System Technologies for More Comfortable and Attractive Railway Services

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ROLES AND FUNCTIONS REQUIRED FOR RAILWAYS

THE environment in which the railway industry operates is being driven by a number of new considerations including looming global environmental problems and a number of factors that were not generally thought of as being relevant to railway transport including the economic crisis that arose in the USA and the change of government in Japan.

In the USA, a number of plans have been announced to construct high-speed railway networks both as a response to environmental problems and as a stimulus measure to boost employment in response to the crisis in the domestic economy. Although the general view is that serious efforts to deal with environmental problems first got underway around the time of the Kyoto Protocol agreed in 1997, more than ten years have passed since then and now the Hatoyama administration has announced a target of reducing CO_2 emissions by 25% relative to 1990 levels by 2020, although this is subject to some conditions. These developments can be thought of as providing favorable conditions for the railway business.

On the other hand, a number of worrying changes for railway transport have also emerged including the potential for changes in the Japanese market resulting from greater openness to international trade, a reduction in transport demand in Japan due to the aging population and fewer children, and the shift by travelers toward greater use of cars resulting from the plan to remove tolls from the freeway network.

The development of technologies for safe and reliable transport is naturally an important issue for manufacturers, and other key issues include the development of technologies that can reduce operating costs at the same time as reducing environmental impacts and technologies that can deliver a boost to the railway industry by improving further the comfort and attractiveness of railway travel.

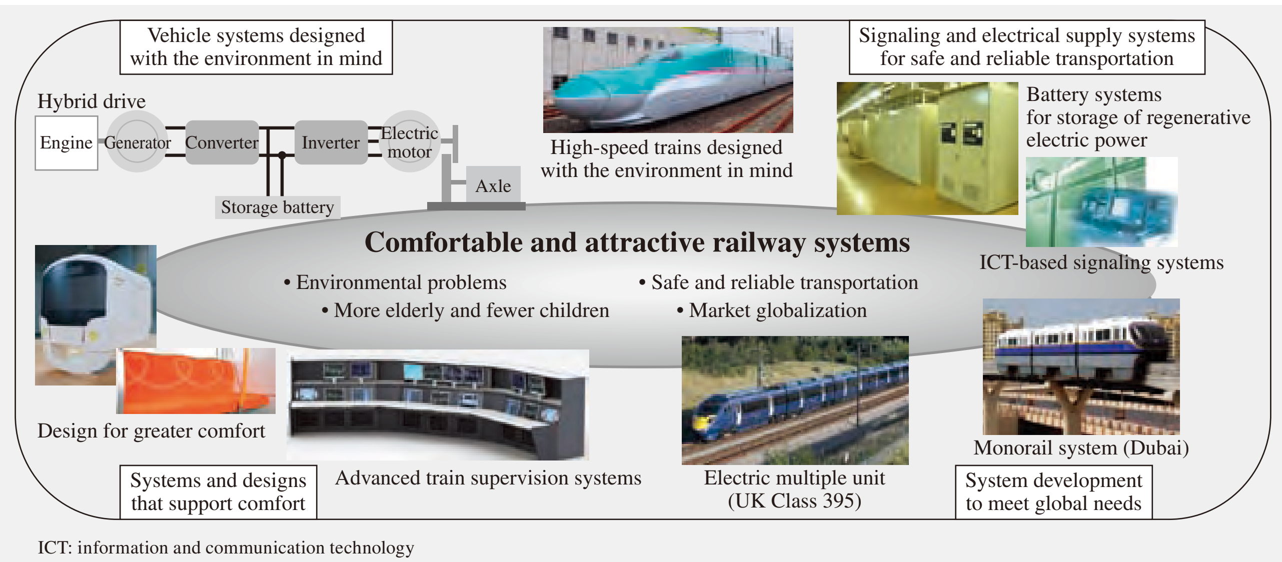

Fig. 1—Development of More Comfortable and Attractive Railway Systems.
Hitachi is developing technologies for attractive railway systems with excellent performance not only in safety and control, but also in terms of factors such as comfort and the environment.

TABLE 1. Issues and Technologies Being Researched and Developed

Hitachi is working on research and development in various fields of technology with the aim of supplying leading-edge solutions to each issue.

