Recent Topics on Power Supply Technology

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After the Tohoku-Pacific Ocean earthquake, saving energy became a central concern for all Japanese railway operating companies, since Japan lost a major source of electric power supply. It follows therefore that R&D at RTRI should focus on power supply technologies. At the same time, for the first half of the 21st Century, Japan will face falling birthrates, an aging society, and a shrinking population, resulting in a rapid decrease of the working population. Consequently, maintenance-free technology is another key subject for RTRI. This paper describes the recent work on power supply technologies.

Keywords: power plant, contact line, substation, energy saving

1. Preface

The energy landscape in Japan was radically altered after the Tohoku-Pacific Ocean earthquake (the Great East Japan Earthquake). Eastern Japan faced acute energy shortages in the aftermath of the earthquake, requiring the introduction of scheduled blackouts. Continuous power-supply shortages over the following summer due to the shutting down of nuclear-power plants, resulted in railway companies in the Kanto cutting power consumption by 15 %, to comply with the Electricity Business Act, during the day between noon and 3:00 pm, thereby managing to contain peaks in electricity consumption by general consumers. Railway companies minimized power use by lengthening service intervals (energy-saving diagrams) and disabling certain service facilities in stations.

Since then, repeated calls have been made on Railway companies all over Japan to save energy in summer and winter. Until then, railway companies sought to save energy to reduce CO₂ emissions in the overall effort to protect the environment and reduce their power bill. Some cases however were difficult, i.e., even though there was a clear case for energy saving, the investment needed to achieve that energy saving could not be offset by savings on the power bill. After the earthquake, though, continuous nation-wide energy shortages moved railway companies to reconsider this position and try to find ways to cut energy use across the overall system, and since then gradual progress has been made to achieve this.

Completion of the extension to the Hokuriku Shinkansen scheduled for spring 2015, and the opening of Hokkaido Shinkansen (planned for spring, 2016), will be followed by a temporary moratorium on any new large-scale railway projects in Japan. Instead, operating companies will pursue their work to find lower maintenance measures, in order to prepare for an aging population and lower birthrate.

Aware of this situation, RTRI has centered its research and development activities for the time being in the fields of electric power supply for saving energy and maintenance and safety issues.

This paper introduces recent research and development in the area of power supply technologies, along with the RTRI’s base plan, outlining subjects projected to be central for the future of railways.

2. RTRI’s position and base plan

Research and development activities at RTRI are organized according to a basic five-year plan, which began in 2006 fiscal year (RESEARCH 2010) aimed at effective management as a global think tank dedicated to railway technology. RTRI also has the responsibility to respond to the needs of industry while contributing to a sustainable railway system.

The following three pillars were determined as way to ensure RESEARCH 2010 is carried out effectively:
R&D for railways in the future (Pillar 1)
Practical technological development (Pillar 2)
Fundamental railway research (Pillar 3)

2.1 R&D for railways in the future

Out of Pillar 1 (R&D oriented for railways in the future), Table 1 is a summary of power-supply related R&D conducted in 2013, fiscal year. There are 15 power-supply technologies in total, falling into five sub-fields under 4 out of five main fields (the field not included is the 4th-Maintenance and deployment of railway networks). Research into seven power-supply related technologies was launched in the fiscal year of 2013, of which one has been completed.

2.2 Energy efficiency

The sub-field “New power-supply system” focuses on developing energy-saving power-supply systems that could replace conventional power systems. It specifically includes technical topics such as developing super-conductive feeder cables and stepping up the feeding voltage for improving power-feeding efficiency, development of a fly-wheel battery with super-conductive bearings for effective utilization of regenerative forces, implementation of distributed power sources such as natural energies, and the development of a simulator for estimating energy levels in order to optimize the power-supplying system (Fig. 1).

The “Development of super-conductive feeder cables (2010 – 2012)” which featured among these research areas, was completed in 2012. Tests were conducted to check that it fulfilled the fundamental functions of the superconducting cable for use on DC electrified lines, up to 12 A and
Table 1  Research and development themes on railways in the future (related to power supply)

