Expected Residual Life Estimation Techniques for High Voltage Rotating Machines

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Abstract

After more than twenty years of operation, many electrical facilities are reaching their time of renewal. However, the general trend of such capital investment has faced the problem of budget cuts. In recent years, the load to the electrical facilities has increased and the maintenance and inspection of such facilities have become increasingly important.

We have developed a technique of estimating expected residual life for electrical facilities. For high voltage and extra high voltage class rotating machines (6kV, 11kV class), we are collecting data regarding nondestructive diagnosis and insulation breakdown. Through the database of statistical diagnostic data, it is possible to estimate the residual life expectancy for rotating machines.

1 Preface

Many electrical facilities manufactured after the 1970s (high economic growth period) are still in operation in Japan. However, financial investment in plant and equipment has tended to be restrained. Recently, the load to the electrical facilities has increased further because of an increase in the facility availability. Under such circumstances, the needs for maintenance and inspection are further increased for electrical facilities.

High voltage or extra high voltage class generators and motors ("rotating machines" hereafter) are essential to electrical facilities. If rotating machines become inoperable, the result cannot be limited to only the shutdown of a plant and the remaining lifeline may be seriously affected. Most rotating machines have been used for more than twenty years and their users are required to take adequate countermeasures such as extension of life for rotating machines or renewal.

This paper introduces the development of our diagnostic techniques (estimation of expected residual life) for the stator windings of 6.6kV rotating machines.

2 Insulation of Windings for Rotating Machines

2.1 Diagnosis

Most causes of failure in rotating machines are related to their windings. When winding deteriorates and insulation breakdown occurs, social and economic losses are substantial. It is therefore essential to assess the state of deterioration in winding insulation so that adequate countermeasures can be taken.

For early detection of deterioration in windings, we are promoting diagnostic services for winding insulation of rotating machines. Fig. 1 shows our

Fig. 1 Meiden Diagnosis Car

Our diagnosis car is shown. One complete set of diagnostic equipment is loaded onto this car. A single car is capable of diagnosing in the field.

diagnostic car. **Table 1** shows the items of diagnosis.

2.2 Factors of Deterioration

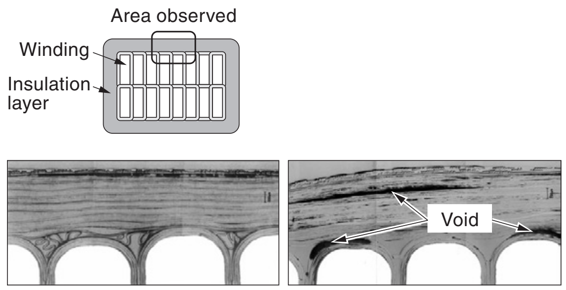
Deterioration can be caused by any one, or combination, of the following factors: thermal, electrical, mechanical, and environmental. Due to these factors, voids and/or cracks are generated within the layers of winding insulation. In a location where voids and/or cracks are produced, partial discharges are generated. Partial discharges give rise to erosion in the insulation layers, thus leading finally to insulation breakdown.

Fig. 2 shows cross sections of a coil observed before and after thermal accelerated deterioration test. These cross sections were viewed as part of the deterioration mechanism study we promoted for rotating machines. After the occurrence of deterioration, a large void can be perceived. Starting with such a void, partial discharges are generated and we surmise that the insulation layer is then eroded by these partial discharges.

Table 1 Items of Insulation Diagnosis

Test items and contents of diagnosis are shown. These are the items of diagnosis applicable to general rotating machines. Each diagnostic item indicates that there is an effect of evaluation in the contents of related diagnosis.

