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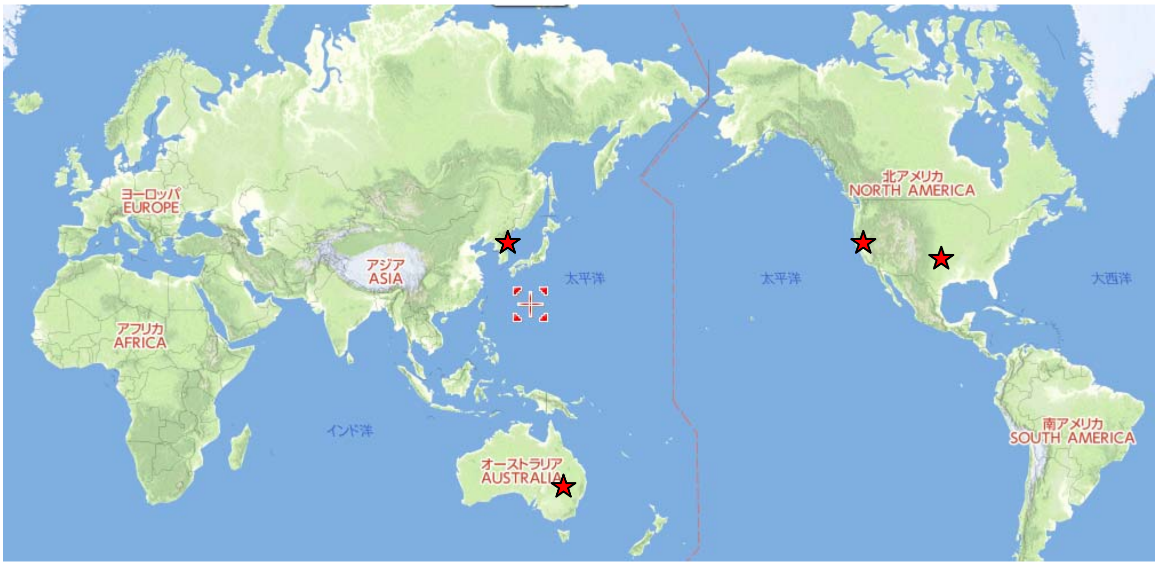
What's New in the World of Superconductivity

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

▸Power Application 전력응용 电力应用 [diànlì yìngyòng]

Demonstration Start：Power Transmission DC Cable 10x Capacity

LS C&S (19 Nov, 2014)

LS Cable & System revealed that it had begun trials of an 80kV superconducting DC cable at its Superconducting Power System Center in Jeju Island, which will last for six months.
The company's President & CEO, Ja-Eun Koo, is quoted as saying, "Superconducting cables are no longer a 'dream cable.' Related projects to a scale of hundreds of billions of won are being deployed in around ten countries including the U.S. and China as well as Korea. LS Cable & System will contribute to high-efficiency and eco-friendly energy industry development by continuously promoting technology

development and overseas market entry."
Superconducting cables can be used for long-distance power transmissions with no power loss, even when AC is not converted to DC, and have greater functional characteristics in built-up environments where demand for power is on the increase but the space for underground cables is saturated with cable tunnels and conduits. Increased power can be delivered by simply replacing existing cables with superconducting cables while continuing to use existing facilities. For example, while as many as five substations are traditionally needed to send power from a power plant to an urban area, using superconducting cable reduces it down to one. Additionally, cable tunnels can be reduced by more than 60 %.
Other companies with expertise in superconducting cable technologies include Nexans of France and Sumitomo of Japan.

Source:" LS Cable & System to start demonstration of power transmission DC cable 10X capacity" (19 Nov, 2014) Press Release
http://m.lscns.com/info/info8_read.asp?idx=2953
Contact: Press Relations D.H.Gem realgem@lscns.com

LOW COST MgB_2 OFFSHORE WIND TURBINES

University of Wollongong (27 Nov, 2014)

Researchers from University of Wollongong (UOW) are developing technologies for next generation offshore wind turbines that could be installed off the coast of Australia in the next five years. Dr Shahriar Hossain, a Materials Scientist from the Institute for Superconducting and Electronic Materials at UOW stated that Australia has more than 35,000km of coastline and there is ample room for offshore wind farms if it is to achieve its target of an 80 per cent reduction in greenhouse gas emissions by 2050. The turbines are expected to be one-third the price and 1,000 times more efficient than existing systems.
Dr Hossain also stated that the current conventional offshore wind turbines cost $15million each to build, are extremely heavy and difficult to ship out to their location, and require a lot of maintenance thanks to a complicated gearbox. The system design by his research team at UOW has no gearbox and thus weight and size can be reduced by up to 40 % by employing a magnesium diboride (MgB_2) superconducting coil to replace the gearbox. They are developing an MgB_2 superconducting coil, which is very cheap and easy to manufacture. Additionally, lossless conversion of wind energy into electricity will reduce manufacturing and maintenance costs by two thirds.
With existing technologies, up to 200 km of coil is required to generate electricity in wind turbines, estimated to cost between $3-5million to manufacture. The sample length of MgB_2 superconducting coil would cost around $180,000, a figure that could be reduced further with economies of scale. The US industry partner, Hyper Tech Research anticipates that MgB_2 coil will cost just $1 per meter to manufacture by 2015.

