Featured Articles

Preparations for Development of Energy Management System Integrating Wayside Devices and On-board Systems

—Accuracy Testing of Railway Total Simulator based on Energy-use Analysis of Okinawa Urban Monorail Line—

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OVERVIEW: Hitachi supplies a wide variety of railway subsystem products. As a means of operating these subsystems in tandem to reduce energy consumption, Hitachi is proceeding with the development of energy management systems that integrate the operation of on-board systems with wayside device systems such as the traffic management system, substations, and power management system. As part of this initiative, Hitachi is studying how energy is used across entire railway systems and developing a "railway total simulator" that simulates a railway system to estimate traffic volumes, energy use, and other parameters. Accordingly, Hitachi has undertaken a joint study of energy use with Okinawa Urban Monorail Inc. to evaluate (1) the effect of different rolling stock operating practices on energy consumption, (2) the energy savings achievable by avoiding having more than one train powering at the same time, and (3) the accuracy of the "railway total simulator."

INTRODUCTION

AWARENESS of environmental problems has been growing around the world in recent years. Although railways are recognized as an energy-efficient mode of transportation that consumes less energy per kilometer for each person carried than alternatives such as cars and airplanes[1], there is a need to achieve even greater energy efficiency in response to environmental problems.

Railway systems are large and complex. In addition to the subsystems associated with train operation, which include the rolling stock that carries passengers, signaling systems that ensure safety, traffic management systems that ensure smooth operation, substations that supply electric power, and power management systems that monitor substations. They also include commercial facilities such as stations and buildings. Since the energy used for train operation accounts for approximately 70% of the total energy consumed by these railway systems, reducing the energy consumption of train operation plays an important role in encouraging energy efficiency[2].

To reduce the amount of energy used for train operation, Hitachi is working on ways of improving the energy efficiency of individual subsystems, and also developing an energy management system that seeks to save energy by integrating the operation of on-board systems with wayside device systems such as the traffic management system, substations, and power management system. Fig. 1 shows an overview of the energy management system. The aim of the system is to further reduce the amount of energy used to power the trains by collating information from the rolling stock, substations, power management systems, and traffic management systems, and by issuing "suspension of automatic departure route setting," "coast operation," and other instructions based on the current system status.

For this purpose we require a highly accurate simulator that can be used to understand how energy is used in the railway system and to study ways of saving energy. Accordingly, Hitachi has collaborated on a study of railway system energy use with Okinawa Urban Monorail Inc., which has been studying how energy is being used and ways of using it efficiently, particularly in relation to train operating practices. The results of this study have also been used to assess the accuracy of the railway total simulator developed by Hitachi to model railway systems and estimate traffic volumes, energy use, and other parameters.

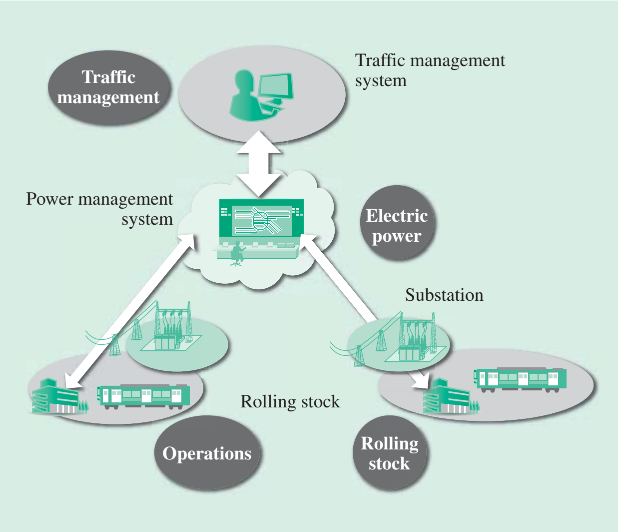


Fig. 1—Energy Management System Envisioned by Hitachi for Integrating Wayside Devices and On-board Systems.
The system is intended to reduce energy use of rolling stock by issuing "suspension of automatic departure route setting," "coast operation," and other instructions based on the integrated information from the rolling stock, substations, power management system, and traffic management system.

