Efficient Train Traction System That Reduces Maintenance Work

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Overview: Recent demands for train traction systems require that they (1) have improved energy efficiency, (2) reduce maintenance work, and (3) incorporate an information system to ensure safe and reliable transportation. To satisfy these needs, vector control technology and slip-slide control based on the estimation of adhesion limit have been adopted for controlling traction. Furthermore, the traction system capable of self diagnosis of circuit breakers in addition to inverter units and conforming to the information control was also developed. In addition, unbalance correction control for the braking force, which improves the riding quality, and generalization control which controls the integrated circuit breakers were developed in multiple inverter groups. A small and lightweight inverter control unit using 3.3-kV IGBTs (integrated gate bipolar transistors) was adopted as the hardware, and an electromagnetic circuit breaker was adopted instead of a conventional compressed air circuit breaker. An electronic fail-safe master controller of a no-contact system conforms to the train information control system.

INTRODUCTION

RECENT train traction systems mainly use high-speed switching IGBTs (integrated gate bipolar transistors) in main circuits. High-speed switching reduces electromagnetic noise generated by the main motor and improves the efficiency of energy conversion. For the inverter control system, vector control is employed to control the torque current component and the exciting current component separately, which are output to the induction motor. Since vector control ensures high-speed torque control, it is also applied to slip-slide control to improve adhesion force.

The maintenance work for contacts and pneumatic parts can be eliminated by replacing mechanical contacts in each unit with electronic contacts and by changing the pneumatic operation system to an electromagnetic one. Fig. 1 shows a diagram of the concept behind the 209-system 950's trial train for

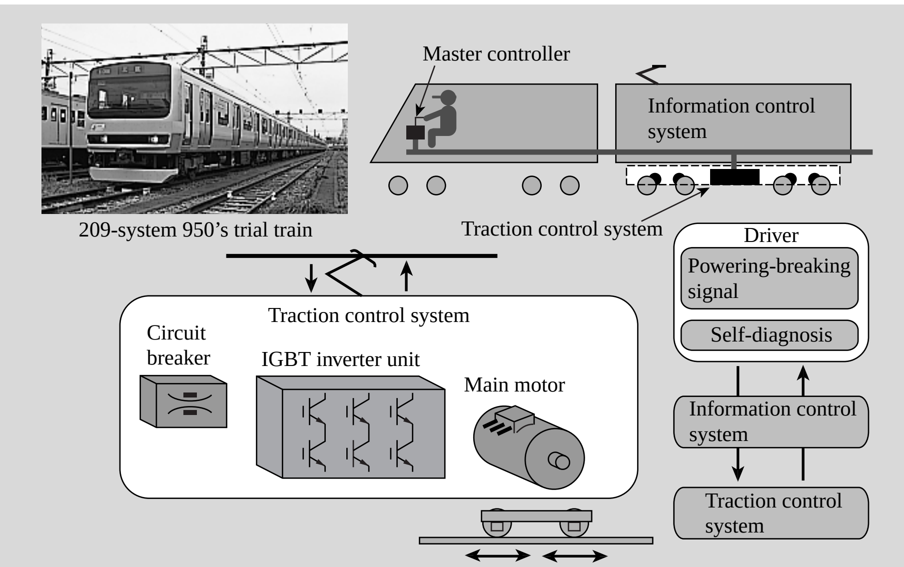
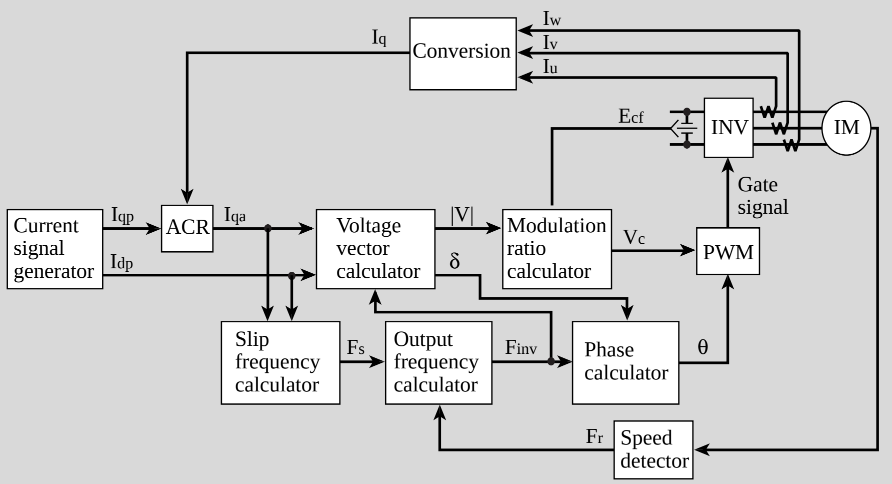


