Thu-Mo-Po.4-12-01 [88]

Mobile Superconducting Magnetic Energy Storage for On-site Estimations of the Electric Power System Stability

Shinichi NOMURA[1], Tanzo NITTA[2] and Takakazu SHINTOMI[3]

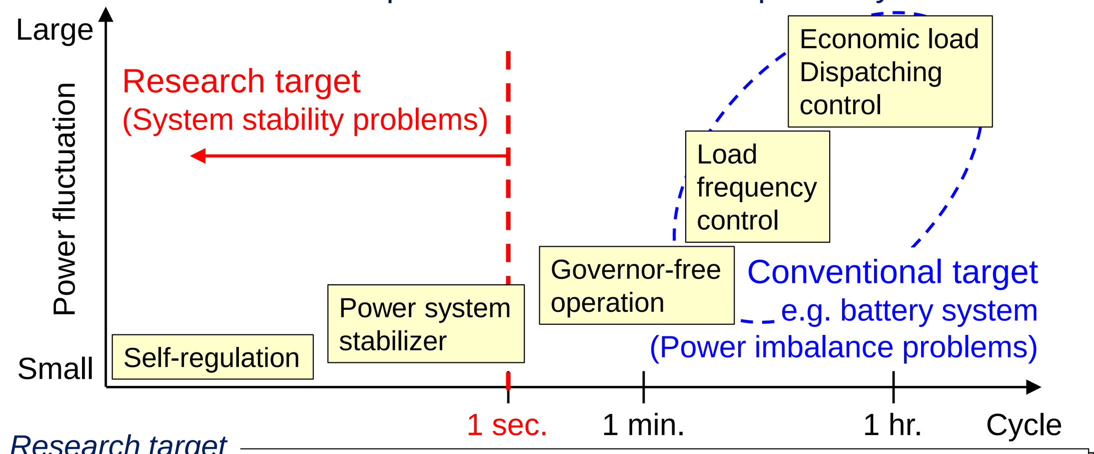
1) Meiji University, 1-1-1 Higashimita, Tama-ku, Kawasaki, Kanagawa 214-8571 Japan

2) The University of Tokyo, Japan, 3) High Energy Accelerator Research Organization, Japan

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Introduction

- Control methods for the power fluctuations in the power system



Research target

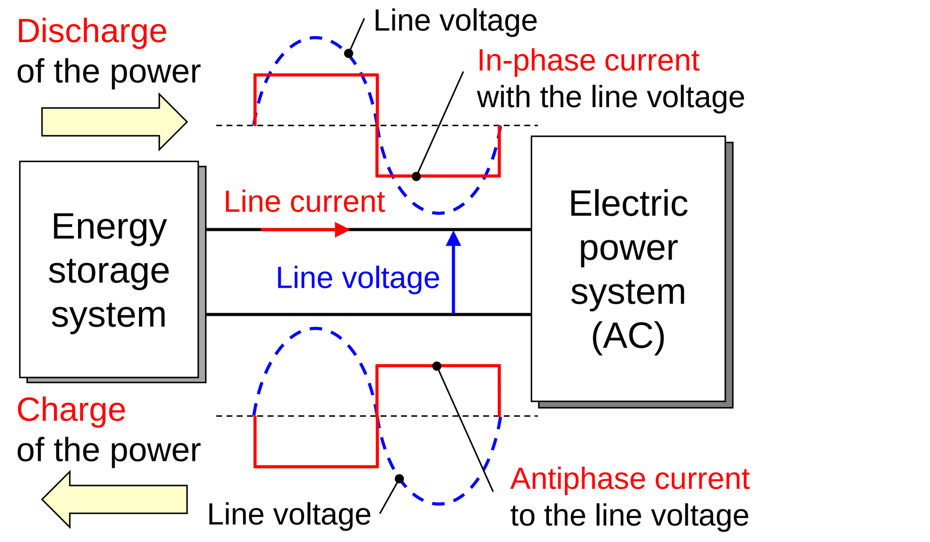
Compensation of the power fluctuations with less than 1 second of the cycle for the enhancement of the system stability.

