DIAGNOSTIC OF CABLE USED IN NUCLEAR POWER PLANT THROUGH VOLUME ELECTRICAL RESISTIVITY AND INDENTER

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Abstract: CSPE (chlorosulfonated polyethylene) as a control cable jacket is widely used in nuclear power plants. Cable monitoring is one of the important factors related with life time extension of nuclear power plants. Diagnostic method of the cable was investigated with volume electrical resistivity and the test results are compared with indenter, ultrasonic and OIT testing. The accelerated thermal aging of CSPE jacket of test cables were carried out for the period equal to 10, 20, and 30 years in air at 90, 100, 110, and 120℃, respectively. The volume electrical resistivity of the specimen were examined through three point method, and the correlation between cable aging and its volume electrical resistivity such as a diagnosis method for the cable jacket was studied. It was showed that volume electrical resistivity of CSPE jacket is dependent on the thermal aging levels. It can be stated that the condition monitoring of cable through a volume electrical resistivity is more convenient than others, and is possible to verify cable insulating capability.

1 INTRODUCTION

Increased life expectancy of nuclear power plants and extension of existing plant life have led to growing interest in utilizing parameters obtained from cable condition monitoring, to approximate remaining cable life with improved accuracy and thus to estimate the optimum time for cable replacement.

Cables for nuclear power plants are designed to endure through the plant life due to heavy cost of cable replacement and also the complexity of the process. However, degradation of cables installed in certain areas such as a containment building may surpass the normal aging rate and affect cable quality amid the designed working life. It is therefore most important to understand cable quality and condition, as well as appropriate replacement times, through the most proper condition monitoring technology.

Various approaches have been studied and proposed for condition monitoring to this day, yet there is no integrated method suitable for all cable types. Verifying electrical parameters is important in monitoring cables that deliver electrical energy and signals. However, most types of cables in previous researches did not demonstrate correlation between insulator or jacket degradation and electrical parameters such as insulation resistance, leakage current, loss coefficient, permittivity and/or breakdown voltage. It is because mechanical malfunction appears preceding the electrical failure in the process of cable aging.

Therefore, this research suggests a cable condition monitoring method using volume electrical resistivity, an electrical parameter that indicates properties of cable materials. The proposed method is applicable for cable materials of all types as it uses electrical properties of cable insulators, and it is possible to draw correlation between measured values and cable aging. Also, it provides direct information on insulator capability of the material and relatively convenient measurement compared to other methods.

2 VOLUME ELECTRICAL RESISTIVITY

Resistance values have conventionally been used to express the state and characteristics of insulating materials. These values, however, change to the aspects such as the shape and size of insulating materials and also the measurement position. Current practice is thus to use the volume electrical resistivity of the material, the absolute value that is unique to the material and unaffected by measurement conditions or material characteristics.

Volume electrical resistivity is normally the computed result of its value multiplied by the value of resistivity correction factor. Resistivity correction factor is applied based on the shape and size of the subject material as well as the measurement position. Calculating accurate volume electrical resistivity must consider the possibility of uneven distribution within the material, and hence the factor is used to add expected change in the filed energy to the estimation.

Use of volume electrical resistivity has become a popular method for material analysis, and the values over 10^8(Ω•cm) normally indicate insulators while values under 10^8(Ω•cm) are categorized as semiconductors. Volume electrical resistivity represents resistivity per 1 cubic centimetre and the unit is Ω•cm. Verifying the exact changes induced by cable aging can be achieved by measuring precise volume electrical resistivity of the insulating material of cables.

2.1 Measurement of Volume Electrical Resistivity

Measuring method and procedure were standardized (IEC 250 and ASTM D 150-81) to ensure accuracy in the measurement of volume electrical resistivity of cable samples. This research also adopted a Mitsubishi HIVRM (high impedance volume resistivity meter) with patented feature of automatic calculation to moderate measurement errors on code.