TABLE 1. Rolling Stock Data
The table lists some of the main items of data measured on rolling stock in this study.

No.	Data
1	Catenary voltage, filter capacitor voltage
2	Operational instructions
3	Brake force instructions
4	Regenerative braking force
5	Speed
6	Passenger load ratio
7	Traction current
8	Auxiliary power supply current

TABLE 2. Substation Data
The table lists some of the main items of data measured at substations in this study.

No.	Data
1	Power reception voltage
2	Power reception current
3	Rectifier primary current
4	DC electrification voltage
5	Regenerative current

DC: direct current

STUDY OF ENERGY USE BASED ON OPERATIONAL TRIALS ON OKINAWA MONORAIL

Overview of Operational Trials

To analyze energy use, measuring devices were installed in the rolling stock and substations of the Okinawa Monorail and trials were conducted (1) to assess the effect on energy consumption of using "cruise operation" (running at constant speed), and (2) to assess the effect on energy consumption of powering two trains simultaneously or preventing simultaneous powering of both trains. Additionally, (3) data were collected over about one month of commercial operation to investigate the degree of variation in the "basic unit of energy consumption" (the amount of energy consumed per car to travel 1 km) for each day. Table 1 lists the rolling stock data collected during these trials and Table 2 lists the substation data.

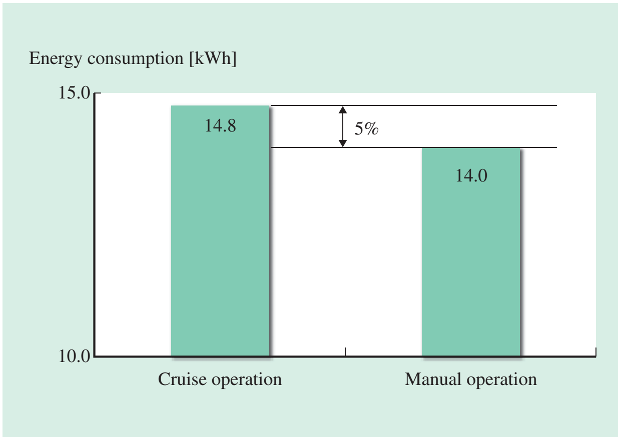


Fig. 2—Effect of Operating Practice on Energy Consumption.
The graph shows the measured inter-station energy consumption for different operating practices.

Results of Operational Trials

(1) Results of trials to assess effect on energy consumption of using cruise operation

Operation was trialed on westbound trains (Shuri to Naha Airport) both using and not using cruise operation (in the latter case, the speed was operated manually by engaging and disengaging the notch setting) and the effect on energy consumption was analyzed. Fig. 2 shows the resulting energy consumption in the two cases. Note that the energy consumption in each case is the difference between the powering energy consumption and regenerative energy consumption. Manual operation used 5% less energy than cruise operation. It was concluded that scope remains for making additional energy savings by modifying driving practices.

(2) Results of using and avoiding simultaneous powering of two trains

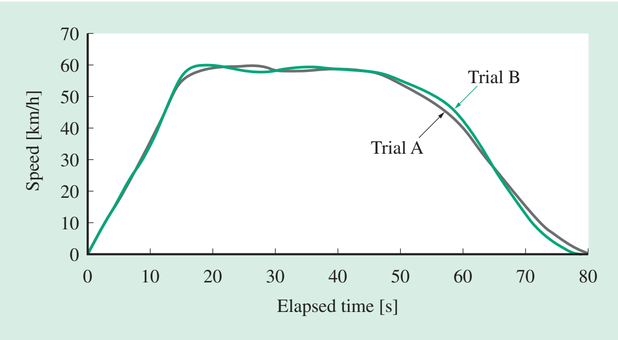


Fig. 3—Difference in Speed Pattern when Using and not Using Simultaneous Powering.
The graph shows the speed patterns when using simultaneous powering (trial A) and when avoiding simultaneous powering (trial B). This shows that the same speed patterns were followed in each case.