SMES becomes a promising candidate.

- ✓ Current supply capability with a minimal influence on the power system.
- ✓ Simple charge/discharge controllability with a rapid cycle.

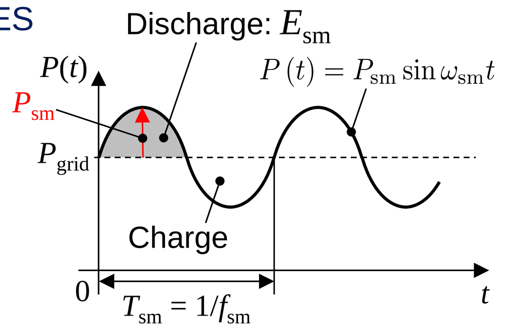
Fundamental Operation of the Storage System

The grid-connected energy storage system requires the same capability of a current supply to the power system.



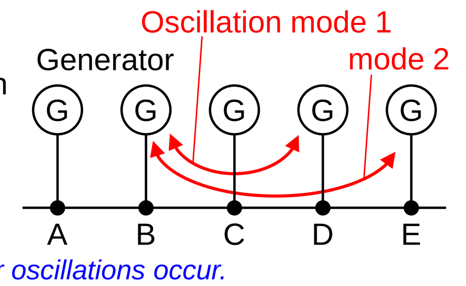
Required Specifications of the SMES System

- Output power and stored energy of SMES
  - ✓ Output power of SMES P_{sm}
    1% of the capacity of the target system
  - ✓ Charge/discharge cycle f_{sm}
    Around the natural frequency: 1~2 Hz
  - ✓ Stored energy $E_{sm} = P_{sm}/\pi f_{sm}$
    Ex) 0.32 MJ in the1-MW and 1-Hz case
    0.95 MJ in the 3-MW and 1-Hz case



- Mobility of the SMES system
  - ✓ Real time variations of the oscillation modes
  - ✓ Complex distributions of the power oscillation

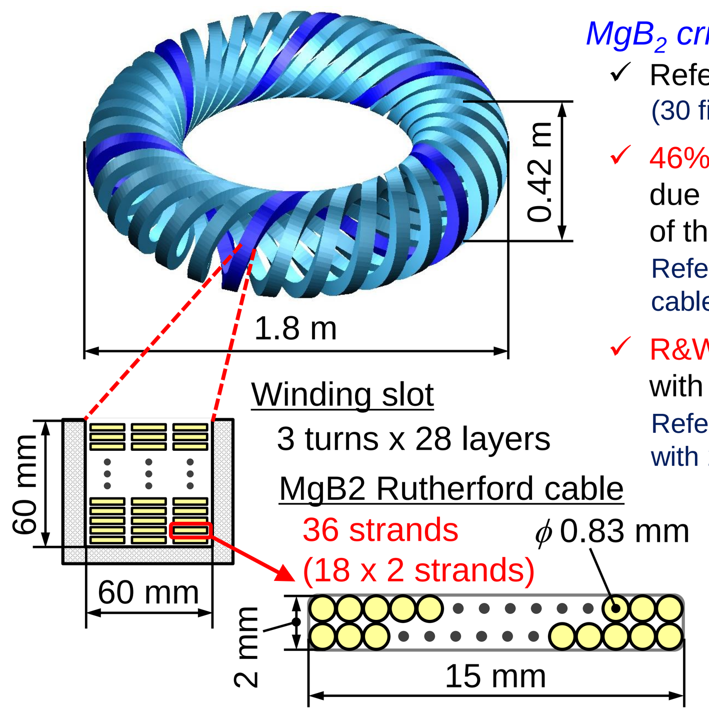
Example



Node	A	B	C	D	E
Mode	none	1 & 2	?	1, 2?	2

Node C: The generator is not oscillated, but the power oscillations occur.
Node D: The oscillation mode 1 mainly occurs. The mode 2 may be difficult to be identified.