Issue	Main research and development fields
Reduce environmental impact	• Technology for efficient storage of regenerative electric power • Analysis of moving train characteristics (air resistance, noise analysis) • Highly efficient batteries with ultra-long life and associated control techniques • New material technologies (SiC, chlorofluorocarbon alternatives, etc.)
Improve comfort	• High-speed/high-quality IT and timely information distribution system technologies • Vibration control, human engineering approaches, and similar • People-friendly universal design
Better safety and more sophisticated functions, global deployment	• Highly safe electronic communication technologies (LSIs, networks, etc.) • System interoperation and assurance technologies, etc. • RAMS support and strength analysis techniques, etc.

SiC: silicon carbide IT: information technology LSI: large-scale integration
RAMS: reliability, availability, maintainability, and safety

COMFORTABLE AND ATTRACTIVE RAILWAY SYSTEMS

As a total system manufacturer, Hitachi undertakes a wide range of system development that relates to the railway industry including vehicle systems designed with the environment in mind, train supervision systems that support high-quality operation, signaling systems that ensure safety, and systems that supply reliable electric power. Hitachi is also undertaking a global expansion into medium- and high-speed trains, monorails, and other systems that can contribute to the progress of railway systems internationally based on technologies developed in Japan (see Fig. 1).

The technological developments used to implement these systems can be broadly divided into the categories listed in Table 1. Specifically, Hitachi is working earnestly on the following developments: (1) materials, rechargeable batteries, and other technologies that reduce the impact on the environment, and analysis technologies including those that reduce air resistance and external noise, (2) technologies that provide convenient data communication services, comfortable passenger spaces, and similar, and (3) control technologies that provide a high degree of safety and perform sophisticated control, and technologies for deploying these on a global basis. Through these technological developments, Hitachi intends to make an even greater contribution to advances in railway systems in the future.

TECHNOLOGIES FOR COMFORTABLE AND ATTRACTIVE TRAIN SYSTEMS AND TECHNOLOGIES FOR GLOBAL DEPLOYMENT

One initiative relating to rolling stock for the Japanese market is work on increasing the speed of the Shinkansen (bullet train). The E5 Series Shinkansen for the East Japan Railway Company will be the first in the country to have a cruising speed in normal operation of 320 km/h and operational trials using a standard production-model front-end car (see Fig. 2) are currently underway. The extension of the service to Shin-Aomori will see significant reductions in travel times to the Tokyo region.

A range of measures were incorporated into the E5 Series to improve its running performance, take

(a) (b)

Fig. 2—E5 Series Shinkansen Belonging to East Japan Railway Company (a) and 30000 Series Train Belonging to Seibu Railway Co., Ltd. (b).
Hitachi is developing technology in ways that include developing advanced technology for high-speed trains and proposing new people-friendly design concepts for next-generation commuter trains.


(a)


(b)

Fig. 3—Monorail Vehicles for Palm Jumeirah Transit System in Dubai (a) and Class 395 High-speed Train for UK (b).
Hitachi has developed technology to meet UK specifications based on the A-train concept and commercialized a monorail system with automatic operation.

account of environmental concerns, and improve comfort. In particular, measures have been adopted to improve the comfort of the passenger cabins by making the cabins quieter and reducing lateral vibration, and an attractive cabin environment has been created with the planned introduction of the Super Green Train (provisional name).

For commuter trains, Hitachi has developed rolling stock with additional design innovations called the "next-generation A-train aluminum rolling stock system" (see Fig. 2). The proposed exterior design conveys a sense of inclusiveness between the railway, users, and others and is in accord with the design image of the railway operator, while the interior design conveys a sense of freshness and openness with a color scheme that takes account of barrier-free requirements and has been proposed from the perspective of a universal design for the hand holds, seating, and other fittings.

For overseas customers, Hitachi is currently working on the deployment in overseas countries of its monorail systems as part of a global expansion. A monorail system was produced for Dubai (see Fig. 3) and has been operating satisfactorily since it entered service in April 2009. Hitachi can offer large, standard-model, and small monorails with different variations to suit passenger demand and the contract for this system was the result of the high regard in which the operating record over many years of monorail systems supplied both in Japan and elsewhere is held. This Dubai monorail was the first to use a double-skin structure[a] and FSW (friction stir welding)[b] for the carbody chassis. To satisfy NFPA[c] fire safety rules, the design used a fireproof floor structure and fireproof doors for the gangways. The monorail operation is also fully automatic and does not require manual intervention by a driver or operation control center staff.