2.2 Test of Volume Electrical Resistivity

The sample material for the test was Chloro Sulfonate Poly Ethylene(CSPE) cable jacket (Taihan Electric Wire, 1995) of graded safety which has been in use for 3 years at Unit-5 of Ulljin Nuclear Power Plants.

In order to simulate 30 years of natural aging process at 50℃ plant temperature, samples tested for time accelerated aging at 90℃, 100℃, 110℃ and 120℃ for 10, 20 and 30 lab years.

2.3 Test Design

Natural aging was processed on a cable sample at temperature 50℃ and for 30 lab years in a thermal aging accelerator (see Figure 2). For comparison, other tested samples were set to 90℃, 100℃, 110℃ and 120℃ and processed for 10, 20 and 30 lab years. The actual duration of tests and corresponding lab years are presented in Table 1.

Table 1: Accelerated aging list of cable specimens

Specimens	Accelerated Aging Temperature(℃)	Accelerated Aging hour(h)	Operating hour(y)	Remarks
90-1	90	292.1	9.95	Operating Temperature : 50℃
90-2	90	697.6	19.6	
90-3	90	1,126.3	29.8	
100-1	100	92.6	10	
100-2	100	238.1	21	Activation
100-3	100	337.3	28.5	Energy :1.35 eV
110-1	110	31.0	10	
110-2	110	75.6	20.1	
110-3	110	103.0	41	
120-1	120	8.4	8.4	
120-2	120	26.6	20	
120-3	120	42.8	30.36	

Figure 1: Cable specimens

Volume electrical resistivity of each processed cable sample was measured for three times using measuring equipment, and the average values were recorded.

2.4 Results

Table 2 contains the results of volume electrical resistivity measurement on CSPE samples.

Table 2: Volume electrical resistivity measurement value of CSPE (unit: Ω·cm)

Time/Temp	90°C	100°C	110°C	120°C	Average
10 years	6.27	2.92	2.52	3.12	3.17
20 years	14.72	17.88	9.61	5.10	11.83
30 years	12.26	15.77	7.86	1.76	9.41

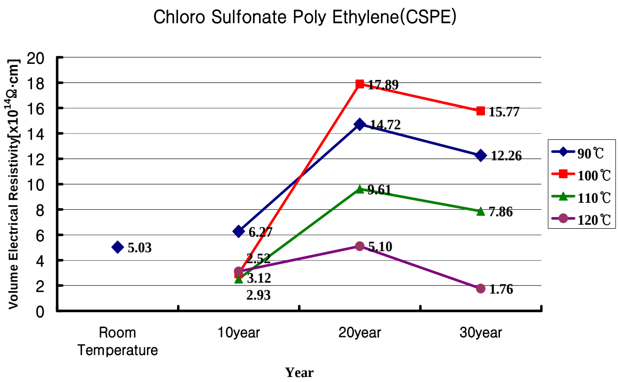

Figure 2: Volume electrical resistivity of CSPE

The test results indicate aging of CSPE material to progress similarly by year in each temperature group. As the Fig. 2 presents in a graph, almost no change in the characteristics of test material was observed for the first 10 years, while improved insulation features present in the period 10-20 years, which decline thereafter. The reason for such results is the stabilizers (plasticizer and antioxidant) used added for usage over the designed plant life (30/40years), which minimizes changes in insulating materials until the effect lapses.

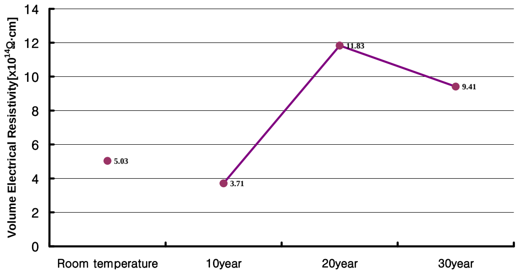

Figure 3: Total average of volume electrical resistivity of CSPE

It also seems that by-products (in gas or liquid form) imported during the insulation process in cable production remain within the insulator and restrict the performance, which improves as they are gradually released over the period by heat generated from field use. Acetophenone (liquid), cumyl-alsohol (liquid) and methane (gas) are mainly known by-products of insulation process. In fact, such substances are reported to produce large amounts of gas upon installation and cause early stage cable malfunctions by inflating components such as cable termination. The results suggest that the measured value of volume electrical resistivity of cable insulating materials to clearly demonstrate aging process of the material. It thus implies the applicability of volume electrical resistivity in monitoring cable condition and potentially for the estimation of remaining cable life, provided the gradient value of insulating degradation to be obtained by testing for extended periods over 30 years.

