systems Product Division. He is currently engaged in the development of power converter systems for electric cars. Mr. Shimada is a member of the Japan Society of Mechanical Engineers.

Seikichi Masuda

Joined Hitachi, Ltd. in 1974 and now works at the Generator Systems Department of the Power & Industrial Systems Division of the Power & Industrial Systems. He is currently engaged in the design of rolling stock motors. Mr. Masuda is a member of the Institute of Electrical Engineers of Japan.