Source: "LOW COST, SUPER EFFICIENT OFFSHORE WIND TURBINES FOR A CLEAN ENERGY FUTURE" (27 Nov, 2014) Media Releases
http://media.uow.edu.au/releases/UOW184359.html?ssSourceSiteId=UOW_Main
Contact: Elise Pitt epitt@uow.edu.au

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▸Wire 선 재료 線材料 [xiàn cáiliào]

Improvement in Wire Performance

STI (18 Nov, 2014)

Conductus® wire, produced by Superconductor Technologies Inc. (STI) demonstrate critical current of 730 Amps/cm @ 77K in self-field and exhibit improved low-temperature characteristics in higher magnetic fields, performed across a wide range of operating temperatures and magnetic fields. These test results are to be presented at the 27th International Symposium on Superconductivity (ISS) being held November 25th to 27th in Tokyo.

"ISS is an ideal conference to meet with new and existing customers and expand business relationships with industry leading companies, and is an excellent forum to present these customer performed test results that demonstrate very significant improvement in Conductus wire performance," said Adam Shelton, STI's VP of Marketing and Product Line Management. He also added, "Conductus wire continues to demonstrate the capability to meet the demanding needs of a diverse set of applications that include superconducting fault current limiters and superconducting power cables, which have the potential to lengthen the service life of equipment and lower system losses for power utilities." For commercialization to occur, the industries require improved availability and performance attributes to improve the economics of high temperature superconducting wire development, and he believes that STI is well-positioned to address this as they ramp capacity in 2014 onwards.

Source: "STI Achieves 30 % Improvement in Conductus Wire Performance"
(18 Nov, 2014) Press Release
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1990556
Contact: Cathy Mattison or Kirsten Chapman Invest@suptech.com

1km RCE System for Commercial Production

STI (4 Nov, 2014)

Superconductor Technologies Inc. ("STI"), reported its 1km RCE system (RCE-1000) completed final assembly, meets all required design specifications and is operational for the commercial launch of Conductus® wire. The focus now is on software testing and process development.

"With our RCE-1000, SDP and IBAD machines operational, we are positioned to produce Conductus wire on a commercial scale," said Jeff Quiram, STI's president and chief executive officer. From his statements, their pilot plant had limited capacities, and thus constraining evaluation and qualification of their wires, which were undertaken by customers. Demand is increasing since the industry focus is now on commercialization of superconducting products. In the 3rd quarter of 2014, STI shipped Conductus wire to four new and six existing customers; Seven of these customers are in Stage 1 evaluation, which includes wire characterization and performance testing, and three are at Stage 2, which involves more rigorous testing to simulate devices for commercial deployment. He is confident that additional orders will continue to outpace supply, and the commercial RCE-1000 will alleviate this constraint by ramping availability in late 2014 onwards.

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Source: "STI Preparing for Commercial Production of Conductus Superconducting Wire"
(4 Nov, 2014) Press Release
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle_Print&ID=1985226
Contact: Cathy Mattison or Kirsten Chapman Invest@suptech.com

▸Electronics 엘렉트로닉스 电子应用［diànzǐyè yìngyòng]

Development of Quantum Computer with Google

UC Santa Barbara (12 Nov, 2014)

Pedram Roushan, a former postdoc from the Martinis Lab at UC Santa Barbara (UCSB) and who is now a quantum electronics engineer at Google, along with several colleagues have been exploring qubits (quantum bits) for quantum simulations. It was earlier this year, John M. Martinis and several members of his UCSB lab joined Google, which established a satellite office at UCSB. In parallel with the development of a general-purpose quantum computer, the team has worked on a novel qubit architecture, which is an essential component for quantum simulation, allowing them to better understand the seven principle parameters necessary for complete control of a two-qubit system.

Superconducting qubits can address specific problems from various fields ranging from chemistry to condensed matter. Roushan stated, "These quantum simulation problems usually demand more control over the qubit system." A qubit can be in either a 0 or 1 state or a superposition of both at the same time, unlike a classical computer bit, thus creating many possible interactions. An analogy to their operation can be had by envisioning the two qubits as people involved in a conversation, and being able to control every aspect such as location, content, volume, tone, accent, etc of their communication. In their studies, topology, the mathematical study of shapes and spaces, was chosen to demonstrate the full control of a two-qubit system, successfully demonstrating a quantum version of Gauss-Bonnet theorem, which relates the total local curvature of the surface of a geometrical object. Dr Roushan explained that by measuring the curvature of the surface (electric field), enables inferences regarding what's inside the surface, the charge, to be made.

