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. Introduction

Faced with a continuing shortage of energy supply across Japan following the March 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake (the Great East Japan Earthquake), railway operators have been devising energy saving measures across all systems and steadily achieving set targets. In the meantime, the Hokuriku Shinkansen started operation in March 2015 while the Hokkaido Shinkansen opened in March 2016. Following these new lines, no further construction of major new lines is planned for a while. At the same time, Japan has an aging society with low birth rates, which is forcing rail operators to find systems which minimize maintenance.

Against this background, RTRI has been and will for the foreseeable future be focusing its research and development efforts on power supply technology, energy saving, minimum maintenance and safety enhancement.

This report presents some of the recent research and development undertaken by RTRI on power supply technology, centering around “research and development for the future of the railways,” which forms one of the pillars of RTRI’s master research plan.

2. RTRI’s position and base plan

Research and development activities at RTRI from 2006 to 2010 were organized according to a basic five-year plan, ‘RESEARCH 2010,’ aimed at effectively managing work at the institute as a global think tank dedicated to railway technology. RTRI also has the responsibility to respond to the needs of the railway industry while contributing to a sustainable railway system.

The following three pillars were determined as a way to ensure RESEARCH 2010 was carried out effectively:

- R&D for railways in the future (Pillar 1)
- Practical technological development (Pillar 2)
- Fundamental railway research (Pillar 3)

In FY2015, RTRI launched a new five-year master plan called RESEARCH 2020 with a renewed outlook while retaining the RESEARCH 2010 targets and pillars, although the “targets” were renamed as “objectives.”

Under the new plan, power-supply technology related efforts will continue to center around energy saving, minimum maintenance and safety enhancement.

2.1 R&D for railways in the future

Research and development for the future of the railways under RESEARCH 2010 was carried out at three different levels; five major themes, subthemes under each major theme, and research and development topics under each subtheme. Power-supply technology related activities, carried out in FY2014 within this framework, are summarized in Table 1. As shown in the table, research and development were pursued and completed for six topics, according to five subthemes coming under all major themes except one, namely, “4. Maintenance and development of rail networks.”

With regard to research and development for the future of the railways under RESEARCH 2020, Table 2 summarizes the five power supply technology-related topics

<table>
<thead>
<tr>
<th>Major theme / Subtheme / Research and development topic</th>
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<tr>
<td>1. Enhanced safety and reliability of railway systems</td>
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<td>○ Enhanced aseismic safety</td>
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<td>2. Efficient energy use</td>
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<td>○ New power supply systems</td>
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<td>- Development of power supply systems using renewable energy sources</td>
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<td>- Development of new power supply systems and evaluation using vehicle power consumption simulators</td>
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<td>- Development of high-voltage DC feeding systems</td>
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<td>- Development of flywheels for practical railway applications</td>
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<td>- Development of longer superconducting feeding cables</td>
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<tr>
<td>3. Maintenance innovations</td>
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<tr>
<td>○ New maintenance monitoring technologies</td>
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<tr>
<td>- Imaging inspection of overhead contact lines and fault detection</td>
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<tr>
<td>4. Maintenance and development of rail networks</td>
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<td>5. Development of railway simulators</td>
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which began in FY2015. These topics all come under the major theme “Railway system innovation based on information networks.”

### 2.2 Energy efficiency

In FY2014, the activities for the research and development topic “New power supply systems” under the major theme “Efficient new energy use” focused on the development of new, more energy-saving power supply systems in place of the current systems. Specifically, the activities covered the following areas: developing superconducting feeding cables and realizing higher feeding voltage for higher power transmission efficiencies; developing a flywheel power storage system using a superconducting bearing for efficient use of regenerable power; diversifying power sources by tapping into renewable energies; and developing energy consumption simulators for evaluation, to optimize power supply systems (Fig. 1).

Under the research and development topic “Development of longer superconducting feeder cables” (2013 – 2014), cooling tests were conducted on a 300-meter-long superconducting cable for DC electric railway to verify the cable’s basic performance, that had both supply and return coolant circuits incorporated into the cable. With this program, RTRI conducted test runs on electric cars on RTRI test tracks (Fig. 2). The program will continue under RESEARCH 2020 to examine the possibility of extending the cable by building on the results of this basic research and as part of development work to produce an entire system including a cooling system.

Under the research and development topic “Development of flywheels for practical railway applications” (2013 – 2014), efforts were made to develop a superconducting bearing capable of supporting a flywheel weighing around two tons in a non-contact state. A range of areas were studied including torque transmission methods between a motor generator and a flywheel, how to cool superconducting coils, kinematic analysis of the flywheel, how to monitor the flywheel, and simulation of the system on a commercial line.

A flywheel power storage system test machine with a superconducting magnetic bearing, rated at 300 kW instantaneous input/output and 100 kWh electric energy, was designed, manufactured and, towards the end of FY2014, assembled. In FY2015, the test machine was installed at a large-scale photovoltaic power plant in Yamanashi Prefecture to test its contribution to output stabilization (Fig. 3).

