Reducing Loss in Railway Power Supply by using Superconducting Technologies

Superconducting technologies to save energy include superconducting feeder cables for power transmission and superconducting magnetic energy storage systems. In this article, I will introduce the superconducting feeder cable used for railway power transmission. Since a superconducting cable has no electrical resistance, it can help save energy by reducing power loss in transmission and reduce the number of substations by preventing voltage drop. RTRI has already conducted running tests to check the power supply performance for railways using superconducting feeder cables.

Dr. Masaru Tomita
Director
Maglev Systems Technology Division

Superconducting technologies for railway operation

Category	Superconducting technologies
Power supply	Superconducting feeder cable*, Superconducting transformer, Superconducting Magnetic Energy Storage*, Current lead, Fault current limiter
Magnetic field application	Superconducting magnetically levitated train system, Superconducting motor, Superconducting magnetic bearing

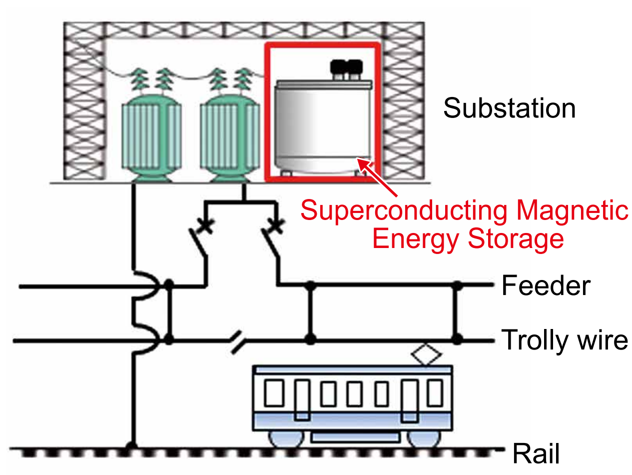
* : Technologies mainly for energy saving

Introduction

The energy loss in power transmission for railway operation is approximately 5%. This means a vast amount of energy is lost in railway operation worldwide. In railway operation, power transmission technologies play an important role, and we still have a lot to do to improve them to further save energy consumption. Superconducting technologies for railways have already been applied to the transformer, current lead, and fault current limiter in power supply systems. As examples of using magnetic field, superconducting magnetically levitated train systems and motors using magnetic field are being developed (*Superconducting technologies for railway operation*). Among them, superconducting magnetic energy storage and superconducting feeder cables can save energy by reducing power supply loss. These technologies will be explained in this article.

Superconducting magnetic energy storage

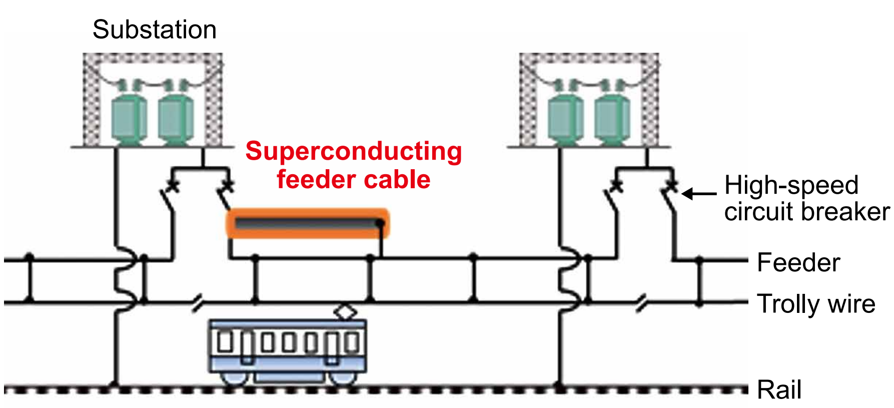
In operating electric railways, power storage devices have been drawing attention because regeneration rate can be improved and power load can be leveled with this technology. However, as the lithium ion battery, a commonly used energy-storage device, has a problem in quick charging, we are developing a Superconducting Magnetic Energy Storage (SMES) capable of rapid charging and discharging (*SMES introduced to a feeding system*). The SMES stores electricity as magnetism directly in the coil made of superconducting wire. This device enables electricity to flow without power loss because the coil has zero electric resistance. This means it will enable instant charging and discharging if necessary. While a lithium ion battery stores electric energy as chemical energy, the SMES stores it directly as electric energy and has high efficiency, longer service life and higher input and output. As the depletion of helium is becoming an increasingly serious issue, we are developing a next-generation superconducting coil using magnesium diboride (MgB_2) wire which does not need liquid helium for cooling[1]. Since a MgB_2 coil can be cooled only by heat conduction from a cryocooler, it does not need any refrigerant. In addition, as liquid hydrogen can be used for cooling a MgB_2 coil, the coil will fit into the future hydrogen-based society with zero carbon footprint.



