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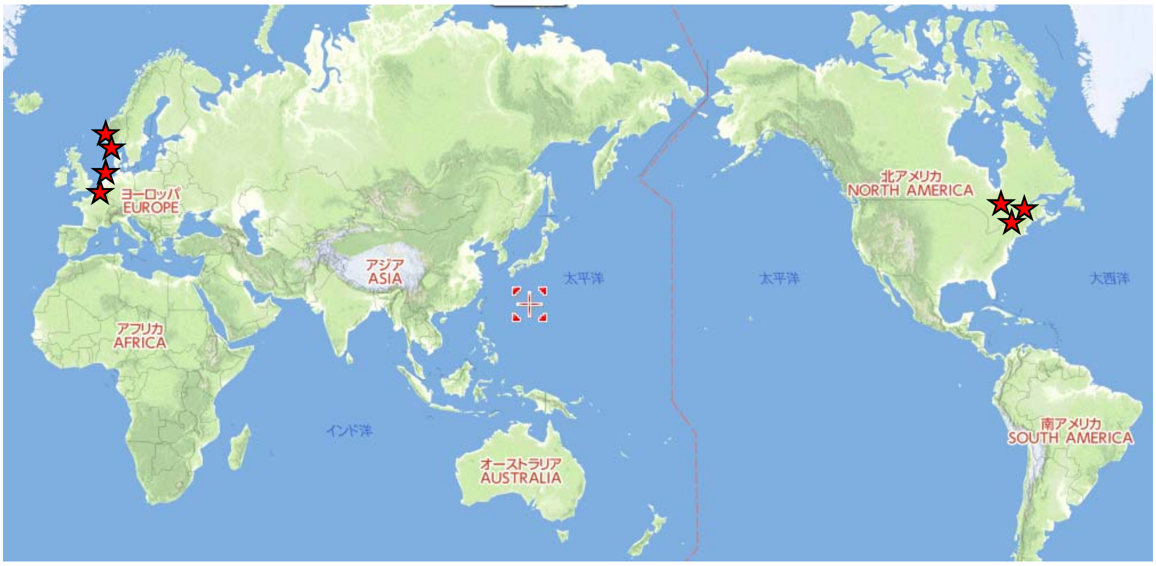
What's New in the World of Superconductivity (December, 2013)

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

►Medical Application 의료응용 医疗应用 [yīliáo yìngyòng]

NIST Developed Calibration Tools for Ultra Low Field MRI

National Institute of Standards and Technology (December 6, 2013)

The National Institute of Standards and Technology (NIST) has developed prototype phantoms for the calibration of an experimental medical imaging technique known as ultralow-field (ULF) magnetic resonance imaging (MRI). NIST has designed, constructed, and tested two prototype phantoms for the calibration of ULF-MRI systems, thereby providing a quantitative means of assessing the performance of

ULF-MRI systems, validating imaging techniques, and directly comparing different experimental and clinical MRI scanners. ULF-MRI enhances tissue contrast in some types of MRI scans and is particularly useful for visualizing prostate tumors, which can be difficult to discriminate using conventional MRI. ULF-MRI has also been used experimentally for brain imaging and the inspection of liquids at airports. Because they operate at much lower magnetic field strengths (in the range of microteslas) than conventional MRI, ULF-MRI instruments are simpler in design, lighter in weight, and less expensive than regular MRI scanners. Operation at such low magnetic field strengths requires the use of superconducting quantum interference devices (SQUIDs) acting as sensitive magnetometers, making it convenient to combine ULF-MRI with other SQUID-based imaging techniques such as magnetoencephalography.

Source:
"NIST calibration tools to encourage use of novel medical imaging technique"
National Institute of Standards and Technology press release (December 6, 2013)
URL: http://www.nist.gov/pml/electromagnetics/ulf-120313.cfm
Contact: Laura Ost laura.ost@nist.gov

World's First Compact 900 MHz Actively Refrigerated Magnet for NMR

Bruker Corporation (December 11, 2013)

Bruker Corporation has successfully installed an Ascend™ Aeon 900 MHz magnet, the world's first compact, single-story NMR magnet with active refrigeration, at the University of California, San Diego (UCSD). The Aeon magnet includes an advanced "helium reliquefaction" refrigeration technology that makes periodic cryogen refills unnecessary. This refrigeration system enables long-term carefree operation without the need for user maintenance and an essentially helium-consumption-free operation. The new magnet is also more compact as a result of advancements in superconductors, jointing technologies, and a novel magnet design. Thus, unlike the two-story laboratories that conventional 900 MHz magnets require, the new Ascend Aeon magnet only requires a single-story laboratory for installation. The development of the new magnet represents a direct response to concerns regarding potential helium shortages and increasing helium costs. The magnet will be used at the UCSD Biomedical Technology Research Center for the molecular imaging of proteins.

