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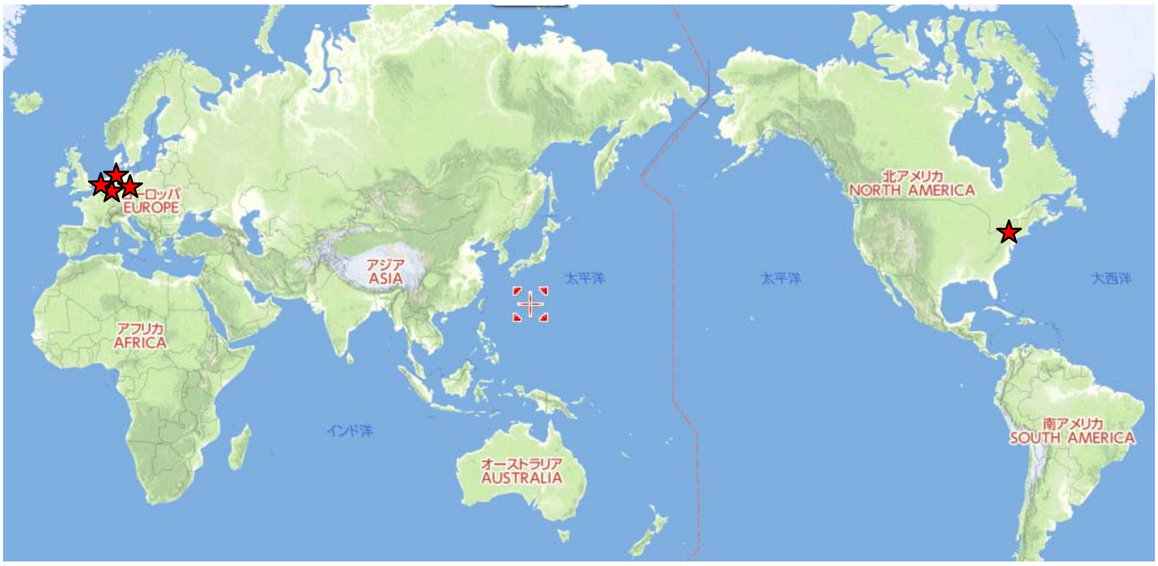
What's New in the World of Superconductivity

초전도 뉴스 −세계의 동향−

超导新闻 −世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC



★News sources and related areas in this issue

▸Basics 기초 基础[jīchǔ]

New High Temperature Superconductor, T_c=190K?

Max-Plank Institute and Nature (12 Dec, 2014)

For over 30 years, researchers have focused on cuprate room-temperature superconductors, which can carry currents without energy loss up to temperatures of 164K (-109 ˚C). However, researchers have demonstrated that hydrogen sulphide exhibits superconductivity at 190K (–83 ˚C) when it is subjected to high pressures, similar to those found at the Earth's core.

Mikhail Eremets working at the Max Planck Institute for Chemistry in Mainz, Germany, placed a tiny sample of hydrogen sulphide between the tips of two diamond anvils and then measured how the material's electrical resistance changed as the system was cooled towards absolute zero. They discovered that the resistance dropped suddenly at around 190K under a pressure of 1.8 million atmospheres, indicating a superconducting transition. The researchers also report having observed a much lower transition temperature (90 K) when they exchanged heavier sulphur deuteride for sulphur hydride. They stated that heavier atoms would impede superconductivity by reducing crystal vibrations. Their findings are available online on arXiv, posted December 1.

The latest research builds on the work of Neil Ashcroft, a physicist at Cornell University in Ithaca, New York, who studied the superconducting potential of hydrogen compounds. Particularly, it aims to investigate recent theoretical predictions by a Chinese research team who predicted that hydrogen sulphide should remain superconducting up to about 80K under a pressure of 1.6 million atmospheres. The electrons in the Cooper pairs are squeezed together under such high pressure, making them less liable to be destroyed by thermal fluctuations.