In its first foray into the UK market, the birthplace of the railway industry, Hitachi supplied 29 sets (174 rolling stock) of its Class 395 high-speed trains (see Fig. 3) which formally commenced commercial operation in December 2009. The Class 395 was developed and designed based on the A-train concept to satisfy the customer's specifications, UK and European rules, and other local requirements including operating practices and infrastructure, and Hitachi is also responsible for conducting operational testing in the UK to confirm the reliability and comfort of the train and for maintenance services after delivery. Particular issues included the fact that standards for areas such as collision,

(a) Double-skin structure
The vehicle structure uses ribbed (reinforced) hollow extrusions with a truss structure in the gap between the two skins. Because of the strength and light weight of the materials used in the double-skin structure, the framework of pillars, beams, and other structural components used with conventional single-skin designs are no longer required. Not only does this result in a simple carbody with benefits that include fewer components and lower welding costs, other advantages include that the interior of the car can be made larger and better noise insulation can be achieved using a uniform double-skin structure.

(b) FSW
FSW is an abbreviation of "friction stir welding." It is a welding technique that generates frictional heat by moving a rotating cylindrical tool called a "rotating tool" along the material being welded. Features include not melting the material being welded which means that it introduces less strain and deformation into the weld than welding techniques that involve melting, keeping both the welding surface and rear surface flat and avoiding the creation of bubbles, cracks and other defects, and high weld strength.

(c) NFPA
NFPA is an abbreviation of the US "National Fire Protection Association." Established in 1896 and incorporated in 1930, the NFPA is a non-profit organization with activities that include formulating fire prevention standards and technical guidelines and conducting fire safety audits. It establishes fire safety standards for a wide range of areas extending from buildings through to fire safety equipment, commercial equipment, fire extinguishers, electrical equipment, and so on. These standards are widely recognized across the USA where they are used as compliance standards or guidelines.

strength, fireproofing, and noise were significantly different to those in Japan, the lack of static rolling stock gauge for existing track which means that rolling stock manufacturers need to establish and verify gauging (rolling stock gauge) themselves, and the confirmation of rolling stock dynamics specific to the UK. In response, Hitachi undertook technology development, design, and production to satisfy these requirements and the trains were audited by the UK certification authority and certified as complying with the standards.

COMPACT DRIVE TECHNOLOGY THAT BOOSTS EFFICIENCY

Next-generation Small High-performance Inverter Technology

Hitachi has led the world in commercializing high-voltage 2-kV IGBTs(d) and IGBT inverters for railway applications that use these devices. The newly developed next-generation small high-performance inverter (see Fig. 4) makes full use of the power electronics technology that Hitachi has developed in the past for use in applications ranging from home appliances through to industrial equipment and car parts.

The motor drive circuit uses the newly developed HiGT (high conductivity IGBT) module together with active gate drive control which obtains maximum performance from the module to achieve both low losses and low noise. Measures to improve quality were adopted from the design stages including the use of analysis-driven design methodologies and automatic program generation tools. Also, a single-CPU (central processing unit) configuration was adopted for the control logic and fan-less operation achieved by selecting low-voltage components.

New techniques were also adopted for control. Cascade-type vector control(e) is a technique developed for control of permanent magnet motors which are widely used in home appliances and elsewhere. Applying this technique to the induction motors commonly used in railway applications achieved significant improvements in control stability and torque responsiveness. It is anticipated that this control technique will deliver significant benefits when used with low-loss induction motors which are more difficult to control.

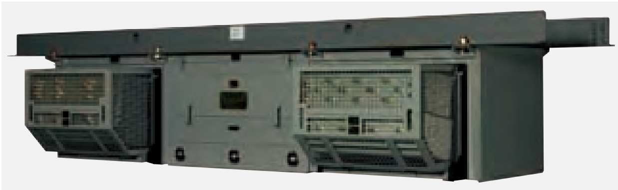

Fig. 4—Next-generation Small High-performance Inverter. Hitachi has achieved small size and high performance through measures that include the newly developed HiGT (high conductivity insulated gate bipolar transistor) and the development of optimum control techniques.

Ethernet* is increasingly becoming the standard communication protocol used in railway applications and it was chosen to provide the interfaces between control equipment.

Efficient Regeneration Systems

Hitachi has led the world in commercializing hybrid traction systems using lithium-ion batteries for railway applications. Hitachi is working on the development of technologies that use this storage battery technology in trains to make effective use of the regenerative electric power produced during braking.