Source:
"Bruker Corporation Announces Successful Installation of World's First Compact 900 MHz Actively Refrigerated Magnet for NMR Spectroscopy"
Bruker Corporation press release (December 11, 2013)
URL: http://ir.bruker.com/phoenix.zhtml?c=121496&p=irol-newsArticle&ID=1883824&highlight
Contact: Dr. Thorsten Thiel, Director of Marketing Communications, thorsten.thiel@bruker.com

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►Power Application 전력응용 电力应用 [diànlì yìngyòng]

UNIVERSITY OF TWENTE. **Breakthrough: One Step Closer to Nuclear Fusion Power Station**

University of Twente (December 14, 2013)

The superconductivity research group at the University of Twente has reported a technological breakthrough that will be crucial to the success of nuclear fusion reactors, enabling a form of clean, inexhaustible energy generation. The most important component of the new development is an ingenious and robust superconducting cable system, which is needed to create a remarkably strong magnet field (13 T) capable of controlling the very hot, energy-generating plasma at the core of such a reactor. The new cables are much less susceptible to heating as a result of a clever method of interweaving, enabling a significant increase in the possibility of controlling the plasma. The wrist-thick cables, which are wound around six coils with a total height of 13 m, consist of interwoven wires with a thickness of 0.8 mm. First, 2 wires of superconducting niobium-tin are bundled with one copper wire, which allows the cable to resist heating during an undesired sudden end of the superconducting state. Three of these first-level wires are then twisted around each other. The weaving process then continues until the desired thickness has been reached. The pitch and mutual proportions between successive weave levels appear to be crucial to the performance of the cable, with an increased pitch at the first weave level enabling the cable to resist immense mechanical forces and to prevent any strong distortions. Surprisingly, the new "pitch proportions" have resulted in a strong reduction in currents between wires, resulting in much less heating of the cables and enabling the persistence of the superconducting state.

Source:
"Breakthrough: One Step Closer to Nuclear Fusion Power Station"
University of Twente press release (December 14, 2013)
URL:
http://www.utwente.nl/en/newsevents/2013/12/136596/breakthrough-one-step-closer-to-nuclear-fusion-power-station
Contact: Hinke Barry-Mulder, h.mulder-1@utwente.nl

►Management and Finance 경영정보 经营信息[jīngyíng xìnxī]

Nexans Global expert in cables and cabling systems **RWE presents Nexans with 2013 Supplier Award for Innovation for AmpaCity superconductor project**

Nexans (December 20, 2013)

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RWE, Germany's second largest energy supplier, has awarded Nexans with a prestigious supplier award for innovation. The award recognizes Nexans' efforts in deploying an HTS power cable in the city of Essen, Germany, as part of the AmpaCity project. The 1-km, 10-kV HTS cable will be used to demonstrate the capability of superconductors in the transmission of electricity with lower losses. The cable, which is the longest superconductor power cable in the world, features three concentric conductor layers manufactured from HTS tapes and is cooled using liquid nitrogen. When used in combination with a superconducting fault current limiter (also manufactured by Nexans), the new 40-MW link will replace a conventional 110-kV installation, showing how HV transformer stations could be eliminated in urban areas.

Source:
"RWE presents Nexans with 2013 Supplier Award for Innovation for AmpaCity superconductor project"
Nexans press release (December 20, 2013)
URL：http://www.nexans.com/Corporate/2013/131220-Nexans_RWE_Innovation_Award_GB.pdf
http://www.nexans.lt/eservice/Sweden-en/navigatepub_153087_-33356_236_40_3120/RWE_presents_Nexans_with_2013_Supplier_Award_for_I.html
Contact: Eva Wallin, eva.wallin@nexans.com
Angéline Afanoukoe, Angeline.afanoukoe@nexans.com