"If the result is reproduced, it will be quite shocking. It would be a historic discovery", says Robert Cava, a solid-state chemist at Princeton University in New Jersey. It is hoped that the BCS theory can shed light on the search for other kinds of high-temperature superconductors, particularly in materials containing light elements such as hydrogen since they generate more rapid vibrations that create stronger bonds between electron pairs. If other groups confirm the findings, then these findings signify a huge increase in the critical temperature – the current record being 39 K, measured in MgB_2. Alexander Gurevich, a theorist at Old Dominion University in Norfolk, Virginia, remains cautious and states that the authors have yet to demonstrate one of the hallmarks of superconductivity, known as the Meissner effect. He notes, "I do hope that this work will stimulate other groups to reproduce this experiment promptly".

Eremets and his colleagues say that it might now be possible to find high critical temperatures in other hydrogen-containing materials, such as carbon-based fullerenes or aromatic hydrocarbons. However, Cava adds that it is still too early to consider possible applications.

Source:"Superconductivity record breaks under pressure"
(12 Dec, 2014) Nature News by Edwin Cartlidge and Nature magazine
http://www.nature.com/news/superconductivity-record-breaks-under-pressure-1.16552
Siemens (2014年12月18日)
Author of the paper: A. P. Drozdov (Max-Planck Institut, Germany) m.eremets@mpic.de

Short-time but Higher T_c at Room Temperature?

Max-Planck Institute (3 Dec, 2014)

In 2013, an international team working with the Hambrug-based, Max Planck researcher Andrea Cavalleri, discovered that when YBCO is irradiated with short infrared laser pulses it briefly becomes superconducting at room temperature – albeit for only a few millionths of a microsecond. Physicists suggested that the laser pulses modified the coupling between the double layers in the crystal, causing individual atoms in the crystal lattice to shift briefly and thus enhance the superconductivity. The precise mechanism remained unclear until the researchers conducted an experiment using the world's most powerful X-ray laser based at LCLS in the USA. Their findings showed that the infrared pulse not only caused the atoms to oscillate, but had also shifted their position in the crystal and briefly making the copper dioxide double layers thicker by two picometres. This in turn increased the quantum coupling between the double layers to such an extent that the crystal became superconducting at room temperature for a few picoseconds.

This Hamburg team has made crucial contributions, which has now been able to present a possible explanation of the effect in the journal, Nature. The findings could assist in the development of materials, which become superconducting at significantly higher temperatures. If complex cooling were no longer necessary, it would mean a breakthrough for this technology.

Source: "Superconductivity without cooling"
(3 Dec, 2014) Research News
http://www.mpg.de/8785897/superconductivity-room-temperature
Contact: Roman Mankowsky, roman.mankowsky@mpsd.mpg.de

Search for Higher T_c Mechanism

Swiss Federal Institute of Technology Lausanne (EPFL) (18 Dec, 2014)

Intense research is ongoing to exploit the physics of cuprates in the hope that we can develop room-temperature superconductors. Cuprates offer great promise for achieving superconductivity at high temperatures (-120 °C). Scientists from EPFL have employed a cutting-edge technique to reveal the way cuprates become superconductors.

Conventional superconductors conduct electricity with no electrical resistance under temperatures nearing absolute zero (−273.15 °C or 0 Kelvin). The electrons in the material form "Cooper pairs", and only when the atoms vibrate and create an attractive force between the electrons. However, cuprate superconductors are electrically insulating at normal temperatures and Cooper pairs do not form. The question here is how does superconductivity arise in cuprates?

A research team led by Marco Grioni at EPFL, has used a cutting-edge spectroscopic technique to explore and provide a novel understanding of superconductivity in cuprates. The scientists employed Resonant Inelastic X-ray Scattering, to interrogate the electronic structure of cuprates as it transitions into being a superconductor. Grioni says, "Normally, superconductors hate magnetism. Either you have a good magnet or a good superconductor, but not both. Cuprates are very different and have really surprised everyone, because they are normally insulators and magnets, but they become superconducting when a few extra electrons are added by gently tweaking its chemical composition." Cuprates do not lose their magnetic properties when they become superconducting, and Grioni believes that their findings could play a major role in the appearance of superconductivity. Their research outcome is published in Nature Communications.

