Environmentally-conscious Substation Systems Designed in Response to Global Warming

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OVERVIEW: At The Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change held in Kyoto in 1997, gases that contribute to global warming were specified, and since then the needs of society regarding environmental conservation have become more and more urgent. Aiming at meeting these needs in the field of railway systems, which are fundamentally benign to the global environment, Hitachi has developed various commercial transformer systems for railway use that contribute to further reduction of greenhouse-gas emissions. In particular, two key products were developed: a regenerative energy absorbing equipment for railway systems that use lithium-ion batteries like those applied in hybrid vehicles; and a completely sulphur hexafluoride (SF_6)-gas-free, 72-kV dry-air insulated switchgear unit that uses absolutely no SF_6 gas (which has a high global-warming potential and has been conventionally used as the insulating medium in transformers). By applying these products, we have been able to construct an environmentally-friendly transformer system for electric railways.

INTRODUCTION

IN accordance with the recent view of society, it is being demanded that electricity substation systems for railway use are constructed to be even more environmentally-friendly than they have been up till now. With satisfying this social need in mind with reducing emissions of greenhouse gases as our leading motive, Hitachi has developed various environmentally-friendly products for railway electricity substation systems. These products include a regenerative energy absorbing equipment for railway systems using a lithium-ion battery, fully gasless (no sulphur

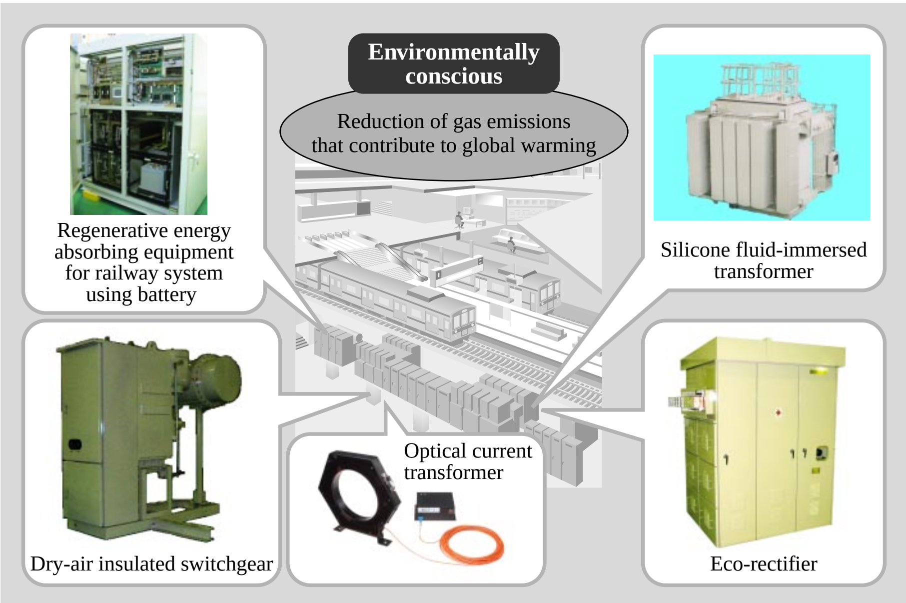

Fig. 1—Hitachi's Product Line-up for Configuring Environmentally-conscious Substation Systems.
By applying products that aim to reduce gas emissions that contribute to global warming, Hitachi has configured an environmentally-conscious substation system.

