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Review on Trend of Diagnostic factor as a Function of Thermal and Multi Ageing Time of 6.6 kV Rotating Machine Insulation System

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SUMMARY

The demand of study on reliability evaluation of rotating machine such as generators on a large ship is increasing, because it takes a lot of time and cost to repair rotating machine in the event of an unexpected failure. Although quantitative diagnostic factors such as partial discharge, loss tangent are used as indicators of the evaluation on residual lifetime of rotating machine, it is essential to obtain diagnostic criteria through each of the tests for reference system because insulation properties of rotating machine have a lot of difference depending on the change of design, insulation materials, and manufacturing processes.

In this paper, the thermal evaluation test and the multifactor evaluation test were carried out based on IEC 60034-18-31:2012 and IEC 60034-18-33:2010 in order to obtain the estimated lifetime and diagnosis data on an insulation system of 6.6 kV rotating machine. To deteriorate test specimens which represent stator of the rotating machine, a sub-cycle including environmental conditioning and thermal/multifactor ageing was carried out. In order to check the condition of the specimens for each of the sub-cycles, high voltage tests and diagnostic tests were carried out. End-point of test according to failure of each specimen was determined by high voltage tests considering the electrical breakdown of turns or mainwall insulation. Partial discharge, loss tangent, and insulation resistance were measured to evaluate trend of diagnostic factors. From the test results, residual lifetime was obtained and reference values (Caution and Risk) of breakdown were proposed. The result data of the reference system through the thermal evaluation test and the multifactor evaluation test can be used to compare the lifetime and reliability of candidate systems.

KEYWORDS

Rotating machine, Insulation system, Thermal index, Ageing, Loss tangent, Partial discharge

1. Introduction

The performance of an insulation system of rotating machine gradually deteriorates depending on operating condition with mechanical damage, electrical performance degradation, and environment factor (vibration, temperature, humidity, salinity, dust, particle, etc.), and finally electrical breakdown occurs. Since an unexpected breakdown of rotating machine causes a lot of time and cost to repair, it is necessary to determine maintenance schedule of insulation system of the rotating machine in advance by predicting residual lifetime. The quantitative value of diagnostic factors such as partial discharge, loss tangent, insulation resistance is measured to determine failure of insulation system. However, it is difficult to predict residual lifetime due to the difference on performance of insulation system depending on the change of design, insulation materials, and manufacturing processes [1, 2].

In this paper, the thermal evaluation test under thermal stress, the multifactor evaluation test under simultaneous application of thermal and electrical stresses were carried out based on IEC 60034-18-31:2012 and IEC 60034-18-33:2010 in order to get the diagnostic information of reference system. Each of the tests is intended to analyze the performance of insulation system of 6.6 kV rotating machine according to thermal or multifactor endurance. Before the tests, specimens with insulation system having a thermal index of F-class (155°C) were produced, and then ageing sub-cycle including mechanical conditioning, humidity conditioning, thermal ageing, multifactor ageing were carried out. Following the ageing sub-cycle, high voltage tests (steep-front-impulse voltage withstand test, AC withstand voltage test) and diagnostic tests (partial discharge, loss tangent, and insulation resistance) were carried out to evaluate condition of specimens according to thermal or multifactor endurance [3, 4]. Through these test processes, accelerated life model and trend of diagnostic factor were analyzed concerning electrical breakdown specimens and live specimens without electrical breakdowns.

2. Experimental setup

2.1 Preparation of specimen

These standards describe construction of the test object and the processes for accelerated life test of insulation system of high voltage rotating machine. Figure 1 shows a test specimen assembled stator coils of 6.6 kV rotating machine. The coil consists of the strand insulation tape, mainwall insulation tape, conductive/semi-conductive tape, shrink tape, and epoxy resin which are having a thermal index of F-class. These coils were inserted into the slots, and then the epoxy resin was assimilated throughout insulation system of the coils by vacuum-pressure impregnation and the insulation system was cured by drying process. Specimens were applied to each ageing section which was selected in 3 different types for each of the thermal evaluation test and the multifactor evaluation test.