Test item		Major contents of diagnosis
DC absorption test	Insulation resistance for 1 minute (MΩ)	Contamination and moisture absorption
	Polarity index	
Tan δ test	tan δ_0 (tan δ of base)	Contamination and moisture absorption
	C_0 (base capacitance)	
	Δtan δ	Void and exfoliation
	$\Delta C/C_0$	
AC current test	ΔI	Void and exfoliation
	P_{i1} (Sudden-increase point of primary current)	
	P_{i2} (Sudden-increase point of secondary current)	
Partial discharge test	Q_m (Maximum electric charge quantity)	Local deterioration
	V_i (Power-frequency sparkover voltage)	



(a) Cross-section of deterioration-free sample

(b) Cross-section of a sample after deterioration

Fig. 2 Winding Cross-Section of Rotating Machine

A cross-section of rotating machine coils is shown for investigation. Compared with a deterioration-free item, a sample after undergoing thermal deterioration shows voids in insulation layer. Such a condition suggests that there has been a progression of deterioration.

3 Investigation into Expected Residual Life Estimation Approach

3.1 Expected Residual Life Estimation Study

We investigated the estimation formula for residual breakdown voltages that will be introduced below. The residual breakdown voltage denotes a insulation breakdown voltage to be measured after the deterioration in windings of rotating machines. The breakdown voltage in windings has sufficient performance for the operation of a rotating machine for a long time. There is, however, some dispersion according to the difference in insulation configuration or specifications.

Therefore, the residual breakdown voltage used in this section should mean the rate of breakdown voltage before and after deterioration. It is difficult to obtain test data of the breakdown from an actual machine. This is reason, we have tried to obtain data from actual machines and also data from accelerated deterioration testing with the use of a model coil as shown in **Fig. 3**. Based on this data, we could draw an estimation formula for residual breakdown voltages, for example on the basis

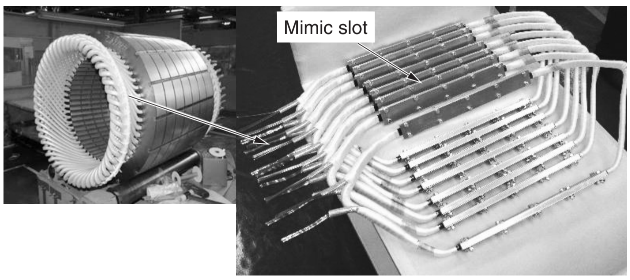


Fig. 3 Model Coil

An external appearance of model coils, used for the testing is shown. These coils are manufactured in the same manner as those of actual machines. In order to set up the condition more like that of an actual machine, mimic core slots are mounted.

of, multiple regression analysis and a neural network method. **Fig. 4** shows an outline of the accelerated deterioration test for model coils.

3.2 Correlation between Diagnostic Parameters and Residual Breakdown Voltage

Fig. 5 shows the correlation between the maximum electric charge quantity "Qm" (operating voltage) of discharge and the residual breakdown voltage. Value Qm is one of the insulation diagnostic parameters and this value is believed to have the closest relationship with the residual breakdown voltage of coils. Along with an increase in Qm, a tendency can be confirmed in the reduction of residual breakdown voltage. Generally, the breakdown voltage needed to assure operation of rotating machines is 2E + 1kV (E: rated voltage) and we define the machine life with this value. The diagnostic judgment standard with Value Qm comes in a variety of figures among manufacturing companies. At our company, 5000pC is regarded as the judgment standard (caution needed) although there are some differences among various machine types. According to the result shown in **Fig. 5**, we recognize that the residual breakdown voltage is lowered to a level of the standard value when Value Qm is greater than 5000pC.

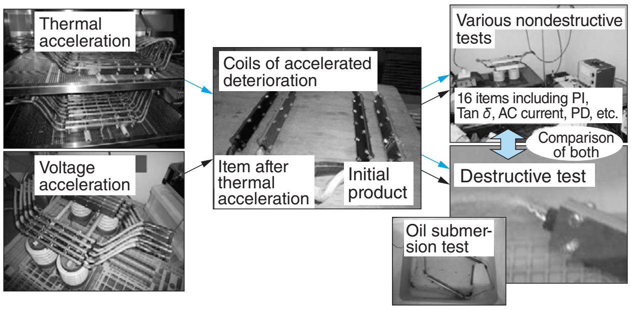


Fig. 4 Accelerated Deterioration Test for Model Coils

Outlined accelerated deterioration test is shown for the model coils. Both thermal and electrical stresses are applied to the model coils. This test is carried out for the presumption of operational life by examining changes in electrical characteristics and those in breakdown voltages, both considered to be caused by deterioration.