The novelty of their research comes from how the curvature was measured, using an ingenious methods proposed by Boston University of sensing the curvature via motion. An analogy can be also had using the Lorentz force law, which states that a charged particle in a magnetic field, which curves the space, is deflected from its straight path. In the quantum system, the research team confirmed that the degree of deflection along one meridian of a sphere's curve was measured and the local curvature at that point deduced.

"The technology for quantum computing is in its infancy in a sense that it's not fully clear what platform and what architecture we need to develop, what we've shown is very crucial for coupling qubits when you're asking for a full-fledged quantum computer," Roushan said.

This work was supported by the National Science Foundation (NSF), the Office of the Director of National Intelligence and the Intelligence Advanced Research Projects Activity. Devices were fabricated at the UCSB Nanofabrication Facility, part of the NSF-funded National Nanotechnology Infrastructure Network and the NanoStructures Cleanroom Facility. Their research appears in the current edition of the journal Nature.

Source: "A Piece of the Quantum Puzzle - UCSB physicists demonstrate the high level of controllability

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needed to explore ideas in quantum simulations" (12 Nov, 2014) Press Release
http://www.news.ucsb.edu/2014/014489/piece-quantum-puzzle
Contact: Julie cohen Julie.cohen@ucsb.edu

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Feature Article: Superconductivity Applications for Renewable Energies - Recent Trends

Yutaka Yamada
Principal Research Fellow
Superconductivity Research Laboratory, ISTEC

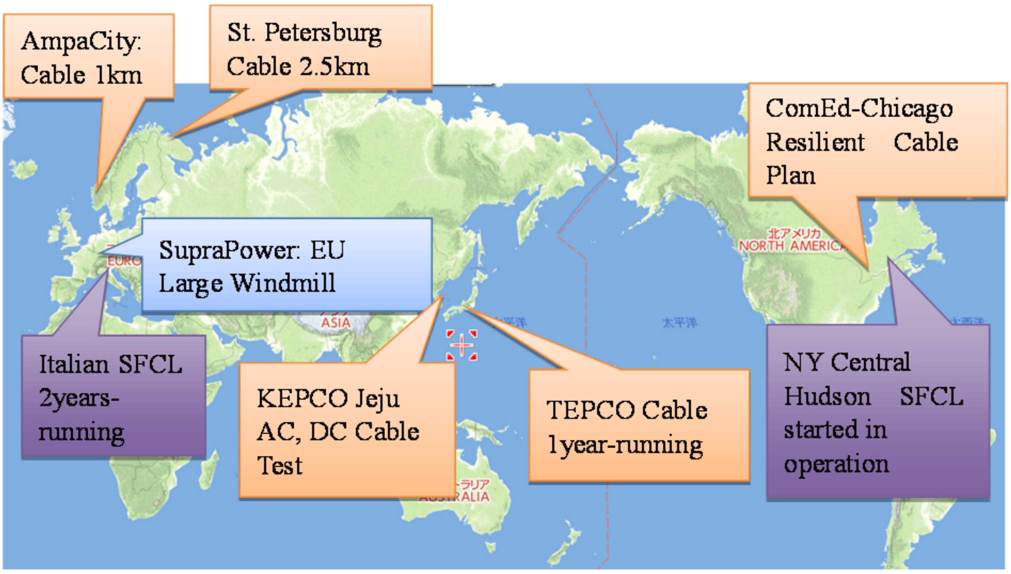

Fig. 1 Major high temperature superconductor projects related to renewable energy
All are grid demonstration trials, except SupraPower-Pj (wind power).
SFCL: Superconducting fault current limiter

○Progress in R&D related to renewable energies: Cables and fault current limiters applications stood out at the ASC 2014.

ASC 2014 took place in Charlotte, USA, on 10-15 August 2014. Superconductivity research related to renewable energies was presented, with many applications relating to cables, fault current limiters, wind power and SMES. Of these, the major applications are shown in Figure 1. With various demonstration trials involving gird connections and continuous operations, further development worldwide has focused on the realization of practical applications.

Under the AmpaCity project (10kV/2.3kA) based in the city of Essen, Germany, demonstration trials utilizing 1 km-long cables and fault current limiters in actual grid operations launched this year. After witnessing nighttime road closures due to cable installation construction and connection to the substation, the author perceived that practical applications are soon forthcoming. (The wires for this project are Bi-based coated conductors manufactured by Sumitomo Electric).

