

## Overview of Series EV-E301 Catenary and Battery-powered Hybrid Railcar



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The Series EV-E301 railcar is equipped with large-capacity batteries, and it can be run in non-electrified sections. In electrified sections, the railcar can run just like ordinary EMUs by raising the pantograph, and it can charge batteries from overhead contact lines. When moving into non-electrified sections, the pantograph is lowered and the railcar runs on power from the batteries. When braking, the batteries are charged with regenerative energy so as to make effective use of electric power. Also, the railcar can make quick charges using a charging facility installed in the station. The Series EV-E301 can achieve elimination of exhaust gases from diesel engines as well as reduction of CO<sub>2</sub> emissions and noise.

●Keywords: Catenary and battery-powered hybrid railcar, Battery for traction circuit, Quick charge, Overhead contact line recognizing device, Reduction of environmental burden

### 1 Introduction

Railways are said to have high energy efficiency compared with other forms of transport. Even so, energy consumed for train operation still accounts for a large percentage of the energy used in railway business. It is thus an important issue for us to reduce energy consumption and CO<sub>2</sub> emissions, and railway operators have taken measures to improve energy conservation with rolling stock by means such as reducing rolling stock weight, improving efficiency of traction power units, and effectively utilizing regenerative braking.

Diesel railcars that run on non-electrified lines cannot be equipped with regenerative brakes in principle, so they are less energy-efficient than EMUs and have problems in terms of exhaust gases and noise as well. We thus developed a test train called a New Energy Train (NE Train) and aimed to reduce environmental burden of rolling stock running on non-electrified lines through innovative drive systems. As a result of the development of the NE Train, we successfully introduced and put into practical use Kiha E200 diesel hybrid railcars on the Koumi Line in July 2007. Then, as hybrid rolling stock for resort area lines, we deployed the Series HB-E300 to the Nagano, Akita, and Aomori areas from October to December 2010.

Meanwhile, battery performance such as output and capacity has been remarkably improved and prices have lowered as development of hybrid and electric automobiles has advanced in the automobile industry. In light of that, the possibility has come into view that rolling stock equipped with large-capacity storage batteries for traction circuits (hereinafter, “storage batteries”) could run on non-electrified lines using electric power from the storage batteries alone. Based on the information obtained in the development of the diesel hybrid railcar, we thus commenced development in 2008 of a catenary and battery-powered hybrid train system that includes wayside charging facilities. In line with that, we also modified the NE Train into a catenary and battery-powered hybrid test railcar (named “Smart Denchi-kun”) and carried out performance checks by technological verification

and running tests.

Using the catenary and battery-powered hybrid railcar system, rolling stock operation between electrified and non-electrified lines can be unified. This will enable improvement of efficiency of rolling stock operation, reduce labor for maintenance thanks to reduction of the number and type of mechanical components of engines and transmissions, eliminate exhaust gases from engines, and reduce CO<sub>2</sub> emissions and noise as well. In the development period to March 2012, practical use of the catenary and battery-powered hybrid railcar system came to appear to be feasible, and we produced and introduced Series EV-E301 mass-production prototype railcars (Fig. 1) to a section of the Utsunomiya Line (between Utsunomiya and Hoshakuji) and to the Karasuyama Line in March 2014.



Fig. 1 Series EV-E301 (ACCUM)

### 2 Catenary and Battery-powered Hybrid Railcar System

On the lines where the Series EV-E301 runs, the section between Utsunomiya and Hoshakuji (11.7 km) of the Utsunomiya Line is electrified, and the Karasuyama Line from Hoshakuji Station to the terminal Karasuyama Station (22.4km) is not electrified. Wayside charging facilities were set up at Karasuyama Station.