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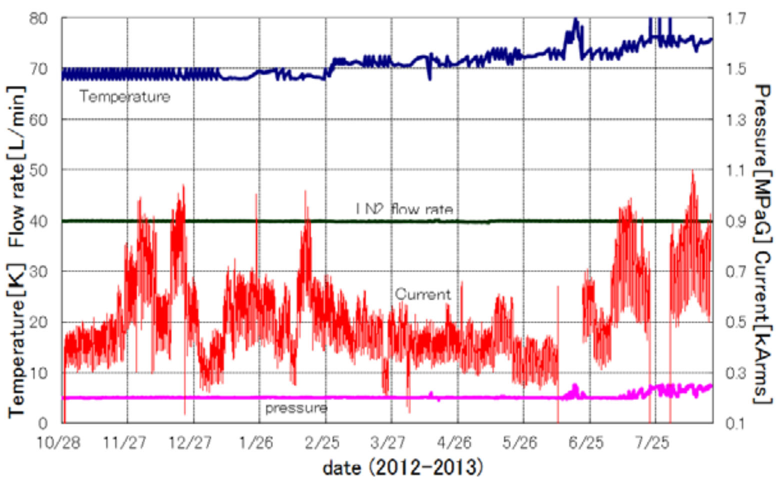
Feature Article: Development of Superconducting Power Equipment Technology
- Ongoing Demonstration Trials of a "High Temperature Superconducting Cable" Connected to the Power Grid

Takato Masuda
Superconductivity Technology Department
Sumitomo Electric Industries, Ltd.

Tokyo Electric Power Company, Sumitomo Electric Industries, Ltd., and MAYEKAWA MFG. CO., Ltd. have progressed the "High Temperatur e Superconducting Cable Demonstration Project," being commissioned by the New Energy and Ind ustrial Technology Development Organization (NEDO). The project b egan 29th October 2012, and demonstrated the operation of a high temperature superconducting cable connected to an actual grid. The cable ha s been in continuous grid operations for around 11 months with no operational issues reported.

On-site operations have been es sentially automated without any human intervention, with self-control able to manage a nd regulate th e temperatur e, liquid nitrog en pressure and flow rate using a cooling system allowing the cable to operate within a certain value or range. A control panel has stored the operational data of the cable allowing it to be collected and analyzed at a later stage. The operational parameters have been assigned threshold values beforehand. The control p anel is desig ned to send warnings to personnel if deviations fro m these thre sholds are e ncountered. Real-t ime operational informat ion is sent to the laboratory of Tokyo Ele ctric Power Company, Osaka Of fice of Sumitomo Electric Industries, Ltd., and Moriya Factory of MAYEKAWA MFG. Co., Ltd, allowing remote supervision.

The graph below shows the operational status beginning from the first day of operation until September this year (201 3). It shows changes in current flow transmitted by the superconducting cable and the liquid nitrogen temperature/pressure/flow rate at the cable entrance.



Long running operations of a high-temperature superconducting cable

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At times of peak demand such as during winter or summer seasons, current exceeding 1000 A is transmitted. Automated cryocoolers were initially employed to maintain the operational temperature of the cable entrance to within 69 ±1 K. With stable operations confirmed even during load fluctuations and changes in ambient temperatures, cable functionality was verified at higher temperatures by gradually increasing the control target temperature. The operational performance of the cable remained steady with temperature increases of up to 80 K. Whilst it has been established that cable thermal losses are accompanied with increases in temperature and load, a worsening trend in cooling capability due to the long-run operation was also highlighted. The author and his group are now making efforts to investigate and solve the factors affecting cryocooling capability together with studying the above-mentioned issues occurring during long running operations. Pressure and flow rate are controlled to more than 0.2 MpaG and 40 L/min, respectively.

The power transmission was bypassed and the superconducting cable was cut off from the grid twice during operations in June and July, for the purpose of inspecting the cable's power supply area as well as measurement of critical current (I_c). The measurement results confirmed that the I_c characteristics maintained their initial value of 6400 A, and also verified that there was no impact due to long-run operations.

It has now been almost one year since grid connection operations began. The accumulation of various data from demonstration trials has almost led to realizing and verifying the operational stability and reliability afforded by a superconducting cable. This project will conclude this financial year. Before completion, power transmission utilizing the superconducting cable is to cease.