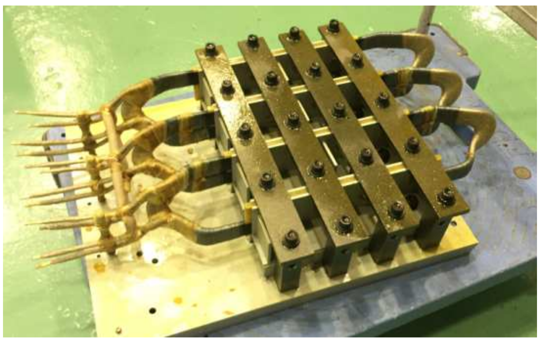
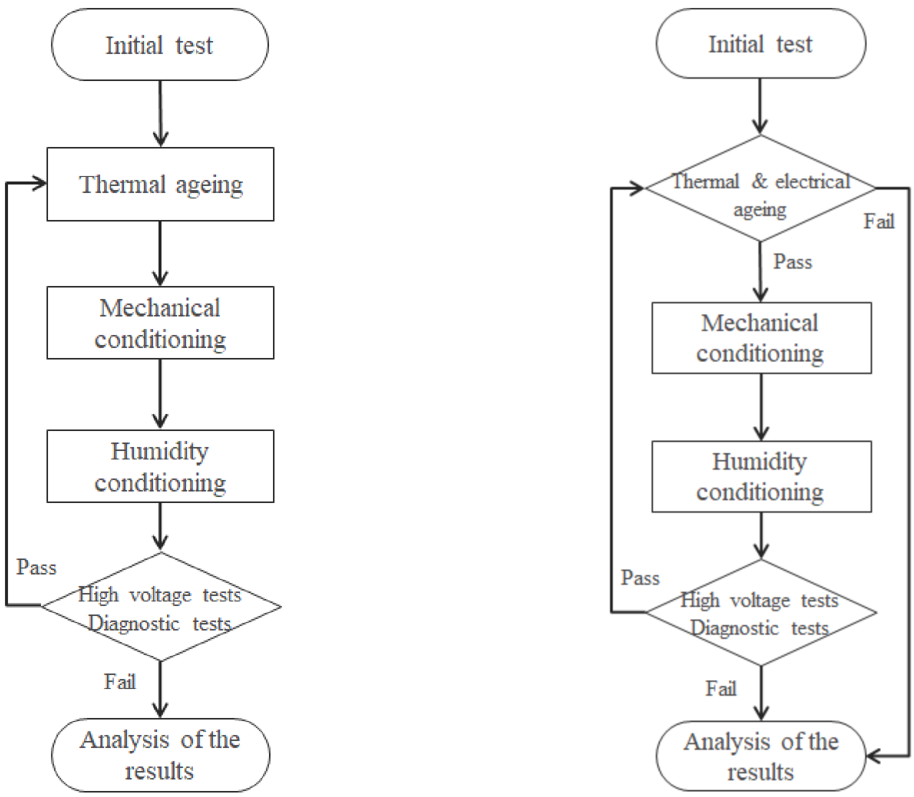


