Easy Maintenance and Environmentally-friendly Train Traction System

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OVERVIEW: Hitachi, Ltd. has been developing converter-inverter systems and auxiliary power converters to which they have applied vector control techniques and high-voltage IGBTs (insulated gate bipolar transistors), airless line breakers, and electronic master controllers. These are applied to make train traction systems more functional, to make maintenance easier, and to reduce energy consumption. The need is growing for diesel-powered train traction systems that are easy to maintain, highly efficient, and environmentally friendly. Moreover, the demand exists for much smaller traction systems for electric trains. Therefore Hitachi developed hybrid propulsion systems for diesel-powered trains to which the traction systems techniques for electric trains was applied, and small cooling equipment that uses water circulation. Both of them were developed jointly with East Japan Railway Company (JR-East). In addition, Hitachi developed sensorless speed vector control that eliminates the need for a speed sensor, and an all-speed range electric brake that can stop a train without pneumatic braking along with technology that uses these two technologies together.

INTRODUCTION

TO make train traction systems more functional, maintenance work easier, and to reduce energy consumption, Hitachi has been developing main circuit technologies to which vector control techniques, high-voltage IGBTs (insulated gate bipolar transistors) are applied.

The need is growing for diesel-powered train traction systems that offer easy maintenance, high efficiency, and environmentally-friendly operation. Moreover, a demand exists for more reliable, more functional, smaller, lighter traction systems for electric trains. Hitachi is developing technologies for these needs, as described below (see Fig. 1).

TRAIN TRACTION SYSTEM REQUIREMENTS

The technical trends in train traction systems are shown in Fig. 2. In line with those trends, Hitachi is developing next-generation electrical-system rolling stock with the following features to meet the demand for reduced maintenance, energy savings, environmental friendliness, and for compact and light-weight structures.

(1) Propulsion equipment

We are developing high power traction converter equipment that uses compact water circulation cooling systems. The main target of these developments are high-speed trains like the Shinkansen.

(2) Speed sensorless vector control

Eliminating the speed sensor of traction motors creates space for increasing their power and improving their maintenability.

(3) All-speed range electric brake control

Hitachi's more accurate speed estimation technology enables the combination of sensorless speed vector control with all-speed range electric brake control. These effectively reduce brake shoe wear and refines train ride comfort.

(4) Traction system for diesel-powered trains

The application of electric train traction technologies reduces maintenance work and improves environmental friendliness in diesel-powered trains.

(5) Storage battery energy management

Storage battery management technology enables storage of brake energy in diesel-powered trains, expansion of regenerative brake energy into high-speed region in electric trains, and a stable DC (direct current) power supply to the auxiliary power converter.

(6) HB (high-speed breaker) technologies using semiconductors and control of high frequency PWM