1-MJ Class SMES Coil Windings



MgB$_2$ critical current properties

- ✓ Refer to the Hyper Tech 30-NM (30 filaments, fill factor: 20%)
- ✓ 46% of the original critical current due to the manufacturing process of the Rutherford cable.
  Refer to the test results of the Rutherford cable with 12 strands [1].
- ✓ R&W method applied to the FBCs with 150 mm of the minimum radius.
  Refer to the single pancake coil design with 269 mm of the inner diameter [2].

[1] M. Jimbo et al., IEEE Trans. Appl. Supercond., vol. 29, no. 5, Art no. 8003305, 2019.
[2] T. Yagai et al., Cryogenics 96 (2018) 75-82.

Conditions of the Heat Load Estimation

- Radiative heat transfer
  - ✓ The surface area of the torus is 6.0 m^2.
  - ✓ The effective emissivity between 300 K and 80 K is 0.020.
  - ✓ The effective emissivity between 80 K and the cooling temperature is 0.016.
  - ✓ The superinsulation effect is 1/10 of the heal load without superinsulation.
- Heat leakage from coil supports
  - ✓ The supports are made of GFRP.
  - ✓ The outer and inner diameters of the supports are 100 mm and 90 mm.
  - ✓ The support length is 300 mm.
  - ✓ The number of the supports is 6 (less than 1/200 of the withstand load).
- AC losses
  - ✓ The hysteresis loss is only estimated.
  - ✓ The hysteresis loss is evaluated by the center toroidal magnetic field.
  - ✓ The magnetization variation in 20 K is assumed to be 0.0002 to 0.0006 T in the magnetic field range of 2.3 to 1.2 T.
  - ✓ The critical current density in 10 K is assumed to be 2.5 times higher than that in 20 K.

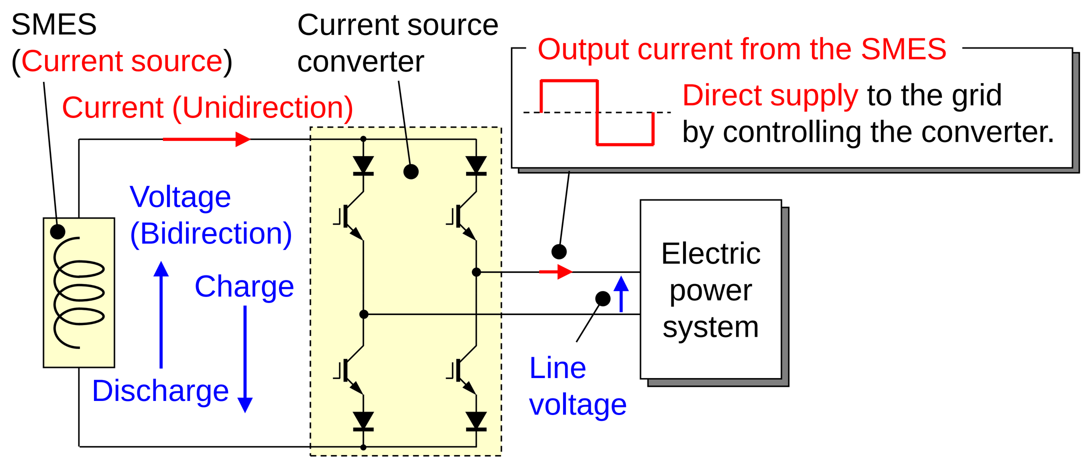
Electric Power System Stability Problems

- Lack of the inertial energy of the generators (Hardware problem)
  - *Conventional power system*
    - ✓ Power fluctuations (less than 1 sec.) can be absorbed by the inertial energy of the synchronous generators in the hydro or thermal power plants.
  - *Renewable energy system (e.g. PV system, wind power)*
    - ✓ Increase in the interconnection through the power converters.
- Limitation of the high-precision stability calculation (Software problem)
  - *Conventional power system*
    - ✓ Economical power system operation is achieved in accordance with the calculation results of the system stability with a suitable margin.
  - *Electric power liberalization*
    - ✓ Difficulty of understanding the properties of the entire power equipment. (Excessive margin is required for the stable power system operation.)
  - *Renewable energy system*
    - ✓ Modeling of the power system becomes an important research theme. (The validity of the modeling should be confirmed in the actual system.)