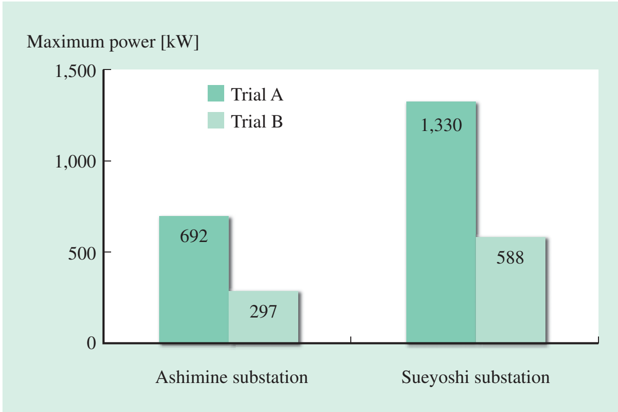


Fig. 5—Maximum Substation Power when Using and not Using Simultaneous Powering.
The graph shows the maximum substation power when using simultaneous powering (trial A) and when avoiding simultaneous powering (trial B). This shows that the maximum power is lower when not using simultaneous powering.

The Okinawa Monorail has three substations. To make it easier to analyze the energy use when using (or avoiding) simultaneous powering of two trains, the trials were conducted using only the two end substations (Ashimine and Sueyoshi substations). When powering both cars simultaneously (trial A), the two trains for which measurements were conducted departed at the same time. When avoiding powering both trains simultaneously (trial B), the departure of one of the two trains was delayed by 15 s. All other conditions were the same. Fig. 3 shows the speed patterns for the two trials. Fig. 4 shows the energy supplied by the substations, and Fig. 5 shows the maximum power at each substation. Because trials A and B used the same speed patterns, as shown in Fig. 3, the powering energy consumption can be expected to be similar in both cases. However, as shown in Fig. 4, the energy supplied by the substations in trial B was 16% lower than during trial A at the Ashimine substation and 13% lower at the Sueyoshi substation. This indicates that significant energy savings can be achieved by avoiding the simultaneous powering of trains. It is believed that the reason for this is because the maximum substation power in trial B was half that in trial A, as shown in Fig. 5. This means lower losses in the catenaries because they need to carry only half the current.

(3) Analysis of results from commercial operation

The data collected during commercial operation was analyzed to acquire the “basic unit of energy consumption” for each day. Fig. 6 shows a graph

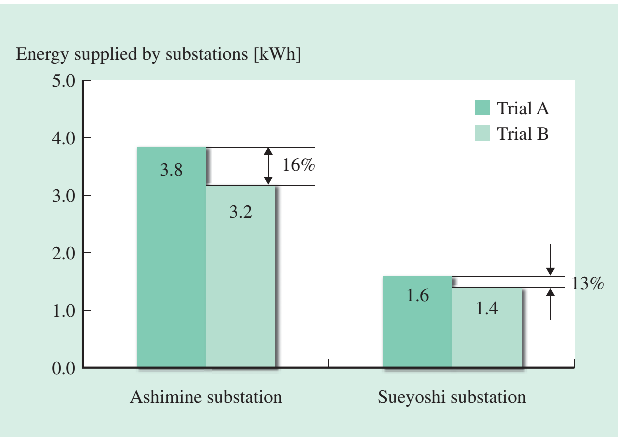


Fig. 4—Energy Supplied by Substation when Using and not Using Simultaneous Powering.
The graph shows the energy supplied by the substations when using simultaneous powering (trial A) and when avoiding use of simultaneous powering (trial B).