SMES introduced to a feeding system

Development of superconducting feeder cable

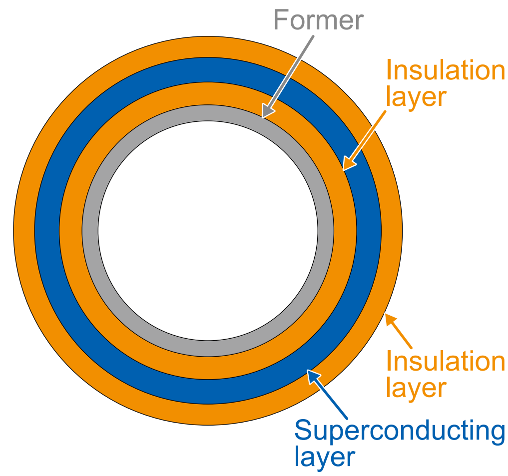
Next, I would like to explain our development of feeder cable using superconducting technologies. Japanese railway lines contain a large number of DC electrified sections and have the energy loss problem stated in the Introduction. European high-speed railways also have the same problem, since urban rail lines in Europe are DC electrified. Superconducting power transmission is highly expected at home and abroad to solve issues of power loss and voltage drop and to improve running stability. In this context, we have been developing technologies to reduce power transmission loss by using superconducting feeder cable for the next-



Superconducting feeder cable introduced to a feeding system (Connecting part of substations)

Analysis of energy-saving effects by introducing superconducting feeding system

	Required energy [kW]		
	Power output at substation	Cooling energy	Total
Superconducting feeding system	9,080	1,238	10,318 (95)
Existing feeding system	10,856	-	10,856 (100)



Cross-section view of superconducting cable core

generation railway systems.

In this development, we have completed material testing and reviewed the system design. Now we are in the phase of confirmation testing on RTRI's test track and commercial lines[2].

Initial model of superconducting feeder cable

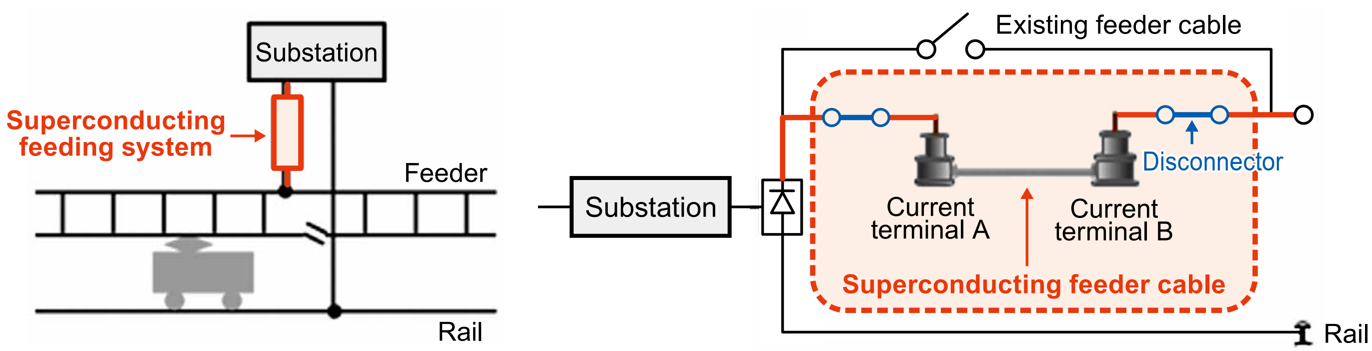
Superconducting feeder cable introduced to a feeding system (Connecting part of substations) shows a schematic of the superconducting feeder cable used in a railway power supply system. In this example, the superconducting cable is connected part of substations to prevent voltage drop that takes place in some sections between substations. The superconducting cable can be introduced to feeding systems in several patterns, depending on conditions. The cable can be connected either an entire section or part of it between substations, or a feeding branch device can be placed between the regular feeder cable and superconducting one. If the whole section between substations is connected with superconducting cable, voltage drop can be reduced. Furthermore, by feeding power from each substation, the maximum current at substations can be reduced and power load between substations can be leveled. It is also possible to transmit regenerated power to distant trains.

