Experimental and Theoretical Study on Power Generation Characteristics of 1 kW Class Fully HTS Induction/Synchronous Generator using a Stator Winding with a Bending Diameter of 20 mm

Tenghui Dong\textsuperscript{1}, Taketsune Nakamura\textsuperscript{1}, Jun Matsuura\textsuperscript{1}, Takanobu Kiss\textsuperscript{2}, and Kohei Higashikawa\textsuperscript{2}, Shigeru Sato\textsuperscript{3}, Peihong Zhang\textsuperscript{2}

1. Department of Electrical Engineering, Kyoto University, Japan
2. Department of Electrical Engineering, Kyushu University, Japan
3. ULTEX, Fukuoka 812-0007, Japan
1. Research background

Generator plays a very important role in the process of energy saving and emission reduction.
2. Advantage of HTS generator

**Advantages:**
- High efficiency;
- High torque density;
- Autonomous stability for variable speed;
- High overload capacity.
- ...
Using HTS conductors in stator windings has great potential to reduce the copper loss and improve the torque density.

Next step:

Fully HTS induction/synchronous generator

Smaller size machines
4. Imbalance between the three-phase impedances

At a specific moment, the superconductors of the A-B-C phases may be at different conducting state, due to the non-linear characteristics of the HTS material.
5. Challenge of making HTS stator coil

High temperature superconducting tape is relatively brittle. It is very susceptible to damage or even fracture when it is bent.

[I-V curve of HTS tape under different bending diameters][2]

Fracture patterns of filaments in HTS [1]

Schematic structure of REBCO tapes[3]

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6. Stator winding with a small bending diameter

- Minimum bending diameter = 20 mm
- Stiff support
- End part of the HTS coil

**Wiring diagram of 3-phase coils**

- Phase number: 3
- Pole number: 4
- Coils per phase: 12
- Winding Type: Concentrated winding
- HTS type of stator: REBCO (SuperPower Inc)
- HTS type of rotor: REBCO (Nippon steel Corp)
7. Manufacturing of the fully HTS generator

HTS rotor fabricated with the REBCO bulk superconducting conductor.

1 kW class fully HTS induction/synchronous generator

HTS stator fabricated with the REBCO coated superconducting conductor.
8. Benchmark test system

Experimental test setup

Schematic diagram of the test system

PM motor (mechanical input)
Non-contact torque transducer
LN2 Cooled metal cryostat
Fully HTS generator

Power analyzer
Mechanical input
Inverter$^1$ of PM

Inverter$^2$ of generator
HTS Generator
LN2 coolant

Torque & speed
Electrical data collection
DC line

Schematic diagram of the test system

8. Benchmark test system
9. Benchmark test procedures

Control the mechanical input (PM) to a predetermined speed

Excite the HTS generator at the Sync frequency by inverter

Gradually reduce the generator’s frequency in small range

Adjust and maintain the voltage at different slip rates

Measurement

Procedure of bench test

Schematic diagram of the test system
10. Test result

Critical current with 90 A is realized in liquid nitrogen.

Stable electric power generation is achieved in full HTS-ISG.

V-I curves of HTS stator in liquid nitrogen (77 K)

Power generation waveform under load: \( f = 40 \text{ Hz} \) & excitation current = 30 A
10. Test result

**Power generation characteristics at different excitation frequency**

**Ascending curve of current with slip rate (40Hz_6V)**

**Power generation characteristics at different voltages**

**Conducting states of HTS coil during power generation**
11. Past reference result

In conclusion, larger critical current capacity on the stator is necessary for realizing 1 kW.

12. Future work to improve HTS-ISG performance

Use specially developed Face-to-Face Double Stack (FFDS) conductor to increase stator coil current and motor torque density.

Bending properties of the Face-to-Face Double Stack (FFDS) conductor

13. Conclusions and prospects

- The HTS tape can maintain good super-conducting after being bent with a diameter of 20mm.
- The critical current of HTS conductor decreases after being bent. That means in addition to the magnetic field and the temperature, the manufacturing process should also be considered in the design stage.
- Stable power generation requires special control methods to assist.

✓ The study will also benefit the realization of the braking energy recovery in the electric drive system with HTS motor.
✓ The relationship between the mechanical input threshold of electricity generation and the excitation frequency needs further exploration.
Thanks for your attention!