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Feature Article: Development of Superconducting Power Equipment Technology
- Long-run Current Application Trials of A 275 kV-3 kA Superconducting Cable

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

As highlighted in the 10th December 2012 issue of Superconductivity Web21, and under the M-PACC project ongoing since 2008, Furukawa Electric Co., Ltd., has been developing YBCO superconducting cables exhibiting high capacities of 275 kV-3 kA, which are equivalent to the overhead transmission lines. A cable with 1.5 GW characteristics exhibit three-times the transmission capacities compared to conventional CV cables, and are therefore anticipated as future electric power trunk lines for practical use.

Fig. 1 Cable transportation to China

Furukawa Electric Co., Ltd. has fabricated a 30m-long cable and demonstration trials have been undertaken at the Shenyang Furukawa Cable Co., Ltd., located in Shenyang city of Liaoning Province, China, since autumn 2012. The demonstration trials involved long-run current trials and included an array of additional diagnostic tests that comprised of cable I_c, dielectric loss and ac loss measurements. The design of a 30m-long cable employed in demonstration trials was optimized based upon the testing results for withstand voltage, partial discharge, ac loss and eddy current characteristics. The cable and its mid-junction part was fabricated in Japan beforehand, transported and installed at Shenyang Furukawa Cable Co., Ltd., the location where the trials took place (Figure 1). Sampling trials involving a 2m-long spare-length of cable was undertaken prior to transportation and confirmed the design I_c characteristics of 6440 A (conductor layer) and 5 920 A (shield layer). Sampling trials involving a 5m-long spare-length of cable confirmed it was partially discharge free at 310 kV, which was assuming this to be an abnormal voltage in the grid. The total design value loss characteristic by combining the dielectric loss with ac loss is 0.80 W/m.

Figure 2 shows the testing facility at Shenyang Furukawa Cable co., Ltd. Future plans are to connect a superconducting cable to the actual grid using a 6 m-diameter cable formed into a u-bend with both terminals of the cable connected to the terminal junctions. The terminal junction guides the high voltage, conducting layer by utilizing thermal insulation and electric field relaxation. Current was applied to the conducting phase using a current transformer along with a power supply transformer, which supplied 200kV. Three CV cables constructed from three-units of the in-air terminal junctions have allowed transmission of 3 kA-class current to the superconducting cable. Long-run, continuous current application trials lasting over 30 days were undertaken under cooling conditions at an average liquid nitrogen

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temperature of 73 K and at a flow rate of 30 l/min, which were required in order to have stable system operation and address the current application of voltage-to-ground of 200 kV. A current of 3000A has been applied for 8 hours during the day, whereas this current was set to zero for 16 hours during night in order to simulate load fluctuations, (Figure 3). Utilizing the driving voltage of the cable, accelerated trials involving the application of 200kV-overvoltage to 160kV-class voltage to ground for a one-month period was equivalent to 30-years of operations. Continuous liquid nitrogen cryocooling circulation allowed month-long current trials to be undertaken. These trials concluded successfully in December 2013. After the long-run trials, commercial power-frequency withstand-voltage tests of the 310 kV-class cable allowed the partial discharge free characteristics to be verified and established (Figure 4). The completion of demonstration trials confirmed that the initial performance characteristics of the cable were valid even after the accelerated 30-year ageing tests.

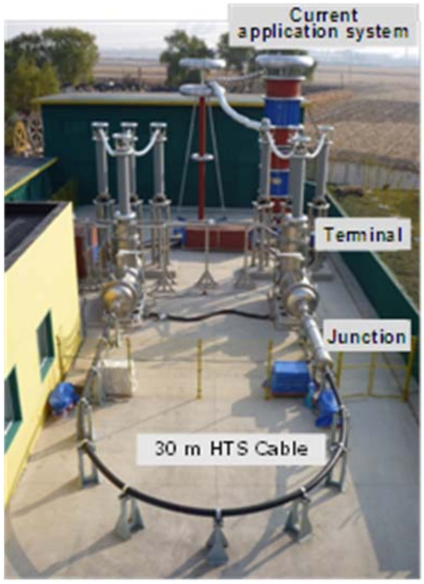

Fig. 2 The facility overseeing the long-run demonstration trials of the 30m-long cable

