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Various Factors Influencing the Lifetime of Suspension-Type Porcelain Insulators for 154 kV Power Transmission Lines

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In this article, we investigated the various influencing factors that degraded the lifetime of suspension insulators in 154 kV transmission lines, and showed the possible solutions to avoid such breakdowns. With respect to achieve safety, reliability and aesthetical considerations, the characteristics of transmission and distribution network power cables should be improved. Suspension insulators are particularly important to study, as they have developed to be the main component of transmission lines due to their ability to withstand the electrical conductivity of high-voltage power transmission. Suspension insulators are mostly made from glass, rubber and ceramic material due to their high resistivity. In Korea, porcelain suspension insulators are typically used in the transmission line system, as they are cheaper and more flexible compared to other types of insulators. This is effective from preventing very high and steep lightening impulse voltages from causing the breakdown of suspension insulators used in power lines. Other influential factors affect the lifetime of suspension insulators that we studied include temperature, water moisture, contamination, mechanical vibration and electrical stress.

Keywords: Suspension insulator, Ceramic material, Lifetime, Mechanical vibration, Power transmission line

1. INTRODUCTION

Improving upon suspension-type insulators has been a hot research area in Korea due to the difficulties posed in servicing them, and because of their innate importance within a transmission line system. The structure of suspension-type insulators consist of several porcelain discs connected in a series by metal links in the form of a string. The number of insulator discs connected in a series can be adjusted for relevant voltage in transmission lines. This quality allows for more flexibility and ease within the transmission line, as the insulator string is free to swing in any direction and can take position where the mechanical stresses are minimal. This promotes the long-term reliability of suspension insulators, which is always required for the optimal electrical and mechanical performance of power transmission lines.

Within Korea, about 99% of the suspension-type insulators are made of porcelain and used in 154 kV power transmission lines [1-4]. These porcelain suspension insulators contain mostly glass, clay, feldspar pottery stone and alumina due to these materials' high resistivity [6-8].

Furthermore, suspension-type insulators with excellent electrical aging resistance have been demonstrated as a major concern in industry, since the most electrical failures in high-power transmission are attributed to electrical aging effects as well as partial discharge and the breakdown of suspension insulators. Electrical aging can be defined as the gradual degradation process that leads to the breakdown of suspension-type insulators. Since the suspension insulators are continuously subjected to high-power electrical stresses, their material properties are in a non-equilibrium state and change with the passage of time. Therefore, the lifetime of suspension insulators always depends upon the magnitude of

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electrical stress and the time duration [5-8]. With the increase of power transmission capacity and voltage, the quality of suspension insulators becomes more significant.

The flashover or electrical breakdown of a suspension insulator occurs mainly due to high and steep lightning surge voltages. During a flashover, an intense localized energy causes abrupt temperature elevation and severe arcing. This can cause a variety of problems. For instance, resulting mechanical vibrations can adversely affect the performance of the suspension-type insulator. In severe cases, the continuous electrical stress can lead to a catastrophic fracture of a ceramic or glass insulator. This may lead to surface airborne contamination, which is one of the biggest problems in high-voltage transmission lines. When surface airborne contamination settles on the insulator surface and is exposed to moisture, an electrolytic film is grown, which leads to corona discharge, surface deterioration and dry band arcing [5-10].

In this paper, we report various factors like temperature, water moisture, contamination, mechanical vibration and electrical stress as influencing the lifetime of suspension-type insulators for 154 kV high-voltage transmission lines. We also report on the possible reasons for the flashover and failure rates of suspension-type insulators.

2. RESULTS AND DISCUSSION

The electrical and mechanical strength of suspension-type insulators defines their reliability [8,9]. Figure 1, above, shows the schematic design of suspension-type porcelain insulators used for 154 kV power transmission lines. The suspension insulators are widely made up of cement, along with metal and magnetic caps, pins, and fittings.

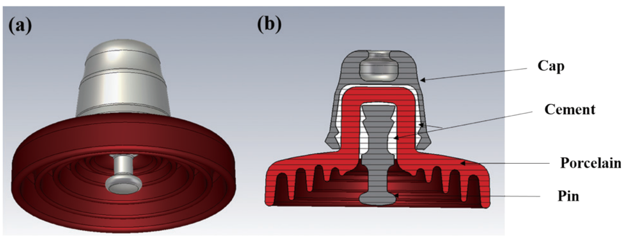

Fig. 1. Suspension insulator used for the 154 kV power transmission line.