Fig. 2 shows an overview of the catenary and battery-powered hybrid railcar system. The following presents separately the

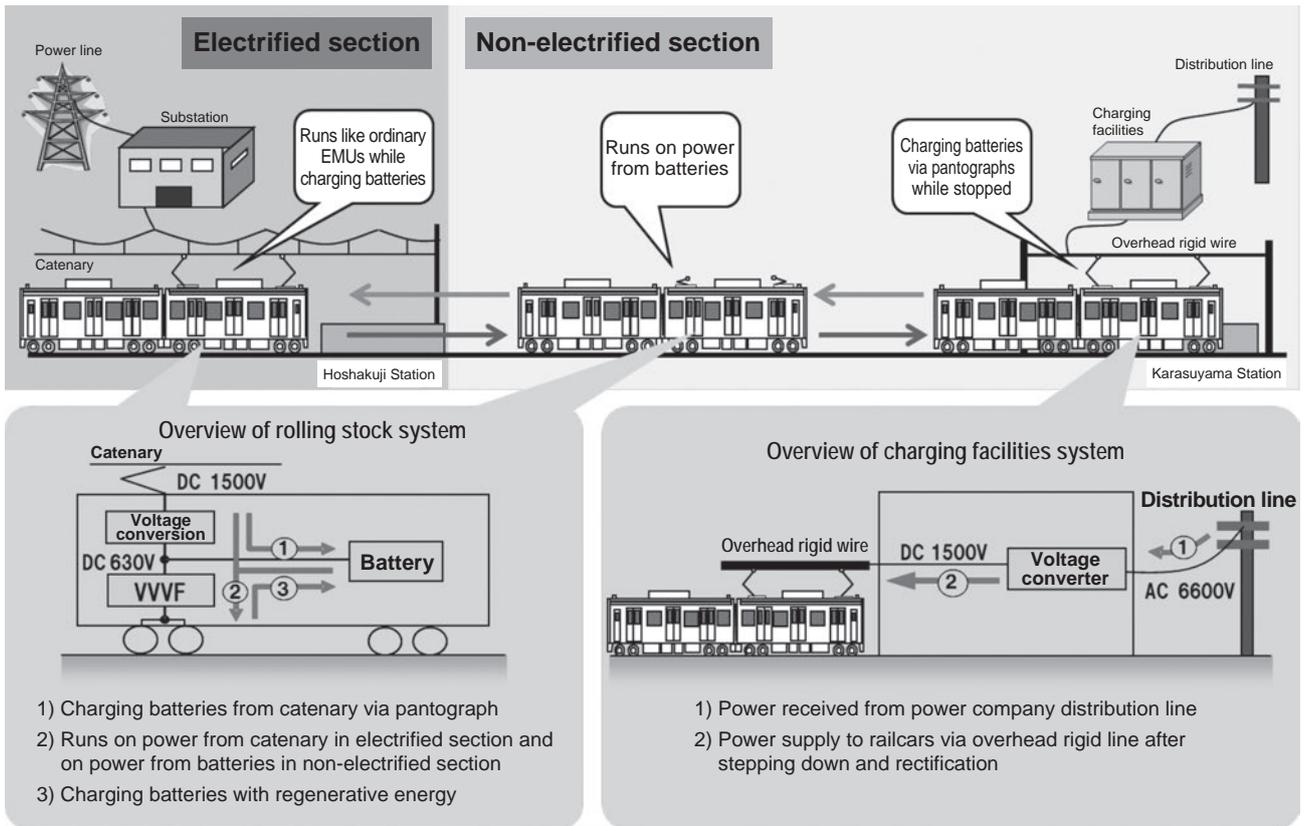


Fig. 2 Overview of the Catenary and Battery-powered Hybrid Railcar System

system operation in the electrified section, non-electrified section, and the turn-back station with charging facilities.

### (1) Electrified Section

In the electrified section, cars raise their pantographs and run on electric power from overhead contact lines just like ordinary EMUs. If the state of charge (SOC) of batteries is low, the railcar charges its batteries with power from overhead contact lines and regenerative energy at braking.

### (2) Non-electrified Section

The cars lower their pantographs and run on power from the batteries alone. They charge batteries with regenerative energy at braking for effective use of electric energy.

### (3) Charging Facilities (Turn-back Station)

Under the charging facility, railcars raise their pantographs and charge their batteries by large collecting current to shorten charging time (hereinafter, “quick charging”). To allow quick charging, we employed reinforced contact strips for pantographs and overhead rigid wires at wayside facilities.