Figure 1. A test specimen assembled stator coils of 6.6 kV rotating machine

2.2 Test procedure

Figure 2 shows the flow charts regarding the process of accelerated life test. Initial test including visual inspection, mechanical conditioning, humidity conditioning, high voltage tests, and diagnostic tests was performed to inspect initial quality of specimen. The mechanical conditioning was applied to the specimen by vibration of peak-to-peak amplitude of 0.2 mm at frequency of 60 Hz for 1 hour, and then the specimen was exposed to moisture of 25°C and 95% relative humidity for 48 hours. Following these environmental conditioning tests, the high voltage tests including the rated steep-front-impulse voltage withstand test and the power-frequency voltage withstand test were carried out in order to detect the defective specimen. Test impulse having a front time of 0.2 μs ± 0.1 μs and amplitude of 20 kV was repeated to 5 times between turns, and between turns and frame of the specimen, 13.2 kV AC withstand voltage was applied for 1 minute between terminals of the specimen and ground. Additionally, diagnostic tests (partial discharge, loss tangent, and insulation resistance) were carried out to obtain data of the initial condition. The only specimens that passed the initial test were subjected to the accelerated life tests. The ageing section to the thermal evaluation test was defined as level 1 (180°C, 21-day/cycle), level 2 (210°C, 6-day/cycle), and level 3 (230°C, 2-day/cycle). The section to the multifactor evaluation test was defined as level 1 (145°C, 1.7*U_N, 25-day/cycle), level 2 (155°C, 1.9*U_N, 4-day/cycle), and level 3 (165°C, 2.1*U_N, 2-day/cycle). The rise/fall time between the initial temperature (25°C) and the target temperature was applied for 2 hours. After each ageing, the environmental conditionings, the high voltage tests and the diagnostic tests were carried out in the same way of the initial test. The failure time according to electrical breakdown of the specimens was recorded at the high voltage tests and the trend of diagnostic factors was analyzed from the diagnostic tests.



(a) Thermal evaluation test (b) Multifactor evaluation test

Figure 2. Flow charts of process of accelerated ageing test

3. Test results

3.1 Accelerated life model

3.1.1 Thermal evaluation test

Table 1 shows the results of the electrical breakdown caused by thermal stress. MTBF (Mean Time Between Failures) of level 1, level 2 and level 3 was calculated as a, b, and c hours respectively.

Table 1. Test results of thermal evaluation test

Section	Cumulative cycle [cycle]	Total number of specimens [each]	Number of specimen with electrical breakdown [each]	MTBF [hour]
Level 1 (180℃, 21-day/cycle)	24	9	0	a
Level 2 (210℃, 6-day/cycle)	25	9	4	b
Level 3 (230℃, 2-day/cycle)	16	6	6	c

- Note 1-1. Censoring of live specimens was carried out at the last cumulative cycle.
- Note 1-2. MTBF of each level was specified in Figure 3.

As shown in Figure 3, the Arrhenius accelerated life model was calculated from MTBF of each section. A temperature corresponding to the MTBF of 20,000 hours was 175℃. From the test results, a performance of more than F-class (155℃) was verified and a lifetime with 79 years (692,000 hours) in continuous operating condition at 120℃ was derived from the estimated lifetime curve of the specimen.

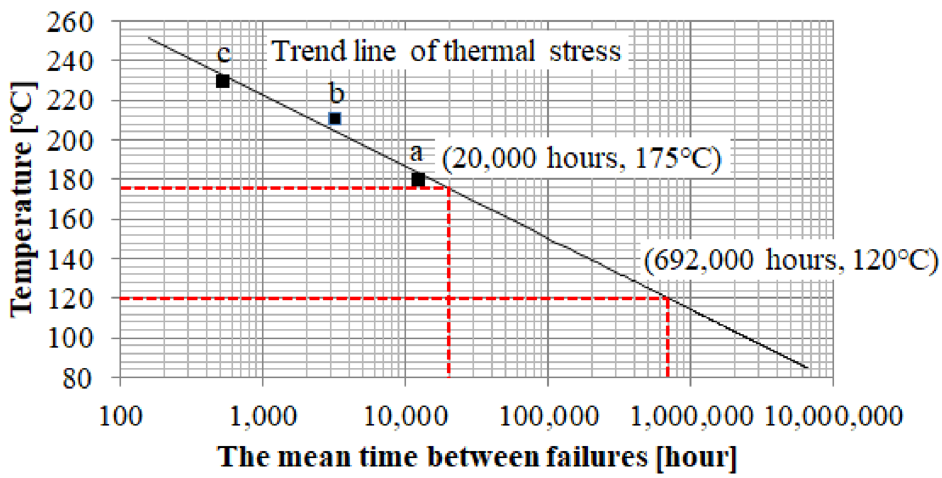


Figure 3. Estimated lifetime curve of specimen through thermal evaluation test

3.1.2 Multifactor evaluation test

The results of the electrical breakdown caused by simultaneous application of thermal and electrical stresses are given in Table 2. MTBF of level 1, level 2 and level 3 was calculated as d, e, and f hours respectively.

