Determination of the Minimum Acceptable Value of Insulation Resistance for Formwound Motor Winding EQ Test

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1. Introduction

Usually, the large motors important to safety for NPPs located outside containment in PWRs. Though they work important part to safety function, they don't have to be environmentally qualified because they are located in mild conditions. But the large motors in PHWRs, important to safety, must be environmentally qualified according to IEEE Std 323 due to their location, inside containment.

Type test are recommended qualifying method for electric equipments, it is determined to carry out the type test to qualify large motors in PHWRs.

To carry out the type test for large motor or motor winding according to IEEE Std 323, IEEE Std 334-2006 and IEEE Std 43-2000 are referred during the whole type test procedure and function test[1].

One of the function test step is insulation resistance(IR) testing. The minimum acceptable value of IR is mentioned in IEEE Std 43-2000 as 100MΩ at 40°C with the approximating coefficient equation regarding to the temperature. The temperature varies 48.8°C to 148.3°C during EQ DBE testing, there is no mention about the acceptable IR value during DBE testing.

In this paper, by the comparison the data using the approximation coefficient equation with the data measured in the experiment, tried to find out the acceptable IR value during motor winding DBE testing.

2. Methods and Results

2.1 IEEE Std application for formwound motor winding

IEEE Std 334-2006 describes criteria for qualification of continuous duty Class 1E motors in order to demonstrate their ability to perform their intended safety functions under all required conditions[1].

The type test sequence is described in section 5.3.3 of IEEE Std 334-2006. During the type testing, functional tests of the sample to establish base line performance and sufficient data shall be taken to verify operability under load at the extremes of the motor's operational characteristics[1].

The first functional test is IR testing. IEEE Std 334-2006 requires the IR testing to perform in accordance with IEEE Std 43-2000. IEEE Std 43-2000 describes the minimum acceptable values of IR is described in section 12.3 in IEEE Std 43-2000 as follows,

The minimum IR after 1 min, IR_{1min}, for ac and dc machine stator windings and rotor windings can be determined from Table 1. The actual winding IR can be, corrected to 40°C, obtained by applying a constant direct voltage to the entire winding for 1 min[2].

Table 1. Recommended minimum IR values at 40°C (all values in MΩ)

Minimum insulation resistance	Test specimen
$IR_{1\ min} = kV + 1$	For most windings made before about 1970, all field windings, and others not described below
$IR_{1\ min} = 100$	For most dc armature and ac windings built after about 1970 (form-wound coils)
$IR_{1\ min} = 5$	For most machines with random-wound stator coils and form-wound coils rated below 1 kV

As shown in table 1, the minimum IR after 1 min, IR_{1min} is 100 MΩ for the formwound coils at 40°C. But during the EQ testing, the IR testing will be executed at various temperatures. For example, during DBE testing, the temperature varies 48.8°C to 148.3°C according to IEEE Std 323-2003 including test margin.

2.2 Theory of temperature and IR

There is a theory between temperature and IR value that IR value halving for 10°C rise in temperature and IR value doubling for 10°C drop in temperature in IEEE Std 43-2000 section 6.3 as follows;

It is recommended that all insulation test values be corrected to a common base temperature of 40°C using Equation 1.

Equation 1. Approximating coefficient equation

$$K_T = (0.5)^{(40-T)/10}$$

Though the corrected value is an approximation, this permits a more meaningful comparison of IR values obtained at different temperatures. The recommended method of obtaining data for an IR versus winding temperature curve is by making measurements at several winding temperatures. When a logarithmic scale is used for the IR and a linear scale for the temperature, the test points should approximate a straight line that can be extrapolated to obtain the corrected value at 40°C by using Figure 1 for resistance halving for each +10°C increment. Note that this is only an approximation and should not be used to calculate IR at very large temperature differentials from 40°C or significant errors could result.