Source:" Electron spin could be the key to high-temperature superconductivity"
(18 Dec, 2014) News Mediacom

http://actu.epfl.ch/news/electron-spin-could-be-the-key-to-high-temperature/
Contact: Nikolaos Papageorgiou, n.papageorgiou@epfl.ch

▸Power Application 전력응용 电力应用 [diànlì yìngyòng]

Current Limiter for Renewable Energy Application

Siemens (18 Dec, 2014)

Large loads of renewable or other decentralized energies can produce short circuits in power supplies operating in medium-voltage power grids. To address problems endangering power supplies, Siemens are installing a resistive-type superconducting fault current limiter (SFCL) at Stadtwerke Augsburg, the municipal utility in Augsburg, Germany. The project, abbreviated as "ASSIST," is being sponsored by the Bavarian State Ministry for Economic Affairs and Media, Energy and Technology, under the Bavaria's Innovative Energy Technologies and Energy Efficiency (BayINVENT) Program. The European Patent Office (EPO) has already granted Siemens several key patents for the technologies used in resistive superconducting fault current limiters. Development work and installation of the medium-voltage power grid utility will be completed by the end of 2015.

Superconducting fault current limiters can limit short-circuit currents in power transmission and distribution grids very quickly, thereby realizing reliable grid operation even under difficult conditions. The grids can also resume normal operation without additional measures soon after a short cooling period. Unlike today's conventional short-circuit limiting reactors with a constant high resistance, superconducting fault current limiters also exhibit another advantage that they are "invisible" to the grid during normal operation since they have no electrical resistance. Superconducting fault current limiters also allow several different power sub-grids to be linked, thereby increasing operational security and grid stability and eliminating the costs associated with frequently replacing or upgrading electrical components.

Dr. Tabea Arndt, head of Superconducting Components and Applications at Siemens Corporate Technology is quoted as saying, "With our innovative partner, Stadtwerke Augsburg, we have a power utility where we can demonstrate how this advanced technology can help master the challenges of the energy transition and grid upgrades successfully." Jürgen Völkel, technical director of Stadtwerke Augsburg, states, "Powerful plants for renewable energies (EEG plants) must be connected to the grid via efficient fault current limiters to protect electrical components."

Source:"Siemens to use superconductors in building the power grid of the future in Augsburg"
(18 Dec, 2014) Joint Press Release
http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2014/corporate/pr2014120086coen.htm&content[]=Corp
Contact: Mr. Harald Hassenmuller, herald.hassenmueller@siemens.com

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▸Electronics 엘렉트로닉스 电子应用［diànzǐyè yìngyòng]

New Superconducting Supercomputer

Office of the Director of National Intelligence (IARPA) (9 Dec, 2014)

Officials at the Intelligence Advanced Research Projects Activity (IARPA), part of the Office of the Director of National Intelligence, stated on Dec. 3 that they had awarded three research contracts to support the first phase of the Cryogenic Computing Complexity (C3) program. According to their announcement, significant technical obstacles had previously prevented the exploration of superconducting computing, however, recent innovations had created foundations for potential breakthroughs to be made in this field.

The initial aims of the three-year C3 program are for researchers to develop the critical components for the memory and logic subsystems and plan the prototype computer, ultimately developing a small-scale supercooled supercomputer prototype that would use exponentially less power and floor space. The federal government has been developing an exa-scale supercomputing system, potentially capable of 1 exaflop floating point operations per second, by 2020, equivalent to 50 of the DOE's current Titan systems. Exascale computing would allow intelligence agencies to decipher ever-stronger encryption algorithms and be able to analyze truly big data.

