Recent Topics on Power Supply Technology

Tetsuo UZUKA  
Power Supply Technology Division (Former)

After the Tohoku-Pacific Ocean earthquake, all Japanese railway operating companies had to tackle the problem of energy saving, since Japan lost a major part of its electric power resources. It followed that RTRI R&D on power supply technologies should adopt a similar focus. In addition, in the first half of this 21st century Japan is being confronted with falling birthrates, an aging society, and a shrinking population, causing a rapid decrease in the labor population. Given these circumstances, maintenance-free technology is another priority for RTRI. This paper describes recent topics related to power supply technologies.

Keywords: power facility, overhead contact line, substation, energy conservation

1. Introduction

Faced with a continuing shortage in energy supply and rising prices across Japan following the 2011 off the Pacific coast of Tohoku Earthquake (the Great East Japan Earthquake) in March 2011, railway operators in Japan have been devising energy saving measures for all types of system and have steadily been achieving set targets [1]. In the meantime, the entire Hokuriku Shinkansen route down to Kanazawa started operations in March 2015, followed by launch of the Hokkaido Shinkansen in March 2016. Following these inaugurations, there are no plans for the construction of major new lines for the moment. Against this background, Japan’s ageing society and low birth rates are forcing rail operators to innovate and develop minimum maintenance systems.

As a consequence, RTRI has been and will continue to focus its power supply technology research and development on energy conservation, minimum maintenance and improved safety in an effort to develop energy-efficient and reliable power facilities.

This report presents some of the recent research and development undertaken by RTRI in the field of power supply technology, centering around “research and development for the future of railways,” one of the pillars of RTRI’s master plan, explained in the following section.

2. Projects being pursued under the RTRI master plan

RTRI has been conducting research and development programs in line with its master plan entitled RESEARCH 2020, which commenced in FY2015 along with the ‘RTRI Vision’. RESEARCH 2020 sets forth the following research and development targets.

1) Safety enhancement
2) Cost reduction
3) Harmony with the environment (adaptation to the changing climate)
4) Higher practical convenience (improving the user-friendliness of railways)

In addition, the following three pillars of research and development are set out in the master plan to yield beneficial results.

1) Research and development for the future of railways
2) Development of practical technologies
3) Basic research for railways

2.1 Research and development for the future of railways

The research and development for the future of railways under RESEARCH 2020 listed in Table 1 summarizes the five topics under which power supply technology-related activities were started in FY2015 and are ongoing in FY2016. Those topics all belong to the major theme 2: “Railway system innovation based on information networks.”

2.2 Energy conservation through energy networks

1) Current status of energy conservation in the railway sector

Figure 1 shows changes over the years in electric power consumption in railway applications (including electricity for railway facilities and operational headquarters and other locations and excluding electricity self-sourced by railway operators), based on electricity sales to industrial users released by the Federation of Electric Power Companies of Japan [2], and volume of passenger traffic released in the annual report of railway statistics supervised by the Railway Bureau of the Ministry of Land, Infrastructure, Transport and Tourism. Up until around 2005, electric power consumption and transport capacity followed a similar trend, showing a rapid increase up to the first half of the 1990s. Since 2005 when the Act on Rationalizing Energy Use was revised, electric power consumption has been declining steadily, clearly showing the effect of energy saving efforts in the railway sector. In marked contrast to the increase in the volume of passenger traffic, electric power consumption, which declined sharply following the 2011 Great East Japan Earthquake and the subsequent radical change in energy use, the decline has continued gradually as energy saving measures are put in place.

In July 2012, the Railway Bureau of the Ministry of Land, Infrastructure, Transport and Tourism in a joint effort with the Ministry of the Environment launched the
Table 1  Research and development for the future of railways under RESEARCH 2020 (Power supply technology-related)