Fig. 1— Concept Diagram of 209-System 950's Trial Train in Eastern Japan Passengers Railways Co., Ltd. and Traction System.
A traction system was developed to reduce maintenance work by replacing mechanical contacts with electronic contacts and to collectively control the information required for train control in cooperation with the information control system.



I_{qp}: torque current signal
I_u, I_v, I_w: motor current
|V|: voltage signal
E_{cf}: filter capacitor voltage
ACR: automatic current regulator
PWM: pulse width modulation
I_{dp}: exciting current signal
I_{qa}: torque control current
δ, θ: phase
V_c: voltage control signal
INV: inverter
I_q: torque current
F_s: slip frequency
F_{inv}: inverter frequency
F_r: rotor frequency
IM: induction motor

Fig. 2— Vector Control Block Diagram.
Vector control conforming to the train traction inverter was developed to control high-speed and high-precision torque and the current of induction motor.

Eastern Japan Passengers Railways Co., Ltd., as well as the train traction system. This system is one of the most computerized information and traction systems in Japan. This paper discusses the system's high-grade inverter control technology, fail-safe electronic master controller and airless circuit breaker, and example applications of recent train control systems.

FEATURES OF TRAIN CONTROL SYSTEMS

Advanced Technologies of the Traction Inverter System

The traction inverter has always experienced problems with adhesion performance and regenerative efficiency. High-speed, high-precision motor torque control and current control are necessary to solve these problems. Fig. 2 shows a block diagram of the developed vector control. The features of this system are as follows.[1)]

(1) Since both multipulse mode and single-pulse mode can be covered by a single control system, discontinuity of torque caused by switching the pulse modes can be prevented. Field weakening control can be automated in the single-pulse mode.

(2) The influences of fluctuations of induction motor constants can be automatically compensated to suppress the fluctuations of torque.

Fig. 3 shows the concept of the re-adhesion control achieved by applying vector control. This system is characterized by (1) the introduction of re-adhesion detection and (2) the addition of a function for estimating the present adhesion force from the slip condition. With these added functions, torque can be recovered immediately after detecting re-adhesion. As a result, the available adhesion coefficient can be improved and the acceleration time can be shortened by 8% compared with the conventional control method. To improve the redundancy of the train traction system, multiple inverter groups are provided to reduce the influences on the run time due to the occurrence of trouble. The following controls can be executed by the mutual transfer of information rather than independent control of these inverter groups.

(1) Equalization of the amount of wear on the brake shoes by appropriately distributing the regenerative brake force.