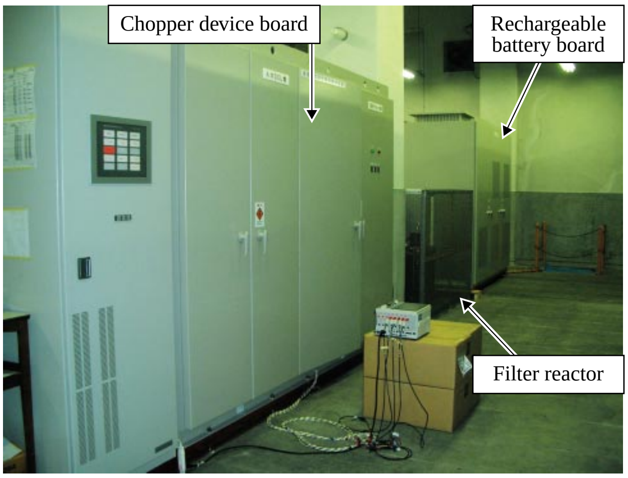

Fig. 2—Scene from Field Tests on Regenerative Energy Absorbing Equipment Using Batteries.
The specification of the field-test equipment consisted of two multi-layered chopper IGBTs (insulated-gate bipolar transistors), four serial and five parallel DC 1,500-V lithium batteries, and operation at 500 kW (operates for 15 s in a cycle of 180 s).

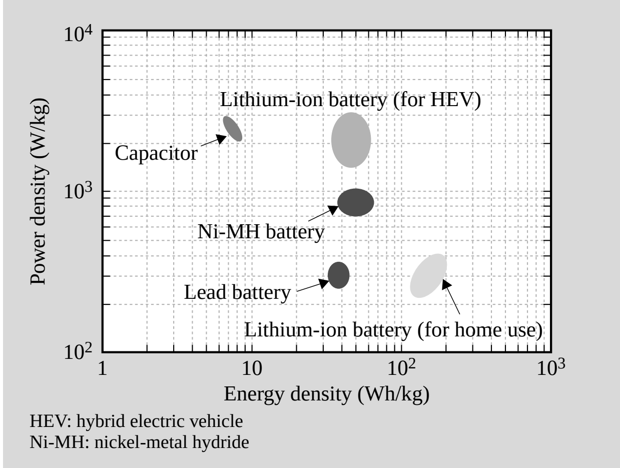

Fig. 3—Performance Comparison of Battery Media.
The performance of a rechargeable batteries, i.e. a lithium-ion battery for HEV use, an Ni-MH battery, and a lead battery, are compared. It is clear that the lithium-ion battery is designed for rapid charging and discharging, and it is well suited to loading by electric trains.

hexafluoride) dry-air-insulated switchgear, a silicone-fluid-immersed transformer using silicon liquid as an insulating medium, and an optical current transformer that contributes to reducing industrial waste and improving recyclability. In the following sections, each of these products and their respective applied technologies are explained.

ENVIRONMENTALLY-CONSCIOUS POWER-ELECTRONICS EQUIPMENT

Hitachi is currently developing a regenerative energy absorbing equipment using batteries as a converter for electrical power (DC: direct current) substations used for railway systems that take account of environmental issues, and an eco-rectifier has already been commercialized.

Regenerative Energy Absorbing Equipment Using Batteries

Background to development

In recent years, Hitachi has commercialized and is implementing a regenerative inverter and a friction-consuming-type regenerative energy absorbing equipment as a measure against the regenerative lapse that occurs in the regenerative trains being developed by various train companies. These devices, however, have both good points and bad points. Accordingly, as a device with the good points of either device, a regenerative energy absorbing equipment using lithium-ion batteries was developed. This unit not only applies conventional measures against regenerative lapses but also applies a voltage-drop measure utilizing an electromotive voltage (for improving acceleration performance of a train). As a result, this unit shows promise in a wide range of applications. At present, with the cooperation of train companies, we have completed field tests of this unit installed at an actual DC electromotive-voltage transformer substation, and commercialization of this unit is continuing (see Fig. 2).

Adoption of Rechargeable Battery

The battery for use in the regenerative energy absorbing equipment is a lithium-ion type. Developed for use in hybrid vehicles, the lithium-ion battery is presently considered suitable to meet the needs for large current charge and discharge as well as large storage capacity. A performance comparison of various battery mediums is shown in Fig. 3. The characteristics of a lithium-ion battery are both high power density and high energy density, so it is superior in those terms in comparison to other battery media. In addition, according to modifications to materials used, etc., long-lifetime technologies for the lithium-ion batteries are well established, and the possibility of using them under the loading conditions and established environments of power substations have been forecast for over 15 years.