Table 2. Test results of multifactor evaluation test

Section	Cumulative cycle [cycle]	Total number of specimens [each]	Number of specimen with electrical breakdown [each]	MTBF [hour]
Level 1 (145°C, 11.22 kV, 25-day/cycle)	11	5	3	d
Level 2 (155°C, 12.54 kV, 4-day/cycle)	8	5	3	e
Level 3 (165°C, 13.86 kV, 2-day/cycle)	11	6	2	f

- Note 2-1. Censoring of live specimens was carried out at the last cumulative cycle.
- Note 2-2. MTBF of each level was specified in Figure 4.

The simultaneous application accelerated life model in Figure 4 was calculated from MTBF of each section. An estimated lifetime of this insulation system was 81 years (710,000 hours) in continuous operating condition at 115°C and 1.1*U_N (7.26 kV).

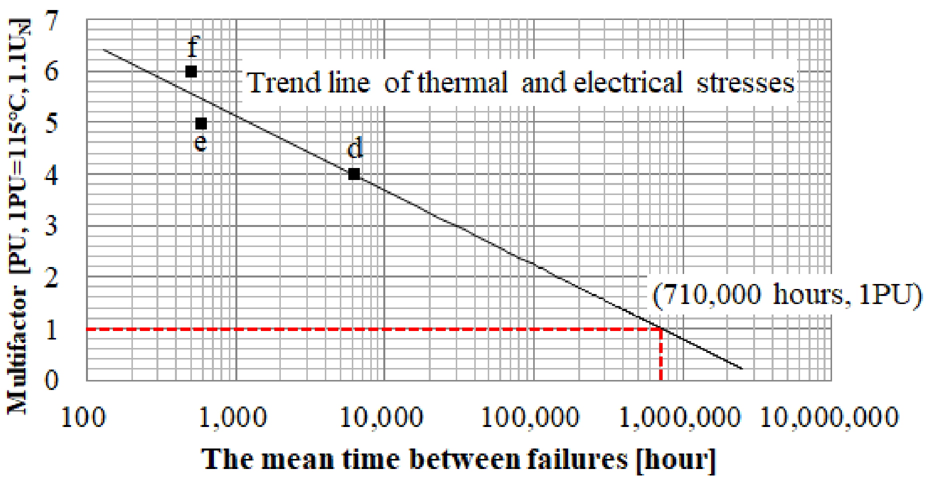
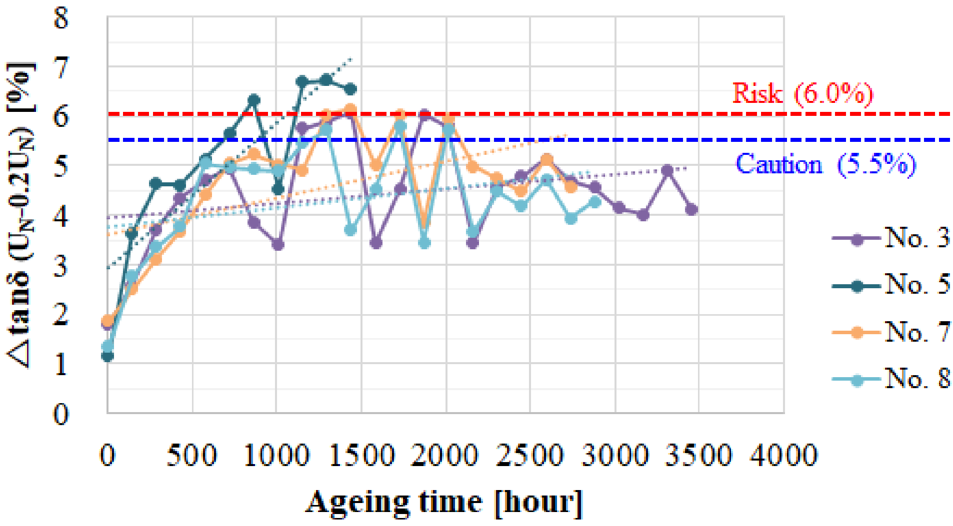