## 3 Structural Characteristics of Catenary and Battery-powered Hybrid Railcars

### 3.1 Traction Circuit Configuration

The traction circuit of the Series EV-E301 consists of a DC/DC converter that lowers the DC 1,500V overhead contact line voltage to DC 630V battery voltage and a power transformer incorporated with a VVVF inverter that controls traction motors using battery voltage as input voltage. Incorporating the VVVF

converter with a power transformer allowed downsizing of devices, reduction of wiring, and also effective use of limited underfloor equipment space. Two-level inverters are employed for the DC/DC converter and the VVVF inverter with an aim of improving quality of equipment by using a smaller number of elements. Cooling fins are used for the DC/DC converter, taking into account quick charging while stopping under the charging facilities, while the VVVF inverter is cooled by the wind of the running train.

Comparing the Series EV-E301 traction circuit with the ordinary DC EMU traction circuit, we see that the traction circuit configuration of the Series EV-E301 differs in that a DC/DC converter and storage batteries are added (Fig. 3).

Regenerative energy at braking is generally collected to the storage batteries. However, when batteries are almost fully charged, the energy is returned to the overhead contact lines.

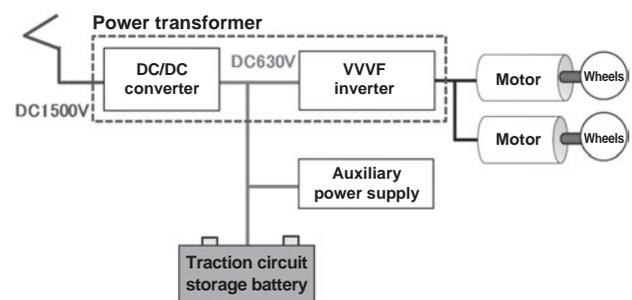


Fig. 3 Traction Circuit Configuration for Series EV-E301

### 3.2 Storage Batteries for Traction Circuit

As a catenary and battery-powered hybrid railcar runs in non-electrified section on the electric power from the batteries alone, large-capacity batteries need to be installed onboard. At the same time, space and allowable weight for the batteries are limited, and quick charging has to be made possible. In order to meet those requirements, we employed lithium-ion batteries for the Series EV-E301 rolling stock. Lithium-ion batteries have advantages of being compact and lightweight and able to handle quickly charging.

We initially considered the cabin as the space where batteries are accommodated. However, taking into account the cabin space that would have to be secured, maintainability of batteries, and cabin safety, we decided to accommodate batteries in dedicated boxes (hereinafter, “traction circuit storage battery boxes”) and mount the boxes in the underfloor space completely separated from the cabin (Fig. 4).

Traction circuit storage battery boxes are of a structure optimal for the temperature conditions required for batteries, such as reduction of battery temperature rise while charging/discharging and reduction of temperature difference between batteries in one box while stopping.



Fig. 4 Traction Circuit Storage Battery Box

Battery capacity is 190.1 kWh per train set. The value was determined taking into account leeway to handle in case of operation disruption and the decrease of battery capacity due to aging in addition to power consumption for running (load for train traction + load for operating air conditioners and other auxiliary units). Fig. 5 illustrates the concept of determining battery capacity. Batteries installed are divided in two groups with redundancy.

### 3.3 Overhead Contact Line Recognizing Device

As the Series EV-E301 runs between electrified and non-electrified sections as shown in Fig. 2, it raises and lowers its pantographs according to the sections with and without overhead contact lines, meaning it conducts those operations more frequently than other trains do. Furthermore, it charges its batteries in quick charging under the charging facilities using collecting current larger than ordinary current flowing through overhead contact

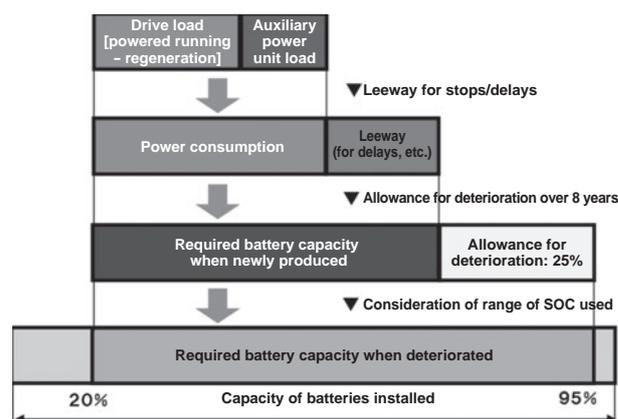


Fig. 5 Setting of Storage Battery Voltage

lines. Thus, that current limit values for the Series EV-E301 vary according to the type of overhead contact line.