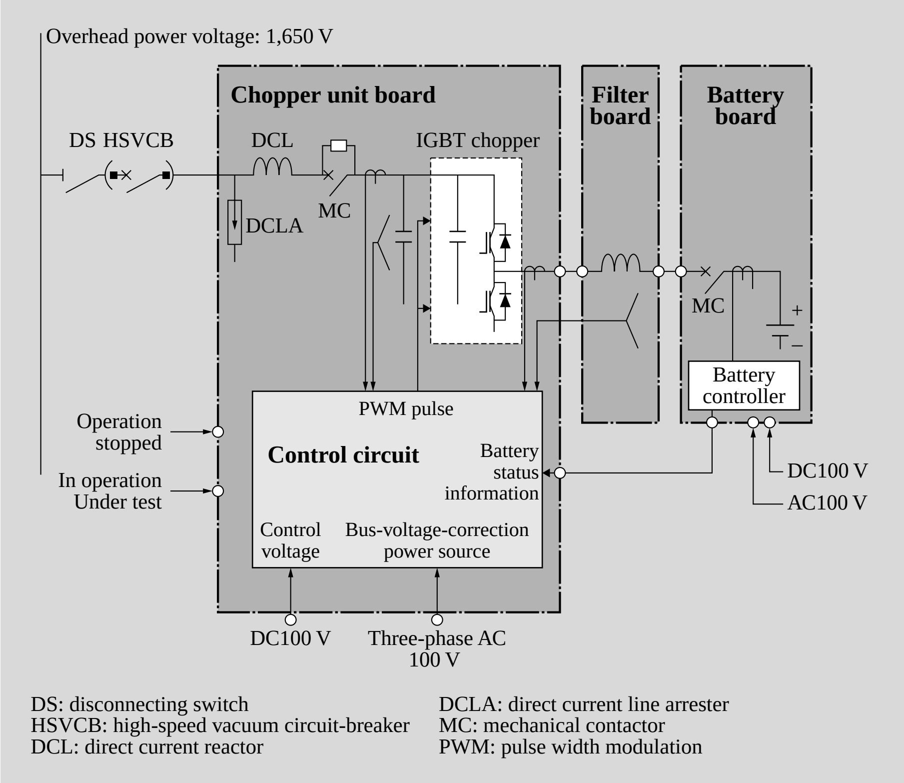

Fig. 4—Circuit Diagram of Regenerative Energy Absorbing Equipment Using Batteries.
A summary of the circuit layout of the developed products is shown.

Product specifications and characteristics

The target product specifications and characteristics of the developed and commercialized regenerative energy absorbing equipment using batteries are listed below:

(1) Rated capacity: 2,000 kW (operates for 15 s in a cycle of 180 s)

(2) Rated voltage: DC 1,500 V/750 V (in the case of 750 V, rated capacity is 1,000 kW)

(3) Switching frequency: 600 Hz (50-Hz regions) or 720 Hz (60-Hz regions)