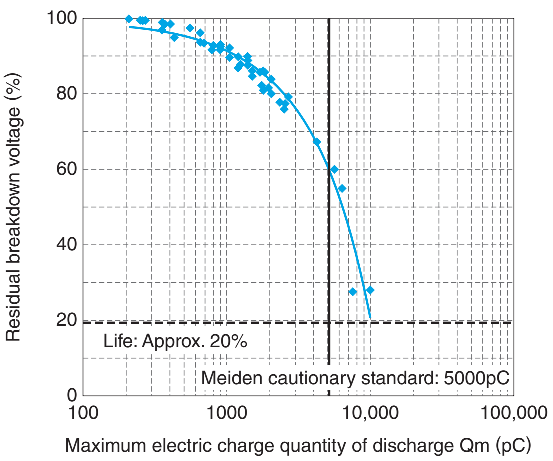


Fig. 5 Correlation between Maximum Electric Charge Quantity of Discharge and Residual Breakdown Voltage

Correlation between maximum electric charge quantity and residual breakdown voltage is shown because it is one of the parameters for insulation diagnosis. As the maximum electric charge quantity of discharge increases, there is a tendency of a decrease in residual breakdown voltage. If our judgment standard (caution needed) of maximum electric charge quantity of discharge 5000pC is exceeded, breakdown is possible.

3.3 Estimation Formula for Residual Breakdown Voltages of High-Voltage Rotating Machines

Using various diagnostic parameters acquired, we have established an estimation formula for residual breakdown voltages of high-voltage rotating machines. When we use this estimation formula, it is possible to estimate a residual breakdown voltage without being influenced by environmental factors such as humidity. If a comparison is made between data from actual machines and values from estimation formula, it is possible to expect the evaluation of expected residual life.

Fig. 6 shows an example of the estimation formula. There is a favorable correlation between actually measured values and theoretical values led from the estimation formula.

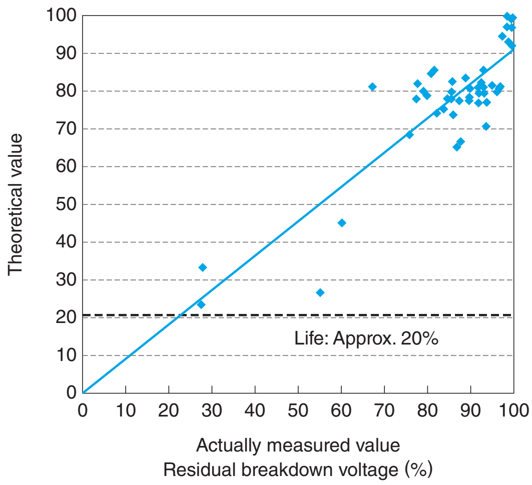


Fig. 6 Introductory Diagram of Estimation Formula for Residual Breakdown Voltage

This diagram shows a comparison between coil breakdown voltage estimated from diagnosis and actual breakdown voltage.

4 Postscript

This paper introduced processes of expected residual life estimation with the use of multiple regression analysis and a neural network. Improvement of accuracy is an important subject for the estimation formula. In this connection, we will continue to collect diagnostic data from actual machines and make efforts to optimize the estimation formula. Rotating machines may involve some peculiar problems such as layer short, slot discharges, vibration sparking, and so on. They are significant phenomena that can give rise to serious insulation breakdown in windings in a short amount of time. Since no preliminary sign can be indicated in advance, it is difficult to carry out preventive maintenance. We have been developing the diagnostic techniques to resolve these challenges.

Going forward, we will make every effort to offer high-quality services to our customers through further reinforcement of diagnostic techniques.