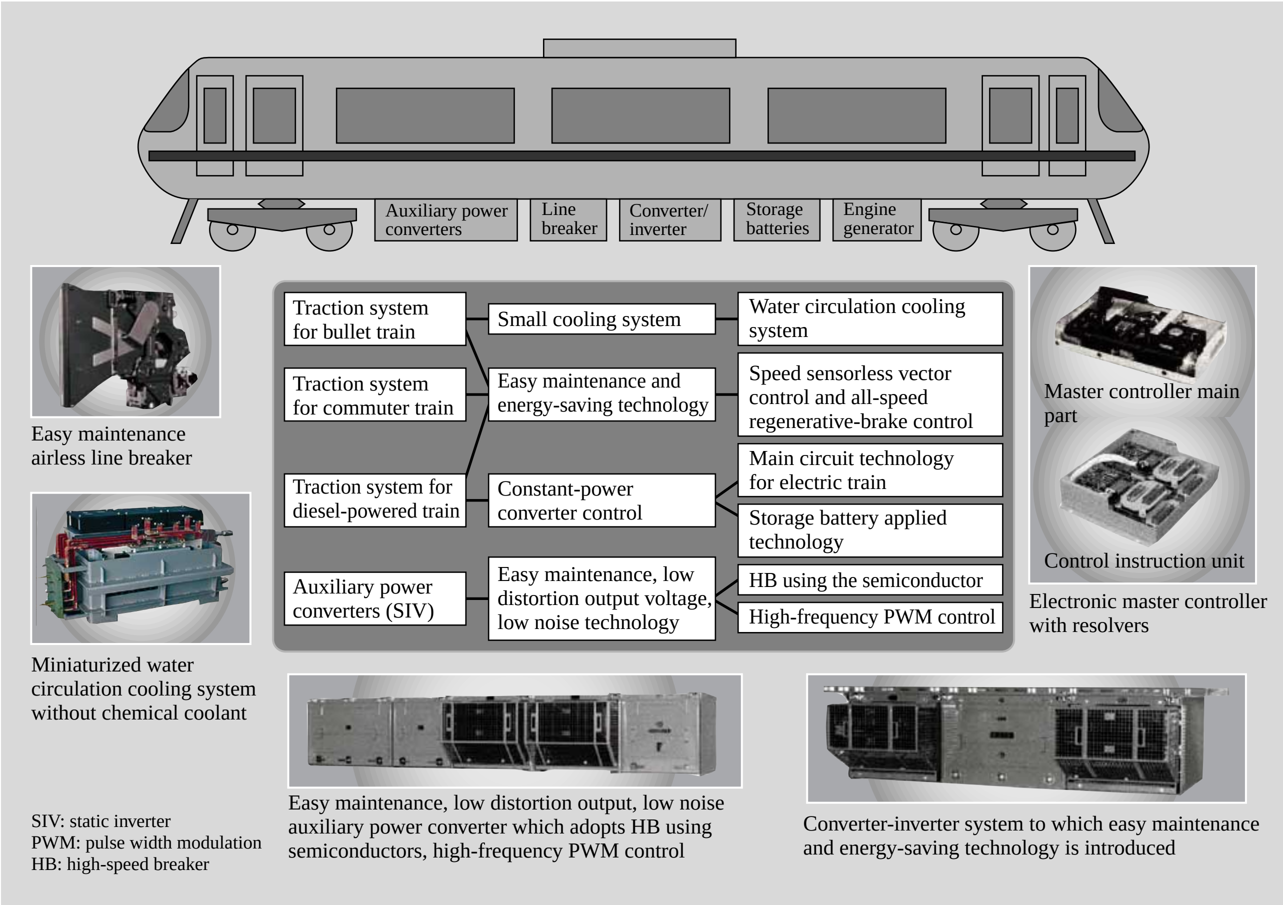

Fig. 1—Hitachi's Train Traction System.
A growing need exists for train traction systems that are easier to maintain, more reliable, more energy efficient, and environmentally friendly. Hitachi is developing a train traction system to meet these needs.

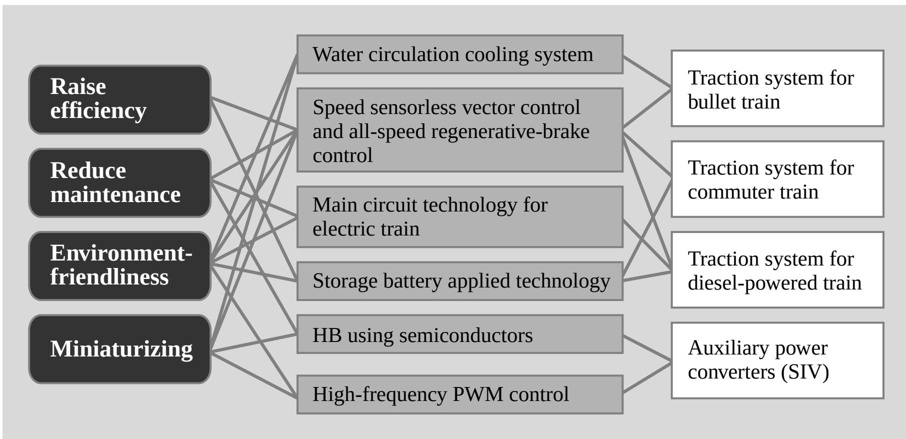

Fig. 2—Requirements for Train Traction Systems and Corresponding Technologies.
The need is growing for train traction systems that require less maintenance, provide higher energy efficiency, and are environmentally friendly.

(pulse width modulation)

These technologies enable auxiliary power converters to decrease distortion of output voltage; this reduces maintenance work and train noise.

HYBRID PROPULSION SYSTEM

Features of Hybrid Propulsion System

As a step toward providing environmentally-friendly propulsion systems, Hitachi has developed a hybrid propulsion system combining an engine generator with storage batteries. This system provides regenerative braking, not previously possible on conventional diesel-powered trains, and this increases energy savings via regenerated energy. The system uses a series-hybrid configuration designed to allow immediate system conversion (by replacing the engine

Fig. 3—JR-East Class E991 Experimental Vehicle (New Energy Train).
The hybrid propulsion system is installed and performance trials are proceeding.