Superconducting Magnetic Energy Storage

SMES is a promising candidate for the system stability problems.

- Development results as a high-response energy storage system.
  5-MVA and 10-MVA SMES systems for bridging instantaneous voltage dips (less than 1 second of the discharging time)
  S. Nagaya et al., Cryogenics 52 (2012) 708-712.
- Load factor improvement of SMES used as a power system stabilizer.



Optimization of the SMES Coil Configuration

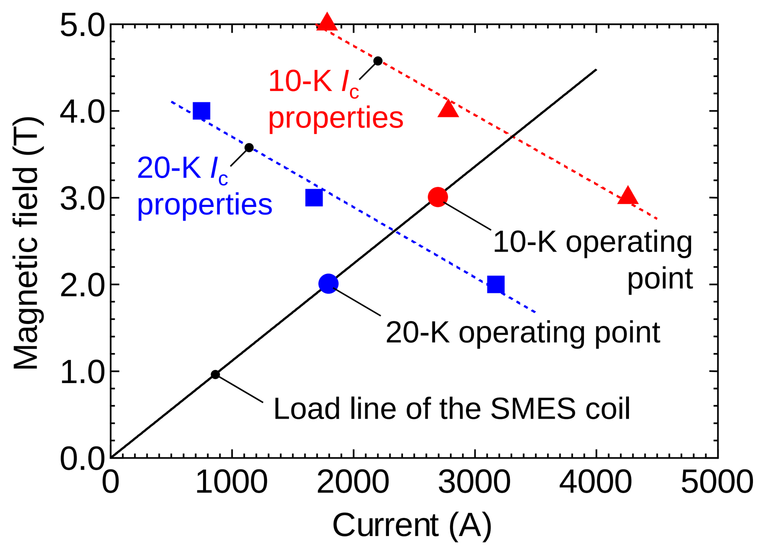
Development target: 1-MJ class mobile SMES system

- Use of MgB$_2$ Rutherford cable
  - ✓ Reduction of the cooling power requirement.
  - ✓ Manufacturability of high current conductors by the effect of round strands.
  - ✓ Design flexibility of the stored energy of SMES depending on the power system conditions by selecting an optimal cooling temperature.
- Mobility and weight saving of the SMES coils
  - Feasibility of the Force-Balanced Coils (FBCs) -

- ✓ Balancing the electromagnetic forces by the effect of the helically winding configuration.
- ✓ Minimization of the mass of the structure for energy storage basing on virial theorem.
- ✓ Improvement of the stress limitation of the superconductors in a high field range.

Manually wound Force-Balanced Coils with 0.53 of the outer diameter. This coil was successfully excited up to 6.3 T without reinforcements for the NbTi strands.

Critical Current Properties



Variations of the operating points

- ✓ 20-K operation: 0.97 MJ, 2.0 T, 1800 A
- ✓ 10-K operation: 2.2 MJ, 3.0 T, 2700 A

Heat Loads and Cooling System

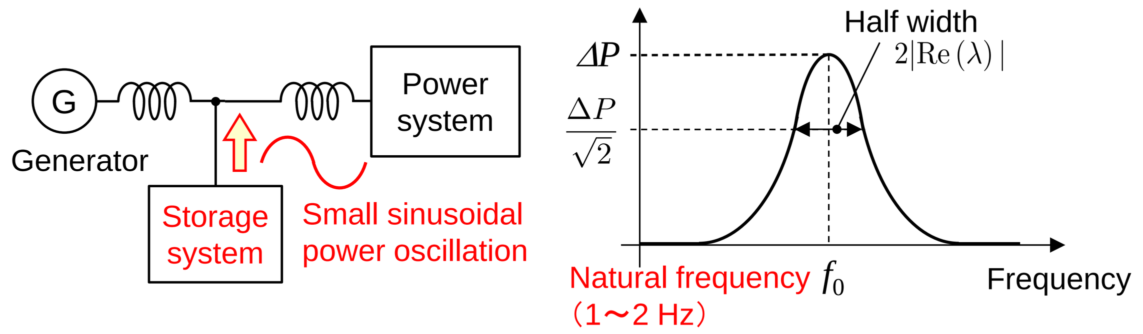
	Case 1	Case 2	Case 3	Case 4
Output power P_{sm} (MW)	1.0	1.0	3.0	3.0
Frequency f_{sm} (Hz)	1.0	1.0	1.0	2.0
Available energy E_{sm} (MJ)	0.32	0.32	0.95	0.48
Max. / Min. magnetic field*1 (T)	1.5 / 1.2	1.5 / 1.2	2.3 / 1.7	2.3 / 2.0
Cooling temperature (K)	20	20	10	10
80-K thermal shield	w/o	w/	w/	w/
Radiative heat transfer (W)	5.6	0.23	0.23	0.23
Heat leakage from supports (W)	3.0	0.25	0.28	0.28
AC loss (Hysteresis loss) (W)	1.7	1.7	5.4	3.4
Total heat load (W)	10	2.2	5.9	3.9
Number of cryocoolers*2 (for 80 K thermal shield)	1 set (none)	1 set (1 set)	2 sets (1 set)	1 set (1 set)

