Latest Railway Substation Systems

— New Environmental Products —

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OVERVIEW: To address the need for railway substation systems that are more compact, incur fewer losses and are easier to maintain, Hitachi has already developed smaller and more compact SF_6 GIS (gas-insulated switchgear), quieter and more efficient transformers for electric railways, and digitally controlled power switching boards. Recently, to meet the growing demand for equipment that is more environmentally safe, efficient, compact and easy to maintain, we have developed (1) an environmentally friendly silicon transformer with superior disaster-proofing, (2) environmental GIS and compact accumulation-type SWGR (switchgear) that contain no SF_6 greenhouse gas, (3) a new eco-friendly rectifier containing no PFCs (perfluorocarbon compounds) in the coolant and which incurs even lower losses, and (4) a BBU (building block unit) capable of online maintenance, achieved by forming the protection controllers as standard units.

INTRODUCTION

DUE to recent changes in social forces, there is a growing need for railway substation systems that are more environmentally friendly, more compact, more efficient and easier to maintain.

To address this need, Hitachi is developing environmental transformers, switching equipment and rectifiers, as well as protection controllers with enhanced maintainability.

This paper discusses the technology and products that Hitachi has developed for railway substation systems (see Fig. 1).

RECENT NEEDS OF RAILWAY SUBSTATION SYSTEMS

The technologies and products that Hitachi is developing to respond to the needs of railway substation systems are as follows (see Fig. 2).

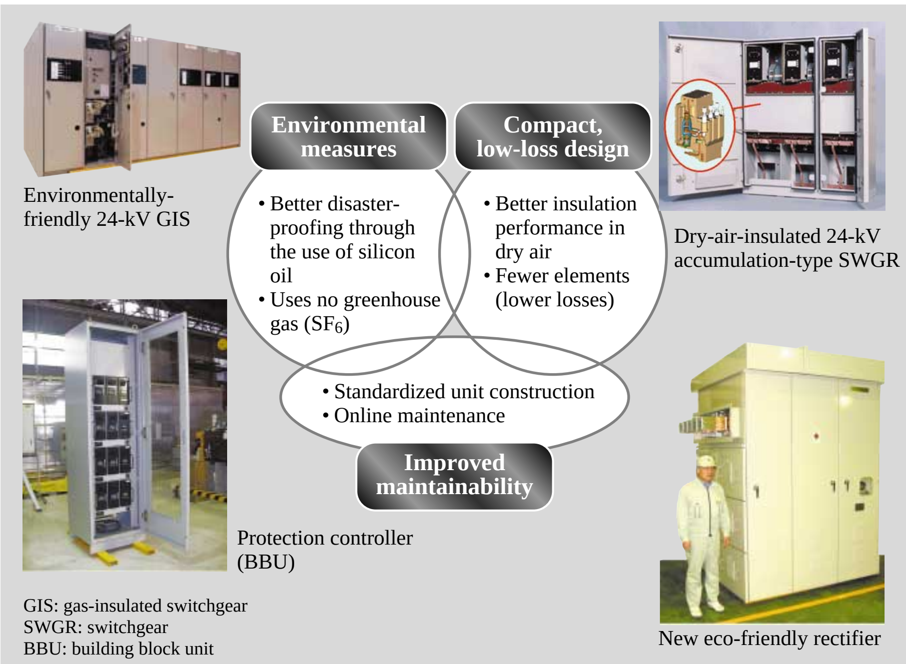


Fig. 1—Environmental Railway Substation System.
Reflecting recent social trends, there is a growing need for railway substation systems that are more environmental, more compact, incur fewer losses and requires less maintenance. Hitachi is developing new railway substation systems to address these needs.

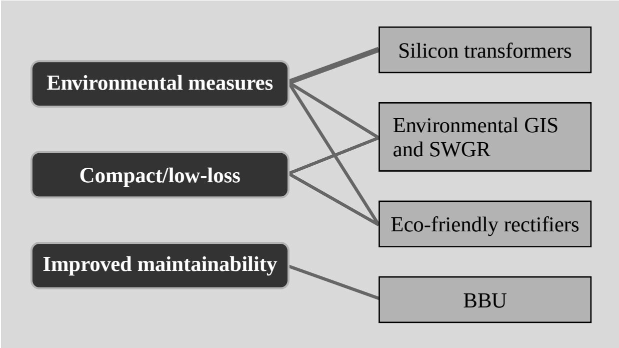


Fig. 2—Products that Meet Needs of Railway Substation Systems.
In railway substation systems, there is a growing need for compact environmental equipment that is easy to maintain and incurs low losses.

Fig. 3—Silicon Transformer.
This figure shows a 22-kV 4,780-kVA silicon transformer. It is roughly the same size as a mineral oil transformer.