Energy savings can be achieved by transferring the power generated by regenerative braking to nearby trains able to consume this power, but this system does not operate effectively in situations such as during off-peak times when few other trains are available to make use of this power. In response, Hitachi is developing the B-CHOP system to store the regenerative electric power in wayside storage batteries and the sequential regenerative brake system in which the storage batteries are installed on the train.

Hitachi is also working on the development of a ground-breaking regeneration system. This is the regenerative brake with effective speed extended which extends the upper limit on the range of speeds at which regenerative braking can operate by using the storage battery to raise the DC voltage of the inverter. Whereas the B-CHOP system and sequential regenerative brake system operate to prevent regenerative electric power

(d) IGBT
IGBT is an abbreviation of "insulated gate bipolar transistor," a semiconductor device that combines characteristics of bipolar transistors and MOSFETs (metal-oxide semiconductor field effect transistors). Because of their low conduction loss even at high voltages, IGBTs are key devices used in high-capacity inverters.

(e) Cascade-type vector control
A control technique for AC (alternating current) electric motors developed by Hitachi. Vector control is the term used to indicate control schemes that resolve the AC into motor torque and rectangular components which are controlled independently, and Hitachi has developed two such control techniques called smart vector control and cascade-type vector control that have different characteristics. Cascade-type vector control uses a different configuration for the current control unit and non-interfering control unit to achieve ideal current control response up to high motor speeds.

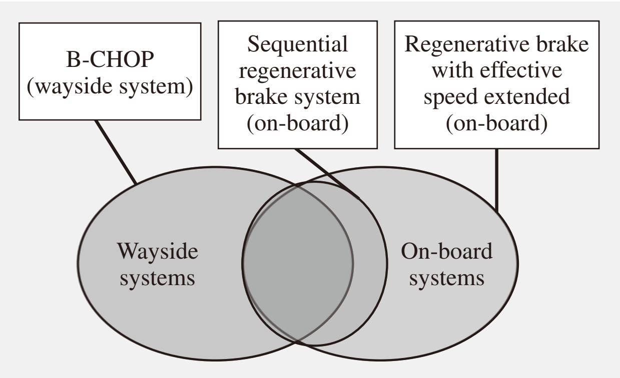

Fig. 5—Efficient Regeneration Systems.
The B-CHOP system (system developed by Hitachi that uses wayside storage batteries to absorb regenerative electric power) and sequential regenerative brake system use rechargeable batteries to store electric power and prevent loss of regeneration. The regenerative brake with effective speed extended delivers new energy savings by extending the range of speeds at which regeneration can be used.

from being wasted within the operating range of the current regeneration system, the regenerative brake with effective speed extended system can deliver new energy savings by extending the range of speeds at which regeneration can be used (see Fig. 5).

NEXT-GENERATION TECHNOLOGIES THAT SUPPORT ADVANCES IN RAILWAY SYSTEMS

Fluid Characteristics Analysis Technique

Hitachi has used analyses run on supercomputers or other computers in many of its past product developments. This section describes thermal fluid technology. With the increasing capabilities of computers, analyses that in the past would have required a long time and significant computing resources can now be run comparatively easily and quickly.

Hitachi is developing performance evaluation techniques that use thermofluid analysis of entire product units including small components. Fig. 6 shows an example of a thermofluid analysis conducted for an LCD (liquid crystal display) projector that considers the entire projector. Although the LCD projector has a complex internal structure, the analysis grid is generated automatically from 3D CAD (three-dimensional computer-aided design) data and the new techniques have made it possible to carry out thermofluid analyses of the entire unit that were difficult to perform using previous methods. Fig. 6 (b) shows the temperature distribution inside the LCD projector with red representing high-temperature regions and blue low-temperature regions, while the white lines in