To assess the effects of introducing superconducting feeder cables, we have analyzed the energy-saving effects of a system that connects substations with superconducting cable in parallel with regular feeder cable[3]. The results of the analysis are shown in Analysis of energy-saving effects by introducing superconducting feeding system. If superconducting feeder cable is introduced to a conventional railway line, required daily energy is reduced approximately 5%, from 10,856 kW to 10,318 kW (*Analysis of energy-saving effects by introducing superconducting feeding system*).

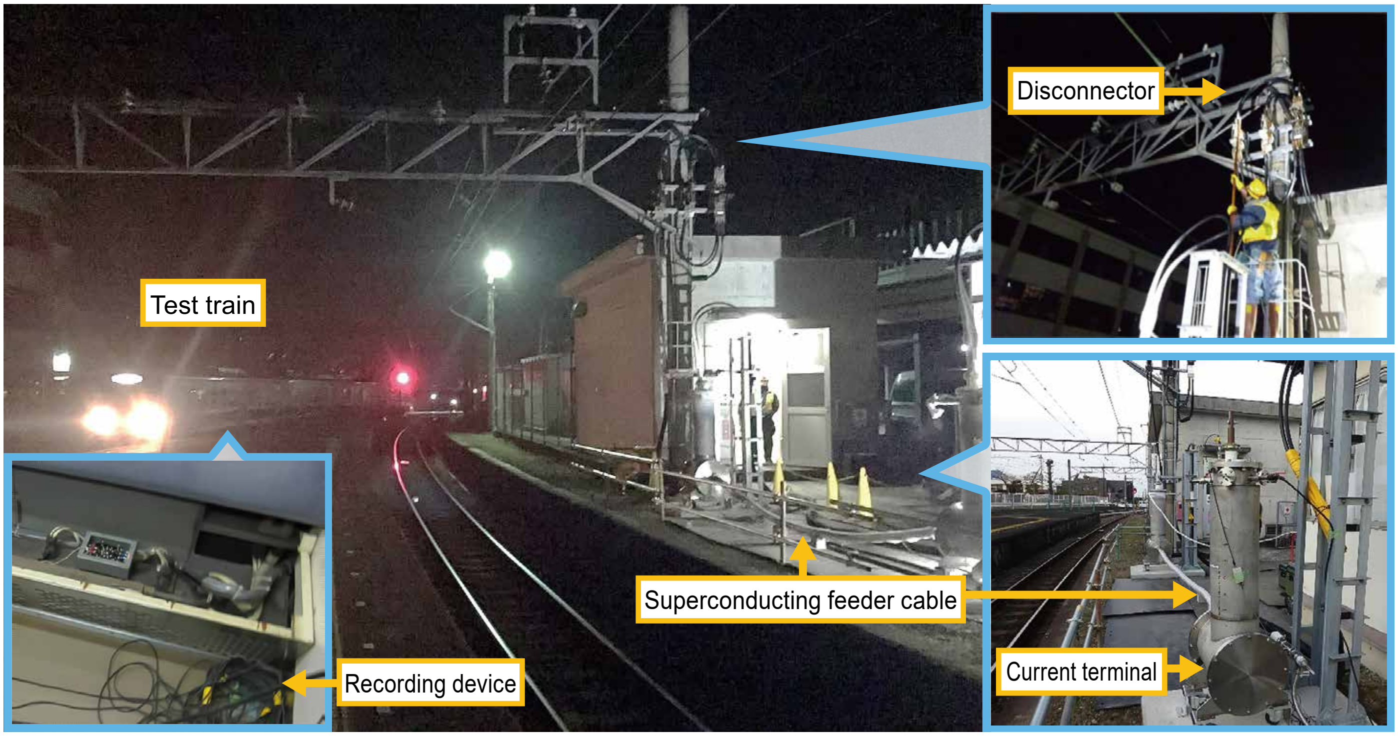
Testing of superconducting feeder cable

As shown in *Cross-section view of superconducting cable core*, superconducting cable is made by winding superconducting tape and insulating paper around the core part. The former is a pipe to wind other materials around. Superconducting tape is made of high-temperature superconducting material to conduct electricity and the insulating paper has a high dielectric withstanding voltage property. As the superconducting tape is subject to mechanical stress when being wound, tests have been conducted to assess how much current can be conducted through the tape when it is bent. As the amount of current passing through superconducting tape fluctuates due to the magnetic field caused by the tape itself, we are also conducting current tests under magnetic fields. Through these tests, we have determined the design policy for manufacturing superconducting cable.