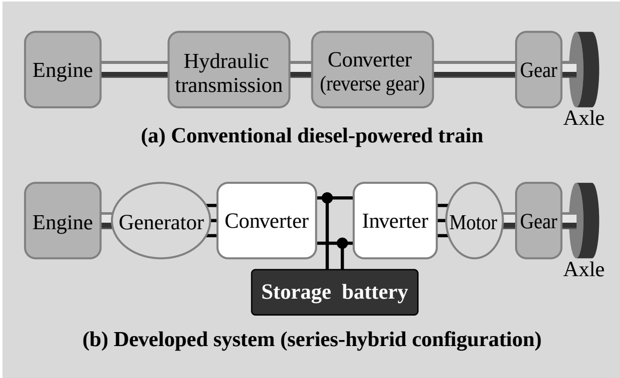

Fig. 4—Hybrid System Comparison.
The series-hybrid system converts the engine output into electrical power and uses only motors for propulsion. This system reduces the high maintenance costs of conventional diesel-powered trains because the developed system's configuration is simplified by abolition of mechanical equipment such as hydraulic transmissions.

generator with a fuel-cell unit) in the future, when fuel-cell technology becomes more widely established.

This hybrid propulsion system was developed jointly with East Japan Railway Company (JR-East) and has been installed in a JR-East Class E991 experimental vehicle for performance trials (see Fig. 3).

Advantages of Hitachi's System

(1) Application of series hybrid system

This system uses a series-hybrid configuration (see Fig. 4) that first converts the engine output into electrical power and then uses only motors for propulsion. The AC (alternating current) output generated by the engine is converted into a VVVF (variable voltage variable frequency) AC supply by the main converter to drive the induction motors. Storage batteries are located on the intermediate DC section of the main converter, and the charging and discharging of the storage batteries are controlled using output adjustments of the converter and inverter.

(2) Environmentally-friendly system

This series-hybrid system allows the engine speed to be set irrespective of the vehicle speed, and thereby it permits high-efficiency power generation by operating predominantly in the engine speed range of low fuel consumption. This also reduces exhaust gases. Using electric train inverter control technology makes possible regenerative braking, and regenerated energy temporarily stored in the batteries can be used as auxiliary power for acceleration. This is expected to give fuel savings of approximately 20% compared with conventional diesel-powered trains. An engine cutout control is also employed to reduce noise and fuel consumption while trains are stopping at stations.

(3) Reducing maintenance work

The series-hybrid system eliminates equipment such as hydraulic transmissions, which entail high maintenance costs on conventional diesel trains. Similarly, commonality of equipment with electric trains saves maintenance work and allows more efficient use of existing inspection equipment.

Control of Total System

(1) Outline of total system control method

The output from the storage batteries and engine is controlled as follows according to running conditions.

(a) Accelerating: the storage batteries alone are used for acceleration at low speeds, and then additional power is provided by the engine generator from the mid-speed range.

(b) Braking: the engine is shut down and regenerated braking power is stored in the batteries.

(c) Constant-speed braking: regenerated power is absorbed using engine braking to prevent overcharging on continuous downhill gradients.

(d) Stationary: the engine is shut down to reduce noise in stations and improve fuel consumption.

(2) Constant-power converter control

The hybrid propulsion system employs constant-power converter control by using electrical power in order to manage the energy balance of the DC section in the system. This is because charge/discharge control is not possible using conventional constant-voltage

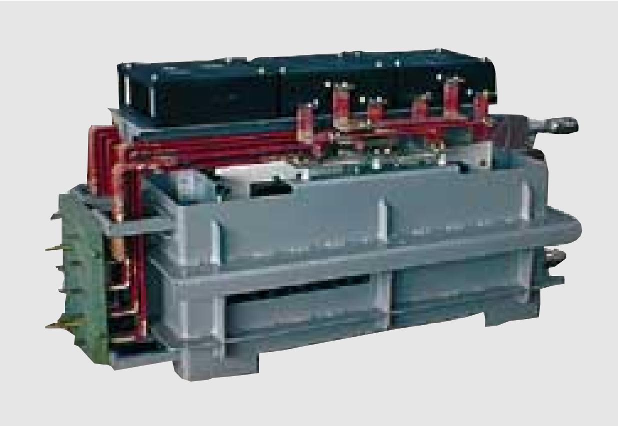

Fig. 5—Compact Cooling System.
The system is about 40% more compact than a conventional one, and improvements in environmental conformity and maintenance work reduction were attempted.

converter control, as the voltage at the DC section between the converter and inverter varies depending on the storage battery energy. New constant-power converter control has been developed to manage the energy balance for the DC section that uses electrical power and allows optimum charge/discharge control.