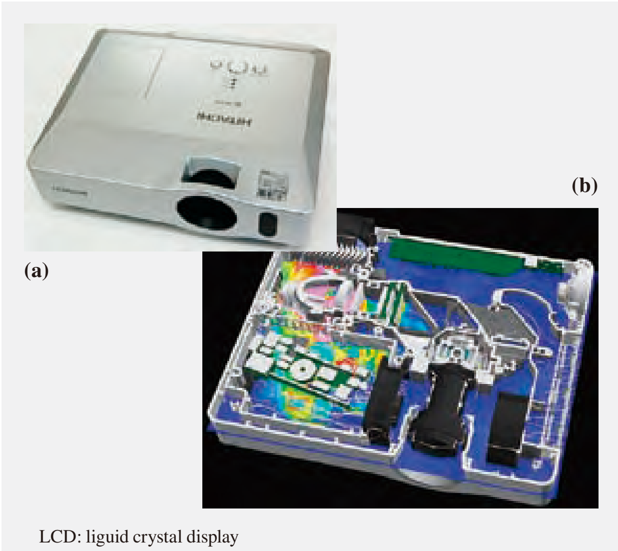

Fig. 6—Application of Thermofluid Analysis to LCD Projector.
Fig. (a) shows the LCD projector and Fig. (b) shows the temperature distribution and flow of cooling ventilation inside the projector unit. The analysis can reproduce the flow of heat, air, and so on in the complex internal space inside the projector.

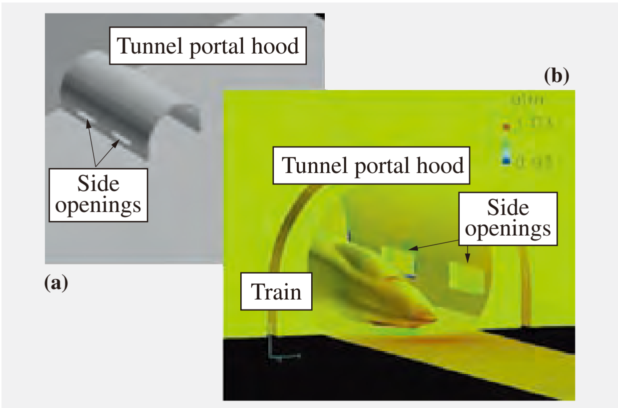

Fig. 7—Analysis of Train Entering Tunnel with Tunnel Portal Hood.
Fig. (a) shows the analysis model including the tunnel portal hood and Fig. (b) shows the pressure distribution at the instant when the train enters the tunnel (looking toward the tunnel entrance from inside the tunnel). Developments in aerodynamics analysis technology have made it possible to evaluate performance at the design stage.

the figure indicate the flow of cooling ventilation from outside the unit. Analyses like these assist in improving product performance and reliability.

Similarly, a wide range of different fluid analyses are used in product development for the railway industry. Fig. 7 shows one example. This analysis analyzes the micro-pressure waves that occur when a train enters a tunnel. This analysis also makes use of 3D CAD data to represent accurately the complex shape of the front end of the train and it has been set up such that the analysis can be performed even for the case when a tunnel portal hood [see Fig. 7(a)] with a complex shape that includes side openings is located at the entrance to the tunnel. Fig. 7(b) shows the results of the analysis in the form of the pressure distribution on the sides of the train and on the tunnel walls at the instant when the train enters the tunnel. Analyses such as this allow the train performance to be evaluated from the design stage.

These analysis techniques allow the pressure fluctuations that occur on the side of the train and on the tunnel walls in cases such as when a high-speed train enters a tunnel or two trains pass each other in the tunnel going in opposite directions to be analyzed with greater accuracy. This in turn makes it possible to do things like evaluating the carbody strength or determining the effect on tunnels and other parts of the railway infrastructure.

Drive Technologies Using SiC Devices

Although Si (silicon) has long been used as a material in power devices such as diodes and the switching devices used in inverter power modules, its potential for further improvement in efficiency is running up against physical limits and accordingly attention has shifted to compounds such as SiC (silicon carbide) for the next generation of materials. One of the characteristics of SiC is its ability to withstand high voltages as it has a breakdown electric field strength nearly 10 times that of silicon. This allows chips to be approximately one-tenth the thickness of equivalent Si devices with a commensurate reduction in resistive loss during conduction, meaning that SiC devices can be expected to be smaller, with simpler cooling systems and higher efficiency.

Table 2 lists the ranges of application of SiC and the optimum device types. Although there is growing interest in SiC-MOSFET[(f)] and SiC-JFET[(g)], Si-IGBT is effective at very high voltages of several kilovolts or more. On the other hand, there is also interest in the use of SiC SBDs[(h)] for the diodes connected in parallel with IGBTs. As SiC-SBDs are unipolar devices that operate with an electron current only, there is no recovery current and therefore it is anticipated that recovery losses can be reduced significantly.

TABLE 2. SiC Voltage Ranges and Optimum Devices
The operating range for SiC and optimum device type are shown.