The contract involves teams led by IBM, Raytheon BBN Technologies and Northrop Grumman. It is highly anticipated that the USA will become the lead as the first nation to break the exaflop barrier in supercomputing. Marc Manheimer, a C3 program manager at IARPA, said the awards are part of a two-phase process for the development of greater-performing replacements to the federal government's current range of supercomputers. He estimated that a supercooled machine would provide 100 petaflops of performance for about 200 kilowatts of electricity, theoretically deliver five times the performance for 1/40th of the power in a much smaller footprint compared to Titan system. IARPA anticipates seeking further proposals in the third year of the first phase for further development.

Source:"IARPA awards contracts for supercomputer development"
(8 Dec, 2014) IARPA in the NEWS
http://www.iarpa.gov/index.php/newsroom/iarpa-in-the-news/2014?start=10
Contact: Federal Computer Week, mrockwell@fcw.com

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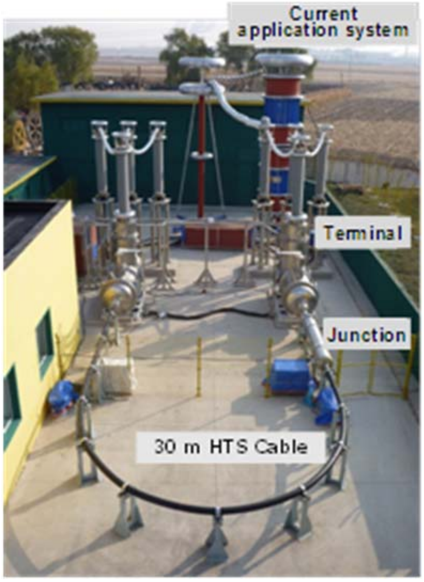
Feature Article: Progress in Superconducting Power Equipment Technology
-The Development of Superconducting Power Equipment Technology at Furukawa Electric

Shinichi Mukoyama, Director
Power & System Laboratories
Furukawa Electric Co., Ltd.

Yttrium-based superconducting coated conductors (2G HTS wires) characteristically can maintain high critical currents in high magnetic field environments. Their utilization is anticipated for realizing low costs due to the reduced consumption of rare earth metals. In fact, several years ago AMSC and Superpower in the USA were the only commercial manufacturers of 2G HTS wires, however more companies, including Fujikura in Japan, have recently started commercial sales. With regards to wire performance, 500m-class wires exceeding 400 A/cm characteristics are being traded on the market and leading to buoyant application research studies. At Furukawa Electric for example, the application development of high-performance 2G HTS wires is progressing to perform feasibility assessments of superconducting cables, power equipment apparatus flywheels and wind power turbines applications.



Demonstration trials of 275kV 3kA 30m-long superconducting cable

1. The development of superconducting cables

The development of a 275kV 3kA superconducting cable, exhibiting the world's highest voltage capability [1) has concluded its month-long current trial at the Shenyang Furukawa Cable Co., Ltd. in Shenyang city, China, during the final year (2013) of its demonstration study. The cable was returned to Japan to undergo remaining evaluation trials (a cable health check and current trial performed by breaking up the cable). Other facilities such as the liquid nitrogen circulation system, power supplies and transmission facilities, and superconducting cable testing terminals still remain in place at Shenyang Furukawa. Thus, if the cable returns to China, testing can resume promptly. A project [2) launched this year actually plans to evaluate cable stability/reliability and involves short circuit trials, evaluating the loss of vacuum in the insulated pipe, the cable behavior and potential impact to the liquid nitrogen circulation system under a variety of problematic scenarios.