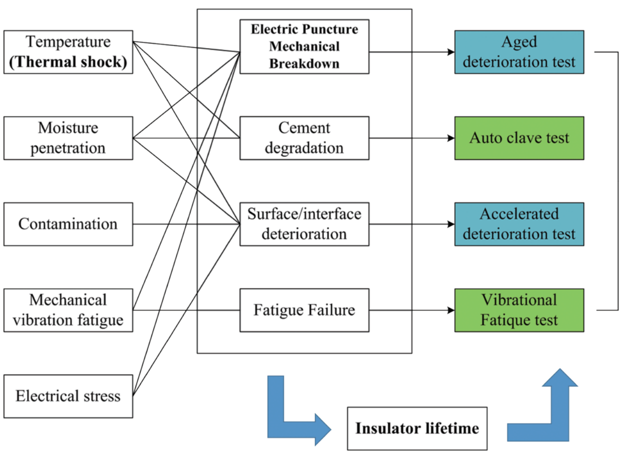

Fig. 2. Influencing factors for the lifetime of suspension-type porcelain insulators for power transmission line in 154 kV.

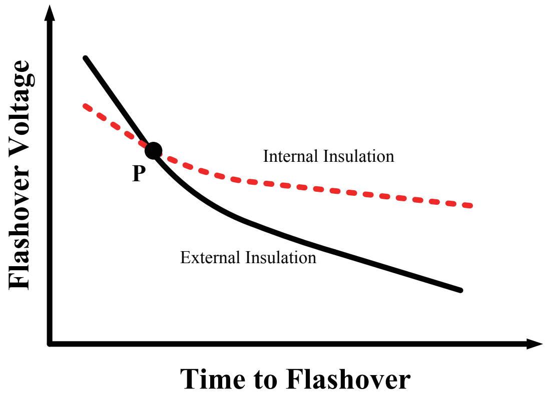

Fig. 3. Flashover voltage-time (V-t) characteristics of suspension-type insulators [14,26].

In evaluating these suspension insulators, we found several influencing factors on lifetime and performance, including temperature, moisture, contamination, mechanical vibration and electrical stress, as shown in the Fig. 2. In many ways, these factors are interrelated.

For instance, regarding temperature, the electrical characteristics of the suspension-type insulators are not directly affected very much by temperature. Rather, the adverse affects of temperature correlate more with the absolute humidity of air as a function of temperature. Thus, in this indirect way, high temperatures are believed to accelerate aging in suspension insulators. Fluctuations in temperature are also problematic in that it causes an increase in mechanical stress that may negatively influence the performance of the insulator.

Another issue is the cracking and erosion of suspension insulators, which take place with exposure to heat and light [13,14]. Wet weather and moisture causes surface/interface deterioration. An electrical breakdown or puncture of a suspension insulator can take place if the moisture penetrates deep into its surface and remains there for long periods. Contamination may result, and form a layer on the surface of the insulators. This contamination or pollution is considered a main reason for flashovers in suspension insulators.

The performance of a transmission line decreases when leakage currents and arcing activities increase on the surface of the insulator. They cause electrical stress and mechanical vibrations, which decrease the lifetime of suspension-type insulators, as they are continuously under a heavy and non-uniform electrical stress. Exposure to excess electrical stress breaks down the suspension insulators either by puncture or flashover.

To improve the performance of suspension insulators, several methods are proposed. Periodic washing of suspension insulators with pressurized water is useful, as it prevents the formation of dry bands and pollution-type flashover. Performance can also be enhanced by replacing porcelain insulators with non-ceramic insulators, since the latter shows better pollution performance. In order to avoid electric puncture or mechanical breakdown, several tests can be periodically conducted, such as an age deterioration test, auto clave test, accelerated deterioration test and vibrational fatigue test [10-16].

The electrical strength of suspension-type porcelain insulators can be assessed by puncture tests. The test aims to check the quality level of the insulator and is effective as a quality conformance test. The test works by applying power frequency voltages to an insulator specimen immersed in oil for avoiding external flashover. Since the magnetic part is shorter than the insulation distance in the air, the application of high voltage can damage the magnetic sensor.

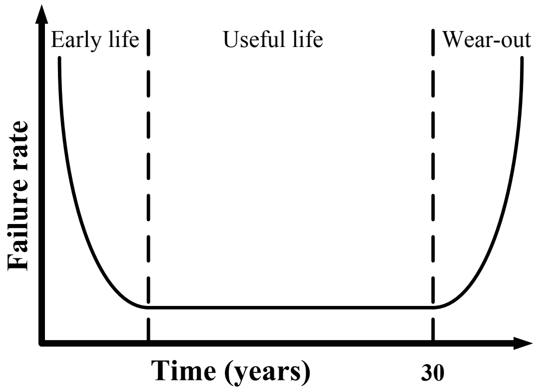

Fig. 4. Life time characteristics curve of suspension insulators [20,21].