In the next phase, train running tests were conducted on a track equipped with superconducting cable for the purpose of basic technical confirmation in commercial line. Connections to actual commercial feeding systems and system operation were confirmed here[4]. In the running tests, we evaluated whether power loss occurs when the current through the superconducting cable is rapidly changed by notching to accelerate and decelerate a train. We have used a 6-meter-long superconducting cable and set the voltage at 1,500 V and current at 2,000 A. The superconducting cable was placed between the power output cable from a substation and an input point to a feeder. We set a simple circuit using the superconducting cable as shown in *Schematic circuit diagram*. A current terminal was placed at each end of the superconducting cable. In this test system, the existing feeder circuit can be shifted to a superconducting feeder circuit by switching a disconnector on and off. *Superconducting feeder cable connected to a track* shows the superconducting cable and the test train. The cable is cooled

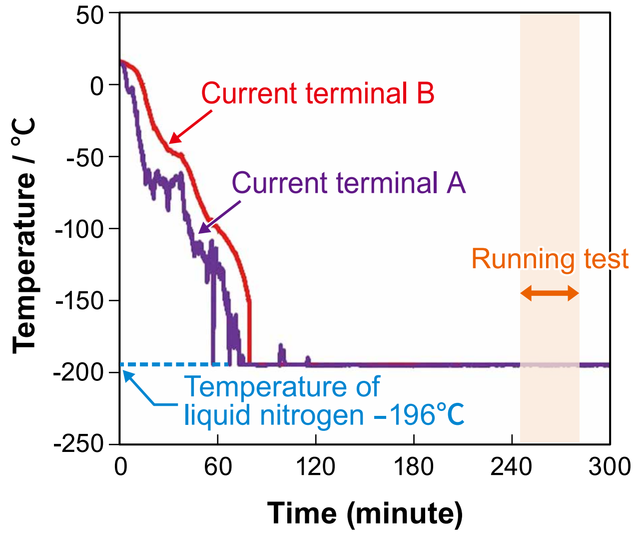


Schematic circuit diagram

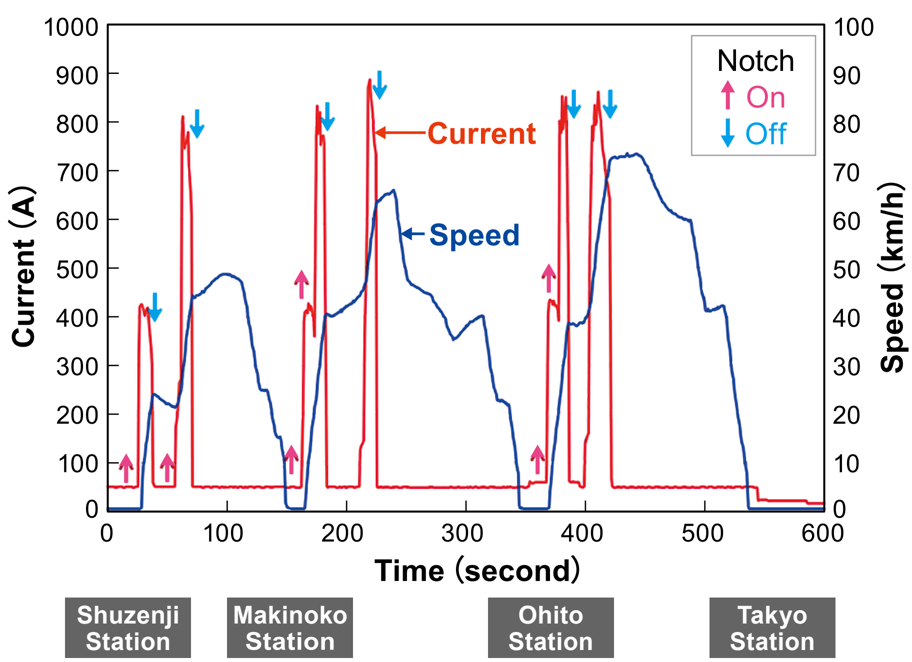


Superconducting feeder cable connected to a track

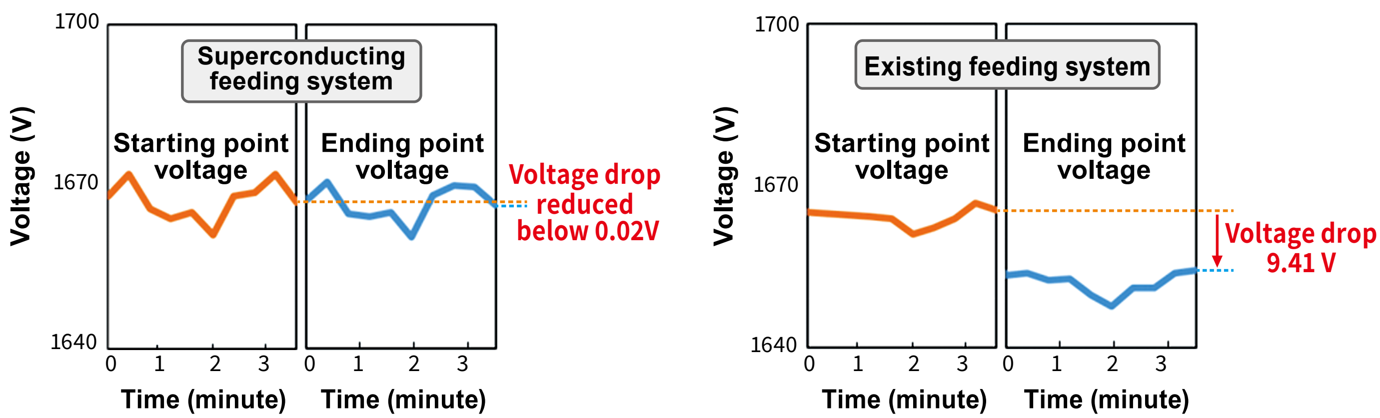
by immersion cooling with liquid nitrogen. *Temperatures of superconducting feeding system* shows the results of cooling by filling with liquid nitrogen from terminal B to A. We can see that the two terminals were cooled down to the liquid nitrogen temperature and initial cooling was completed in 80minutes after the filling started. After cooling, train running tests were conducted, and the current and train speeds were recorded by a vehicle-mounted recording device. The results are shown in *Results of test running with superconducting feeder cable*. A maximum 880 A current was supplied via the superconducting cable to the 3-car test train running the 5.6 km between Takyo and Shuzenji stations. The test running was successful. Although the cable current