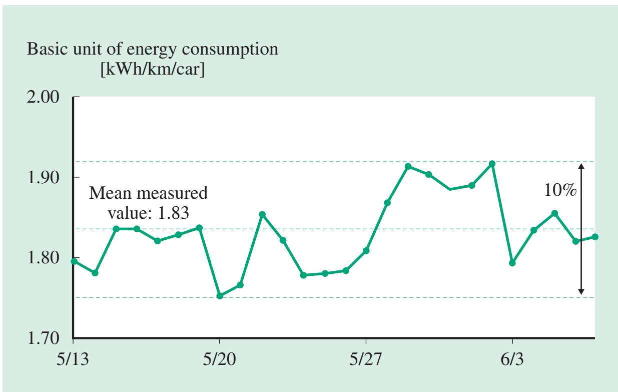
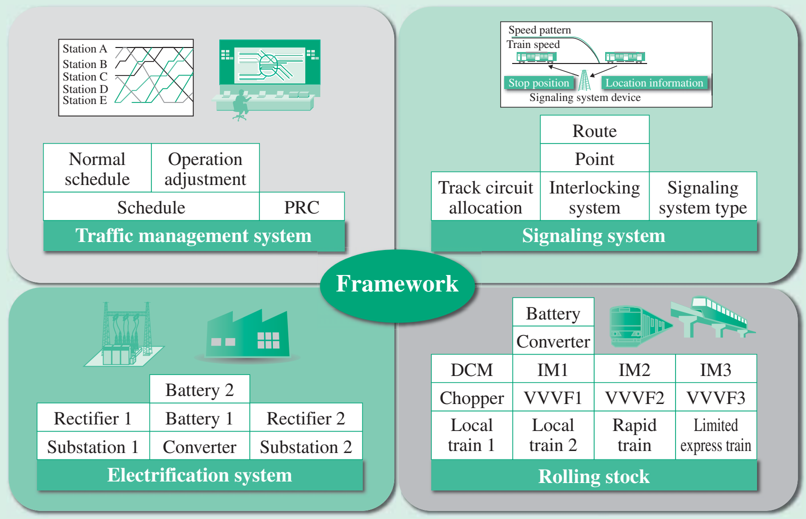


Fig. 6—Trend in Daily Basic Unit of Energy Consumption.
The graph plots the “basic unit of energy consumption” for each day of the measurement period.



PRC: programmed route control DCM: direct current motor IM: induction motor
VVVF: variable voltage variable frequency

Fig. 7—Features of Railway Total Simulator.
The user can select the required subsystems and equipment to include, which allows the study of any configuration, from individual devices up to the entire system.

of this parameter. The results indicate that the value varies from day to day, with a variation range of 10%. It is believed that the differences are due to cases of simultaneous powering and arise from differences between the planned and actual schedules.

OVERVIEW OF HITACHI'S RAILWAY TOTAL SIMULATOR

As shown in Fig. 7, the railway total simulator consists of models of train operation subsystems such as rolling stock, signaling system, traffic management system, and the electrification system comprising the substations and the power management system. These models are integrated on a common framework. The model of each subsystem is comprised of a number of component models. The electrification system model, for example, has models for direct-current (DC) electrification and alternating-current (AC) electrification [auto transformer (AT) electrification, and booster transformer (BT) electrification]. Similarly, the energy saving equipment modeled for the DC electrification system includes resistor or battery-based devices for absorbing regenerated power and a regeneration inverter (see Fig. 8). The energy saving equipment for the AC electrification system includes a model of a railway static power conditioner (RPC) system (see Fig. 9).

Ways of saving energy on specific lines can be devised by coupling these various models together and by optimizing control systems. Because accurate simulation is important for this work, the development of the railway total simulator has targeted an accuracy of 5% or better for rolling stock energy consumption.

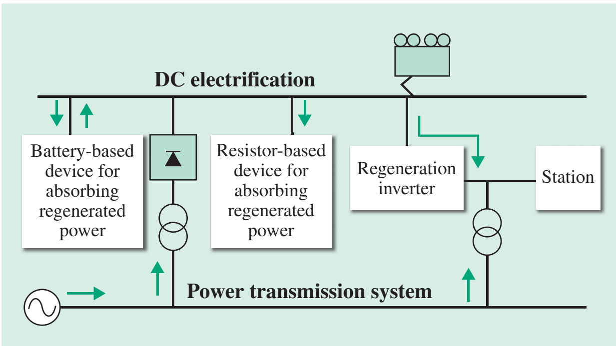
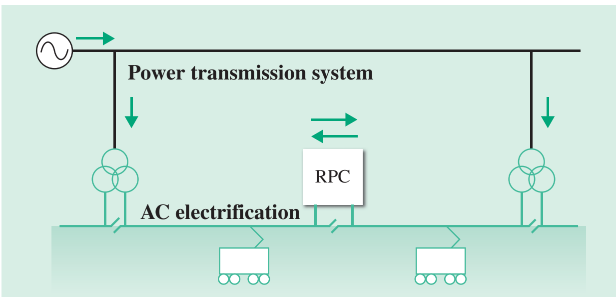


Fig. 8—Resistor- and Battery-based Devices for Absorbing Regenerated Power and Regeneration Inverter.
The simulator models devices for absorbing regenerated power with DC electrification to evaluate the consequences of installation.