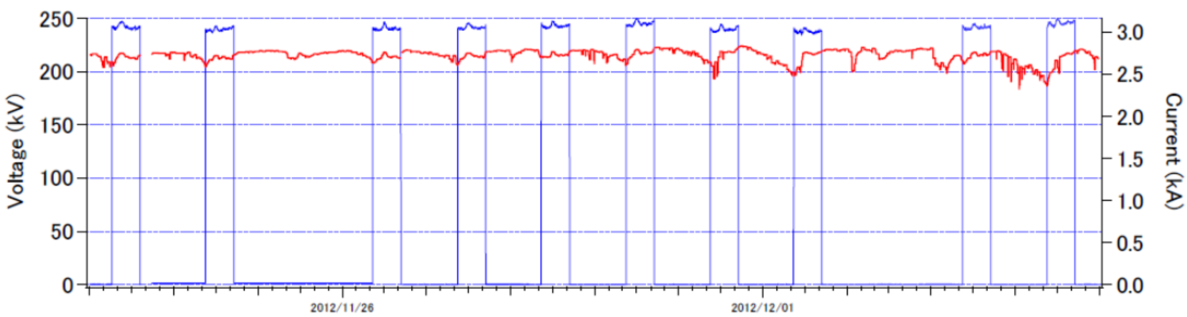

Fig. 3 Part of current-voltage chart measured during the long-run current application trials

Fig. 4 Screen and partial discharge signal of current transformer at partial discharge test

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Further research trials at this demonstration facility have been agreed with NEDO. Currently, the research involves data acquisition related to cable reliability such as determining the damage caused to the cable by repeated thermal treatments as well as investigations on the performance limits of the cable caused by over-voltage potential.

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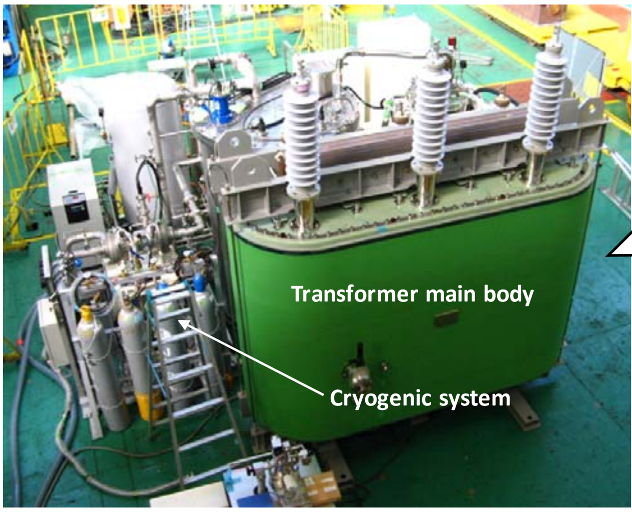
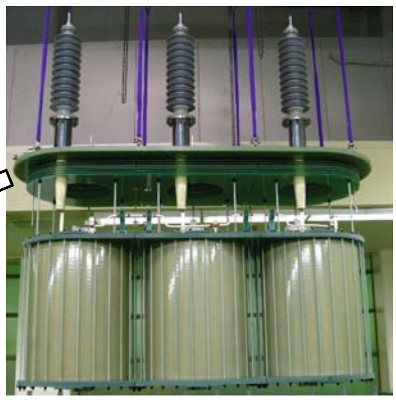
Feature Article: Development of Superconducting Power Equipment Technology
- Technology Development of A Superconducting Transformer

Hidemi Hayashi, Sub-leader
Superconducting Transformer Group
R&D of Yttrium-based superconducting Power Development

A transformer can be made highly efficient and compact by employing a superconducting wire exhibiting low ac-loss characteristics. In particular, Yttrium-based (hitherto Y-based) superconducting wires have large critical current properties even at high temperatures. Additionally, the filament process applied to superconducting wires further reduces ac losses and is expected to reduce wire costs in the future. Therefore, the earlier realization of a Y-based superconducting transformer intended for practical use is anticipated.

Under the “Technology Development of Y-based Superconducting Power Equipment,” a superconductivity technology development project led by NEDO, the author and his group have developed and demonstrated a 66kV/6kV-2MVA high-temperature superconducting transformer. The transformer is the world’s largest class Y-based superconducting transformer, fabricated to determine the performance attributes and to investigate the fabrication methodologies required for the ultimate realization of a 20 MVA-class superconducting transformer for practical use. Additionally, the current limiting functionality afforded by superconducting wires has been verified by employing a several-hundred kVA-class prototype transformer. Kyushu Electric Power Co., Inc. has led the consortium with collaborations between Fuji Electric Co., Ltd, Taiyo Nippon Sanso Corporation, International Superconductivity Technology Center (ISTEC), Fujikura, Showa Cable Systems Co., Ltd, Kyushu University, Iwate University, and Japan Fine Ceramics Center (JFCC), for the periods between 2008-2012.Figure 1 shows a 2 MVA-class superconducting prototype transformer used for demonstrations in this study.