Some grid operational trials have been successful. For example, in Japan a one-year cable demonstration trial (240m, 66kV/1.75kA) successfully concluded at the Asahi Substation, TEPCO. Improvements to cryogenic cooling performance are being currently progressing towards practical applications. In Italy, Recerca sul Sistema Energetico SpA (RSE) and a2a Reti Elettriche (multi-utility company based in Milano), successfully completed a joint two-year operational trial of superconducting fault current limiters (12kV/4.6MVA) at a substation in the suburbs of Milano, and a press release highlighting this event was published this year.

Reflected in these achievements is Central Hudson in USA, which in July 2014, installed superconducting fault current limiters to a substation (115/14.4 kV) located in the suburbs of New York City. Applied Materials manufactured the superconducting fault current limiters, employing superconducting wires manufactured by SuperPower (Furukawa). System testing and evaluation began in May 2014 and will be conducted over a year, with the performance data given to the New York State Public Service Commission.

AMSC announced a deployment strategy designed to strengthen Chicago's electric grid with the installation of Risilient Cable fabricated utilizing their high-temperature superconductor technologies, under a fund granted by the Department of Homeland Security (DHS). A 3-mile (about 5 km)-long cable will be installed in the grids of ComEd based in Chicago, over a 4-5 year period beginning 2014. The total cost is expected to be around 6 billion yen. In Korea, KEPCO plans AC (154kV/600MVA-1km) and DC (80kV/500MVA-500m) cable demonstrations at Jeju Island. DC cable demonstrations will commence current-loading trials from October 2014 onwards.
As mentioned above, R&D activities related to superconducting power applications and renewable energy applications have been actively progressed at respective research institutions worldwide.

○Wind power application: Intensifying cost competition
Amongst all the renewable energies currently available wind power is the most prevalent. IEA's projection (Table 1) shows that offshore wind farms worldwide will increase to 375 GW and 1150 GW in 2030 and 2050, respectively. The mainstream commercially available 2 MW wind power generators are expected to increase approximately to 200,000 and 600,000 units in 2030 and 2050, respectively. Development is progressing towards greater system capacity in order to bolster power generation (for example, 7 MW wind turbine at the offshore wind farm based in Fukushima, Japan). However, it is currently assumed to be difficult to realize greater than 10 MW since there is a limitation in supporting several hundred ton-class power generators on the top of a wind turbine located more than 100 m above ground. Thus, worldwide investigations have focused on reducing weight and increasing system capacities by employing superconducting power generators. Amongst these, the SupraPower project in Europe has commenced studies for an ultra 10 MW system employing low cost MgB_2 wires. The project participants include major European research institutions including Acciona WindPower, Oerlikon-Leybold Vacuum (refrigerator manufacturer), superconducting wire manufacturers and the Karlsruhe Institute of Technology, with Technolia (Spain) leading the overall project. According to their report, the competitive nature of the wind power market has intensified and ultimately led to cost issues. For this reason low costs MgB_2 wire were selected, albeit at the cost of low operational temperatures. The total cost of the project is expected to be 540 million yen from December 2012 to the end of 2016. Essentially, the project aims to construct a 200-ton superconducting power generator instead of a conventional 10 MW-class 380-ton power generator. The cost of a 10 MW-class system fabricated using enhanced conventional technologies is expected to be €2.8 million (equivalent to 380 million yen), however, the project aims to reduce costs further.
Guina Energy based in Australia was the new participant at the ASC2014, with a total of six presentations on themes related to wind power and other renewables. This, the author believes, also signifies the

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expansion of superconductivity R&D related to renewable energies.

Table 1 Projection of offshore wind power installations: (from the IEA2010World Energy Outlook)

2020	203	2050
EU 40GW	150	460
World 100GW	375	1150

○**Summary**
In recent years, EPRI has announced analyses into the USA's CO_2 emission forecast and the effectiveness expected by the introduction of new technologies. Without particular measures undertaken, CO_2 emissions in 2030 are expected to increase 1.5 times current levels. It is estimated that the array of technologies introduced, which include renewables, can reduce CO_2 emissions by 45 %, down to the levels of 1990 (Please refer to photo 3 in ASC2014 report published in this Web21 issue). Europe also reports that on some days, the power generated from renewable energy sources in Germany and Spain already exceeds 40 % of the entire power generated. The author contemplates that further integration of superconductor technology with wind power applications, superconducting cables, fault current limiters, and SMES has now created a great opportunity to significantly contribute to energy savings and reduce CO_2 emissions of our future society.

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Feature Article: Superconductivity Applications in Renewable Energy -Superconducting Fault Current Limiter Aimed at Renewable Energy Applications

Tsutomu Watanabe, Managing Director
ISTEC

○Impact to power grids by utilizing large amounts of renewable energy
Wind and photovoltaic power generation, which would make up the majority of renewable energy sources, has relatively large volatility in their outputs characteristics. The mitigation measures such as Introduction of battery cells could accommodate some degree. However, it is presumed that this would significantly impact power grids especially those with relatively low voltages of less than 6-70,000 V (hitherto local grids) because the generation capacity would be relatively large compared with the system capacity.