2. The development of flywheels

Power generation derived from natural energies such as wind turbines and solar photovoltaics produces output power fluctuations due to temporal instability characteristics of natural energy sources, which can lead to unstable grid frequencies. The development of the next-generation superconducting flywheels is currently ongoing, led by Furukawa Electric, Railway Technical Research Institute, KUBOTEK, MIRAPRO, and Yamanashi prefecture [3]. This superconducting flywheel comprises of superconducting magnets fabricated from YBCO bulk superconductors and 2G HTS wires, allowing non-contact levitation of the flywheel producing high rotational speeds. This technology can thus eliminate losses due to bearing friction, which have been a weakness of flywheels until now, with no requirements of associated regular maintenance and replacement. Eventually, a rotational speed of around 6000rpm for a 10 ton-class flywheel can be realized. Project deliverables include the development of superconducting magnetic bearings and a 300 kW, 100 kWh-class flywheel energy storage systems comprising of such bearings. A finalized flywheel energy storage system will be installed at the Mount Komekura photovoltaic power plant belonging to Yamanashi Prefectural Enterprise Bureau and grid-connection demonstrations are planned later.

3. The development of superconducting wind power generators

Wind power generators are symbolic of power generation utilizing natural energy sources. The trend now is towards developing larger-scale wind turbines and increasing the numbers of offshore installations that present better wind conditions, and from the viewpoint of construction cost ratio per unit of power generated, this further reduces the cost associated with power generation. In particular, since a 10MW-class ultra large-scale wind turbine has difficulty as a ground-based installation due to its huge size an offshore installation is under investigation. Furukawa Electric, in collaborations with National Institute of Advanced Industrial Science and Technology and Mayekawa MFG, has progressively undertaken feasibility studies involving a superconducting 10MW-class ultra large-scale wind turbine [4]. The generator rotor comprises of an iron core and a superconducting magnet fabricated from 2G HTS wires, allowing the power unit design to be compact and lightweight, which otherwise would occupy a large space within the nacelle. Future research development plans involve the fabrication of a life-size single-unit racetrack coil and cooling testing, which aims to address issues associated with a superconducting rotor, an important component for these demonstration studies.

The author believes that power equipment can be categorized as three technological applications; “power transmission”, “power storage”, and “power generation”. Thus, “superconducting cable”, “flywheel” and “wind turbine”, in that order, can be promising superconducting power equipment applications, and Furukawa Electric is best placed to advance the development and realization of practical systems in collaboration with joint developers including NEDO.

Reference:

1) “Technology development of Yttrium-based superconducting power equipment” commissioned by the Energy Conservation Technology Department, NEDO (2008-2012)
2) “Demonstration studies of stability/reliability of next-generation transmission systems” promoted by the Energy Conservation Technology Department, NEDO (2014-2016)
3) “Technology development of reliable/low cost large-scale energy storage systems” promoted by the Smart Community Department, NEDO (2011-2015)
4) “R&D projects for practical applications of wind turbines: Research studies into 10 MW-class wind turbine” commissioned by the New Energy Technology Department, NEDO (2013-2014)

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Feature Article: Progress in Superconducting Power Equipment Technology
-Progress in the Technology Development of High-current Superconducting Cables

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Sumitomo Electric Industries, Ltd.

Tokyo Electric Power Company, Sumitomo Electric Industries, and MAYEKAWA MFG have progressed the "High Temperature Superconducting Cable Demonstration Project", commissioned by the New Energy and Industrial Technology Development Organization (NEDO). The project commenced on 29th October 2012, and demonstrated the operational characteristics of a superconducting cable connected to an actual grid. The cable has accomplished a year-long grid operation on 25 December 2013, and realized continuous operation with no significant problematic issues reported. Thus, the stability and reliability of the superconducting cable has been successfully verified.

As part of the evaluation trials, the critical current characteristics of the cable were measured by a scheduled separation from the grid during operation. The critical currents were also measured after the trials to assess the cable characteristics. There were no measurable changes before and after grid connection. Measurements of partial electrical discharge were taken randomly during the operational period and with no signal detected thereby validating the favorable electrical insulating characteristics throughout.

