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A Study on the Integrity Assessment of Cables for the Nuclear Power Plant

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1. Introduction

A lifetime of the cables could be shortened by the degradation due to severe conditions induced by thermal and radiation environment and the damage due to errors in design, fabrication, and installation process. The cables should satisfy the electrical and physical condition specified in IEEE standards and also stand against severe conditions and design basis accident such as LOCA(Loss of Coolant Accident) during an estimated lifetime. The most significant factors to the lifetime of the cables are temperature of the surrounding and a kind of insulation material of the cables. A temperature rise in the cable is induced by internal heat generation. Heat has been internally generated by electrical current in conductors, insulators, shields, or jackets that are components of the cables. In the paper, internal heat generation in the power cables for RCP and lower pressurizer that have been located under the most severe conditions in the containment has been analyzed with a method specified in IEEE Std. 835.

2. Test and Calculation Methods

2.1 Test methods

The power cables for RCP and lower pressurizer in the containment have been selected for the integrity assessment. The power cables for RCP and lower pressurizer was fabricated with 15kV and 600V EPR insulating materials, respectively. Each cable was designed to stand against LOCA under thermal and radiation environment. The heat generated from conductors, insulators, shields, or jackets of the cable could be calculated with thermal equivalents circuit that is IEEE Std. 835 test method. The cables are divided into high voltage and low voltage cables. The temperature in the cable increases with the current density and should not exceed the limit for the integrity of the cables that is known as an insulation temperature of the cable. For example, the insulation temperature of the cables with EPR insulating material is 90℃.

The actual conditions of the cables for RCP and lower pressurizer have been used for estimation of the internal heat generation in the cables. The actual temperature of the cables is assumed as the sum of the temperature of the surrounding and temperature rise due to the internal heat generation.

2.2 The Calculation Method for Internal Heat Generation in Conductor

Generally temperature of the cables are measured on the surface of jacket. The temperature of conductor is approximately calculated with the method of IEEE Std. 835

2.2.1 Thermal Equivalents Circuit

The internal heat of the cables were generated due to current in conductors, insulators, and shields and emitted to the outside through insulators, shields, and jackets. Thermal equivalent circuit is similar to Ohm's law and Kirchhoff's law.

2.2.2 Resistance Heat by Conductor Resistance

$$Q_c = I_c^2 R_c \quad \text{(watt/ft)}$$

2.2.3 Resistance Heat in Dielectric Substance

$$Q_d = \frac{0.000106 f E^2 K \cos\varphi}{\ln \frac{d_i}{d}} \quad \text{(watt/ft)}$$

f : Frequency(Hz)
E: Electrical Voltage in the Conductor(kV)
K : Dielectric Constant
cosΦ : Insulator Power Factor
d_i : Insulator Outer Diameter(inch)
d : Conductor Outer Diameter(inch)

Below 7500V, heat generation from dielectric substance could be negligible.

2.2.4 Heat Generation from Shields

$$Q_s = I_c^2 R_s 10^{-6} \frac{X_m^2}{R_s^2 + X_m^2} \quad \text{(watt/ft)}$$

I_c : Current for One Conductor (A)
R_s : Resistance of a Shield (Micro-ohms/ft)

$$R_s = \frac{\rho_s}{8trm} \quad \text{(micro-ohms/ft)}$$

ρ_s : Electric Moment of the Resistance of Shield (ohms-cmil/ft)
rm : Mean Diameter of Shield (inch)
t : Thickness of Shield, Sheath, or Wrapping (inch)

$$X_m = 0.3831\,[f\,(ln \frac{\sqrt[3]{(D_{12})(D_{13})(D_{23})}}{rm})]$$

D_{12}, D_{23}, D_{13} : Length between the Centers of Shields and Conductors (inch)

2.2.5 Temperature Drop through Insulator and Jacket

$$\triangle T_{ij} = (T_c - T_{cs}) = 0.00522\,[(Q_c + Q_d)\rho_i (\ln\frac{d_i}{d}) + (Q_c + Q_d + Q_s)\rho_j (\ln\frac{d_j}{d})]$$

T_c : Temperature of Conductor (℃)
T_{cs} : Temperature of Cable Surface (℃)
ρ_i : Heat Resistance of Insulator (℃-cm/watt)
ρ_j : Heat Resistance of nonmetal jacket material (℃-cm/watt)

2.2.6 Temperature drop from Cable Surface to Internal Wireway

$$\triangle T_{sc} = R_{sc} \times Q_{cd}$$

Q_{cd} : Total Heat Generation of Internal Wireway

$$R_{sc} = \frac{A'}{D's + B'}$$

R_{sc} : Heat Resistance between Cable Surface and Internal Wireway
D's : Total Diameter of Cables in the Wireway
A' ,B' : Constants Depending on Wireway Material and Environment

2.2.7 Temperature Drop through Wireway

$$R_{cd} = 0.00522 \rho_{cd} \ln\frac{D_{co}}{D_{ci}}$$ (℃-ft/watt)

D_{co} : Outer Diameter of Wireway (inch)
D_{ci} : Inner Diameter of Wireway (inch)

Temperature drop is calculated with the heat resistance and the total internal heat generation of wireway as follows:

$$\triangle T_{cd} = R_{cd} \times Q_{cd}$$

The sum of the temperature rise of each layer and the surrounding temperature is the actual insulation temperature of the cable. The cable should be designed and managed under the limit of insulation temperature.

3. Result and Discussion

3.1 Temperature rise of the Cable

Table 1. Temperature rise of the cable in the containment

	Classification	Increased Temperature[℃]	
		13.8kV(15kV)	480V(600V)
		RCP	lower pressurizer
1	Insulator & Jacket	13.6	11.3
2	Cable Surface	3.23	2.07
3	Wireway	0.52	0.21
	Sum	17.35	13.58

13.8kV RCP power cable is fabricated with 15kV EPR cables(3-1/C, 750 MCM). 480V lower pressurizer power cable is fabricated with 600V ERP cables(3-1/C, 500 MCM). These properties have been used to calculate the temperature rises in the cables. The calculation results of the temperature rises in insulators, shield, and internal wireway are listed in Table 1. The temperature rises in the power cables for RCP and lower pressurizer were estimated as 17.35℃ and 13.58℃, respectively. The results do not exceed the limit of the insulation temperature that is 90℃. Operation Licence Renewal Report of US Oconee 1, 2, and 3, showed that the internal heat generation could be reached to 29.65℃

3.2 Integrity Assessment Method and Aging Management Plan of Cables

The temperature rise of the cables in the containment is calculated according to IEEE Std. 835 test method with the actual physical conditions of the cables in the containment. So far as the sum of the temperature rise of the cable and the surrounding temperature does not exceed the limit of the insulation temperature, the cables satisfy the design criteria and could be judged as operable. Thus, applying the mathematical modeling of internal heat generation proposed in this paper to lifetime extension of the cables, the optimal aging management methodology should be developed.

4. Conclusion

Because of the conservative design of the nuclear power plant, the power cables installed in the containment have designed, fabricated, and verified to perform the proper safety functions even under all of the plant conditions for a design life of 40 years. The new temperature assessment method of the cable for the lifetime management of the nuclear power plant can be used to mitigate an excessive conservation and to extend the verification period of the cables. Improving the reliability of assessment with considering the material and physical condition of conductors, insulators, shields, and jackets. It is expected that the calculation method on the internal heat generation according to the IEEE Std. 835 can be utilized for the integrity assessment of the cables.

References

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