Series EV-E301 railcars therefore have an overhead contact line recognizing device. That automatically recognizes the overhead contact lines of the current location of the railcar based on the location data transmitted from wayside.

The railcar switches the position of its pantographs as follows according to the recognized condition of power collection system. Fig. 6 shows a rough image of pantograph and power collection control.

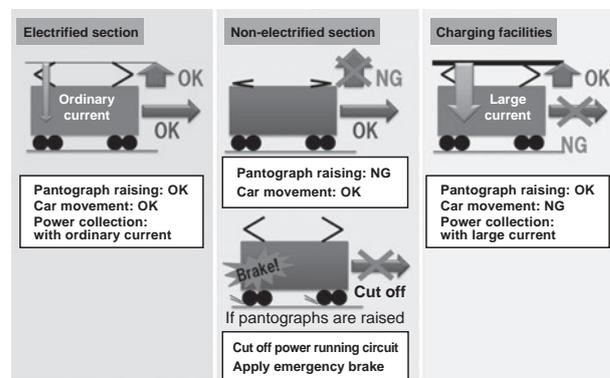


Fig. 6 Identification and Control of Power Collection System Using Overhead Contact Line Recognizing Device

#### (1) Pantograph control

- Prevent pantographs from being raised in non-electrified sections
- Limit raising/lowering of pantographs during quick charging under charging facilities to protect pantographs and overhead contact lines

#### (2) Railcar movement control

- Prevent railcar from entering non-electrified section with pantograph raised
- Cut off powered running circuit and apply emergency brake if pantographs are raised in non-electrified sections
- Prevent railcar from starting to move during quick charging

#### (3) Limitation of collecting current to pantographs

- Control collecting current value according to conditions of power collecting system (prevent pantograph damage and fusing of overhead contact lines)

### 3.4 Onboard Display Panel

We attached an onboard display panel to the upper part of the rear wall of the cabin to inform passengers whether the railcar is running on power from overhead contact lines or from batteries. The display shows arrows indicating power flow between devices according to the current operation of the railcar, such as it being in powered running, coasting, and braking. It also indicates SOC of batteries and charging status using animation. Fig. 7 is a photo of the onboard display panel.

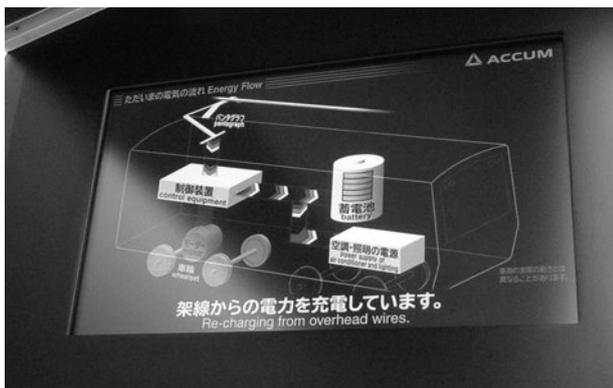


Fig. 7 Onboard Information Display

## 4 Train Set and Major Specifications

A Series EV-E301 train is a fixed two-car train set consisting of a Type EV-E300 railcar as car No. 1 at the Utsunomiya end and a Type EV-E301 railcar as car No. 2 with pantographs at the Karasuyama end.

We added EV (Energy storage Vehicle) to the rolling stock type name to indicate being a catenary and battery-powered hybrid railcar.

In terms of performance, maximum speed is 100 km/h, acceleration is 2.0 km/h/s, and deceleration is 3.6 km/h/s. The maximum operation speed on the Karasuyama Line is 65 km/h; however, we set the above maximum speed taking into account running on the Utsunomiya Line.

