VLF Tan Delta Measurement for Used XLPE Power Cables

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1. Introduction

Medium voltage power cables in nuclear power plants are currently managed through the visual inspection or by monitoring environmental factors such as the temperature and radiation levels. However, these methods are insufficient to monitor aging degradation of power cables. The NRC requires an additional monitoring program to detect the aged degradation, especially for safety-related power cables which are inaccessible or installed underground [1, 2].

EPRI suggested that very low frequency (VLF) tan δ test be included in MV power cable diagnostic programs [3]. In addition, the VLF tan δ test was recently adopted for domestic submarine distribution cable diagnostics. KEPRI suggested that the impacts of leakage current should be controlled in VLF tan δ test for the submarine cables [4].

As a pre-process to develop such a program, tan δ tests have been performed for 4.16 kV cables which were removed from the domestic nuclear power plant after approximate 30 years of service to analyze the degradation of long time serviced cables and the effect of leakage current from the both ends of cables.

2. Methods and Results

2.1 Cable Description

The removed cables comprised 12 lines and approximate 400m totally. They were 5kV rated, 4/0 AWG, and insulation materials were cross-linked polyethylene (XLPE). As shown in Fig. 1, they passed duct banks in a concrete structure located in the turbine building basement to supply 4.16kV of power to four raw service water (RSW) pumps located in a separate building.

Fig. 1. RSW pump cables passing through duct banks before removal

After removal from their service location, the cables were cut into pieces approximately 100m long each for the test and transportation.

2.2 Leakage Current Consideration

Because the removed cables were kept outdoors for several days without a final treatment such as cable end sealing, moisture might permeate into the cable insulation and the layer located between the jacket and insulation. It could lead the leakage current flow from the conductor to the ground via the cable insulation surface easily. In addition, water tree can grow up and increase the resistive current of the total leakage current. Therefore, they may induce unintended distortion of VLF tan δ measurement.

Several activities were performed to minimize their impacts of moisture permeation. Firstly, nitrogen gas purging was performed to eliminate the moisture in the conductor and on the insulation surface. And then, 0.5m long cable jacket and outer semi-conductor layer from each cable end were cut out to minimize the leakage current from cable conductor to surface. Finally, guard rings were installed on the cable insulation at the both ends of the cable to let the leakage current bypass the cable itself, as shown in Fig. 2.

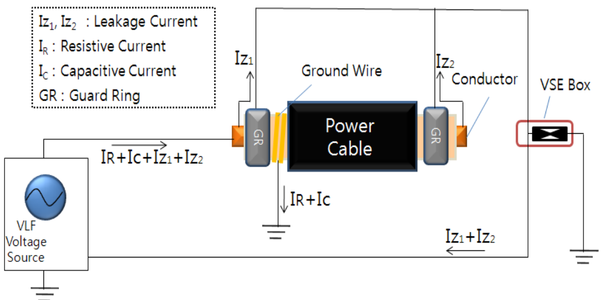

Fig. 2. Schematic diagram of VLF tan δ test adopting guard ring

2.3 VLF Tan Delta Measurement

Tan δ test which is called dissipation factor test determines the ratio of the resistive leakage current to the capacitive current through the insulation. VLF tan δ test device has advantage in size and weight. It is quite smaller than tan δ test device which uses commercial frequency of 60Hz because the VLF device uses 0.1Hz voltage source for the cables, and generally VLF tan δ devices are portable.

The applied voltages were $0.5U_0$ (U_0; phase-to-ground operating voltage in RMS), $1.0U_0$, $1.5U_0$ and $2.0U_0$ as an ordinary way. The resulting measured values of tan δ are shown in Fig. 3. With regard to the Δ tan δ($2U_0$ - $1U_0$), if the state of cable is good, the tan δ value should remain stable or increase very slightly as the induced voltage is raised. Specimen 3 and 6 can be assessed to be in a highly degraded condition according to the tan δ at $2U_0$, Δ tan δ and drop down curve of tan δ values. IEEE Std. 400 as shown in table I was referred for the assessment criteria of XLPE insulation. When the semiconductor layer of specimen no. 6 was shaved off, a hole caused by the conductor wire was found as shown in Fig. 4. The highest tan δ and Δ tan δ was caused by this hole, and it might be created by inappropriate treatment during removal or transportation.

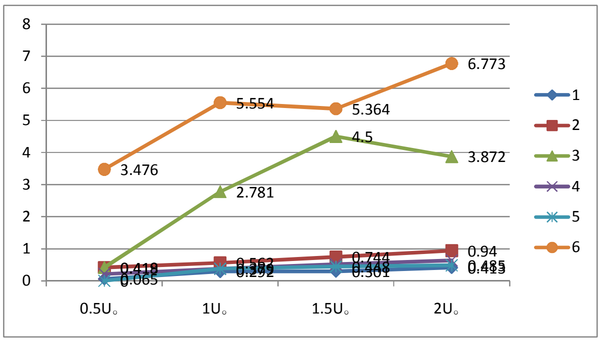

Fig. 3. VLF tan δ profile with guide ring installed

Table I. Tan δ Assessment Criteria for XLPE Cable

Tan δ at $2U_0$	Δ tan δ ($2U_0$ - $1U_0$)	Assessment
Less than $1.2x10^{-3}$	Less than $0.6x10^{-3}$	Good
Greater than or = $1.2x10^{-3}$	Greater than or = $0.6x10^{-3}$	Aged
Greater than or = $2.2x10^{-3}$	Greater than or = $1.0x10^{-3}$	Highly degraded

Fig. 4. A hole in cable insulation of specimen no. 6

2.4 Leakage Current

In the initial stage of test, both ends of cable insulation surface were cleaned with alcohol to observe the impact of leakage current by moisture permeation. There was little difference in the tan δ values before and after cleaning.

Without the guard ring, measured values of tan δ are shown in Fig. 4. Specimen 3, 5 and 6 are in a poor state. This is different with the result of measurement with guide ring installed. It means guard ring affects on the accuracy of tan δ measurement severely, and resistive current increases without the guard ring.

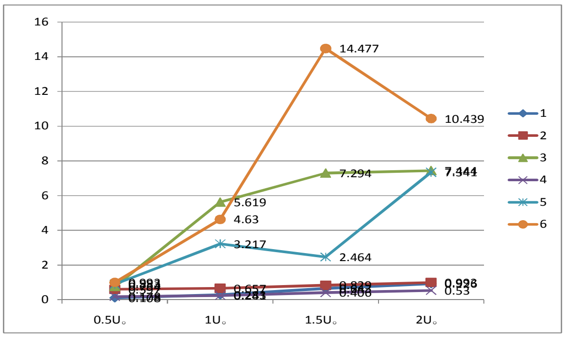

Fig.4. VLF tan δ profile without guide ring

3. Conclusions

In order to reduce the impact of leakage current for accurate VLF tan δ measurement, guard ring installation is much more useful than cleaning with alcohol of cable insulation surface.

With the guide ring installed, specimen 3 and 6 had tan δ and Δ tan δ values which exceed the limitation based on IEEE Std. 400. Especially specimen no. 6 has a hole on insulation. The defect can decrease the accuracy of tan δ and Δ tan δ significantly.

Even though two specimens are in poor state, condition of the other cables are good. This result shows not all cables are in aged degradation even if the cables have been fully served in the power plant without management or have used in wet environment. Accelerated cable life test is required to estimate remaining life time because correct cable state cannot be found based on just cable operation environment.

REFERENCES

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