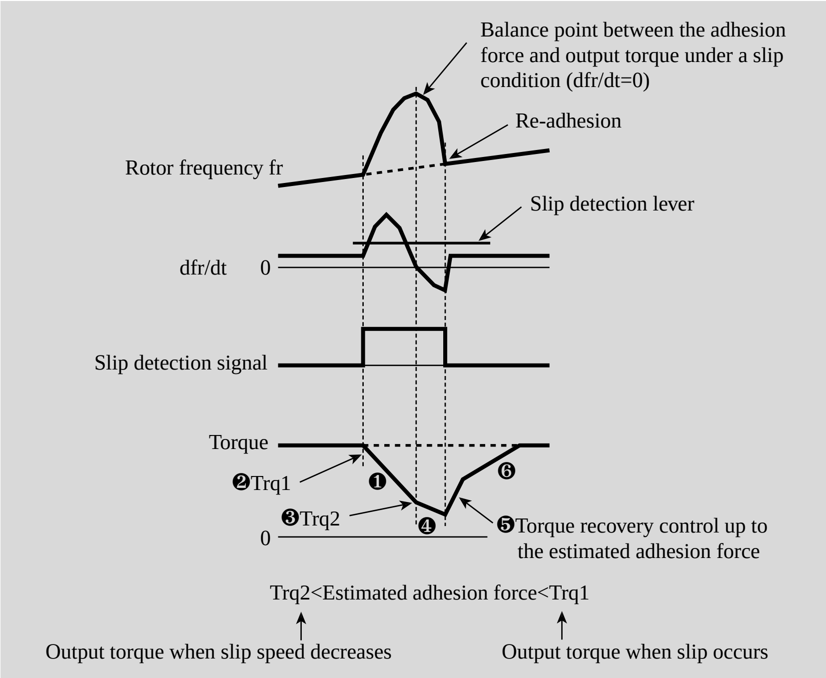
(2) Indexing of the wheel diameter differences and equalization of the available adhesion coefficient during powering by comparing the number of motor revolutions.

(3) Control condition monitoring and automatic release.

Cooperative control of multiple inverter groups has been executed by means of the above-mentioned control methods and the generalization control having a control function of integrated circuit breakers.

Traction Control System for AC Train

Three years have passed since the main converter using IGBT was first applied to 732-system AC trains for the Hokkaido Passengers Railways Co., Ltd. [2)]



❶ Torque reducing control in the occurrence of a slip signal
❷ Torque detection in the occurrence of a slip signal ... Trq1
❸ Torque detection at the balance point (dfr/dt=0) between the adhesion force and output torque under a slip condition ... Trq2
❹ Torque reducing control when dfr/dt<0
❺-1 Calculation of estimated adhesion force [Estimated adhesion force=K(Trq1-Trq2)+Trq2(0<K<1)]
❺-2 (Torque recovery control up to the estimated adhesion force)
❻ (Torque recovery control up to the command torque)

Fig. 3— Re-adhesion Control by Applying the Vector Control.
The acceleration time was shortened by 8% by introducing the re-adhesion detection and adding a function of estimating the present adhesion force from the slip condition.

The main converter was shown to have an excellent AC regenerative power ratio (exceeding 20%) for saving energy, a very low level of higher harmonic current generated by PWM (pulse width modulation) converter for reducing the influences on the substation facilities, and other excellent characteristics. The main converter was applied to 653-system AC/DC trains in Eastern Japan Passengers Railways Co., Ltd. At present, the main converter has been given a larger capacity by using a 3.3-kV, 1,200-A IGBT, and it is currently being used in 700-system "Shinkansen" trains for the Tokai Passengers Railways Co., Ltd. (see Fig. 4).

Technology for Reducing Maintenance Work

The trouble and periodical exchange of parts due to wear and deterioration can be reduced by utilizing a no-contact design and changing from pneumatic controlled parts to electronic controlled parts. This would save man-power in maintenance work.