The output volatility leads to fluctuation of voltage, reactive power and phase angle in local grids, which would seriously affect the neighboring customers (by the excess 0fluctuation in a power supply voltage etc.), might risk the local grid stability.

○ Mitigation of the impact by renewable energy utilization and the effect on increase in fault current levels
A method to prevent voltage fluctuations and increase stability limit ideally should involve the installation of an AC power sources in proximity. As seen in many countries, the operation of AC power sources should be maintained as many as possible to cope with the increase in renewable energies. In general, main focus is put on the frequency maintenance effect by the operation of AC power to harness renewable energies introduction. Still, the effects to mitigate the voltage fluctuations or improve the stability aspects should be paid attention in the local grids. In this sense, the installation of an AC power source in proximity is technically is equivalent to decreasing the impedance between the AC power source and the local customers or substations. This can be also realized by such as increasing power transmission lines or substation facilities, application of loop operation in the originally radial operated system, mesh system operation in originally sparsely looped operation. These measures would be more economical compared to the installation of new power generation. However, these potentially preferable methods, which would bring about “decrease in impedance” in low cost, accompany the increased in fault current levels. As the fault current increases and should exceed the tolerance level in the power grid and customer facilities it causes serious damage to the facility at a power failure. Therefore, these methods should be carefully examined.

As shown in the figure, even though the opening operation of a breaker is undertaken soon after a power failure, a fault current in the case of exceeding the breaker capacity leads to the destruction of the breaker itself and the power failure should continue (a status of no power supply continues). However, if the grid impedance is low during normal operation and increases only while a fault current occurs, which decreases the fault current level, any concerned problems will disappear.

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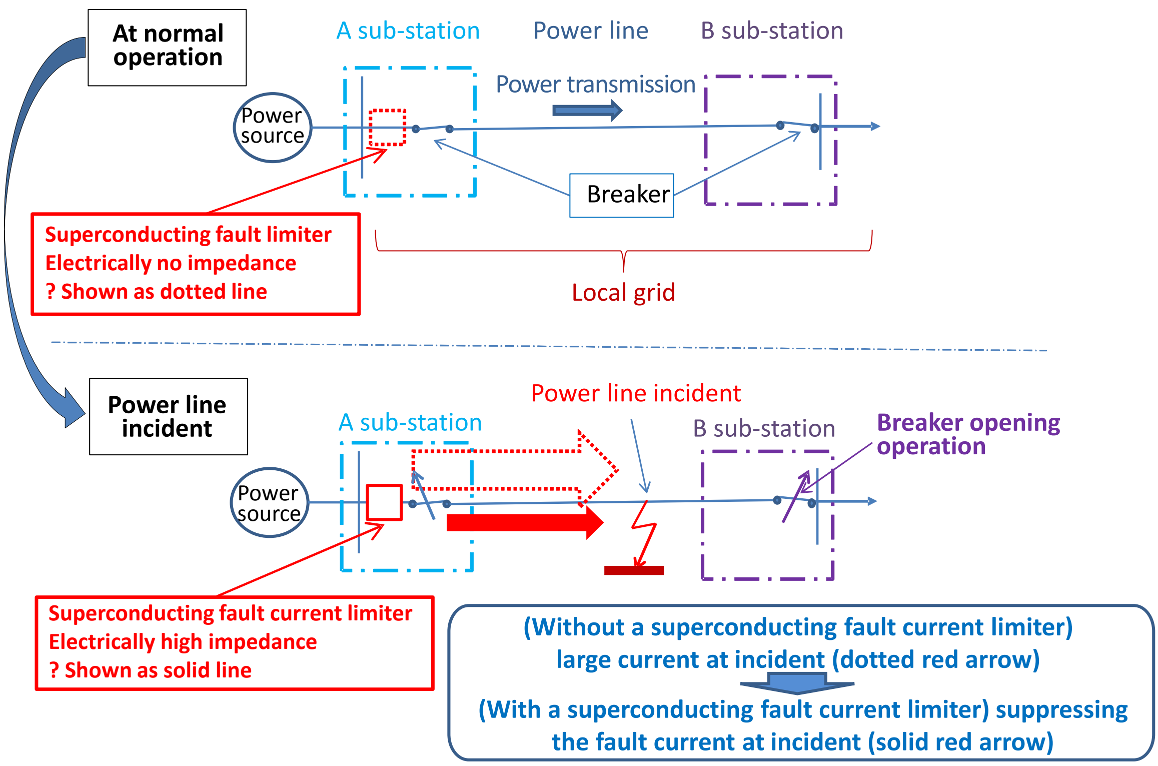