(4) Lithium-ion batteries: four in series and 20 in parallel

The circuit configuration of the unit is shown in Fig. 4. The unit is configured with a chopper board, a filter board, and a capacitor board. By combining these devices with a DC circuit breaker, it is possible to not only install the unit at established locations but also at optional locations such as close to train stations (where regenerative lapses occur most) and between substations (where electromotive voltage decreases). The chopper device is composed of a multistage chopper that utilizes a 3.3-kV, 1,200-A IGBT (insulated-gate bipolar transistor) element, and staggering the switching phase of four IGBTs in parallel makes four multiple configurations possible, thus reducing ripple current on the feeder side and capacitor side. The lithium-ion rechargeable batteries—used just as in hybrid vehicles—is set up as the standard four in series and 20 in parallel. Furthermore, the operation status of each individual battery, such as charge ratio, is monitored by a battery controller, and that data is transmitted to the chopper device side to enable optimum operation of the each battery. As regards control of the chopper device, the voltages at the start of charge and discharge are altered according to the charge ratio of the lithium batteries, and under the optimum charge range, by means of building in charge and discharge control using the lithium batteries and charge-ratio control for keeping down charge ratio during stand-by time waiting for the next charge (i.e. regenerative power absorption), both constant control of electromotive voltage and control for long battery life can be achieved. This control set up has already been applied to a field test machine, and its effectiveness is being demonstrated under actual operation.

Eco-rectifier

Background to development

As regards track-side-based transformers for DC electric railways, to provide DC to the trains, a silicon

Fig. 5—External View of 6,000-kW Eco-rectifier.
An external view of the eco-rectifier that dispenses with materials which cause global warming is shown.

Fig. 6—External View of Dry-air-insulated Switchgear.
An external view of the world's first 72-kV-class dry-air-insulated switchgear is shown.

rectifier is used to convert AC (alternating current) to DC. Up till now, as the cooling medium for the diodes used in the rectifier, PFC (perfluorocarbon) has been used. In the case of the current development, however, aiming to eliminate materials that contribute to global warming, we have developed and commercialized an "eco-rectifier" utilizing heat-pipe cooling with purified water as the cooling medium (see Fig. 5).

Features of product

The main features of the eco-rectifier are listed below:
(1) Elimination of greenhouse gases: for diode cooling, heat-pipe cooling by purified water as the cooling medium is used.
(2) Normal operation even at –20˚C: utilizing a VCHP (variable-conductance heat pipe) allows normal operation even at –20˚C
(3) Compact design saves space: the installation area for the eco-rectifier is 50% smaller than a conventional one.
(4) Low loss: by using high-voltage diodes, it is possible to reduce the device number by half, thereby reducing loss by 40%.

GASLESS (NO SF_6)-DEVICE

As a way of eliminating the use of SF_6 gas in transformers, implementation of 24-kV C-GIS (cubicle gas-insulated switchgear)[1] is being continued, and dry-air conversion of 72-kV class GIS has recently been completed. Aiming at removal of SF_6 from an SF_6-gas insulating transformer, we have developed a silicone fluid-immersed transformer (using silicon liquid as the insulation medium) and an optical current transformer (which is outstanding in terms of environmental friendliness and reduction of waste materials through its recyclability).

72-kV-class Dry-air-insulated Switchgear

Background to development

Although SF6 gas has extremely good insulating and current-breaker performances in regards to high voltages, it has been designated a greenhouse gas, so its emission into the atmosphere must be reduced drastically. Focusing on high-pressure gas with the same composition as the atmosphere, Hitachi has developed and commercialized the world's first 72-kV-class dry-air-insulated switchgear (see Fig. 6).

As a continuation from the 24-kV class switchgear, we developed this 72-kV class switchgear from the viewpoints of performance as a GIS and as an insulation medium [namely, fundamental characteristics, conversion to a VCB (vacuum circuit breaker) for current cut-off current, switching performance of internal switches, and composite insulation technologies of internal conductors].

Product specifications and characteristics

The main specifications of the 72-kV-class dry-air-insulated switchgear are listed below:
(1) Rated voltage: 72 kV; rated current: 1,200 A
(2) Rated cut-off current: 25 kA
(3) Rated dry-air pressure: 0.45 MPa (VCM compartment); 0.5 MPa (main bus/breaker compartments)

The key features of the GIS are summarized below:
(1) Optimization of a compound insulation structure composed of high-pressure dry air and internal conductors, conductor equipment, and gas storage makes the GIS more compact.