*1 *The center toroidal magnetic field variation during the discharge/charge operation.*
*2 *The heat capacity at 50 Hz: 40 W in the 20-K case, 5.4 W in the10-K case.*

On-site Estimation of the System Stability

Direct measurement technique of the system stability (eigenvalue)

Eigenvalue λ : Parameter of an oscillation mode of the power system.



High-response energy storage is required for the eigenvalue identification.

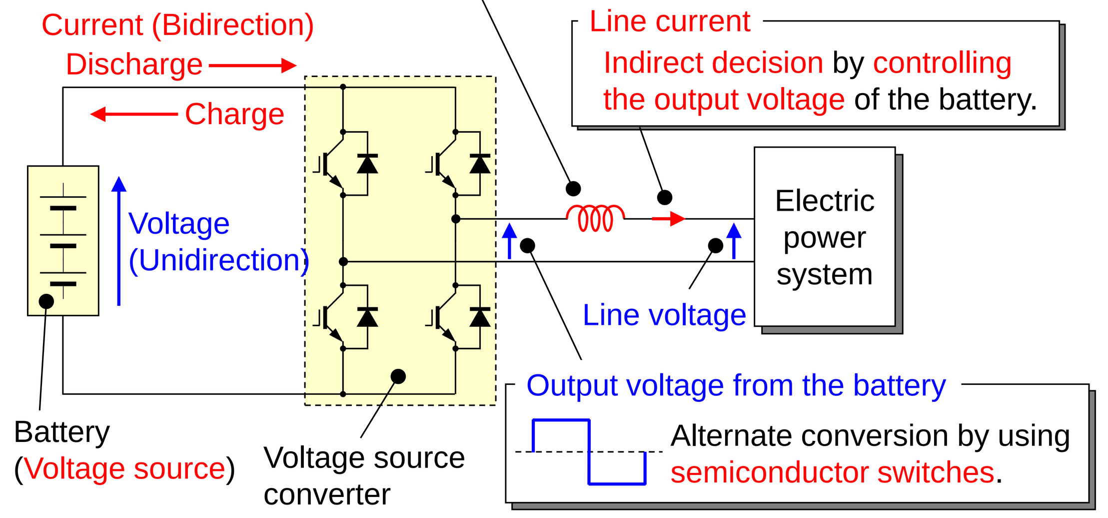
- Experimental results of SMES using an analog simulator
  Peak power of SMES: 0.01 p.u. (Generator (0.4 p.u.) ×2+Infinite bus)
  Required capacity of SMES is almost 1% of the capacity of the target system.
  T. Yonezu, T. Nitta, J. Baba, IEEE Power and Energy Society General Meeting 2008.