Fundamental concept of a superconducting fault limiter

○Feasibility of superconducting fault current limiter applications for fault current decrease

Equipment that limits fault current is referred to as a *fault current limiter* of which there are various types. Characteristically, superconductors exhibit S-N transitions, i.e. when a current above a certain level flows, the transition "naturally" goes from a superconducting state (zero resistance) to normal conducting state (large resistance). When the above-mentioned "reduction in grid impedance during normal operation" occurs, superconductors have no issues since they have zero resistance. When an power failure transpires, the superconducting fault current limiter operates, and ideally, performs to protect against increases in fault current levels amidst increasing impedances at the initial stage when the fault current starts to increase. Therefore, the "natural characteristics" of superconductivity suits as the component of fault current limiters It is therefore assumed that the need of superconducting fault current limiters will increase accompanied with the utilization of large amounts of renewable energy sources.

○Issues arising in the development of superconducting fault limiters for a wide range of applications

Although superconducting fault current limiters suit the fundamental needs there are also some issues to be referred to. For example, in Japan particularly, operations at facilities need to be resumed within a short period of time soon after an power failure is cleared. Here, fast reclosing system is adopted for overhead transmission line protection system and a superconducting fault current limiter exhibiting compatible characteristics with this methodology is required. Specifically, it is necessary for it to go from a normal

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conducting state to a superconducting state within short period of time. If this cannot be realized, then this causes a high impedance (resistance) at the time when operations are resumed and thus is inadequate for the fundamental requirements of “reducing impedance”. Therefore, technological developments are needed in order to realize high-speed S-N transitions into the superconducting state. Since short-time reclosing is not performed at the underground cable and substation facilities (including the customer premises), high-speed S-N transition characteristics are not necessary for fault current limiters specified for such applications.

Next, issues to address the compactness of superconducting fault current limiters and the realization of their economic potential well suited for local grids are required. The majority of local grid facilities are compact and installation footprint for fault current limiters are therefore limited. Compactness is an important developmental factor. Since local grid facilities are constructed using relatively low cost facilities, it is predictable that the facilities required for large-scale initial investments or large operational costs will not be widely employed at local grids. The development of superconducting fault current limiters addressing those issues are therefore highly anticipated.

Worldwide, many countries employ loop and mesh operations for local grids (Japan fundamentally employs radial operations). With the high levels of fault currents, there have been conventional issues addressing protection from increased fault currents. Therefore, the needs of superconducting fault current limiters are highlighted and the developments are now ongoing in many parts of the world. The author anticipates that a potential competitive fault limiter that will be developed by Japan’s superconductivity technology could lead to a wider acceptance in the marketplace in future.

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Feature Article: Superconductivity Application in Renewable Energy -Effective Utilization of Renewable Energy by Employing SMES at the ALCA Project

Takataro Hamajima, Professor Emeritus
Tohoku University

Global-scale carbon-dioxide reduction is an important and crucial issue for establishing a sustainable society. Whilst the utilization of eco-friendly renewable energy is desirable, their transmission capacities in power grids are limited due to frequency fluctuations, which occurs when the directly transferred output power to a commercial utility grid increases. This is because renewable energies stochastically fluctuate at random. It therefore becomes necessary to utilize power storage facilities effectively to eliminate power fluctuations and convert the renewable power into a controlled electrical power. Amongst the power storage options available include superconducting magnetic energy storage (SMES), which exhibit rapid responses to large input and output power and endure a number of repeated charge and discharge cycles. Also a hydrogen system comprising of a fuel cell power system (FC) and water electrolysis system (EL) offers the potential of greater storage capacities. Both storage systems compensate each other and thus forming a hybrid storage system can be applicable in converting the rapid fluctuating renewable energy source into controllable electrical power. Additionally, SMES can be wound using economical MgB_2 wires and cooled using liquid hydrogen (20 K) since the critical temperature of MgB_2 is 39 K. In the near future, a potential hydrogen gas station for fuel cell vehicles will be able to utilize liquid hydrogen coolant since it is more economical and environmentally beneficial. An advanced superconducting power conditioning system (ASPCS) composed of above-mentioned systems is shown in Figure 1 [1].