(1) Environmental
(a) Transformers with better disaster-proofing that use silicon oil instead of mineral oil
(b) GIS and accumulation type SWGR that contain no SF_6 greenhouse gas
(c) Eco-friendly rectifiers that use pure water as a coolant instead of PFCs (perfluorocarbon compounds)
(2) Compactness and efficiency
Rectifiers with reduced losses due to reductions in the number of diode elements
(3) Improved maintainability
BBUs capable of online maintenance based on protection controllers formed as standard units.

ENVIRONMENTAL MEASURES FOR TRANSFORMER EQUIPMENT

Electric Railway Transformers Using Silicon Oil

Hitherto, SF_6 gas-insulated transformers have been used for transformer substations in urban districts by virtue of their disaster-prevention characteristics. However, now that SF_6 has been found to be a greenhouse gas, it is important to cut back on its use. Also, an amendment to the Fire Prevention Act in July 2001 ruled out the use of anything with a flash point of 250°C or above as a dangerous material, and since we are already experienced in the use of silicon oil in transformers for vehicles, we developed a silicon transformer that can also be used for electric railways (see Fig. 3). The properties of each type of insulation medium are compared in Table 1.

The benefits of silicon transformers include the following:
(1) Disaster-proofing: it has a high flash point and does not readily ignite. It is also flame resisting and self-extinguishing properties, making it difficult to burn.
(2) Reliability: it is stable and non-corrosive.
(3) Environmental safety: it readily breaks down in the environment and can be broken down into natural substances (silica being the main constituent).

Environmental GIS and Accumulation Type SWGR

Overview of environmental 24-kV GIS

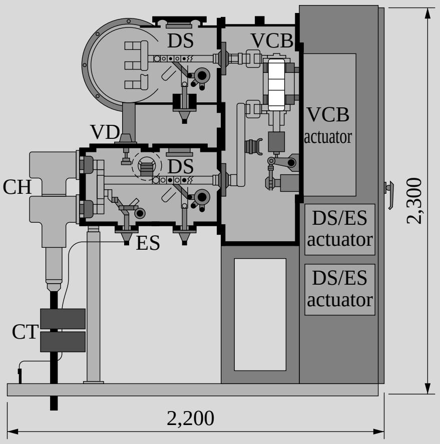
In the environmental GIS (see Fig. 4), we used dry air as the substitution gas.

The properties of dry air are as follows:
(1) Safety: it is a non-toxic, stable, non-flammable gas.
(2) Insulation: its insulation performance is about one-

TABLE 1. Properties of Various Insulation Media
This table compares the specifications of transformers using silicon oil, conventional mineral oil and SF_6 gas. Silicon oil performs as well as mineral oil, and has better disaster-proofing properties.

	Mineral oil	SF_6 gas	Silicon oil
Applied voltage	22 kV, 66 kV≥	22 kV, 66 kV≥	22 kV, 66 kV≥
Flash point	145°C	—	>250°C
Specific gravity	0.87	—	0.96
Flow point	–30°C	—	–60°C
Relative size of equipment	100%	120%	100%
Relative mass of equipment	100%	120%	105%
Overload capacity	Large	Small	Large

Compared item	Existing model	Environmental model
Insulation medium	SF_6	Dry air
Rated gas pressure (MPa)	0.1	0.35
Lowest guaranteed gas pressure (MPa)	0.07	0.3
Structure and parts dimensions	—	Inherited from conventional parts



DS: disconnecting switch
VCB: vacuum circuit-breaker
VD: voltage detector
CH: cable head
ES: earthing switch
CT: current transformer

Fig. 4—Characteristics and Outline Structure of Environmental GIS.
The structure and size of the 24-kV 1,200-A environmental model are inherited from a conventional device.

third that of SF_6 gas.
(3) Interception and arc-extinguishing: its performance is not as good as that of SF_6 gas.

In developing this product, we investigated the following items:
(1) Increasing the gas pressure in the VCB and its enclosure

To improve the insulation performance, we increased the gas pressure from 0.1 MPa (as used with SF_6 gas) to 0.35 MPa.

In this class of circuit breaker, a VCB is used because a pressure difference must be maintained between the vacuum part and the external pressure. Here, we developed and used a VCB capable of withstanding an external pressure of up to 0.4 MPa.
(2) DS lead/lag small-current switching

Since the breakdown characteristic of dry air is worse than the performance of SF_6 gas, we devised a shape for the main circuit conductors of the disconnecting switch that made it possible to achieve the required performance.
(3) Size and configuration of component parts

The component configuration was the same as in a conventional design, allowing parts to be replaced easily. The use of dry air insulation is also advantageous from an environmental viewpoint because it greatly reduces the amount of industrial waste.