In order to increase current for electric motor cars in high-density line sections, the standard DC 1500 V system needs to be increased to 3000 V. This in turn requires vehicles to be modified to accommodate the increased voltage. In the “study on high-voltage DC feeding systems” (2013 - 2014), a method was proposed whereby high voltage rectifiers and transmission lines are installed while reversible current chopper devices, designed to lower transmission voltage to feeding voltage (overhead contact line voltage), are installed at certain intervals. This proposal does not require the current standard 1500 V for feeding and overhead contact lines to be increased (Fig. 4). The proposed system, which allows the current vehicles to be
used without any modification, sends high-voltage power through transmission lines while collecting regenerated power. Through further study into this method, RTRI aims to achieve reduction in power loss, minimum voltage fluctuation, efficient use of regenerated power and extension in distance between substations. Currently, the study has reached the feeding loss simulation and weathering test stage on high-voltage DC feeding lines, based on the proposed configuration.

Rail operators have been introducing power storage systems to effectively overcome not only fluctuation in rolling stock load but also variation in power generation from solar, wind and other renewable energy sources. In the “development of power supply systems using renewable energy sources” (2012 – 2014), calculations found that improved energy saving could be achieved by combining power storage systems and renewable energies, and subsequently experiments were conducted on RTRI’s test track to verify the calculations.

Furthermore, a power simulation tool, designed to make comprehensive evaluations by combining these and other energy saving methods, was developed. In the “development of new power supply systems and evaluation using vehicle power consumption simulators” (2012 - 2014), a vehicle power consumption 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 (Fig. 5). In the subsequent verification testing that was conducted with cooperation from railway operators, the required accuracy of the simulation was confirmed.

Part of the “New power supply systems” efforts were subsidized by the Ministry of Land, Infrastructure, Transport and Tourism, the Ministry of Education, Culture, Sports, Science and Technology and New Energy and Industrial Technology Development Organization (NEDO).

2.3 Enhanced safety and reliability of railway systems

The subtheme “New maintenance monitoring technologies,” under the major theme “Maintenance innovations” aims to enable continuous monitoring of the medium to long term state of railway systems. This involves improving sensor durability, making replacement operations easier and establishing techniques for optimizing the design and application of maintenance information networks. Future challenges include the establishment of methods for predicting age deterioration of facilities based on change in their condition, optimization of monitoring frequencies and establishing other practical maintenance methods.

In the “improvement in overhead contact line diagnostics” (2012 - 2014), a method for diagnosing overhead contact line specifications based on contact force measurements and a facilities diagnostics method using image pro-
cessing, were developed. These enable estimation of contact wire height based on contact force and locating faults in overhead contact lines (Fig. 6) as well as estimation of wire tension in overhead contact lines based on images (Fig. 7).

3. Research and development of practical technologies

Under the theme “Research and development for practical technologies,” a wide range of topics were pursued based on requests from JR companies. Two of the 11 topics undertaken in FY2014 are outlined below.

In the “current collection performance improvement in response to change in overhead contact line conditions” (2012 - 2014), wire tension in overhead contact lines and contact wire height were closely studied in relation to temperature change and contact wire wear while taking into consideration tensioner operation hysteresis and tunnel temperature (Fig. 8).

In the “development of arrester leakage current measuring method” (2012 - 2014), a portable, easy-to-use fault detector was developed. The arrester uses Rogowski coils as a current sensor to process output through a bandpass filter, taking advantage of the characteristics of leakage current that were found in an analysis of leakage current from arresters with degraded zinc oxide elements (Fig. 9).

In the “evaluation of weathering deterioration in contact line components” (2012 - 2014), a range of components were evaluated to help with fault prevention and improve their performance reliability. In FY2014, galvanized steel tubing installed along the track was examined for deterioration to help with future maintenance.

In the “clarification of current collecting material wear mechanisms in high-speed and high-current conditions” (2012 - 2014), clarification was obtained about how a contact wire and strip wear as they slide against each other in the current collection process for given contact voltages, material melting points, corrosion film resistance and other conditions, and a wear prediction method was proposed (Fig. 10).

5. Future research and development

While recent studies on power supply technology have centered around improving energy saving measures and minimizing maintenance, as described earlier, RTRI has also been actively involved in other topics, as this report shows.

On vehicle power consumption, rail operators have been introducing a range of measures. Next steps include further improving efficiency by coordinating work on vehicles, operations and electricity related areas. As for minimum maintenance, it would be necessary to develop monitoring sensors, accumulate data and develop systems to process this collected data. These challenges will part of the work which shall be continue on from FY2015, as part of the RESEARCH 2020 plan.

RTRI will continue to advance research and development to meet rail operator needs.

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