Development target: 1-MJ class mobile SMES system

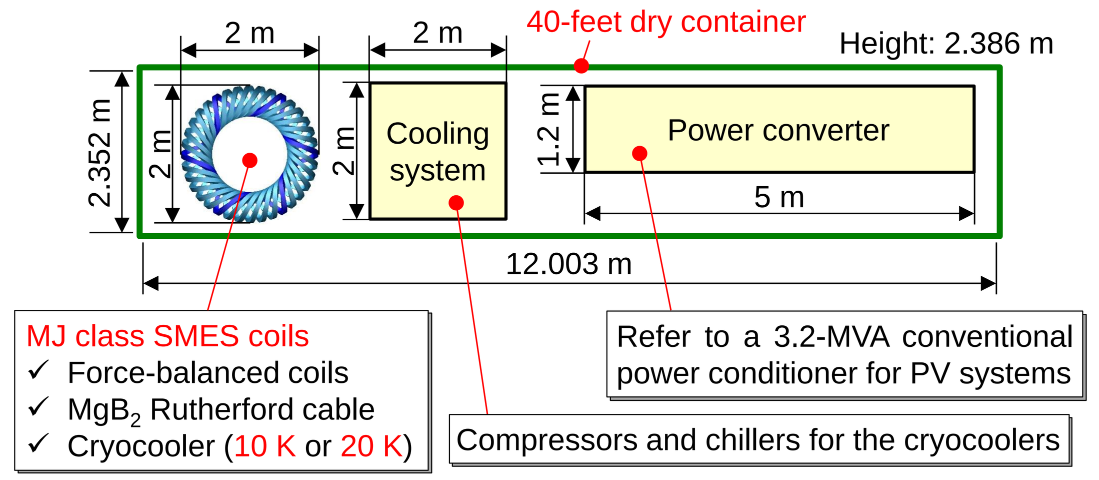
Comparison to the Battery Energy Storage

The battery system will be more suitable for the power imbalance problems between supply and demand in the renewable energy system.

Necessity of a grid-connected reactor
(Impossibility of the direct connection between the different voltage sources.)



Schematic Layout of the Mobile SMES System



Examples of the installation sites

- Substations (100 MVA class): Eigenvalue measuring device use
  (Power system stabilizer use will be realized by increasing the SMES units.)
- Solar power plants (1 MW class):
  - ✓ Eigenvalue measuring device use with 1% of the rated power of SMES.
  - ✓ Power system stabilizer use with the rated power operation.

Key Parameters of the 1-MJ Class SMES Coil

Major radius / Minor radius	0.72 m / 0.18 m	
FBC helical windings	6 x 6 x 84 turns	
MgB$_2$ Rutherford cable length	4.1 km	
Mass of the MgB$_2$ Rutherford cable	6.2 x 10^2 kg	
Mass of the winding form (GFRP)	4.2 x 10^2 kg	
Total mass of the SMES coil	1.0 x 10^3 kg	
Cooling temperature	20 K	10 K
Maximum magnetic energy	0.97 MJ	2.2 MJ
Maximum magnetic field	2.0 T	3.0 T
Coil current	1800 A	2700 A
Max. stress in the MgB$_2$ Rutherford cable*	6.1 MPa	14 MPa
cf. single solenoid case	28 MPa	64 MPa

*Maximum stress is estimated from virial theorem.

By the effect of the FBC winding configuration, the electromagnetic forces can be supported by the tensile stresses in the MgB$_2$ Rutherford cable.

Conclusions

- SMES becomes a promising candidate for the system stability problem in the power system. For the on-site identification of the eigenvalue, the 1-MJ class SMES components can be installed in a 40-feet dry container.
- Design study on the 1-MJ class SMES using MgB2 Rutherford cables was carried out. By the effect of the FBC design, the SMES coil can be excited up to 2.0 or 3.0 T without reinforcements for the MgB2 Rutherford cables.
- The 1-MJ class SMES coil can be cooled by 1 or 2 sets of the conventional cryocoolers even when the cooling temperature is 10 K. Especially, in the case of 20 K, the SMES system can be operated without a 80-K thermal shield.

Future works

- Investigation of the effective installation sites for the eigenvalue identification through the power system analysis.
- Experimental verifications of the design study results by developing a laboratory prototype using MgB2 Rutherford cables.

Acknowledgement

The authors would like to thank RASMES: Research Association of Superconducting Magnetic Energy Storage for their valuable discussions and their collaborative works.