RPC: railway static power conditioner

Fig. 9—RPC System for AC Electrification.
The simulator models the power distribution systems used with AC electrification to evaluate the consequences of installation.

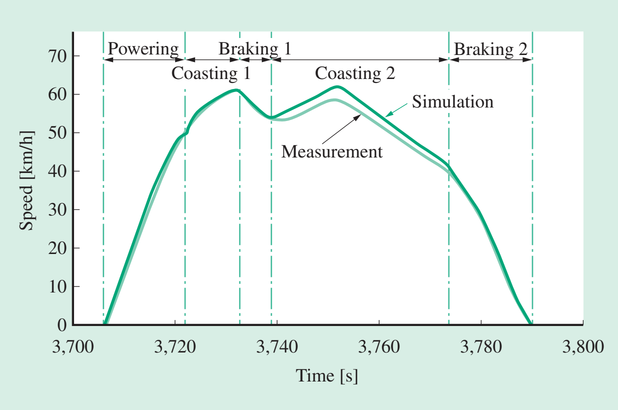


Fig. 10—Example Comparison of Speed Patterns.
The graph shows a comparison of measured and simulated speed patterns.

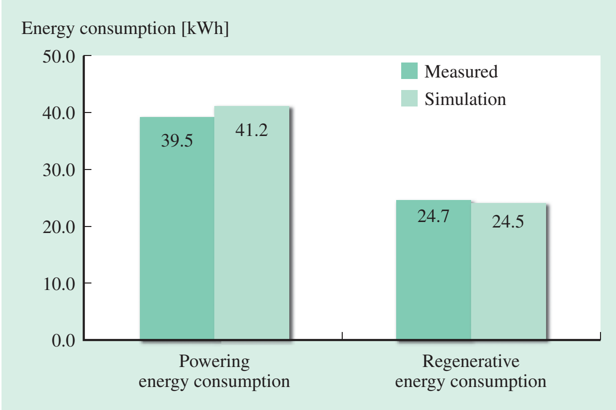


Fig. 11—Comparison of Powering Energy Consumption and Regenerative Energy Consumption.
The graph shows a comparison of the powering energy consumption and regenerative energy consumption obtained by measurement and simulation respectively.

ASSESSMENT OF ACCURACY OF HITACHI'S RAILWAY TOTAL SIMULATOR

The accuracy of the railway total simulator was assessed using the results of operational trials (measurements). Fig. 10 shows example results for comparing speed patterns. This shows that the measured speed patterns and those predicted by the railway total simulator are closely matched. Fig. 11, meanwhile, shows a comparison of the results for powering energy consumption and regenerative energy consumption for a run along the entire length of the line. The difference between the measured powering energy consumption (39.5 kWh) and that predicted by the railway total simulator (41.2 kWh) indicates an error of about 4%. For regenerative energy consumption, the measured consumption (24.7 kWh) and predicted consumption (24.5 kWh) are nearly the same.

CONCLUSIONS AND FUTURE OUTLOOK

Okinawa Urban Monorail and Hitachi have undertook a joint study of energy use. The study found that the monorail could potentially improve energy efficiency by modifying train speed patterns. It was also found that further energy savings could be achieved by avoiding simultaneous powering of trains.

The results demonstrated that Hitachi's railway total simulator is capable of predicting rolling stock energy consumption to within about 4% of the measured value, indicating that the target accuracy of 5% or better was achieved. In the future, Hitachi intends to continue using this system to offer a variety of energy-saving measures to railway operators.

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