Study Committee B2

OVERHEAD LINES

10698_2022

A Study on the Life-Time Assessment Ways and Various Failure Types of 154kV Porcelain Insulators Installed in South Korea

Jabin KOO[1] , Wonkyo LEE[1] , Taeyong KIM[2]

1 KEPCO; 2 Sungkyunkwan University

Motivation

- In Korea, as of 2021, about 1,200,000 154kV Porcelain insulators are installed. Of these, about 800, 000 have been used for over 30 years.
- Porcelain insulators used in transmission lines must have high electrical resistance, mechanical strength, stability and the ability to maintain satisfactory performance under various environments.
- The mechanical strength and aging properties of Porcelain materials differ from ordinary Porcelain materials due to their composition and microstructure.

Method/Approach

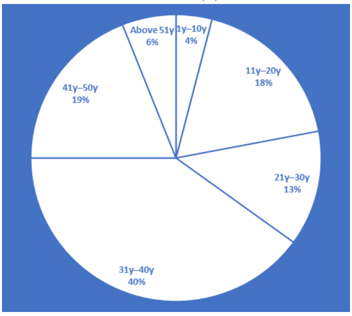
- A two-parameter Weibull analysis was performed.

$$f(L;\beta,\eta) = \frac{\eta}{\beta}\left(\frac{L}{\beta}\right)^{\eta-1} \cdot e^{-\frac{L^{\eta}}{\beta}}$$

- where f is a probability density function for tensile load L, β is a shape parameter, and η is a scale parameter.

Objects of investigation

- Porcelain Insulator statistics by year installed in Korea



- Aging samples were prepared for mechanical and electrical aging characterization. The types and quantities of specimens used for analysis. Each specimen was used in a 154kV transmission line in an area with similar climatic conditions.

Experimental setup & test results

- Microstructure Characterization by XRF
- In the case of porcelain, the main elements were Si(SiO_2), Al(Al_2O_3), K(K_2O), Fe(Fe_2O_3) Na(Na_2O), and Mg(MgO)
- The Electromechanical failing load test of the Porcelain insulator
- The flashover test

Discussion

- Through experiment, it was confirmed that the Porcelain insulator with a high corundum content improved the mechanical strength and aging resistance of electrical performance.
- On the other hand, aging of ceramics is considered to be the main cause of stress corrosion cracking due to changes in moisture and pH under stress conditions. Water molecules weaken the SiO2 bonds of the material, leading to cracks. In this process, aluminum ions reduce the non-crosslinking oxygen and increase the resistance to corrosion by strengthening the bonding of the silica matrix. They also increase the resistance to crack propagation due to the dispersion strengthening effect of corundum particles.

Conclusion

- In this study, the mechanical properties of aged insulation materials were analyzed based on quantitative microstructure analysis according to the corundum content of insulation materials. In addition, the Weibull distribution was analyzed data through the over-electrical fracture load test and the commercial frequency dry flashover test of Porcelain insulators for various corundum contents and aging.
- As a result of the Porcelain insulator microstructure analysis, it was confirmed that quartz, cristobalite, corundum, and mullite particles were distributed in the silica matrix. As the corundum content increased, the cristobalite content decreased.
- As the corundum content increased, the mechanical strength, electrical performance, and aging resistance of Porcelain insulators improved. This is because the corundum particles compensate for the difference in the thermal expansion that occurs during the sintering process of the ceramic material to reduce the residual stress inside the material and form mullite to strengthen the bond between the particles.

Study Committee B2

OVERHEAD LINES

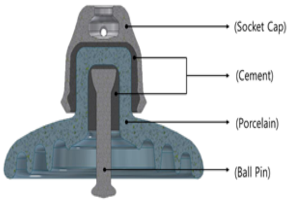
10698_2022

A Study on the Life-Time Assessment Ways and Various Failure Types of 154kV Porcelain Insulators Installed in South Korea

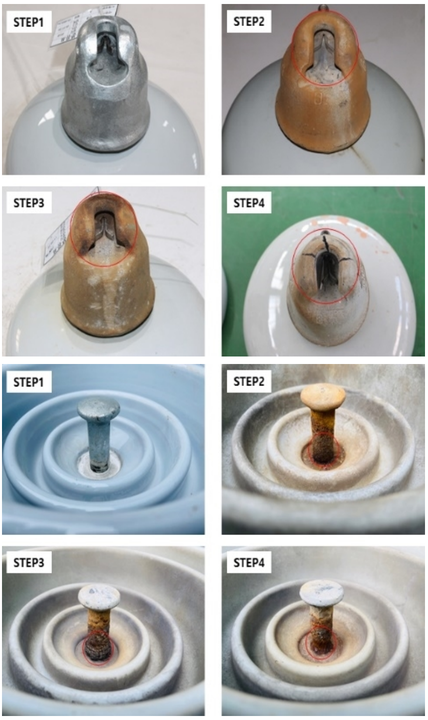
continued

Analysis of the failure type of Porcelain insulator

- The cross-section of a Porcelain insulator of a foreign company used in a 154kV transmission line in Korea.