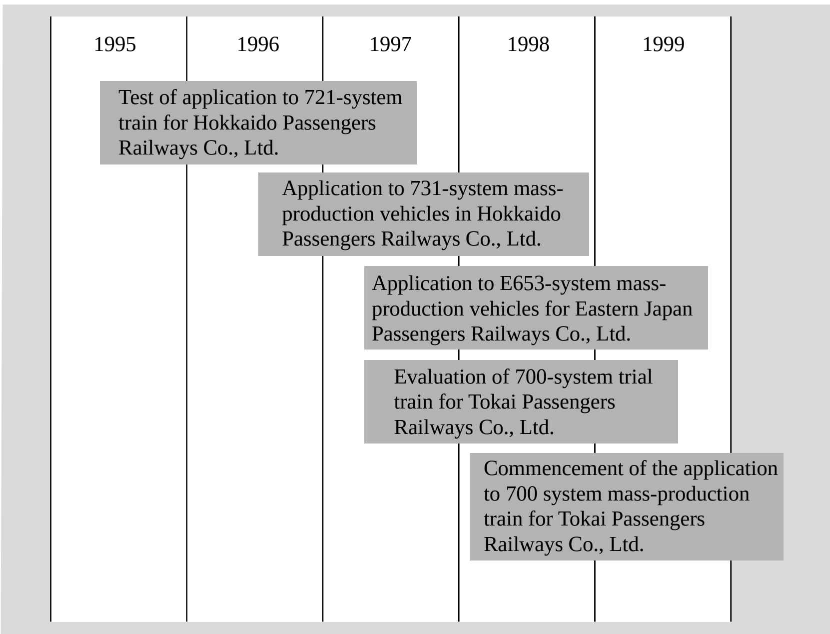


Fig. 4— Results of Hitachi IGBT Main Converter for AC Trains.
The application of IGBT main converter to AC trains was expanded because of its high reputation due to the improvement of AC regenerative power ratio and reduced influence on substation facilities.

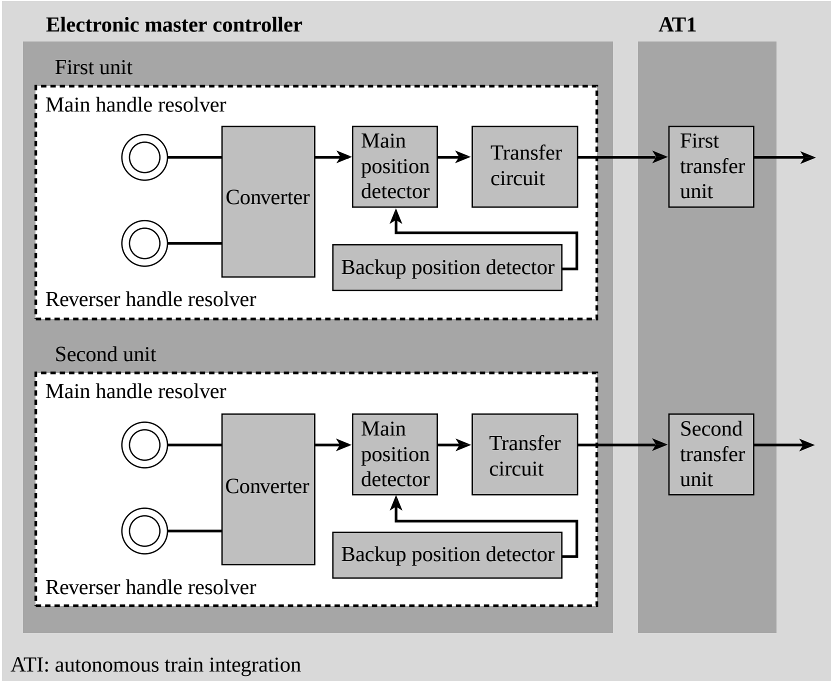


Fig. 5— Configuration of Fail-safe Electronic Master Controller.
Fail-safe characteristic is improved by using a resolver for the main position detection and the dual system design of each system by backup position detection.

(1) Fail-safe electronic master controller

Handle position detection by microcomputer and serial signal transfer were adopted for the no-contact system of the master controller. A fail-safe system was designed by modifying each system to be a dual system by adding backup position detection and detecting troubles by means of mutual monitoring. Fig. 5 shows the configuration of the fail-safe electronic master controller.

Fig. 6 shows the hardware structure of the airless line breaker. The closing time control and trouble detection can be done by contact position detection, so that this line breaker provides a self-diagnostic function.

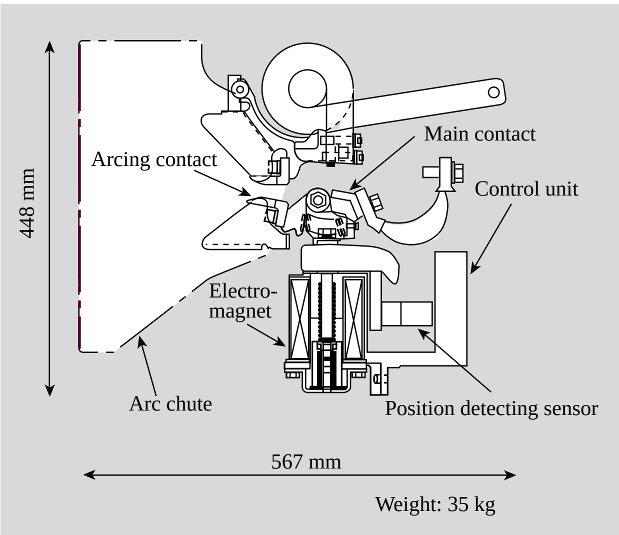


Fig. 6— Hardware Structure of Airless Line Breaker.
An airless line breaker was developed for closing time control and trouble detection.