TABLE 2. Main Specifications of Accumulation Type SWGR
This table shows the main specifications of a 24-kV accumulation type SWGR which contributes to substantial reductions in the installation area.

Item	Ratings and specifications
Switch	An accumulation type vacuum circuit breaker with 4 positions (energize — intercept — disconnect — test/earth)
Insulation system	Vacuum — dry air — epoxy mold composite insulation
Rated voltage and current	24 kV, 200/400/600 A
Interception electric current	25 kA
Interception time	5 cycles
Max. current	25 kA, 1 s

24-kV accumulation type SWGR

By employing a dry air insulation system as in the GIS, we aimed to implement environmental measures even for the 24-kV accumulation type SWGR where it is possible to make substantial reductions in the installation area (about 6% for a nature interruption edge SWGR). The specifications of an accumulation type SWGR are shown in Table 2.

New Eco-friendly Rectifier

PFCs have hitherto been used in the coolants that cool the rectifier diode elements. However, to eliminate greenhouse gases we developed an eco-friendly rectifier with a heat pipe cooling system that uses pure water as the coolant (see Table 3).

TABLE 3. Main Specifications of New Eco-friendly Rectifier
By using pure water as the coolant, PFC greenhouse gases have been eliminated.

Item	Specification
Name	Heat pipe self-cooled silicon rectifier
Ambient temperature	-20°C to + 40°C
Coolant	Pure water
DC voltage	1,500 V
Ratings	6,000 kW (type E) 100% (continuous), 120% (2 h), 300% (1 min)
Basic connection scheme	6-pulse, parallel 12-pulse
Dimensions (external)	2,000 (W) × 1,600 (D) × 2,995 (H) mm

Product characteristics

(1) Elimination of greenhouse gases: the diode elements are cooled using a heat pipe with pure water as the coolant
(2) Normal operation at –20°C ambient temperature: the use of a variable conductance heat pipe allows the device to be operated at ambient temperatures as low as –20°C (without the need for a frost-preventing heater).
(3) Compact space-saving design: the device occupies 50% less space than a conventional rectifier.
(4) Low loss: the use of high-voltage diode elements allows the number of elements to be halved, resulting in losses that are 40% lower than those of a conventional rectifier.

Application of new techniques

(1) New cooling system

A drawback of heat pipes that use pure water is that they cannot be used in cold climates due to freezing of the water. In the eco-friendly rectifier we developed, a VCHP (variable conductance heat pipe) is used to cool the rectifier elements. In this VCHP, the pure water coolant is injected together with a noncondensable gas that regulates the amount of heat dissipation. This allows the device to exhibit stable cooling performance without freezing of the coolant. The operating principle of a VCHP is illustrated in Fig. 5.

(2) Rectifier elements

For the diode elements, we used newly developed high-voltage components. This allowed us to halve the number of elements, resulting in a compact low-loss rectifier.

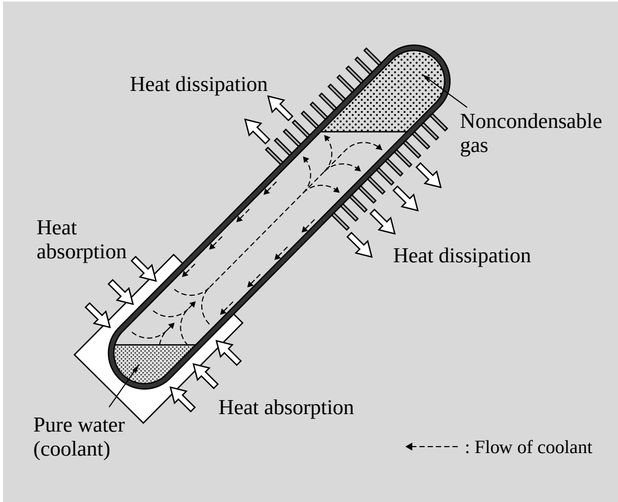


Fig. 5—Cooling Principle of New Eco-friendly Rectifier.
The pure water coolant is prevented from freezing by injecting it into the heat pipe together with a noncondensable gas that regulates the amount of heat dissipation.