3 COMPARATIVE MEASUREMENT

3.1 Indenter

The values of indenter modulus were measured for the specimens that were assessed in the volume electrical resistivity test. A specialized device (independently developed by Korea Electric Power Research Institute) was used to measure indenter modulus of the samples after accelerated aging, 10 times per sample to record the average. Indenter modulus (kgf / mm) is calculated by the indentation test, measuring the depth (mm) of indentation on the insulating material divided by applied force (0.5 kgf). The greater modulus value means extensive hardening of sample's surface by aging process.

Table 3 contains the results of indenter modulus measurement on CSPE samples.

Table 3: Indenter modulus measurement value of CSPE (unit : kgf/mm)

Hour/Temp	90°C	100°C	110°C	120°C	Average
10 year	744	712	722	702	720
20 year	776	803	722	735	759
30 year	787	817	759	760	781

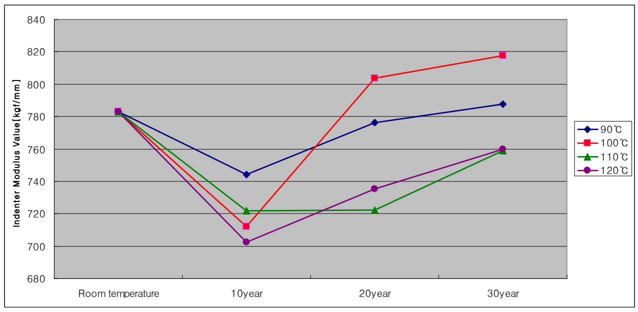

Figure 4: Indenter modulus of CSPE

A data analysis on the measures of indenter modulus presents shared trend by aging year for each temperature group. The above (Fig. 4) is the graph of the overall mean, which describes that elasticity of cable samples improve for the first 20 years of aging compared to the non-aged material at room temperature. Also, it confirms the elasticity of non-aged material to be maintained through 30 years aging process.

3.2 Ultrasound Reflection Time

The ultrasonic diagnostic method for insulator or jackets of the cables measures ultrasonic propagation velocity for axial direction of the material as the non-destructive degradation diagnostic parameter. Reflection time was checked several times for the same samples to get the average values. The testing result does not show a consistent trend of velocities in cable samples aged at different levels. The ultrasonic velocity is directly proportional to the density of the material that ultrasound pass. The velocity differences are so small that the results can hardly overcome an uncertainty during testing.

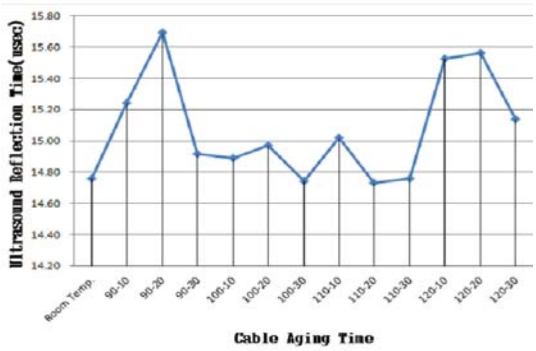

Figure 5: Ultrasonic test results

3.3 OIT test

Oxidation induction time is a measure of the time at which rapid oxidation of a test material occurs when exposed to a predetermined constant test temperature in a flowing oxygen environment. In this testing 0.05g sample at constant temperature 200℃ was evaluated to compare with the results of the volume electrical resistivity. The results show that antioxidants were dissipated due to thermal acceleration proportionally and the trend indicates cable degradation by ageing. The results show as follow figure 6.