RECENT TRAIN CONTROL SYSTEMS

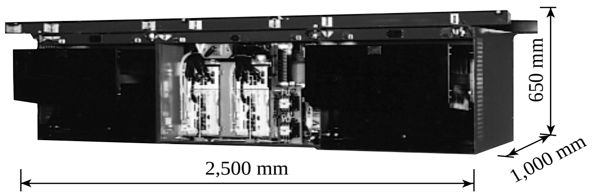
IGBT Inverter Unit Delivered to Eastern Japan Passengers Railways Co., Ltd.

Eastern Japan Passengers Railways Co., Ltd. developed and newly manufactured 209-system 950 trains prior to mass production trains to replace commuter trains in the Metropolitan area. The main circuit consists of 2-group inverter systems, each inverter control four 95 kW main motor units, and applies 3.3 kV 1,200 A IGBT. This system has realized a compact and lightweight unit. Fig. 7 shows a photo of the manufactured IGBT inverter unit.

The vector control using a 32-bit microcomputer is adopted for the controller for high-speed response of light load regenerative control and high-performance slip and slide re-adhesion control. This unit also executes the vehicle information control and high-speed command transfer as its self-diagnostic function.

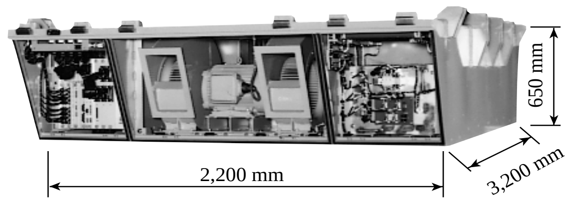
IGBT Main Converter Unit Delivered to Tokai Passengers Railways Co., Ltd.

Tokai Passengers Railways Co., Ltd. evaluated trial main converter unit for 700 system “Shinkansen” trains for about one year, and then started manufactaring



Weight: 850 kg

Fig. 7— IGBT Inverter Unit of 209-System 950's Trains Delivered to Eastern Japan Passengers Railways. Co., Ltd.
The 3.3-kV, 1,200-A IGBT gives this unit a compact and lightweight structure.



Weight: 1,660 kg

Fig. 8— Main Converter Unit for 700-System "Shinkansen" Trains Delivered to Tokai Passengers Railways Co., Ltd.
This small and lightweight unit is characterized by reduced higher harmonics, reduced noise, and improved maintenance.

mass production train.

Fig. 8 shows a photo of the main converter unit for 700-system "Shinkansen" trains which uses a 3.3-kV, 1,200-A IGBT. This unit controls four 275-kW induction motor units, provides a small and lightweight structure, reduces higher harmonics, reduces noise, and improves maintenance.

FUTURE

The following technical developments will be necessary for the train traction system in the future.
(1) Small and lightweight design and improved energy conversion efficiency by high-voltage and large-current main circuit devices.
(2) High-grade control technology which utilizes vector control and generalization control of inverter.
(3) Improvement of self-diagnostic technology to conform to the extension of maintenance interval in cooperation with the information control system.
(4) Reduced need for maintenance work by replacing mechanical contacts with electronic contacts.

CONCLUSIONS

This article described the inverter control technology, including vector control, adhesion control, and generalization control, as well as the fail-safe electronic master controller developed by Hitachi, Ltd. for saving energy and reducing the amount of maintenance work of the traction system. It also described the future developments for the fail-safe electronic master controller with electronic contacts instead of mechanical contacts, the self-diagnostic airless line breaker, and other traction systems.

Hitachi will continue its efforts to develop a higher grade traction system to satisfy various needs.

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