Wire winding of superconducting transformer

Fig.1 Outline of a 2 MVA-class high-temperature superconducting transformer (Main body of transformer; length 1.6 m, width 3.2 m, height 3.7 m)

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The developmental status of component technology and the transformer system technology was introduced in the November 2011, December 2012 and June 2013 issues of Superconductivity Web21. This article summarizes the attributes of a superconducting transformer equipped with fault current limiting (FCL) function, with the research findings determining the feasibility of such a system.

1. Investigations of a superconducting transformer equipped with FCL function

The wire windings of a transformer equipped with FCL were cooled using sub-cooled liquid nitrogen in order to maintain the insulating characteristics. A non-magnetic GFRP vessel was employed and in addition, the iron core was set to room temperature to prevent thermal loads affecting the cooling system due to core loss. The % impedance of transformers with and without current limiting functionality was set at 10 % and 15 %, respectively.

To take advantage of the attributes afforded by a superconducting transformer, it was necessary to reduce the iron core volume by increasing the superconducting wire winding volume. This, however, increases the impedance, which has to be adjusted by increasing the number of magnetic paths between the wire-windings. Figure 2 shows the resulting weight of the iron core, wire length and wire-winding height utilizing voltage between turns as a comparison parameter. An optimized design voltage was 41.5 V/turn when considering each of these factors.

A cable comprised of a Y-based superconducting wire and CuNi wire allowed the transformer to have current limiting functionality. Figure 3 shows the analysis results of resistance required for current limiting functionality, categorized by the thickness of the CuNi-layer and thickness of the silver layer in

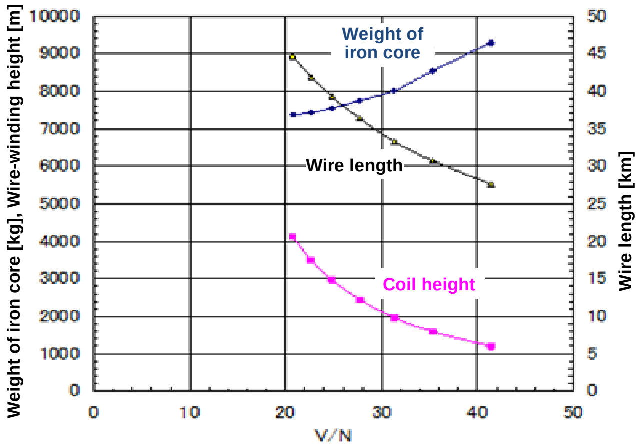

Fig.2 V/N dependency of voltage between turns of transformer

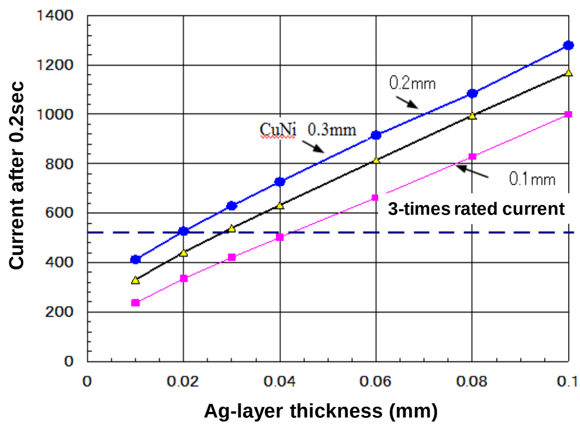

Fig.3 The variation in short-circuit after 0.2 sec and the Ag-layer thickness

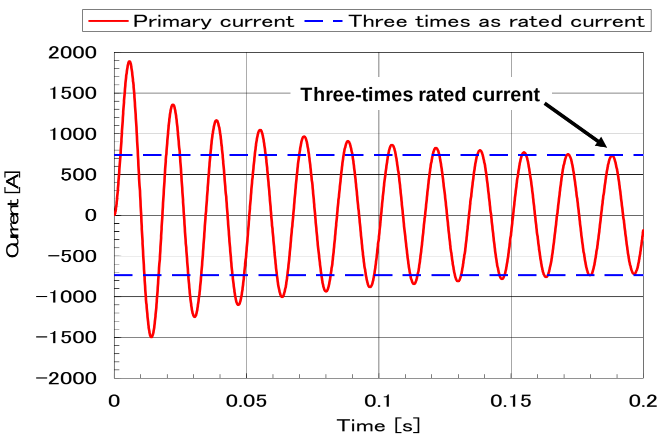

Fig.4 Short circuit current analysis of transformer equipped with current limiting functionality