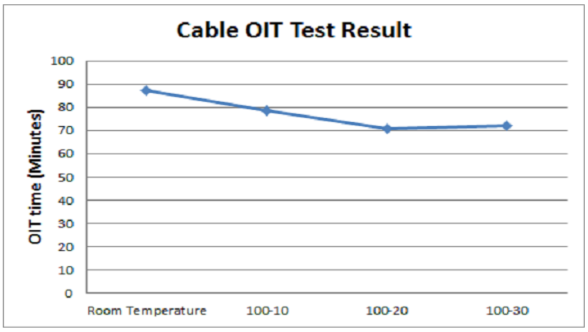

Figure 6: OIT test result

3.4 X-ray Micro-analysis

The cable surfaces were enlarged with scanning electron micro meter (SEM) to examine the condition of the samples. The samples are magnified 400 and 2,000 times respectively. The upper photos are 400 times, hardly distinguished porosities on the surface but more enlarged photos show air bubbles between polymer compounds.

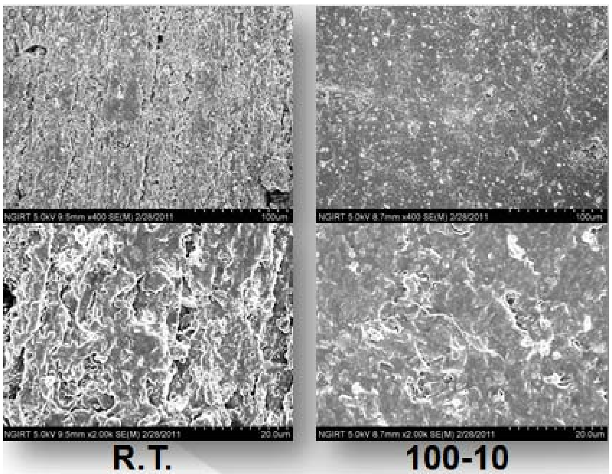

Figure 7: X-ray Micro-analysis photos

4 COMPARATIVE ANALYSIS OF MEASURED DATA: VOLUME ELECTRICAL RESISTIVITY, INDENTER MODULUS, ULTRASONIC AND OIT

The aging process of cable samples drawn by the indenter modulus and OIT test exhibits close similarity to what is illustrated by data analysis of the volume electrical resistivity measures but ultrasonic results didn't indicate a similar trend. In particular, the indenter modulus values of specimens with pre-conditioned aging acceleration for 30-year period maintained stability compared to the insulation characteristics of cable samples before the aging process, which parallels the analysis results from the volume electrical resistivity test.

5 CONCLUSION

The test cables in use at a currently operating nuclear power plant were sampled (CSPE jacket) for simulating natural cable aging at 50℃ system temperature for 30 lab years, to evaluate the applicability of volume electrical resistivity in cable condition monitoring at nuclear power plants. Accordingly, accelerated aging was applied on samples for 10, 20 and 30 lab years for each of temperature groups set to 90℃, 100℃, 110℃ and 120℃. Measuring volume electrical resistivity of each samples, prepared with accelerated aging for 30 lab years, allowed calculating changes in volume electrical resistivity to the temperature and time. The measures also indicated certain trend in relation to cable aging. Thus, it suggests possibility of evaluating cable aging state based on volume electrical resistivity measures.

The results of test data analyses indicated little change in insulating characteristics of the material for the first 10 years and improvement for the period 10-20 years. The functionality decreases after 20 years, but not to the extent lower than the state of non-aged cable sample before accelerated aging. The aging characteristics of cable samples obtained from the volume electrical resistivity test are similar to those resulted from the data analysis of intender modulus and OIT on the identical samples. This is mainly due to stabilizers such as plasticizer and antioxidant for long-term use throughout the designed plant life (30-40 years), minimizing changes of insulating materials until the effect lapses. Additionally, the insulation process inevitably allows import of by-products that remain within the material and released for certain period of time, which is believed to stabilize molecular structure.

6 REFERENCES

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