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MITSUBISHI ELECTRIC Changes for the Better
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Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10650

Joint R&D project on development of electric power equipment using new functional insulating materials

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Motivation

- In Japan, the number of aging electrical devices is steadily increasing and must be replaced soon. It is preferable to replace obsolete equipment with high-performance counterparts.
- Nanocomposites and functionally gradient materials (FGM) are innovative materials studied for decades and can dramatically increase the performance of insulators.

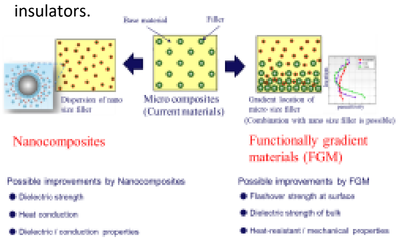

Figure 1. Principles of insulating material improvement

Methods/Approach

- We launched the joint R&D project with the aim of developing new high-performance insulating materials for electric power equipment using nanocomposites and FGM.
- The project consists of ten educational research organizations, six companies, and two research institutes, with a grant from the New Energy and Industrial Technology Development Organization (NEDO) (JPNP12004) , 2017–2021 FY.

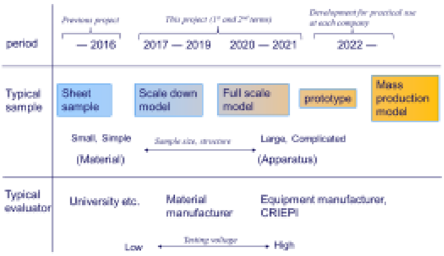

Figure 2. Development and evaluation stages

Object of investigation

- Insulation materials for following equipment

Stator of Large-scale Rotating Machine
- Mitsubishi Electric

GIS Spacers
- Fuji Electric & Toshiba ESS

Windings of Medium- and Small-Scale Rotating Machines
- Sumitomo Seika Chemicals

Figure 3. Target equipment

- Common platform technology

Measurement and Evaluation Techniques
- CRIEPI with Nagoya Univ. and Kyutech (Joint research)

Experimental setup & test results

- At each participating institution, various samples were prepared according to equipment type and development stage and were used for testing.
- The following are samples for demonstrating the insulation performance of each device used in the final stage of the project.

Stator of Large-scale Rotating Machine
- Coil model using the nanocomposite - mica composite

Insulating Materials for GIS Spacers
- Full scale cone-type model spacers for 245 kV class GIS

Windings of Medium- and Small-Scale Rotating Machines
- Demonstration rotating machine manufactured using newly developed enamel-insulated wire

- For example, the large-scale test equipment used in this project includes the CRIEPI high-voltage experiment used for the impulse withstand voltage test of the GIS spacers and the AC withstand voltage test, as shown in Figure 4.

(a) Exterior (b) Power supplies

Figure 4. High voltage laboratory of CRIEPI

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Insulating material for stator of large-scale rotating machine

- Figure 5 shows the basic concept for developing insulators using epoxy resin with nanofillers/mica composites.
- Reductions in windage losses are expected due to the high thermal conductivity, high dielectric strength, and partial discharge of the nanocomposite.

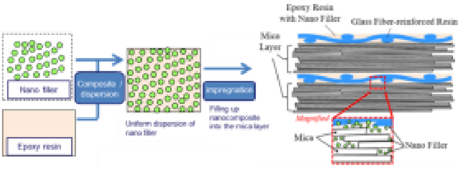

Figure 5. Concept of stator coil insulation

- Figure 6 shows the results of the V-t test on epoxy resins filled with nanoparticles. From this result, the nanocomposite life could be estimated, and the evaluation progressed to the electrode system close to the actual machine, including the conductor and mica tape.

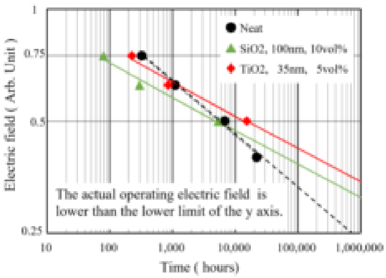

Figure 6. V-t curves of test bar models with mica/nanocomposite insulation

- In addition to empirical tests, research on the mechanism of partial discharge resistance development, evaluation of the degree of aggregation of nanofillers, and methods of controlling aggregation during nanocomposite production were conducted mainly at universities with which we collaborated.