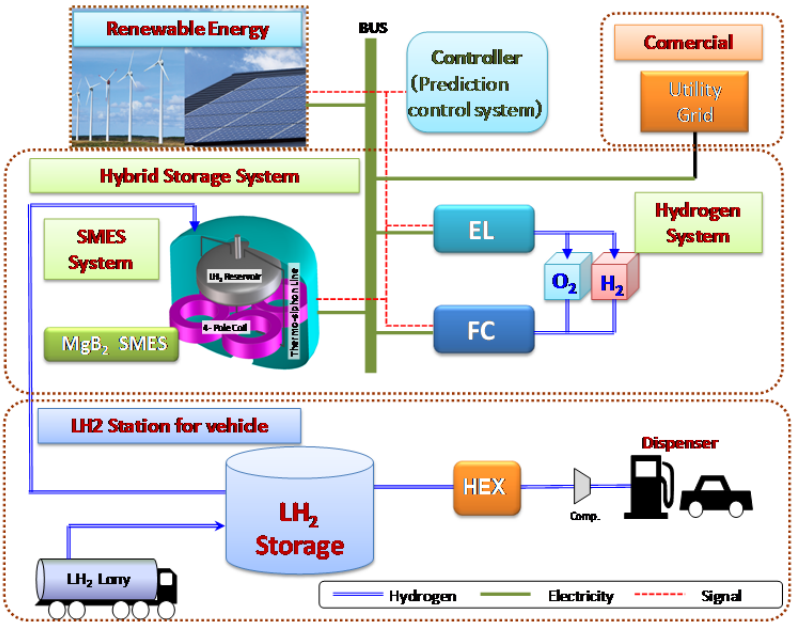

Fig.1 Concept of ASPCS

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In order to use effectively both SMES and hydrogen systems it is necessary to resolve the renewable energy into suitable components. The wind turbine power generated by randomly changing renewable energy can be resolved into an average trend and a rapidly changing component. The trend component is relatively slow and is suitable for hydrogen systems having large storage capacities. The rapidly changing component is suitable for SMES, which exhibits frequent input and output characteristics. The slower trend component can be predicted by applying the Kalman filter algorithm. Figure 2 was measured waveforms during 20,000-22,000 second. The upper graph in Figure 2 shows a 5 MW-class wind power waveform P_{wind}, a predicted trend waveform of P_{pred} associated with the wind and a constant output power P_{out}. The lower graph in Figure 2 shows the waveform from each component, resolved into the supplied power by the fuel cell (FC) $P_{FC} = P_{pred} - P_{out}$, the absorbed power by the EL $P_{EL} = P_{out} - P_{pred}$, and SMES input and output power $P_{SM} = P_{wind} - P_{pred}$ [1]. The figure reveals that the trend well predicts the wind power with slight time lag. It is clear that the SMES input or output energy is frequently charged and discharged whilst a hydrogen storage system exhibits slow but large input/output capacity characteristics. Figure 3 shows a histogram of SMES input and output energies and its frequency performed over 20 hours, almost a day. Table 1 shows the data processed statistically. The figure reveals that the majority of the SMES input/output energy is the repeated charges and discharges of small energy. The number of charges and discharges per day is 2,000, which equates to 720,000 per year. The SMES's repeated tolerance characteristics can be fully utilized here. Since the energies are not so large the SMES's stored energy can also be small. Figure 4 shows the results from a calculation performed to estimate the electric efficiency as a function of the constant output power to the utility grid. Electric efficiency of SMES, EL and FC were 95, 80, 40 %, respectively. In the figure, there are some cases where the efficiency exceeds 80% by appropriately selecting the

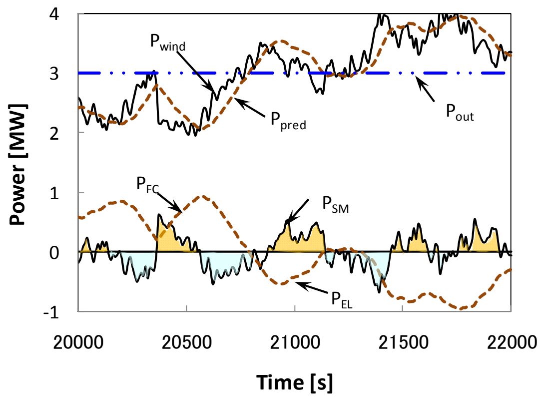

Fig.2 Waveforms of Wind power P_{wind}, Trend prediction P_{pred}, Constant output power P_{out}, SMES P_{SM}, FC P_{FC}, and EL P_{EL}

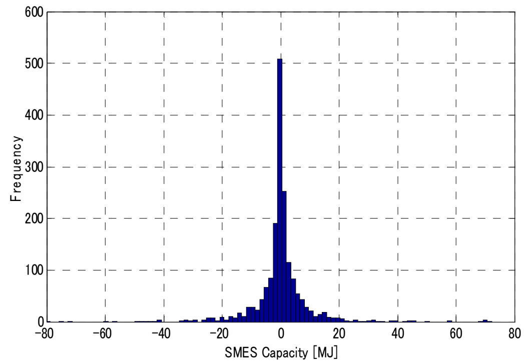

Fig.3 Histogram of SMES input and output energies

Table 1 Statistics of SMES's charge-discharge energy

Charge-discharge frequency	1,780
Average charge-discharge power	0.13 MW
Average charge-discharge energy	5.1 MJ
Dispersion of charge-discharge energy	10 MJ
$\pm 3\sigma$	60 MJ