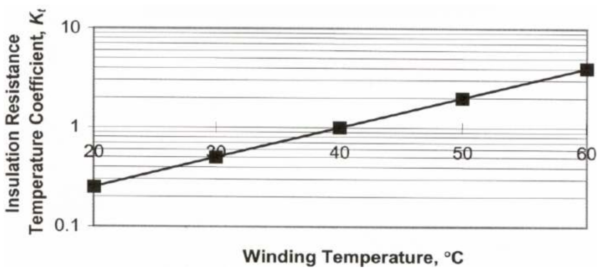

Fig. 1. Approximate IR coefficient, K_T, for insulation halving for 10 °C rise in temperature

2.3 Application of the theory

Using the theory, the minimum acceptable values of IR can be calculated at 90°C and 140°C

In case of 90°C, $K_T = (0.5)^{(40-90)/10} = 1/32$

∴ The corrected value = 100MΩ / 32 = 3.1MΩ

In case of 140°C, $K_T = (0.5)^{(40-140)/10} = 1/1024$

∴ The corrected value = 100MΩ / 1024 = 0.1MΩ

In the IEEE Std 43-2000 theory, there recommends this theory should not be used to calculate IR at very large temperature. But there is no mention about 'very large temperature'.

2.4 Experiment result

The acceptable value of the IR at 140°C is calculated as 0.1MΩ. But this result is open to argument that 140°C is 'very large temperature' or not. So the additional experiment is executed to verify the theory can be applicated at 140°C.

The test specimen is motor winding used in 4.16kV motor as shown in Figure 2. After putting the specimen into the electrical furnace as shown in Figure 3, raised the temperature each 10°C and measured the IR from 60°C to 150°C.

Fig. 2. Specimen

Fig. 3. Testing in furnace

The measured IR from 60°C to 100°C was infinite, there were changes from 110°C as shown in Table 2.

Table 2. Measured IR at each temperature

Temperature	60℃	70℃	80℃	90℃	100℃	110℃	120℃	130℃	140℃	150℃
Measured IR	∞Ω	∞Ω	∞Ω	∞Ω	∞Ω	50G Ω	33.9G Ω	16.0G Ω	7.33G Ω	3.70G Ω

As shown in the result, after 110°C, the measured IR is almost halving at each 10°C increase. This result can be shown easily in Figure 4.

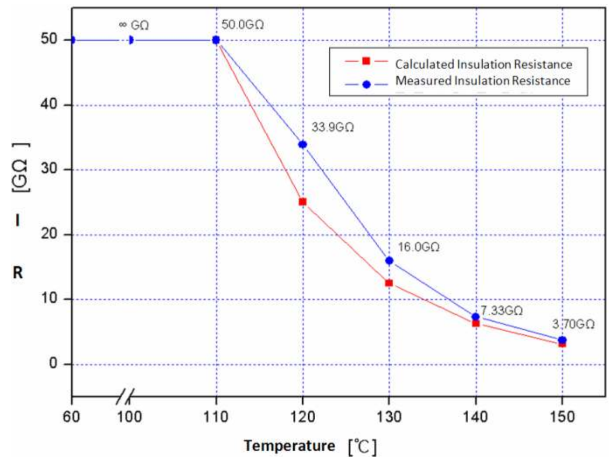

Fig. 4. Measured IR compared to calculated IR

In the Figure 4, the blue line is measured IR and the red line in calculated IR on each temperature.

3. Conclusions

The minimum IR after 1 min, IR_{1min} are obtained the corrected value at 40°C as the theory mentioned in IEEE Std 43-2000 'IR value halving for 10°C rise and IR value doubling for 10°C drop'.

To compare the calculated IR value with the measured IR value at 60°C to 150°C, additional experiment was executed.

At the temperature 60°C to 150°C environments, it is verified that the calculated values and measured values are almost same.

The theory mentioned in IEEE Std 43-2000, 'IR value halving for 10°C rise and IR value doubling for 10°C drop' can be used at least 150°C or less temperature.

The minimum acceptable value of IR is determined according to the temperature, 40°C-100MΩ, 90°C-3.1MΩ and 140°C-0.1MΩ. These results will be used as acceptance criteria for motor winding EQ type test.

REFERENCES

[1] IEEE Standard, "IEEE Standard for Qualifying Continuous Duty Class 1E Motors for Nuclear Power Generating Stations", IEEE Std 334-2006

[2] IEEE Standard, "IEEE Recommended Practice for Testing Insulation Resistance of Rotating", IEEE Std 43-2000