Thermal data characteristics of the cable have been collected over four seasons. In direct sunshine the surface temperature of the exposed parts on the ground increased significantly, which then tended to produce increases in heat leakage. It was confirmed that a light-shielding coating applied to the parts exposed to direct sunlight was effective. The cable terminal area having a large surface area was more prone to vacuum degradation due to outgassing during increases in temperature. The situation was however addressed by drawing a vacuum along the way.

The cable operational characteristics proved favorable during grid connection and the results verified normal operation throughout. Now, our research team plans to investigate the cable characteristics under a number of scenarios involving incidents at grids, which can potentially occur when the cable is operated for the long term in practical transmission lines. Thus, superconducting cable reliability and recovery measures during incidents are currently being investigated under a new NEDO project entitled, "Demonstration studies of the stability/reliability of next-generation transmission system," which launched in July last year. As part of this project, Sumitomo Electric plans to investigate the superconducting cable behavior under various scenarios including short-circuit faults, ground faults, extensive damage etc, together with verification tests to determine effects to ancillaries, as well as explore incident-recovery measures. The author will continue his efforts towards the realization of practical superconducting cables.

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Feature Article: Progress in Superconducting Power Equipment Technology
-Cable-related Technology-
66kV 5kA-class Yttrium-based High Temperature Superconducting Cable

Kazuo Watanabe, Executive Research Scientist
Superconductor Business Development Department
New Business Development Center
Fujikura Ltd.

Fujikura's technology related to high-temperature superconducting cable is introduced herewith. Fujikura has intensively developed Y-based coated conductors, employing its own Ion Beam Assisted Deposition (IBAD) and Pulsed Lase Deposition (PLD) techniques for their fabrication. An appearance of a Y-based coated conductor is shown in Figure 1, with Table 1 listing the typical examples of wire products line-ups. Currently, the critical currents (I_c) of standard products measured at liquid nitrogen (77 K) are over 500 A per 10mm-width (over 250 A per 5 mm-width). IBAD-PLD fabricated wires exhibiting high I_c characteristics of 600 A/cm-w (@77 K,s.f.) were manufactured as cables for the first time under a NEDO project (April 2012–February 2013), which successfully demonstrated the high current/low AC loss characteristics as anticipated. Figure 2 shows the configuration of a 66 kV 5 kA-class Y-based superconducting cable that was designed and fabricated. Conductors and shield wires are all 4mm in width and exhibit high I_c characteristics of 240 A/4mm-w(@77 K, s.f.). Figure 3 shows the entire view of the facilities used for the current loading test. A demonstration cable system approximately 22 m-long, having terminal joints and cooling testing facilities was constructed at the Fujikura Sakura Plant to verify AC transmission characteristics. The results from the test confirmed the current properties as designed, with around 98 % of the current being induced in the superconducting shield layer during current loading test. Also, at liquid nitrogen temperatures of 77 K it was established that the AC loss at 5000 A was sufficiently low compared to the targeted value of 2.0 W/m (@5kArms). At 67 K, a reduction of half the targeted loss value was also realized.

Table 1 Product line-ups of Y-based superconducting coated conductors

Model No	Wire-width (mm)	Thickness (mm)	Metal substrate (μm)	Cu stabilizer layer (μm)	Critical current(A) (@77K, s.f.)
YSC-SC05	5	0.16	75	75	> 250
		0.21	100	100	> 250
FYSC-SC10	10	0.16	75	75	> 500
		0.21	100	100	> 500

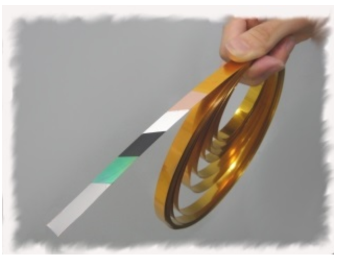

Fig. 1 Appearance of a Y-based coated conductor

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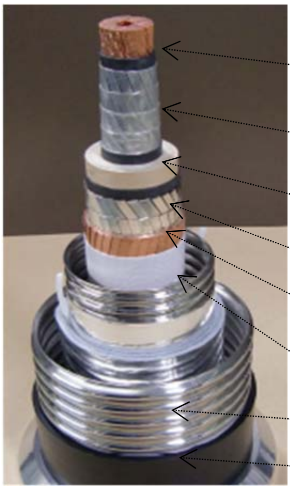