With each railcar, the front bogie is a trailing bogie and the rear bogie is a driving bogie.

Table 1 lists major specifications of the Series EV-E301.

## 5 Design

The overall concept of the Series EV-E301 is to be a next-generation railcar that leads to a people-friendly future. We tried to express the catenary and battery-powered hybrid railcar as being advanced, incorporating the image of the area along the Karasuyama Line too.

(1) Exterior

· Keyword 1: Advanced

For the shape of the car nose and the coloring of stripes, we gave the Series EV-E301 sharpness that expresses it being advanced.

Table 1 Major Specifications of Series EV-E301

	EV-E300 (car No. 1)	EV-E301 (car No. 2)
Train set		
Maximum speed	100 km/h	
Passenger capacity (seated)	133 persons (48 persons)	133 persons (48 persons)
Weight	37.7 t	40.2 t
Major dimensions	Body length 19,570 mm Body width 2,800 mm Roof height 3,620 mm Floor height 1,130 mm	
Cooler	Centralized cooling system	
Safety equipment	ATS-P, Digital train radio, emergency brake/one-push button emergency devices, train protection radio	
Control	VVVF inverter control, with regenerative brake	
Brake device	Electric command/regenerative brake equipment, Straight air reserve brakes, Snowproof brakes, Holding brakes	
Traction circuit storage battery	Lithium-ion battery DC630 V(95 kWh)	Lithium-ion battery DC630 V(95 kWh)
Structure of driver's cab	No front gangway door, full cabin width, capable of one-man operation	
Seat arrangement	Longitudinal seats, wheel chair space	
Doors on sides	3 double doors on each side, Semi-automatic, Pneumatic door closer	
Other equipment	Devices for one-man operation, Ceramic particle sprayer	

· Keyword 2: Eco-friendliness

With the ratio of silver to green in the color scheme, we expressed harmony with the landscape of the area along the line, eco-friendliness, and a feeling of being refreshed.

· Keyword 3: Catenary and battery-powered hybrid railcar

By coloring the underfloor traction circuit storage battery box and the pantographs green as a visual feature, we tried to emphasize the most important characteristic of the Series EV-E301: it being a catenary and battery-powered hybrid railcar.

(2) Interior

· Keyword 1: Advanced

Aiming to build an advanced cabin image never seen before with conventional commuter vehicles, we introduced continuous indirect LED illumination, a novel cross-sectional shape for the ceiling, and coloring of the cabin including black upper part of end walls to distinguish the information display area for passengers.

· Keyword 2: Next-generation service

Based on the concept of universal design introduced with the Series E233, we aimed to design a more user-friendly vehicle for everyone by means such as enhancing the wheel chair space.

· Keyword 3: Potential of the Karasuyama Line

In the design of the material of seats and flooring, we expressed features of the area along the Karasuyama Line. Those include greenery of the landscape with seasonal beauty, the cultural richness of *washi* (Japanese paper) and other traditional crafts, and the vigor seen in the *Yamaage Matsuri* festival that enlivens the Karasuyama area.

## 6 Overview of the Railcar

### 6.1 Body Structure

The car body, excluding a part of the underframe that requires special strength, is a lightweight stainless structure. The head is reinforced as a countermeasure against level crossing accidents. As the Series EV-E301 has a larger car body mass, we made additional reinforcements to improve car body strength. On the other hand, we needed to cut car weight down to curb battery power consumption. We thus took measures to reduce weight as much as possible, such as changing materials (to aluminum) and adding holes, after confirming their impact on car body strength.

The car body shape is straight. Among the major dimensions, car body length is 19,570 mm, width 2,800 mm, and height 3,620 mm. The car body height when pantographs are lowered is 3,980 mm, taking into account running in small tunnels. The floor height is 1,130 mm.

### 6.2 Passenger Cabin

The two cars of a Series EV-E301 train have a passenger cabin of common appearance with longitudinal seats and an equipment room on the rear side. Each car has 48 seats with two 12-person seats between three doors on each side. Fig. 8 is a photo of the cabin.