Fig. 7—External View of Silicone Fluid-immersed Transformer.
This transformer can meet the various needs of electrical-power substations for railway use.

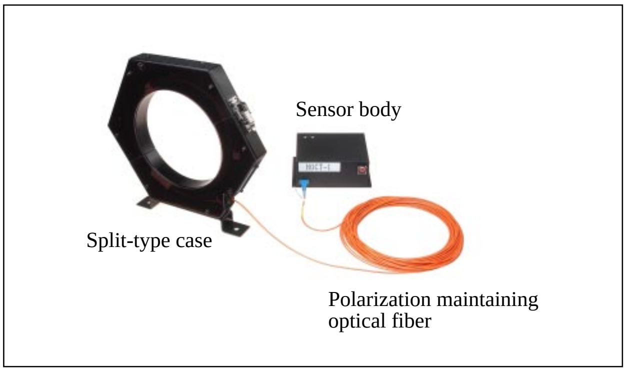

Fig. 8—External View of Optical Current Transformer.
Since optical fiber is used for the sensor part, recyclability is excellent.

(2) A newly developed high-pressure bellows for the VCB part improves reliability.
(3) Separation of the gas compartment from the VCB and other regions, improvement of VCB maintainability and prevention of oxygen deficiency due to non-usage of SF_6 gas, and absence of toxic products owing to the above-mentioned air composition improve the safety of the GIS.

Silicone Fluid-immersed Transformer

Background to development

As regards removal of SF_6 gas from eliminating the use of SF_6 gas from insulated transformers, we focused on silicon fluid, like that successfully used in transformers for compartments of bullet trains, as an alternative insulating material. By carrying out basic research on various properties such as insulating and cooling performance under high voltage, we applied this insulating material and commercialized it in a silicone fluid-immersed transformer that operates up to the very-high-pressure class. Accordingly, we are currently meeting the needs of electric-railway transformers by applying this silicone fluid-immersed transformer (see Fig. 7).

Product and characteristics

The characteristics of silicone fluid-immersed transformer are summarized below:
(1) Since ignition point is above 250˚C, fire risk is low, and self-extinguishing nature of the transformer is beneficial regarding accident prevention.
(2) Its non-corrosivity makes its composition stable.
(3) Silicon is the main component, so it can be reduced by hydrolysis back to natural components in an environmentally-friendly fashion.
(4) It can tolerate a large electrical load, so it can be applied as a rectifier for electric railways.

Optical Current Transformer

Background to development

Continuing our research and development on photoelectric sensors (based on the polarization principle by which an electromagnetic field can propagate a photon beam down a fiber), Hitachi has developed and commercialized an optical transformer as a measuring device for DC and AC in railway transformer substations (see Fig. 8). Since the optical transformer uses optical fibers for the sensor parts, its recyclability is good. Moreover, compared with conventional wound-type DC transformers, waste materials produced by upgrading, etc. are significantly reduced.

Product characteristics

The characteristics of the optical current transformer are summarized in the following:
(1) It is lightweight and compact, and directly wrapping the fiber insulation (sensor head) around the measurement target makes it possible to measure current in the target.
(2) Measurement accuracy of DC and AC is ±20 kA and ±10 V at speed of response of 0.5 ms.
(3) Robustness against electromagnetic interference is outstanding, and dynamic range is wide.
(4) Under normal operation, a split-type sensor-head case is used, and the optical fiber is wrapped around the inside of the head.

CONCLUSIONS

In this work, aiming at reducing emissions of greenhouse gases, we have developed transformer substation equipment composed of environmentally-friendly transformer systems. From now onwards, in response to the social demands for more environmental conservation, Hitachi will strive to improve its technologies and develop new railway-use transformer systems in line with the speed of the various social changes.

REFERENCE

(1) N. Kawamura et al., "Latest Railway Substation Systems," *Hitachi Hyoron* **85**, pp. 585-588 (Aug. 2003) in Japanese.

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