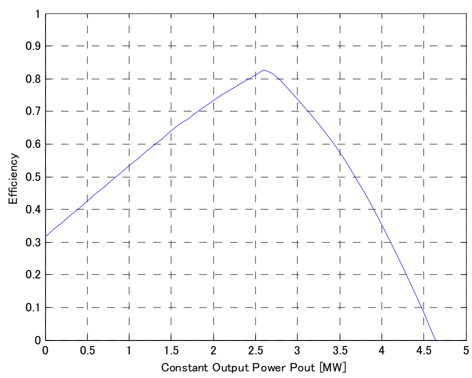

Fig.4 Electric efficiency of ASPCS as a function of the constant output power P_{out}

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constant output power [1]. It is therefore anticipated that by exploiting SMES characteristics, the effective utilization of renewable energy will lead to new potential superconducting applications. A 1kW-class compact ASPCS is currently being constructed to verify the concept of this system and will be tested at the Iwatani R&D Center (Amagasaki city).

This research was partially supported by Japan Science and Technology Agency (JST) and Advanced Low Carbon Technology R&D Program (ALCA), with receipt of collaborations of members listed below.
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Feature Article: Superconductivity Application in Renewable Energy - Wind Heat Power

Toru Okazaki, Director
Public Relations Division/International Affairs Division
ISTEC

Studies into wind heat power are progressing by Kakenhi for scientific research funding. As published by the New York Times[1)], it is being recognized that heat storage is a more advantageous method compared to batteries in stabilizing volatile renewable energy. This is because the cost per kW-h for heat storage largely falls to around 1/20 compared to batteries. The efficiency of converting stored energy to electrical power is low at around 40 %, which compares to around 70% for battery. However, with diminishing storage costs and grid-scale track records realized by concentrated solar power (CSP), viable heat storage is becoming a greater probability. Figure 1 shows the heat storage facility at a CSP plant currently in operation. It is significant to note the stability performance track record at this large-scale facility.

Stability here refers to long-term energy storage of more than several hours. Since thermal systems typically have difficulties changing their output over the short term, batteries and SMES are more suited in providing stable energy flows over the short-term for ancillary services.

Fig. 1 23m-diamter tank can store the equivalent of 300 MWh energy

It is advantageous to transform the energy derived from wind power directly to heat, similar to what is currently undertaken at CSPs, and especially in situations where heat storage is beneficial in stabilizing renewable energy. This concept is what is referred to as *wind heat power*. The upper portion of a wind tower generates eddy currents that produce a heating effect by a magnetic field applied to a rotating conductor. A circulating heat transfer medium collects heat energy. Depending upon the conditions, power generation costs are half that compared to battery stabilization systems and equivalent to existing wind power systems, including associated costs with back-up thermal power etc. With the wind power systems currently available, it is impossible to reduce the number of thermal power plants no matter how many more wind powers are constructed. This absolutely negates the intended purpose of CO_2 reduction [2)]. In Japan, this potential cost slightly adds to the price of electricity, which is passed to the wide customer base. For example, the price of electricity in Denmark has become extremely expensive and is attributed to the significant costs associated with the introduction of large numbers of wind turbines.

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For heat conversion it is desirable to have temperatures as high as possible. The greater the temperature the higher is the thermoelectric conversion efficiency. For example, latest gas turbines can achieve efficiencies exceeding 60 %. A variety of thermochemical reactions are also possible and offer a wider range of applications including hydrogen production using water electrolysis, natural gas reforming, ammonia synthesis, and carbon dioxide capture. Such reactions require temperatures greater than 800 °C, but magnetic characteristics in iron etc. are lost at such high temperatures and thus eddy current heating becomes problematic. Superconductors however, can produce greater magnetic fields without magnetic materials being present. A precedent is the world's first superconducting furnace system, which has tactically utilized superconducting characteristics to induce high magnetic fields in non-magnetic materials. When closed in a ceramic container, temperatures can reach the boiling point of the conductor. This improves thermoelectric conversion efficiencies and the easier realization of applications based on thermochemical reactions. There are almost no developmental issues since the superconducting magnet employed operates sufficiently at DC 1-2 Tesla. At adjacent temperatures of -250 °C and +800 °C, there is a track record of single crystal silicon growth furnace.

In Japan, the wind farm market with the installation of ground-based wind turbines is expected to be 20 GW by 2030. Worldwide, nearly 1,000 GW installations are planned for only ground-based wind turbines [3]. Thus, for 2 MW-class wind turbines, this equates to the construction of nearly 10,000 units in Japan and 500,000 units worldwide. Therefore, there lies a significant market potential if the feasibility of superconducting wind heat power is verified economically.

Fig. 2 Superconducting furnace system currently in operation. Continuous operation without the awareness of superconductivity.

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