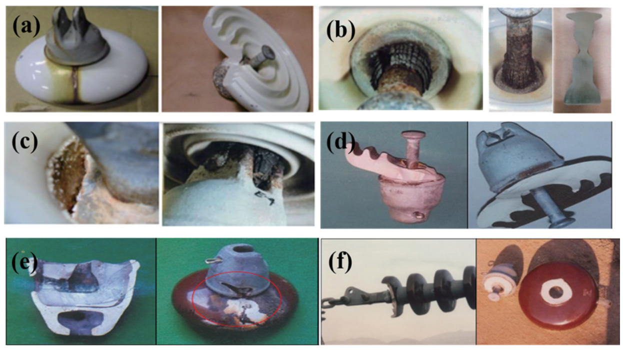

Fig. 5. Various failure and accidents reported for suspension-type insulators.

The dielectric breakdown of suspension-type insulator has the voltage time (V-t) characteristics. When studying the steep impulse voltage characteristics of the suspension insulators, we have to pay attention to (V-t) characteristics of external insulation of air and internal insulation of insulator head inside the cap [17-20].

Figure 3 shows how the lightning impulse flashover voltage in the air increases with higher steepness, while increases in the rate of puncture voltage of the solid dielectric material is not so high in such a period of time. The flashover will occur in the short-time region on the left-hand side of the point (P), at which both the (V-t) curves intersect. This shows that the flashover is influenced not only by the voltage, but also by the number of voltage applications. The fatigue breakdown phenomena of the solid dielectric material may also be considered [17-20, 23-26].

The lifetime curve of a suspension insulator can be given by two parametric Weibull distributions as [27]

$$F(t) = 1 - e^{-(t/\alpha)^{\wedge}\beta} \quad (1)$$

The exponent of the Weibull distribution in equation (1) provides very useful information about the failure rate. Figure 4 shows the lifetime characteristics of suspension-type insulators. The failure rate is quite high in the beginning period of a few years. The failure rate gradually decreases and then becomes uniform for a period of many years thereafter. This uniform failure rate is often known as the useful life of the suspension insulators.

The initially high failure rate can be attributed to the many influencing factors that continuously assault the suspension insulators all at once. In most suspension insulators, useful life is around 30 years [15-17, 20-22].

Flashover and breakdown by air or pollution do not cause physical damage to the insulators and the system can be restored by auto closing.

There are few other influencing factors that damage the surface/interface of suspension insulators. Figure 5 shows various accidents and failure modes of suspension insulators reported at different times. Figure 5(a) and 5(b) show how the suspension insulators suffered with the degradation and corrosion of metal pins. Figure 5(c) and 5(d) show how the suspension insulators suffered with moisture degradation and self-destruction by arc. Figure 5(e) and 5(f) show how penetration accidents caused insulator failure due to magnetic and cap breakage [1, 5, 9, 22-25].

3. CONCLUSIONS

Suspension-type porcelain insulators require high electrical and mechanical strength, long-term dimensional stability and an ability to maintain normal performance under a variety of environments. These insulators have been used widely in power transmission lines due to their flexibility and low prices, as compared to other insulators. Glass, porcelain and ceramic materials are mostly preferred for the manufacturing of suspension-type insulators. The aging of suspension insulators is the term referred to as degradation by electrical stress and different environmental effects. We reported on various factors, like electrical stress, temperature, water moisture, contamination and mechanical vibration as influencing the lifetime of suspension-type porcelain insulators within 154 kV power transmission lines. Various suggestions and tests are proposed to improve the performance and reliability of suspension insulators. The lifetime characteristics and flashover process of suspension insulators are also shown.

REFERENCES

[1] W. K. Lee, I. H. Choi, K. Y Shin, K. C. Hwang, and S.W. Han, *Trans. Electr. Electron. Mater.*, **9**, 147 (2008). [DOI: http://dx.doi.org/10.4313/TEEM.2008.9.4.147]

[2] S. W. Han, H. G. Cho, K. H. Park, D. I. Lee, and I. H. Choi, *J. Kor. Inst. Electr. Electron. Mater. Eng.*, **16**, 842 (2003). [DOI: http://dx.doi.org/10.4313/JKEM.2003.16.9.842]

[3] W. M. Carty and U. Senapati, *J. Am. Ceram. Soc.*, **81**, 3 (1998). [DOI: http://dx.doi.org/10.1111/j.1151-2916.1998.tb02290.x]

[4] K. Hamano, Z. Nakagawa, and M. Hasegawa, *J. Ceram. Soc. Jpn.*, 100, **1066** (1992). [DOI: http://doi.org/10.2109/jcersj.100.1066]

[5] J. E. Schroeder, *Am. Ceram. Soc. Bull.*, **57**, 526 (1978).