Items	Specifications
Former	Copper wires 20mm ϕ
Superconductive layer	4-layer, all 4mm-width wires
(Ic=14 kA)	Ic=240 A/4 mm-wide(77 K,s.f.)
Insulation layer	Craft papers (6mm-thickness)
Superconductive shielding layer	2-layer, all 4mm-width wires
(Ic=12.7 kA)	Ic=240 A/4 mm-wide(77 K,s.f.)
Copper shield layer	Copper tapes, 44 mm ϕ
Protection layer	Non-woven fabric tapes, 45 mm ϕ
Thermal insulation pipe	Double stainless steel corrugated pipes
	Vacuum thermal insulating method
Anticorrosion layer	PE 114mm ϕ

Fig. 2 Appearance and structural dimensions of Y-based superconducting cable

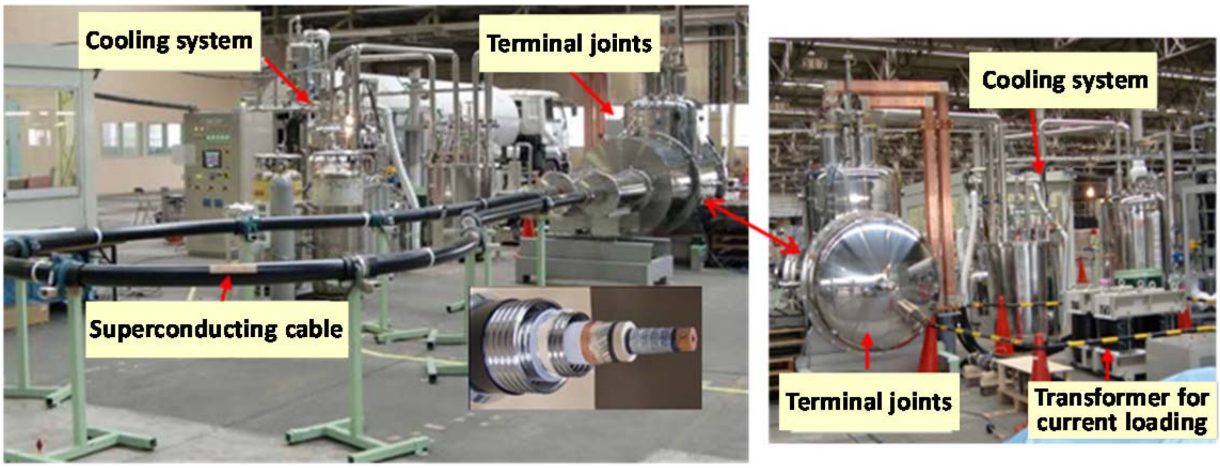

Fig. 3 Current loading test line for superconducting cable

As mentioned above, the targeted high current/low loss characteristics at liquid nitrogen temperatures of 77K were successfully realized for the first time and are suitable for practical use. It was also possible to not only verify the possibilities to reduce loss by reducing load factors associated with high I_c but also regulate the temperature parameters for designing a cooling system applicable for practical transmission lines. In the future, the author anticipates that with the advantageous outcomes achieved superconducting cable attributes including low voltage high currents (large capacity) and low loss will be further enhanced, eventually leading to a compact cable system.

This research was undertaken as part of the “Technology Development of Yttrium-based Superconducting Power Equipment”, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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Feature Article: Progress in Superconducting Power Equipment Technology
-Long-term Demonstration Results of High-temperature Superconducting Cables

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1. Project Outline

Tokyo Electric Power Company (TEPCO), Sumitomo Electric Industries and Mayekawa MFG were involved in a project entitled, "High-temperature Superconducting (HTS) Cable Demonstration Project in the grid," commissioned by the New Energy and Industrial Technology Development Organization (NEDO), for the period 2007-2013. A 66 kV and 240 m-long HTS cable system was constructed at Asahi substation of TEPCO and was connected to a real grid for the first time in Japan. This project aims were to establish the operational performance of the entire system technology including design, construction, operation, maintenance. The following is the results acquired from the long-term in-grid operation.