Figure 4. Estimated lifetime curve of specimen through multifactor evaluation test

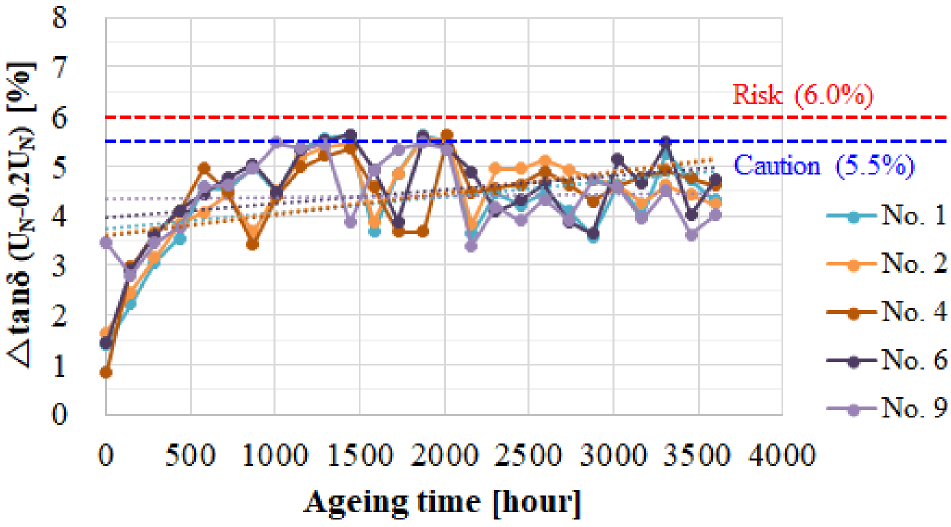
3.2 Trend of diagnostic factor

Although it is difficult to predict electrical breakdown by applying data of partial discharge and insulation resistance, a failure can be predicted using the trend of the loss tangent through the thermal evaluation test.

As shown in Figure 5 and Table 3, the trend of electrical breakdown specimens and live specimens was analyzed with a value of delta-tan delta (U_N - 0.2U_N) according to deterioration of inside defect of insulator. The maximum values of the specimens with electrical breakdown (No. 3, No. 5, No. 7 and No. 8) were 6% or more or 6% close. From the trend line, Caution (5.5%) and Risk (6.0%) were proposed.



(a) Electrical breakdown specimens



(b) Live specimens without electrical breakdown

Figure 5. Trend of loss tangent value through thermal evaluation test at level 2 (210℃)

Table 3. Maximum value of loss tangent through thermal evaluation test at level 2 (210℃)

Division	Specimen	Maximum value [%]	Ageing time [hour]
Electrical breakdown	No. 3	6.07	1440
	No. 5	6.72	1296
	No. 7	6.14	1440
	No. 8	5.80	1728
Without electrical breakdown	No. 1	5.62	1872
	No. 2	5.58	1872
	No. 4	5.62	2016
	No. 6	5.65	1440
	No. 9	5.48	1008

4. Conclusions

The estimated lifetime and trend of diagnostic factors on insulation system of 6.6 kV rotating machine were obtained from the tests based on IEC 60034-18-31:2012 and IEC 60034-18-33:2010.

(1) The reference system has a performance between F-class (155℃) and H-class (180℃) according to a temperature corresponding to the MTBF of 20,000 hours.
(2) The estimated lifetime of this insulation system is about 79 years in continuous operating condition at 120℃
(3) The estimated lifetime of this insulation system is about 81 years in continuous operating condition at 115℃ and 1.1*U_N.
(4) Loss tangent was selected as trend of diagnostic factor, Caution (5.5%) and Risk (6.0%) were proposed for a value of delta-tan delta.

The results of diagnosis data of the reference system will be utilized to improve lifetime and reliability of candidate systems.

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