Development of the Wayside Charging Facilities of Catenary and Battery-powered Hybrid Railcar System

Wayside facilities to charge onboard batteries are indispensable for achieving a catenary and battery-powered hybrid railcar system. In through service between electrified sections and non-electrified sections, trains can charge their batteries from catenaries while running in electrified sections and run in non-electrified sections on the charge power alone. Such a running mode, however, requires excessively large onboard batteries. We thus decided to develop and set up dedicated wayside charging facilities. We also decided to provide the prototype wayside charging system with large-capacity batteries for the purpose of reducing power received. Test production of the wayside charging system started in 2010, and field charging/discharging tests combined with a railcar were conducted in 2011 and 2012 to verify and assess the functions and equipment specifications needed for practical use.

1 Introduction

We undertook the development of a catenary and battery-powered hybrid railcar system in fiscal 2008 as a system that allows through service between DC electrified sections and non-electrified sections. Vehicle charging systems are classified as systems where trains charge their batteries only in electrified sections and run in non-electrified sections without charging and systems where trains charge at some stations provided with charging facilities in non-electrified sections. However, the former system has a disadvantage in car weight and drive energy because cars require large-capacity batteries, and the latter also has a disadvantage that large facility enhancement might be involved depending on the power company's current power supply status because the system needs equipment that can supply power in the same range as that of substations.

In order to overcome those problems, we examined installing batteries to wayside charging facilities. Those wayside batteries are charged while no train is present, and onboard batteries are quickly charged from those wayside batteries at the arrival of the train. In this way, power received will be reduced and load leveled. We therefore decided to develop this system with wayside batteries.

2 Requirements of the Wayside Charging System

2.1 Power Transforming Equipment

For DC power supply to trains, the charging facility needs to have performance equal to that of substations for train operation. Utilization rate of the equipment will be low for local lines with little train service, however the maximum power reception and capacity of the facility cannot be reduced since onboard batteries have to be charged in a short time at the arrival of the train. This allows for reduction of power received and capacity of the wayside charging facility while maintaining the output needed for quick charging.

Fig. 1 Reduction of Power Received According to Presence of Batteries

2.2 Charging Catenary

For charging from the facility to trains, pantographs and catenaries are used as in electrified sections. Trains are charged while stopped. As the large current at charging might raise the catenary temperature over the acceptable value, we measured the temperature rise at the contact between the catenary and the pantograph to identify usable catenary type. The results are described in section 4.

3 Development of the Wayside Charging Facilities

3.1 Circuit Configuration

The wayside charging facilities, as shown in Fig. 2, consist of a transformer circuit that transforms received power to DC, a battery circuit that charges and discharges power, and a feeder circuit that supplies power to the car.

Fig. 2 Basic Circuit Configuration of Wayside Charging Facility

We specified that the battery circuit be DC 600V based on the applicable standard battery voltage and the feeder circuit be DC 1,500V, equal to the voltage in electrified sections, because trains run through electrified and non-electrified sections. For the transformer circuit, either DC 600V or DC 1,500V is applicable, because cars require large-capacity batteries, and the latter also has a disadvantage that large facility enhancement might be involved depending on the power company's current power supply status because the system needs equipment that can supply power in the same range as that of substations.

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proposals are shown in Fig. 3 and 4 and the comparison results in Table 1.

3.2 Charge Control Method

When charging onboard batteries, control is needed according to conditions such as the arrival/departure of the train. In the development, that control is performed in the following flow 1) to 5), combining onboard battery control and wayside charging facility control.

1) System starts up. Wayside charging facility batteries are charged. After completing charging, wayside charging facility waits for the train with the catenary powered.

2) Train arrives and raises its pantograph. Train detects catenary voltage and starts low-current charging.

3) Wayside charging facility detects with a current transformer (CT) the car starting to charge. The charging facility increases output voltage and switches to large-current discharging (battery output).

4) Train detects battery output by the difference of voltage at pantograph contact and starts quick charging. Train finishes charging when the specified state of charge (SOC) is met.

5) The equipment detects charge completion with CT.

Current detection and catenary voltage control in this way achieved quick car charging without using dedicated communications equipment and the like.

3.3 Control in an Emergency

The control method of the wayside charging facility in an emergency was developed based on the following logic.

1) Wayside Battery Failure Control

In the event that wayside batteries fail while quickly charging onboard batteries, the facility trips the battery circuit and switches over to direct charging from the rectifier.

2) Over-discharge Prevention

In the event that the SOC of the wayside batteries reaches its lower limit while quickly charging from wayside batteries to
onboard batteries, the facility ceases battery discharge and switches over to direct charging from the rectifier.

3) Onboard Battery Priority Control

In the event that a train arrives while the wayside batteries are still being charged, the facility ceases charging wayside batteries and switches over to quick discharging to the train.

4 Charging/discharging Test

We produced a prototype charging facility that had the functions explained above and carried out charging/discharging tests in combination with a catenary and battery-powered hybrid railcar.

4.1 Testing Location

We carried out the test in the Utsunomiya Depot and Karasuyama Station on the Karasuyama line. Fig. 6 is the photograph of the prototype wayside charging facility based on Proposal 1 in Fig. 3, and Fig. 7 is a photograph of the catenary for charging and the test car.