(3) Engine brake control

The hybrid propulsion system uses engine brake control so as to maintain a constant speed (holding speed) on downhill gradients. The series-hybrid system achieves engine braking by using the braking power generated by the traction motors and inverter to drive the converter and generator in reverse and absorb energy with the engine load. This has the advantage of allowing the engine braking power to be set irrespective of the vehicle speed, which enables the hybrid propulsion system to provide stable, constant-speed operation under any running conditions.

LATEST TRAIN TRACTION SYSTEM

Compact Cooling System

In traction motor controllers for Shinkansen trains, semiconductors (IGBTs) are attached to the side faces of radiator, which are made of aluminum and enclose PFC (perfluorocarbon). They are cooled by a blower sending air to the radiator.

Because of this formation of the equipment, the cooling unit, which consists of radiator and electrical devices (including IGBTs), occupies most of the central portion of the controller. Consequently, the controller needs a large space. Therefore, making this equipment more compact is essential to making Shinkansen trains faster.

As a technology to solve these problems, we have designed a water circulation cooling system. In this system, electric devices are installed on both sides of a water-cooled plate with water-flow channels that is made of aluminum to make the power unit smaller. In addition, putting the radiator in vacant areas between other equipment uses space effectively.

An outline of the newly developed cooling system is shown in Fig. 5. We attained about 40% greater compactness than that of a conventional system. In the developed system, conformity to the environment is improved by using water as a coolant instead of PFC.

In addition, dry filter capacitors have been adopted instead of oil-filled ones in order to enhance environmental conformity. Also, construction has been adopted that lumps together connections for main circuits to reduce maintenance work.

All-speed Range Electric Brake Control System

Traction inverter used on railways performs on the basis of rotor frequency as detected by speed sensors installed on the motor. However, such speed sensors operate under severe conditions in terms of vibration,

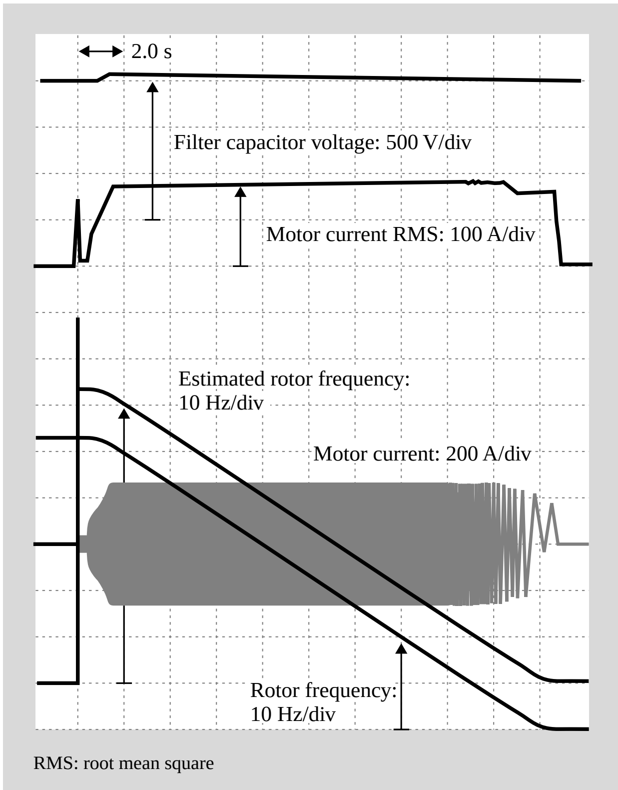

Fig. 6—Operation Waveforms under All-speed Range Electric Brake System.
Sensorless speed vector control estimates rotor frequency based on motor current and inverter voltage. The developed system enables electric braking to attain from a high speed to 0 km/h.

temperature, and other factors, and consequently require periodic maintenance.

To reduce this maintenance, Hitachi has developed sensorless speed vector control having a level of performance equivalent to or greater than that of conventional vector control using speed sensors. Sensorless speed 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 work.

Hitachi has been developing an all-speed range electric brake control system by using the sensorless speed vector control. In this system, the braking force from high speed to 0 km/h is generated only by electric brakes without pneumatic braking. Higher accuracy of stop position and lower frequency of maintenance due to reduced load on the brake shoes can be expected from use of the all-speed range electric brake control system. (see Fig. 6).

CONCLUSIONS

In this report, we have described a hybrid propulsion system, compact cooling system, and control technologies for meeting the new demands of train traction systems.

For the future, Hitachi intends to continue tackling development of technologies that require less maintenance, provide more energy efficiency, and are environmentally friendly.

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