Temperatures of superconducting feeding system



Results of test running with superconducting feeder cable



Voltage drop under superconducting and existing feeding

fluctuates significantly due to notching to stop and start trains, system temperature does not fluctuate (*Temperatures of superconducting feeding system*) and it was confirmed that power loss did not occur.

Next, we conducted power feeding tests using a 408-meter-long superconducting feeding system to examine its energy-saving effects. The capacity was set at 12 MW (8000 A, 1,500 V) to fit the capacity of the test track. The superconducting system was connected along the track in parallel with the existing feeder and the power was transmitted from a substation to a depot via the superconducting cable. 1,250 A current was flowed to ten 10-car trainsets in the depot for air-conditioning and lighting of all the vehicles. When feeding with the superconducting feeding system, the voltage is almost same level at the start and end points, and voltage drop was confirmed to be reduced to 0.02 V compared to 9.41 V measured when feeding with the existing cable (*Voltage drop under superconducting and existing feeding*). It was confirmed that power loss in superconducting feeding can be reduced about 7 kW for this 408-meter section.

Conclusion

Based upon these testing results, we will continue power feeding simulations targeting actual train lines and choose appropriate lines to introduce the superconducting feeding system. We are also examining the possibility of a long-distance system to be used for transmission between substations. We will keep developing superconducting feeder cables that can be applied to commercial railway lines.

Part of this project has been supported by the subsidy for railway technical development by the Ministry of Land, Infrastructure, Transport and Tourism, a research initiative "Superconducting Technology Innovation Creating the Next-Generation Railway Systems" by the Japan Science and Technology Agency (JST) and the Advanced Low Carbon Technology Research and Development Program (ALCA).