The seats are cantilever type, and they have an independent cover riser that accommodates a heater, a pneumatic controller, and electric devices under the seat. S-shaped springs are used for the seat cushion to improve sitting comfort. Those S-shaped springs are incorporated to the seat frame to improve workability in assembling/disassembling of the frame. The seat cushion and seat back are contoured to have an effective width 460 mm, making the space for one person to sit easily identifiable.

For lighting, indirect LED illumination is employed (Fig. 9) to reduce power consumption. A seamless arrangement of LEDs over the cabin ceiling length creates a cabin image never seen before. The side ceiling has novel cross-sectional shape angled in three phases, and the middle part is colored in *washi*-like black to give an accent in design. The cabin panels are for the most part made of melamine resin.

In order to improve barrier-free functions, an LCD fare/information display panel is attached to the center of the upper part of the end wall behind the driver's cab. When doors open/close, door chimes ring and red lamps turn on as guidance for passengers with visual or hearing impairments. Yellow door stop rubber improves visibility of doors both from inside and outside of the railcar.

Height of straps and baggage racks was lowered by 50 mm in the area of the 12-person seat with priority seats on the cabin front side, taking into account convenience for shorter passengers. The stanchion poles in front of the priority seats are curved and nonslip-surfaced for easier gripping. Baggage racks are made of aluminum round pipes for weight reduction.



Fig. 8 Cabin



Fig. 9 LED Cabin Illumination



Fig. 10 Wheelchair Space

A wheelchair space is located on the rear side of the cabin, and an emergency telephone device is attached at a height a person in a wheelchair can easily reach to enable communication with the crew (Fig. 10). At the gangway connecting cars, a sliding door that automatically closes by a gravity-assisted door closer is installed. Taking into account limited ability of the driver to operate doors in one-man operation of trains, an 800 mm effective gangway width is secured to allow wheelchairs to pass through with.

## 6.3 Driver's Cab

The driver's cab is of the full cabin width with no front gangway doors to enable one-man operation (Fig. 11). In order to protect the driver in case of collision, the front structure of car body is reinforced and an emergency exit is located behind the cab. LEDs are used for the front marker lights.

The Series EV-E301 has in its driver's cab the switches for quick charging, the overhead contact line recognizing device, etc. required for a catenary and battery-powered hybrid railcar. Those switches are arranged taking into consideration situations for and order of switch operation and prevention of mis-operation. Fig. 12 shows, as an example, the arrangement of the switches used for quick charging on the side opposite where the driver sits.

The driver's cab monitor has a newly added function of displaying items such as SOC of batteries, energy flow between devices, and situation of the power collecting system the railcar recognizes. This is addition to conventional functions including displaying operation and car information, crew support functions such as control of devices for one-man operation, control functions for service devices functions such as coolers and heaters, and inspection functions such as failure recording and those related to testing.



Fig. 11 Driver's Cab



Fig. 12 Equipment Arrangement on the Side Opposite Driver

## 6.4 Device Arrangement

### (1) Underfloor device arrangement

Auxiliary power devices and other related devices are installed to the underfloor space of car No. 1 and power transformers and other devices related to traction circuits to car No. 2. Traction circuit storage battery boxes are installed in a group (five boxes) to each car for a total of ten boxes in a train set.

### (2) Rooftop device arrangement

In order to enable quick charging, two pantographs with reinforced pantograph contact strips are mounted on car No. 2. An air conditioning device and a train radio antenna are also installed to each car.

## 7 Conclusion

We have confirmed functionality for Series EV-E301 railcars by means such as performance and quick charging tests and have conducted crew training runs. On March 15, 2014, a mass-production prototype train set started commercial operation on the Karasuyama Line, and it has been viewed highly by passengers. It is our sincere desire that the railcars will be widely accepted by users and residents of the area long into the future. At the same time, we expect that technical advancements in storage batteries and accelerated efforts in battery-powered railcars will lead to greater advancement of catenary and battery-powered hybrid railcars.



Fig. 13 Series EV-E301 Charging Batteries at Karasuyama Station

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