Device	Switching element		Diode element	
	Up to 2 kV	2 kV or more	Up to several kV	Several kV or more
Application of SiC	Yes	No	Yes	In some cases
Remarks	SiC-MOSFET and SiC-JFET, etc.	Si-IGBT	SiC-SBD	SiC-PN diode

MOSFET: metal-oxide semiconductor field effect transistor
JFET: junction field effect transistor IGBT: insulated gate bipolar transistor
SBD: Schottky barrier diode

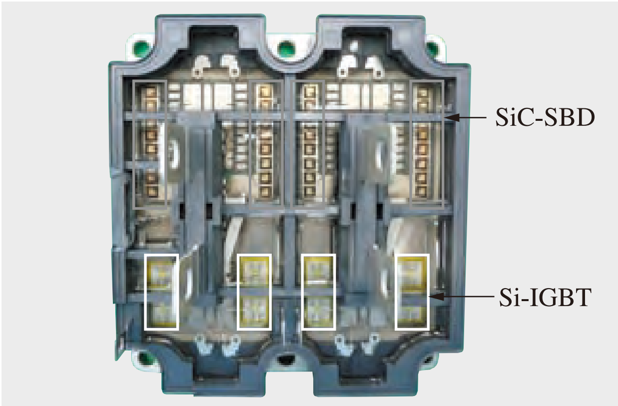

Fig. 8—Hybrid Module (3 kV/400 A).
Hitachi has verified that combining SiC-SBDs and Si-IGBTs can achieve an overall reduction of approximately 30% in the electrical conversion losses in the main converter unit used for the AC overhead wiring.

Following on from this interest in SiC-SBDs, Hitachi has now built and tested prototype hybrid modules that combine SiC-SBDs with Si-IGBTs (see Fig. 8) to verify the benefits of their use in rolling stock inverters.

The SiC-SBD developed by Hitachi have a JBS (junction barrier Schottky) structure that combines p-n and Schottky junctions to take maximum advantage of the characteristics of SiC. A problem with past SBD

(f) MOSFET
MOSFET is an abbreviation of "metal-oxide semiconductor field effect transistor." FETs (field effect transistors) consist of three elements: a gate, drain, and source. The voltage applied to the gate controls the current flow between the source and drain. An FET made of three layers consisting of a metal gate, an oxide insulator, and a semiconductor is called a MOSFET. Because of its ease of miniaturization, MOSFET is widely used for applications such as sensor elements or logic in integrated circuits.

(g) JFET
JFET is an abbreviation of "junction field effect transistor." In contrast to FETs with insulated gates which are called MOSFETs, JFETs have a junction. They are characterized by high input impedance and low noise.

(h) SBD
SBD is an abbreviation of "Schottky barrier diode." Whereas standard diodes have rectification characteristics from the junction between the p and n regions of the semiconductor (the p-n junction), SBDs utilize a rectification effect that occurs at the junction between metal and semiconductor (a "Schottky barrier"). Compared to a p-n junction diode, the characteristics of SBDs are low forward voltage and fast switching operation. Because of their good frequency characteristics, they are often used in high-frequency applications.

that used a Schottky junction is that, although they can switch at higher speeds than p-n junction diodes, attempting to reduce their conduction loss by lowering their resistance causes an increase in the size of the leakage current that occurs when a reverse voltage is applied in the direction opposite to the current flow direction. The JBS structure resolves this problem by simultaneously minimizing conduction loss and leakage current to achieve a high maximum reverse voltage of 3.3 kV and a low conduction voltage of only 2 V.

Hitachi has verified that, by adopting hybrid modules that use these newly developed SiC-SBD along with high-speed drive technology, turn on loss and recovery loss can be reduced to approximately one-sixth and one-tenth that of previous inverters with Si diodes respectively, and that the electrical conversion losses in the main converter unit used for the AC overhead wiring can be reduced by approximately 30% overall. This results in reducing the amount of heat generated by the inverter and should allow the overall inverter system including cooling systems to be made smaller and lighter.

DEVELOPMENT OF TECHNOLOGY TO MEET EXPECTATIONS FOR RAILWAYS

With factors such as global environment problems steadily increasing the expectations being placed on railway systems not just in Japan but around the world, the development of technologies such as those that take account of the environment as well as providing safe and reliable transport and those that will lead to railways being selected as a means of transport is increasing in importance. As a total-system integrator of railway systems, Hitachi's objective is to meet these expectations.

For this purpose, Hitachi intends to aggregate the technical capabilities of various group companies to realize railway systems that are more comfortable and attractive.

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