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<tr>
<th>Main field / sub-field / R&amp;D activity</th>
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<td>1. Improvement of safety and reliability of railway systems</td>
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<td>○ Improvement of safety and reliability with smart trains</td>
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<td>○ Improving safety during earthquakes</td>
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<td>・ Development of disaster-mitigation methods for overhead contact line structures</td>
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<td>2. Energy Efficiency</td>
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<td>○ New power-supply systems</td>
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<td>・ Implementation of power-supply system utilizing natural energy</td>
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<td>・ Implementation of new power-supply system and its assessment via a power simulator</td>
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<td>・ Development of high-voltage D.C. feeding system</td>
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<td>・ Development of implementation technology for railway fly-wheels</td>
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<td>・ Development of elongation technology for super-conductive feeder cables</td>
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<td>3. Maintenance renewal</td>
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<td>○ New system for condition monitoring and maintenance</td>
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<td>・ Imaging for inspection and detection of abnormalities in overhead wires</td>
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<td>4. Maintenance and deployment of railway networks</td>
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<td>5. Development of railway simulators</td>
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-cooled conditions, using a short length of super-conductive cable (5 m) which was manufactured, with all incoming/outgoing refrigerant (overcooled liquid nitrogen) paths arranged in a uniaxial configuration (Fig. 2). This research was followed by further studies to extend the length of the superconducting cable - “Implementation of an elongation technology for super-conducting feeder cables (2013–2014)” and experiments conducted in July, 2012 within the research center, this time using a 30 m super-conducting feeder cables with uniaxial configuration of outgoing/incoming paths to verify its performance for D.C. electric railways. Results showed that the overall system including the refrigerator circuits functioned according to plan, which was followed by the world’s first tests, performed in July, 2014, on a real train (Fig. 3) [1]. An in-house experimental facility was then built with a 300-meter super-conductive feeder cable for cooling tests and used for vehicle tests in July, 2014. At present, further elongation of super-conductive cable is being studied on the basis of the results of these first experiments, in order to pursue system development, including refrigerators.

Research on the “Development of railway fly-wheels applying advanced super-conductive bearings (2010–2012)” [2], was to verify that super-conductive magnetic bearings could afford contact-free support to a rotational object. This was done by manufacturing an experimental device simulating vertical loads (thrust) exerted by a rotor. The study also examined rotor dynamics and cooling technology for bearings through rotational tests and confirmed that the newly developed attenuation device was effective for guaranteeing rotational stability at high-speed.
Implementation technologies for railway fly-wheels (2013 – 2014) was mainly to develop magnetic bearings capable of supporting 2-ton fly-wheels, and to investigate the torque-transmission process between motor generators and fly-wheels, the cooling process of super-conductive coils, dynamic analysis of fly-wheels, monitoring process of fly-wheels, and system assessment supposing the installation on a line in operation. A super-conductive magnetic bearing 10 kWh fly-wheel is now being designed and manufactured (Fig. 4).

The “Studies on application of low-loss semiconductor elements for electric trains (2010 – 2012)” [3], investigated the rectifiers and D.C. high-speed circuit breakers required in high-voltage D.C. feeding, and focused on the loss and other basic performances, where the loss characteristics of a semiconductor element were evaluated for rectifiers, by manufacturing a small-capacity full-wave circuit using schottky-barrier diodes, showing a possibility of reducing the loss in high-voltage environments compared to the characteristics of conventional Si (silicone). Losses from the electrified test and current-limiting effects were also verified here through a short-circuit interruption test, by applying a Si IGBT (Insulated Gate Bipolar Transistor).

Although a shift of the D.C. standard voltage (1,500 V) to a level of 3,000 V is effective as means for increasing the vehicle current in areas of high traffic density, action needs to be taken on the vehicle side. The “Studies on high-voltage D.C. feeding process (2013 – 2014)” offers a feeding system for high-voltage D.C. while keeping the standard voltage (1,500 V) for the conventional overhead wires by newly installing high-voltage rectifiers and power-supplying cables to replace current-reversible choppers for voltage step-down at a constant interval (Fig. 5). This can help reduce losses, and suppress voltage fluctuation, the generative power can be used effectively, and intervals increased between substations, while continuing to use conventional vehicles. A simulative calculation of the current-feeding loss based on the configuration studied here and a weatherability test of heavy-duty D.C., demonstrated that feeder cables were making progress.

Distribution of power-storage facilities across the railway network is also an effective measure to mitigate the effect not only of fluctuating railway loads but also unstable power supply from natural energies. RTRI has confirmed through calculations that higher energy-saving can be achieved by combining methods, and is ready for operational tests. RTRI is also developing a power simulator for holistic assessment of variable energy-saving measures.

This R&D issue “New power supply systems” is partially subsidized by the Ministry of Land, Infrastructure, Transport and Tourism and funded by the scientific research fund of the Ministry of Education, Culture, Sports, Science and Technology, and also sponsored by the New Energy and Industrial Technology Development Organization (NEDO).

2.3 Enhancement of safety and reliability of the railway system

“Improving safety during earthquakes” is a sub-field in “Improvement of safety and reliability for railway systems” and sheds light on safety issues related to current seismic design, such as seismic leeway (capacity to momentarily withstand tremors exceeding the design critical value) for railway facilities and residual capacity, in order to build a methodology for reasonably evaluating safety against exceptionally violent earthquakes. It also comments on risk mitigation and offers new reasonable countermeasures including seismic dampers and ground isolators.