4.2 Control Check Test

Using the prototype wayside charging facility, we checked the charging control method introduced in section 3.2, and confirmed that charging of wayside batteries and quick discharging to onboard batteries were controlled as shown in the above flow.

Next, we carried out emergency charging control described in section 3.3 and confirmed that control in situations such as emergencies was all performed as set.

4.3 Test Measurement of Catenary Temperature Rise

4.3.1 Test Details

In order to identify the type of catenary applicable for quick charging of railcars, we measured temperature rise at the pantograph contact of three types of catenaries: simple catenary equipment (Cu110mm², Cu170mm²) and overhead rigid wires. For the measurement, we used a thermocouple. Current at the pantograph contact was set at 500A, 300A, and 150A, and power was applied for 10 minutes, 20 minutes, and 35 minutes respectively, taking into account the power needed for train running. Fig. 8 shows the test overview, and Table 2 lists the test items.

4.3.2 Test Results

Fig. 9 shows the results of test No. 1-1 to 1-3, Fig. 10 those of test No. 1-4 to 1-6, and Fig. 11 those of test No. 1-7 to 1-9.

As the charging catenary of the wayside charging facility is not worn by the pantograph, we set the acceptable temperature rise \( \Delta T \) as 60K or less, complying with the standard for new catenary equipment as the judgment criteria.

The current value for railcar quick charging is assumed to be around a maximum of 500A per pantograph. However, the value of \( \Delta T \) exceeded 60K with both types of simple catenary equipment (Cu110mm², Cu170mm²). On the other hand, \( \Delta T \) with the overhead rigid wire was less than 60K. We thus found that the type of overhead contact line applicable for quick charging is overhead rigid wires only.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Catenary type</th>
<th>Current</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>Simple catenary equipment Cu110mm²</td>
<td>500A</td>
<td>10 min.</td>
</tr>
<tr>
<td>1-2</td>
<td></td>
<td>300A</td>
<td>20 min.</td>
</tr>
<tr>
<td>1-3</td>
<td></td>
<td>150A</td>
<td>35 min.</td>
</tr>
<tr>
<td>1-4</td>
<td>Simple catenary equipment Cu170mm²</td>
<td>500A</td>
<td>10 min.</td>
</tr>
<tr>
<td>1-5</td>
<td></td>
<td>300A</td>
<td>20 min.</td>
</tr>
<tr>
<td>1-6</td>
<td></td>
<td>150A</td>
<td>35 min.</td>
</tr>
<tr>
<td>1-7</td>
<td>Overhead rigid wire</td>
<td>500A</td>
<td>10 min.</td>
</tr>
<tr>
<td>1-8</td>
<td></td>
<td>300A</td>
<td>20 min.</td>
</tr>
<tr>
<td>1-9</td>
<td></td>
<td>150A</td>
<td>35 min.</td>
</tr>
</tbody>
</table>
4.4 Assessment Test of Overhead Rigid Wire

4.4.1 Test Details
In order to assess the effect of contact wire aging on temperature rise, we installed 1.5 m of overhead rigid wire that had been used for around a year (new) and 1.5 m of overhead rigid wire used for at least around 10 years (old). At the same time, to determine whether temperature rise varies according to the number of feeding branching units attached to the overhead rigid wire, we carried out four patterns of tests with a disconnecting switch to switch between use of a single feeding branch unit (at an end of the overhead rigid conductor equipment) and use of two branching units (at both ends of the overhead rigid wire). Current at the pantograph contact was 500A, and power application time was 10 minutes. Fig. 12 shows the test overview, and Table 3 lists the test items.

4.4.2 Test Results
Table 4 shows the results of test No. 2-1 to 2-4.

The judgment criteria was $\Delta T$ of 60K or less, the same as the aforementioned test. In the test, temperature rise of each setting or pattern including the old overhead rigid wire was less than the judgment criteria, confirming that aging of around 10 years causes no problems in use.

We found no particular effect of feeding branch units on reduction of temperature rise, even when using two feeding branch units.

5 Conclusion
For the catenary and battery-powered hybrid railcar quick charging system, we test-produced dedicated wayside charging facilities using batteries, developed control methods for charging railcars, and developed control methods for situations such as emergencies. Furthermore, using the prototype wayside charging facility, we carried out temperature rise tests of the charging catenary and concluded that overhead rigid wire is suitable for quick charging.

We plan to further assess the test data and make proposals and recommendations in deciding the specifications of the equipment and components for practical use.

Reference:
1) Mitsuo Shinbo, Hiroshi Nomoto, Ichiro Masatsuki, Shin’ichiro Tokuhiro, "Development of the Battery Charging Facilities on the Ground for the Catenary and Battery Powered Hybrid Train System," (S-3-3-3), Proceedings of 17th Jointed Railway Technology Symposium (J-Rail 2010) (December 2010)
4) Ichiro Masatsuki, "Development of Catenary and Battery-powered Hybrid Railcar System," Proceedings of the 9th World Congress on Railway Research, Challenge B (May 2011)