Insulating materials for gas-insulated switchgear (GIS) spacers

- As shown in Figure 7, the principle of GIS compactification is focused on the control of the electric field distribution around the spacer using FGM technology.

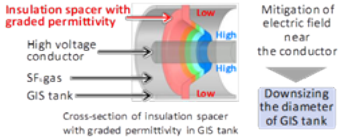

Figure 7. Downsizing of GIS tank diameter by cone-shaped spacer with graded relative permittivity

- Full-scale cone-shaped spacers for 245 kV class GIS have been manufactured and used for various tests. Dielectric strength estimation using the inverse solution method and volume time theory was used to obtain the permittivity distribution for optimizing the electric field around the spacer. Figure 8 shows the electric field distribution around the spacer obtained by electric field calculation.

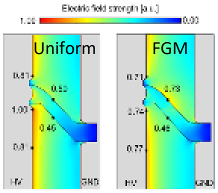

Figure 8. Electric field distribution around spacer

- The LIWV test and the temperature rise test using the bus model were performed on the spacer, whose diameter was reduced by about 20% using FGM, and superior results were obtained.
- The study of resin injection behavior was also conducted by flow analysis and experiments for the production of actual products, as shown in Figure 9.

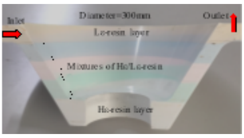

Figure 9. Experimental result of resin injection behavior in one-inlet model

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Insulating material for windings of medium- and small-scale rotating machines

- As shown in Figure 10, the insulation thickness can be reduced using enamel whose partial discharge resistance is dramatically improved by the nanocomposite. We aimed to reduce copper loss by about 7% by increasing the cross-sectional area of the conductor as the insulation thickness decreased.

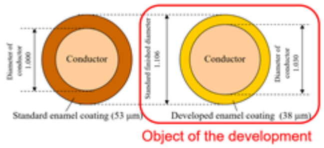

Figure 10. Cross-sectional view of enamel wires for small- and medium-sized rotating machines

- Figure 11 shows the results of the V-t test on the sheet sample. The material developed has excellent partial discharge resistance.

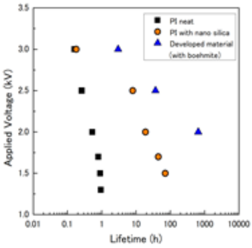

Figure 11. V–t characteristics of enameled wires

- Sumitomo Seika Chemicals manufactures enamel wire using the developed material, applies it to a rotating test machine as shown in Figure 12, confirms energy efficiency, and has cleared the target of 7%.

(a) Enamel wire (b) Test rotating machine

Figure 12. Developed enamel wire and test rotating machine

Measurement and evaluation techniques

- We are developing several electrical test methods and approaches for evaluating the dispersibility of fillers in materials as basic technologies that can be used to evaluate the insulating materials of each device.
- Figure 13 shows an example of analysis via micro-Raman spectroscopy used as one of the methods of dispersity evaluation.

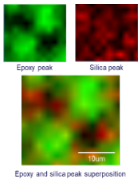

Figure 13. Filler dispersion evaluation by Raman scattering spectrum intensity mapping in silica filled epoxy resin

Discussion

- It is possible to reduce the size of the insulator or increase the cross-sectional area of the conductor by improving the insulation performance of polymer insulating materials, while maintaining the outer shape.
- The energy saving effect can be exhibited by increasing the cross-sectional area of the conductor and enhancing the thermal conductivity.
- In the case of the switchgear, the energy required to manufacture the container can be saved mainly due to the miniaturization. It is also possible to reduce the amount of SF_6, which is a greenhouse gas.
- Enamel wire is particularly versatile and is applied to a wide range of fields, including the automobile industry.

Conclusion

- We have outlined the processes and outcomes of the project related to the development of new insulators for electrical apparatuses using nanocomposites and FGMs in Japan.
- We have succeeded in developing new insulation materials for each device and are currently conducting various evaluations and clarification of the insulation mechanism using full-scale samples.
- As a common technology, we are continuing R&D of evaluation techniques such as a technique for quantifying the state of filler dispersion in materials.