[6] M. Amin, M. Akbar, and M. Salman, *Sci. China Ser. E-Tech. Sci.*, 50, **697** (2007). [DOI: http://dx.doi.org/10.1007/s11431-007-0053-x]

[7] L. Mattyasovszky-Zsolnay, *J. Am. Ceram. Soc.*, **40**, 299 (1957). [DOI: http://dx.doi.org/10.1111/j.1151-2916.1957.tb12626.x]

[8] G. Gralik, A. L. Chinelatto, and A.S.A. Chinelatto, *Cerâmica*, **60**, 471 (2014). [DOI: http://dx.doi.org/10.1590/S0366-69132014000400004]

[9] W. E. Blodgett, *Am. Ceram. Soc. Bull.*, **40**, 74 (1961).

[10] G. Blaise and W. J. Sarjeant, *Electrical aging and breakdown in dielectric materials* (Academic press, 1999). p. 29.

[11] P. W. Olupot, S. Jonsson, and J. K. Byaruhanga, *Int. J. Chem. Mol. Nucl. Mater. Metall. Eng.*, **7**, 267 (2013). [DOI: http://waset.org/publications/11565]

[12] E. Akbari, M. Mirzaie, A. Rahimnejad, and M. B. Asadpoor, *Int. J. Eng. Tech.*, **1**, 407 (2012).

[13] W. Chen, W. Wang, Q. Xia, B. Luo, and L. Li, *Energies*, **5**, 2594 (2012). [DOI: http://dx.doi.org/10.3390/en5072594]

[14] K. Morita, Y. Susuki, and H. Nozaki, *IEEE Trans. Power Del.*, **12**, 850 (1997). [DOI: http://ieeexplore.ieee.org/

document/584404/]

[15] S. W. Han, I. H. Choi, and D. I. Lee, *Proc. Electrical Insulation Conference and Electrical Manufacturing Expo* (Nashville, USA, 2007). [DOI: https://doi.org/10.1109/EEIC.2007.4562601]

[16] N.A.B. Thazali, *Ph. D Investigations of ageing mechanism and electrical withstand performances of the field aged 132 kv pmu skudai's ceramic post insulator*, p. 13, Universiti Tun Hussien Onn Malaysia, Johor (2013).

[17] J. Zheng, Q. Yu, and X. Chen, *Proc. Second International Conference on properties and Applications of Properties and Applications of Dielectric Materials* (Beijing, China, 1988). p. 16. [DOI: https://doi.org/10.1109/ICPADM.1988.38320]

[18] Shodhganga, Chapter 1, Introduction; http://shodhganga.inflibnet.ac.in/bitstream/10603/16454/6/06_chapter%201.pdf

[19] K. Morita and Y. Suzuki, *IEEE Trans. Power Del.*, **12**, 850 (1997).

[20] C. Sumereder, M. Muhr, and R. Woschitz, Unpublished material; https://online.tugraz.at/tug_online/voe_main2.getVollText?pDocumentNr=36597&pCurrPk=9093.

[21] U. Schichler and E. Kynast, *Proc. Presented originally at HIGHVOLT Kolloquium* (Dresden, Germany, 2007).

[22] A. Roula, K. Boudeghdegh, and N. Boufafa, *Cerâmica*, **55**, 206 (2009). [DOI: http://dx.doi.org/10.1590/S0366-69132009000200014]

[23] M. Amin and M. Salman, *Rev. Adv. Mater. Sci.*, **13**, 93 (2006).

[24] S. W. Han, H. G. Cho, I. H. Choi, and D. I. Lee, *Proc. IEEE International Symposion on Electrical Insulation* (Toronto, Canada, 2006) p. 118. [DOI: https://doi.org/10.1109/ELINSL.2006.1665271]

[25] E. L. Brancato, *IEEE Trans. Electr, Insul.*, **13**, 308 (1978). [DOI: https://doi.org/10.1109/TEI.1978.298079]

[26] I. H. Choi, J. H. Choi, D. I. Lee, Y. G. Choi, H. G. Cho, S. W. Han, and Y. C. Park, *J. Kor. Inst. Electr. Electron. Mater. Eng.*, **18**, 96 (2005). [DOI: https://doi.org/10.4313/JKEM.2005.18.1.096]

[27] A. L. Hartzell, M. G. da Silva, and H. Shea, *MEMs reliability*, (Springer, 2011). p. 15. [ISBN: 978-1-4419-6017-7]