2. Results from long-term in-grid operation

Figure 1 shows the loading current and liquid nitrogen (LN_2) characteristics of the HTS cable system during the 400-days operation. Table 1 shows the operation results of the HTS cable. Twice of regular maintenances were undertaken to evaluate the performance reliability of the HTS cable while the HTS cable was separated from the grid. Excluding this period, around 400-days of in-grid operation had been realized without critical failures, thus confirming the continuous and stable operation. The system also remained stable against the suddenly fluctuating current by network switching. The operation kicked off with the temperature of LN_2 at the cable inlet controlled within a range of 69 ±1 K. Then, the temperature was increased to 79 ±1 K to verify the stability at higher LN_2 temperature operation. After in-grid operation, residual performance tests were undertaken and no degradation of critical current and electrical insulation characteristics was confirmed. It was confirmed that keeping high vacuum of cryostat-pipe for a long time and improvement of refrigerator performance such as capacity and efficient were necessary for practical use of HTS cable system.

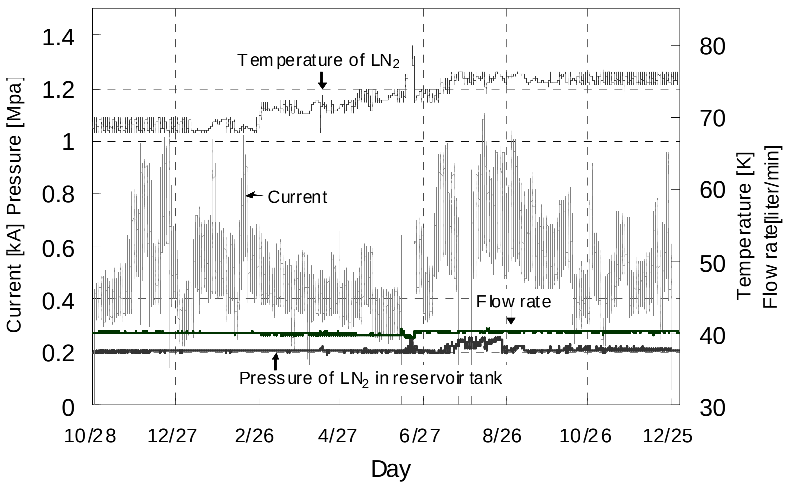

Fig. 1 Loading current and LN_2 characteristics of the cable system

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Table 1 Results of HTS cable's operation

Item	Details
Operation period in grid	10.29.2012 – 12.25. 2013 About 400 days: Excluding maintenance term
Maintenance period	6.10 – 6.21. 2013、7.22–7.31. 2013
Max current	1127 A_{rms} (8.10. 2013)
Voltage in grid	63.9–67.1 kV
Unbalanced current rate	About 6.9 %
Shielding current rate	About 89 %
Network switching	More than 50 times
Overloading	Not detected
Impulse	Not detected
Fault current	Once (Caused by ground fault in external part of the HTS cable)

3. Future plans

To enhance the technologies of the above-mentioned issues and thereby realize a potential system for practical use, the "Verification project for safety and reliability of next-generation transmission system," commissioned by NEDO, commenced in July 2014. In this project, further safety test such as verification against an accident and development of higher capacity/efficient refrigerator system are been conducting. The former plan is evaluation of the behavior of the HTS cable including LN_2 in case of the accident, such as short circuit fault and ground fault. Another plan is to install the higher capacity/efficient refrigerator system at the Asahi substation during 2014 and to operate this system from July 2015 with connecting the 240 m-long HTS cable for evaluation of its long-term performance.

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