<table>
<thead>
<tr>
<th>Major theme / Subtheme / Research and development topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pursuing railway systems with even higher safety</td>
</tr>
<tr>
<td>○ Advanced railway disaster prevention/mitigation technologies</td>
</tr>
<tr>
<td>○ Enhanced passenger safety</td>
</tr>
<tr>
<td>○ Improvement in train running safety</td>
</tr>
<tr>
<td>2. Railway system innovation based on information networks</td>
</tr>
<tr>
<td>○ Train operation utilizing information networks</td>
</tr>
<tr>
<td>○ Efficient maintenance with ICT</td>
</tr>
<tr>
<td>• Methods for risk assessment and life-cycle cost calculation for overhead contact lines</td>
</tr>
<tr>
<td>• Development of advanced monitored maintenance components for power collecting systems</td>
</tr>
<tr>
<td>○ Energy conservation through energy networks</td>
</tr>
<tr>
<td>• Development of energy network control methods based on prediction of energy consumption by vehicles and ground facilities</td>
</tr>
<tr>
<td>• Installation of superconducting feeding cables</td>
</tr>
<tr>
<td>• Development of high-performance rectifiers</td>
</tr>
<tr>
<td>3. Shinkansen speed-up (introduction of higher running speeds for Shinkansen)</td>
</tr>
<tr>
<td>○ Mitigation of wayside environmental load from faster running Shinkansen</td>
</tr>
<tr>
<td>○ Development of basic technologies for Shinkansen speed-up</td>
</tr>
<tr>
<td>4. Development of railway simulators</td>
</tr>
<tr>
<td>○ Development of virtual railway test tracks</td>
</tr>
<tr>
<td>○ Coordination of individual simulators</td>
</tr>
</tbody>
</table>

Fig. 1  Changes in passenger traffic volume and electric power consumption

Eco Rail Line Project, which aims to cut CO₂ emissions from the railway sector by around 20% by 2030 in relation to FY2010 levels and offers support to tramway and railway operators who systematically strive to achieve electric power-saving, low-carbon operations.

(2) Progress in energy conservation

Energy conservation innovations in the railway sector have been developed and implemented individually by the vehicle, operations and ground equipment divisions. In order to foster further improvements in traction power conservation for electric motor vehicles, active information sharing and coordination software will have an important role to play.

In FY2016, for the subtheme “Energy conservation through energy networks” under main heading, “Railway system innovation based on information networks,” RTRI will continue its efforts to achieve the goal of a 10% cut in energy consumption through equipment efficiency improvements and other hardware-related measures and a further 10% cut through software-related measures.

(3) Energy networks and their function

Proposals are currently being made for an energy network, which is a tentative name for an information network that will connect power facilities and trains to share information for coordinated real-time control.

Energy networks would have the following three functions: (See Fig. 2)

a) Information network connecting power facilities with trains
b) Predictive simulation and power control algorithm
c) Real-time controlled power equipment

(4) Information network connecting power facilities and trains

Conventional power control does rely on sharing infor-

Fig. 2  Three functions of energy network
mation between power facilities, such as substations, and trains. As such, the proposal is to build an information network linking power facilities, trains and dispatchers (See Fig. 3).

Substations send out information on feeder voltage and current while power storage equipment sends out information on charge levels, charge/discharge current, etc.

Trains send out information on powering/braking notches, running speed, train and pantograph positions, etc.

Dispatchers send out train schedules and operational statuses, energy-saving targets, etc. to power facilities and trains.

Based on this exchange, power facilities would be able to detect the status of trains in the area and, while predicting situations several dozen seconds to several minutes ahead, control the charge/discharge of power storage equipment and the voltage of substations. This type of information would be collected by dispatchers for area-wide management including sending instructions to power facilities and trains, as needed.

(5) Current status of development projects

With regard to hardware for energy conservation through energy networks, a 400 meter-long superconducting cable with practical-application specifications for a DC electric railway is being developed [3] for evaluation tests under the research and development heading, ”Installation of superconducting feeder cables (2015–2016).” Under RESERCH 2020, evaluation tests will continue while at the same time the entire system, including a cooling system, is further refined.

On the “Development of high-performance rectifiers (2015–2017),” a voltage regulator consisting of an IGBT element and a reactor is installed between components of a conventional rectifier to achieve real-time voltage regulation (See Fig. 4). While not equipped for regenerative electric power, the high-performance rectifier, for which an early introduction to practical application is foreseen, is less expensive. The current planning is to produce a reactor in FY2016 and carry out a unit test around the end of FY2017 combining a rectifier and a controller. Also being studied is a control method for the rectifier when it is incorporated into the energy network.

On the “Development of flywheels for practical railway applications (2013–2014),” a superconducting magnetic bearing capable of providing contactless support to a flywheel weighing around two tons has been developed. A flywheel test unit with the superconducting magnetic bearing, rated at 300 kW instantaneous input/output and 100 kWh electric energy, was then designed and manufactured (See Fig. 5) [4].