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Y-based superconducting wires. Current-limiting requirements that offer protective coordination of the transmission system necessitate the short circuit current to be set to less than three-times the rated current for 0.2-sec short circuit durations. Figure 4 shows the transient analysis results of short circuit current measurements for a transformer employing an 18μm silver layer and 0.3mm-CuNi layer in superconducting wire. The findings reveal that the favorable operational characteristics of the wire have short circuit currents of less than three-times the rated current.

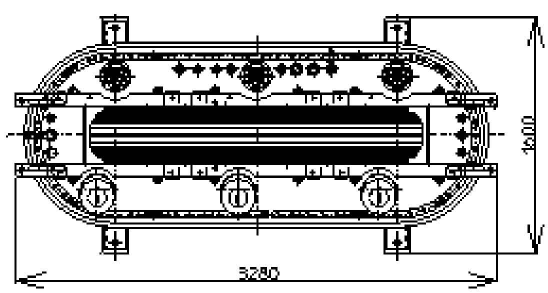
Table 1 shows comparison transformer specifications without current limiting functionality and a 66kV/6.9kV three-phase 20 MVA-class superconducting transformer equipped with current limiting functionality, and based upon the research outcomes detailed in this article. Wire-length was reduced by about 7 %. Table 2 shows a comparison with a conventional oil-immersed transformer. The measured loss was 46 % of an oil-immersed transformer, even taking into account the cooling drive having a COP of 0.06, as well as its weight and its footprint reduced by half. This confirmed greater efficiency and compact characteristics compared to existing transformers. Figure 5 shows an outline of a transformer equipped with current limiting functionality.

Table 1 Comparisons of superconducting transformers with or without current limiting functionality

	With current limiting functionality	Without current limiting functionality
Number of phases, wire connection type	3Φ, Y-Y	
Rated voltage	66 kV/6.9 kV	
Rated current	175 A/1,674 A	
% Impedance	10%	15%
Number of turns	918/96	1033/108
V/N	41.5	36.9
Cable structure	3/24 parallel	3/24 parallel
Wire length	33.1 km (8.0/15.0 km)	35.6 km (19.3/16.3 km)

Table 2 Comparisons of superconducting transformers and oil-immersed transformers

Type	Superconducting transformer	Oil-immersed transformer
Loss	46%	100%
AC Loss/ohmic loss	31 % (AC Loss)	91 % (ohmic loss)
Core loss	7%	9%
Thermal leakage	8%	
Efficiency	99.7 %	99.4 %
Weight (including cryocooling)	50%	100%
Footprint (ditto)	51%	100%



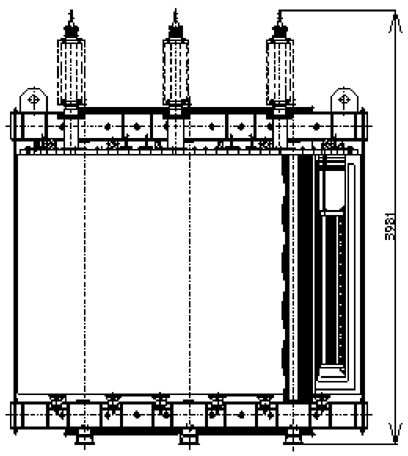


Fig. 5 Outline of a 66kV/6.9kV three-phase 20 MVA-class transformer equipped with current limiting functionality

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2. Feasibility of superconducting transformer applications

Figure 6 shows a potential transformer with current limiting functionality applied to power transmission systems. The figure aims to denote the effectiveness in loop operations and the protection offered by increased short circuit capacity utilizing a dispersed power source, in addition to potential current limiting effects observed in conventional power transmission lines. Figure 7 shows the system comprising of the superconducting cable and superconducting transformer. The effectiveness of a transformer equipped with current limiting functionality is highly anticipated to offer protection from increased risk of short circuit capacity due to a large-current superconducting cable.