The R&D issue completed in the 2013 fiscal year “Development of disaster-mitigation methods for overhead contact-line structures (2011 – 2013)” studied countermeasures for reducing damage to catenary masts and involved real-scale shaking-table experiments to verify their effectiveness. The research also describes a 3-D analytical model for non-linear characteristics that reproduces the load-displacement relations obtained from alternate loading tests on a sand-packed foundation. These R&D results were incorporated into the revision of “Guidelines for seismic design for wiring facilities” after the 2011 off the Tohoku-Pacific Ocean earthquake [4].

This R&D was partially subsidized by the Ministry of Land, Infrastructure, Transport and Tourism.

The “New system for status monitoring and maintenance” conducted as part of the “Maintenance renewal” research area, aimed to optimize the technologies for designing and operating maintenance information and improving the sensor durability while simplifying the renewal procedures to enable continuous monitoring of status variations of the railways over intermediate to long periods. It also included practical proposals for maintenance procedures such as optimization of monitoring frequency by establishing a methodology for predicting the change over time.
based on the conditions of each facility.

“Improvement of diagnostic process for wiring conditions (2012 – 2014)”, following on from the previous area of research, addresses the development of an overhead-wire structure inspection method, using contact-force measurement and image processing.

3. Practical R&D Issues

“Practical R&D issues” includes a variety of R&D fields reflecting the needs of JR operating companies. Some of the major outcomes from among the 11 fields investigated in the fiscal year 2013 are outlined below.

“Implementation of a detection method for high-resistance ground currents in D.C. feeding circuits (2012 – 2013)”, reports on the development of a system for detecting voltage changes in support equipment by using protective wires and components made with diodes and varistors. This system was designed to protect against high resistance ground-fault accidents in contact lines in DC feeder circuits. This type of accident originally was difficult to detect and prevent in substations, because the ground fault current value and the normal load current value are difficult to distinguish. After initial tests, the system was tried on a commercial line, using artificial faults.

“Insight into contact line behavior while running at high-speed and assessment of metal-fitting vibration tests (2011 – 2013)" was used to produce an evaluation standard for increasing running speed, by measuring the actual wind speed around the pantograph of a high-speed train when running through a tunnel (Fig. 6). An analytical process was developed, to gain insight into contact line connector fatigue phenomena and to clarify the metal-vibration conditions, using FEM simulation which was then compared with results from the strand-cable tests [5].

“Development of a surge-detection locator for Shinkansen (2011 – 2013)" describes application of a method to locate fault points on Shinkansen lines based on the time taken for a surge voltage to appear as a failure (Fig. 7). From the results of actual measurements on surge-propagation speed, it was demonstrated that the effect of a voltage surge from the switching breaker inherent in Shinkansen facilities, can be isolated from feeding-voltage fluctuations, and that the cabling delays in the substation should be considered.

"Insight into and assessment of faults and their mechanisms in current-collector materials from arcs (2011 – 2013)" aimed to understand the abrasive phenomena between overhead wires and pantograph contact strips and implement a contact wire loss detector, using UV rays.

"Optimization of pre-stretching effect against long-term elongation of trolley wires (2011 – 2013)" was a study into the effects of pre-stretching on re-cabling overhead wires from two perspectives: winding relief of wiring materials and creep characteristics. It then showed that pre-stretching was effective for relieving wire-windings and does not affect creeping. It concluded that using this method, it was possible to shorten working time to about 15 minutes.

4. Fundamental R&D Issues

Three topics were investigated in 2013 as part of the institute’s “Fundamental R&D”, as outlined below.

"Assessment of contact line component deterioration, due to environment (2012 – 2014)" evaluated materials separately with a view to preventing contact line equipment faults, for more stable operation. Work in 2013 included confirming the residual lifetime of wires through evaluation, to show that durability against fatigue degrades not only through age. The study also reproduced brittle fractures in FRP members using nitric acid solution, and assessed cable-end treatments through exposure deterioration tests on high-voltage cables.

"Gaining insight into abrasive mechanisms in current-collector materials subject to high running speeds and large currents (2012 – 2014)" was designed to understand contact-point melting phenomena of certain current collecting materials, such as electrified overhead contact wires or carbon contact strips, through various tests.

5. Summary

While recent research into power technologies has centered on energy/maintenance saving, as stated above, this paper introduces a number of other positive R&D initiatives.
Various measures have been applied by Japan’s railway operating companies to reduce traction power consumption. Later studies will focus on cross-cutting collaboration between vehicles, operation, and electricity divisions. Methods to reduce maintenance will require the further development of sensors for monitoring the state of the railways, data collection, and systemization of these procedures.

RTRI also plans to conduct R&D in response to the needs of railway operating companies.

References


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