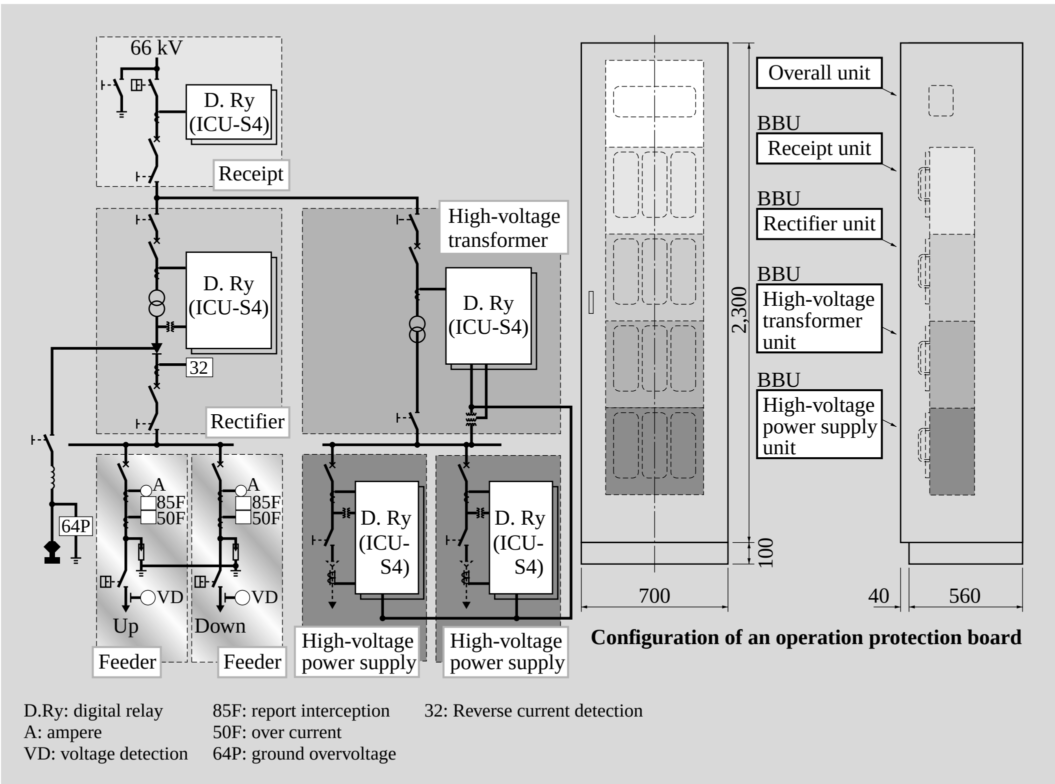


Fig. 6—Example of Block Configuration for Each BBU Transformer Substation.
The transformer substation facility is divided into various blocks—receipt, rectifier, feeder, high-voltage transformer, and high-voltage power supply—and units are provided to perform protection control separately for each block.

TRENDS IN PROTECTION CONTROLLER EQUIPMENT

Distributed Protection Control System (BBU)

Conventional protection controllers are configured as systems that extend across an entire power supply board. Consequently, the maintenance and alteration of these controllers involve large-scale power outages and large amounts of time and labor. But in the BBU we developed, a railway's transformer substations are separated into blocks for each facility, and a system is configured in which the unit that performs the protection control of each block is accommodated in an operation protection board (see Fig. 6). This makes it possible to employ separate structures for the systems of each unit, making it much easier to maintain (see Fig. 7).

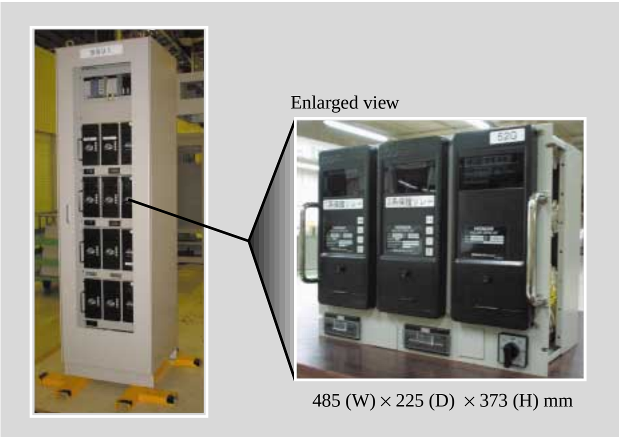


Fig. 7—Operation Protection Board Incorporating BBUs (left), and Appearance of Single BBU (right).
This figure shows an operation protection board incorporating 4 BBUs and a sequencer for overall control, and the appearance of a single BBU.

BBU Characteristics

(1) The operation protection board is configured from standardized units corresponding to each facility. By providing a spare unit, maintenance and alterations can be performed simply by switching out the affected unit, thereby improving the maintainability.
(2) The use of digital relay doubling ensures high reliability.
(3) The wiring requirements are greatly reduced by employing the field network and mounting the units on the main machine side.

CONCLUSIONS

We have discussed our transformer equipment and protection controllers that address the latest needs of railway substation systems.

In the future, Hitachi plans to continue developing railway substation systems that meet the needs of customers by employing the latest technology and environmental measures, striving for compact efficient designs, and producing equipment that is easy to maintain.

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