The test unit was installed at the system test facilities in a photovoltaic power plant where the following tests were conducted: levitation and rotation tests on a large-diameter flywheel with the superconducting magnetic bearing; and abnormal condition performance tests in which refrigeration was stopped by cutting the power supply, etc. These tests demonstrated the unit’s stable levitation and rotation and its appropriate design for safe operation. This brings into reach superconducting magnetic bearings capable of supporting a heavy load for railway applications through the improvement of the current design (See Fig. 5).

As a power consumption simulation tool based on a range of energy conservation methods described above, a traction power simulator was developed that combines accurate operation, main circuit and feeding circuit simulations of electric motor cars and a wide range of power storage system simulations (See Fig. 6) [5]. On the “Development of energy network control methods based on prediction of energy consumption by vehicles and ground facilities (2015–2017),” energy conservation methods are being developed using a number of trains with the cooperation of railway operators.

Part of the subtheme “Energy conservation through energy networks” is subsidized by the Ministry of Land, Infrastructure, Transport and Tourism, the Ministry of Education, Culture, Sports, Science and Technology and New
2.3 Efficient maintenance with ICT

The subtheme “Efficient maintenance with ICT” which comes under the major theme “Railway system innovation based on information networks” aims to improve the reliability of sensors, develop easier renewal methods and establish technologies for optimum designing and operation of maintenance information networks for mid- to long-term continuous monitoring of railway property conditions. In future, efforts will be invested into establishing condition-based methods for predicting age-related deterioration of facilities leading to proposals to optimize monitoring frequency and other practical and efficient maintenance methods.

Under the heading “Methods for risk assessment and life-cycle cost calculation for overhead contact lines (2015–2017),” long-term data on accidents involving overhead contact lines is being reviewed to analyze and classify related events for calculation of accident probability for risk assessment and to analyze and calculate initial, maintenance, accident-related and disposal costs for calculation of life-cycle cost (See Fig. 7).

On the topic of “Development of advanced monitored maintenance components for power collecting systems (2015–2017),” facilities diagnostics based on image processing are being developed. As part of this, imaging-based measurement of the condition of multiple lines and image recognition methods for hanger/dropper fittings are being developed (See Fig. 8) [6]. In addition to an ongoing imaging test using running trains on a test track on RTRI premises, measuring tests are planned on a commercial line. Fault finding and diagnosis methods for overhead contact lines are also being developed that incorporate contact-force based overhead contact line inspection technologies. As a next step, power collection performance simulation and evaluation based on the results of overhead contact line inspections is envisioned.

3. Research and development for practical technologies

Under the heading, “Research and development for practical technologies,” a wide range of topics are being pursued based on requests from JR companies. Key results of activities conducted in FY2015 are discussed in separate papers in this issue of RTRI’s QR.

Considering that power facility failures can often significantly disrupt scheduled transport, another focus on research and development is the development of facilities with low failure rates, early fault detection, and maintenance. Under the project “Development of measures against overhead contact line failures at insulated overlaps (2016–2017),” which was started this fiscal year, overhead contact lines with low failure rates will be proposed and tested on RTRI premises and on a commercial line for possible commercial applications. In addition, the following research and development topics are being pursued: “Clarification of impact of viaduct vibrations caused by passing trains on overhead contact lines (2016–2018)” and “Evaluation of overhead contact line behavior during earthquakes (2014–2017).”

On the “Reclassification of damage to contact lines and practical application of corrosion resisting supports (2015–2017),” the classification of contact lines damaged by salt attacks was redefined with resources including sensor in-
Fig. 9 Evaluation results of hinged cantilever steel pipes for corrosion

puts, based on the results of evaluation of galvanized steel pipes used on commercial lines for the degree of corrosion (See Fig. 9) [7].

4. Basic research for railway

In FY2016, three basic research projects were launched. In addition, the "Evaluation of contributing factors to contact wire freezing/frosting" which ended in FY2015 is featured in this issue of QR of REPORT.

5. Future research and development

While recent research on power supply technology at RTRI has centered around energy conservation and minimum maintenance, this paper shows the RTRI has also been active in other areas of research.

RTRI will continue to advance research and development to meet railway operators’ needs.

References


Author

Tetsuo UZUKA
Director, Power Supply Technology Division (Former)
Research Areas: Power Electronics, Fixed Installations

QR of RTRI, Vol. 58, No. 4, Nov. 2017