- The corrosion phase occurs as shown in the following figure and reduces the cross sectional area of the cap and pin, resulting in a decrease in mechanical strength.



- A Porcelain penetration typically appears on the inside edge of a cap where high electrical stress is present. Although perforated, the Porcelain retains its mechanical strength and can continue to support the transmission line for extended periods of time.

Specimen Preparation

Sample	Age	Quantity	Capacity [lbs]
A-1	0	10	25,000
A-2	42	30	
A-3	43	30	
C-1	0	34	
C-2	50	30	
C-3	52	30	

- Each specimen was used in a 154kV transmission line in an area with similar climatic conditions.

Microstructure Characterization by XRF of Porcelain Insulator

Sample	$SiO_2(\%)$	$Al_2O_3(\%)$
A-1	59.5	**32.9**
A-2	65	**28.1**
A-3	59.5	**25.6**
C-1	63.8	**26.6**
C-2	65.3	**21.5**
C-3	61.3	**19.9**

- The analysis was carried out by dividing the porcelain into porcelain, which normally receives a lot of damage, the porcelain that is closer to the bracket, and the porcelain that comes down to the umbrella model, which is relatively less damaged, but there was no difference in composition. Since the main components are Al_2O_3 (corundum) and SiO_2 (cristobalite), the combined average value of SiO_2 and Al_2O_3 accounted for more than 85%.

Study Committee B2

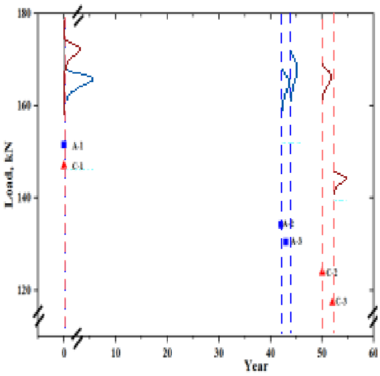
OVERHEAD LINES

10698_2022

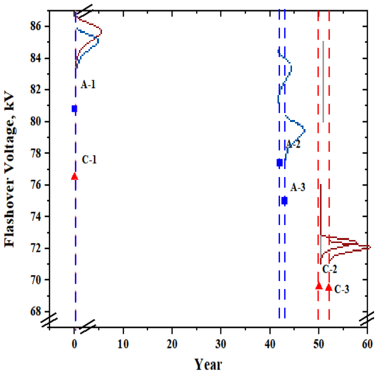
A Study on the Life-Time Assessment Ways and Various Failure Types of 154kV Porcelain Insulators Installed in South Korea

continued

Fracture load of Weibull distribution depending on different corundum contents



Flashover Voltage of Weibull distribution depending on different corundum contents



Results of Weibull analysis of Fracture load

sample	Aging years(y)	Shape para (β)	Scale para (η)	$L_{0.001}$ (kN)
A-1	0	63.5	169.0	151.6
A-2	42	29.7	169.3	134.2
A-3	43	23.9	174.3	130.5
C-1	0	42.9	172.7	147
C-2	50	20.9	172.3	123.9
C-3	52	33.1	144.6	117.3

- The $L_{0.001}$ value of A-1 insulator containing 32.9% corundum before aging was 151.6 kN, and the $L_{0.001}$ value of C-1 insulator containing 26.6% corundum was 147 kN. showed a decreasing trend in The decrease in $L_{0.001}$ became larger as the distribution became wider.

Results of Weibull analysis of Flashover Voltage

sample	Aging years(y)	Shape para (β)	Scale para (η)	$L_{0.1}$ (kV)
A-1	0	36.8	85.9	80.8
A-2	42	25.2	84.6	77.4
A-3	43	30.7	80.1	75.0
C-1	0	38.8	88.9	76.5
C-2	50	54.1	72.5	69.6
C-3	52	63.3	72.2	69.5

- The $L_{0.1}$ value of A-1 insulator containing 32.9% corundum before aging was 80.8kV, and the $L_{0.1}$value of C-1 insulator containing 26.6% corundum was 76.5kV. All showed a decreasing trend. Since the transmission line does not fail just because a flashover occurs, it is assumed that L0.1, which has a failure probability of 10%, is managed.