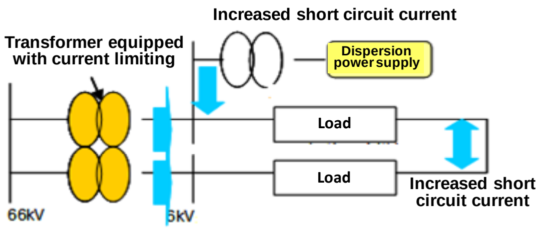

Fig. 6 An example application of a transformer equipped with current limiting functionality applied to power transmission system

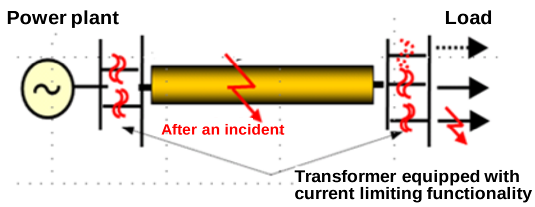

Fig. 7 An example application of a superconducting cable and transformer equipped with current limiting functionality

Figure 8 shows examples of superconducting transformer applications employed in the entire grid system. Arrays of applications include transformer, power supply, grid system, transmission, industrial and transportation use, etc. When superconductivity is applied to transformer applications and current limiting functionality is added, expectations such as compactness, higher efficiency, and effectiveness in short-circuit protection will be realized.

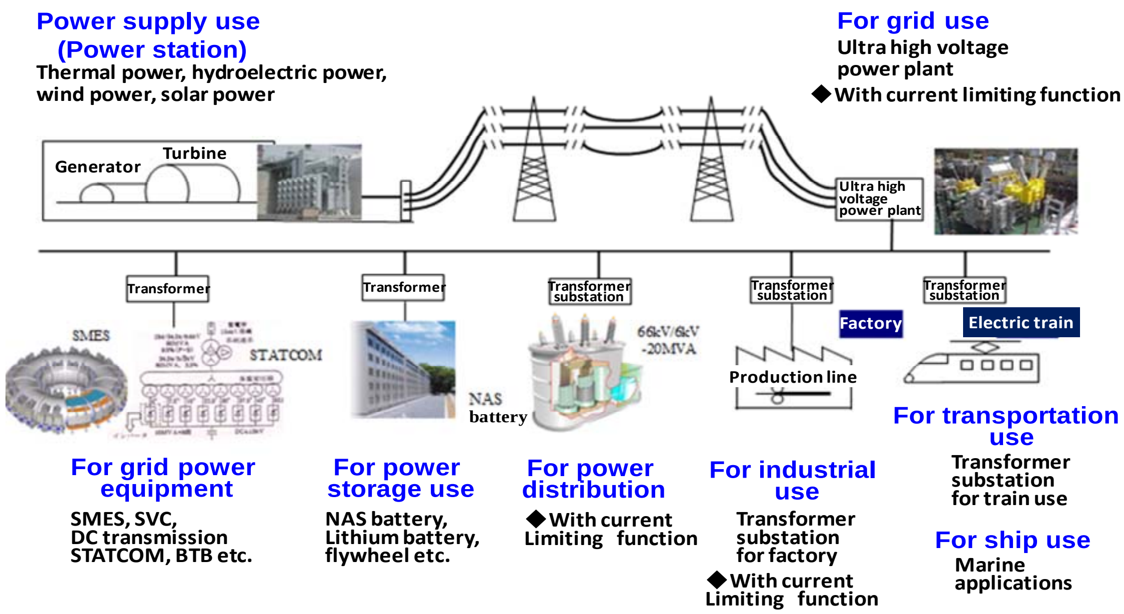

Fig. 8 An example of a superconducting transformer application

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3. Conclusions

R&D investigations into a superconducting transformer equipped with current limiting functionality confirmed a % reduction in impedance and additional cost reduction due to a reduction of wire length. An example of a transformer equipped with current limiting functionality applied to the grid system as well as feasibilities of superconducting transformers applied to the entire grid system were also explained. The author anticipates that based upon the research outcomes, superconducting transformers will be realized for practical use in industry and power utilities in the future.

The technology development was undertaken as part of the Y-based superconducting power equipment technology development project, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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