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Evaluation of Material Characteristics of Suspension-Type Porcelain Insulators for 154 KV Power Transmission Lines

In-Hyuk Choi[a,†], Joon-Young Park, Tae-gyun Kim, and Yong-Beum Yoon
KEPCO Research Institute, Daejeon 34056, Korea

Junsin Yi[b,†]
School of Electronic and Electrical Engineering, Sungkyunkwan University, Suwon 03063, Korea

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The suspension arrangement of insulators provides flexibility and assists in power transmission in transmission lines. The performance of the insulator string is strongly influenced by the environmental conditions to which it is exposed, its shape and the inherent material properties of suspension-type insulators. The suspension-type insulators are mostly made from glass, porcelain and ceramic material due to their high resistivity. Irregularity in charge distribution throughout the porcelain insulator may lead to accelerated aging and electrical breakdown. A very high and steep lightning impulse voltage may also cause breakdown of suspension-type insulators. We investigated various material characteristics such as alumina addition, surface morphology, x-ray diffraction pattern and relative density of suspension porcelain insulators manufactured in 1989 (36,000 lbs.), 1995 (36,000 lbs.) and 2001 (36,000 lbs.) by the KRI Company for use in 154 kV high power transmission lines. We compared the material characteristics of these porcelain insulators with that of the top-of-the-line porcelain insulators (36,000 lbs.) manufactured by the NGK Company in 2000. These suspension-type porcelain insulators were exposed to arc and flashover tests to examine their electrical and mechanical strength. It was noted that alumina addition (17 wt.%) for K-2001 was one of the major contributors to the enhancement of the performance of the porcelain insulators and to their ability to withstand very high current generation during the arc test. The porcelain insulators manufactured during 2001 also showed the highest relative density of 95.8% as compared to the other insulators manufactured in 1989 and 1995 respectively 94.2% and 91.5%. We also discuss reports of various failure modes of suspension-type porcelain insulators.

Keywords : Porcelain insulator, Lifetime, Pin corrosion, Arc test, Alumina addition, Power transmission line

1. INTRODUCTION

With the continued development of industrial technology, researchers have focused their efforts on the transmission of power to enhance voltage and power transmission capacity in a safe and reliable manner. Suspension-type insulators are used extensively as they provide a link from the transmission tower to the transmission lines with the help of supporting wires. The suspension arrangement of insulators is preferred as it provides flexibility and easily connects power transmission lines [1,2]. Glass, porcelain, clay and alumina are the main raw materials used in suspension-type insulators due to their high resistivity. Within South Korea, most of the suspension insulators are porcelain types and used in 154 kV power transmission lines. The mechanical and electrical performance of high power transmission lines is inexorably linked with the long-term reliability of suspension-type porcelain insulators [1-4].

Various power transmission voltage lines such as 66 kV, 154 kV, 345 kV and 765 kV are used in South Korea. Presently, 345 kV power transmission lines comprise the major network components while 66 kV and 154 kV networks are used in local systems. Most of the 66 kV transmission lines have been removed or replaced by higher voltage lines due safety concerns. Recently, construction has been accelerated on high voltage (HV) 765 kV transmission line facilities.

† Author to whom all correspondence should be addressed:
E-mail: a: junsin@skku.edu, b: inhyukchoi@kepco.co.kr

The HV 765 kV transmission lines are able to transmit electricity stably between large power plants and customers which is necessary given the rapid increase in the power demand in metropolitan areas [5,6]. The 154 kV power transmission lines were introduced in South Korea 60 to 70 years ago but are still being used due to their simplicity and longer lifetime. The large volume of old transmission system components are prone to many technical issues which need to be handled properly. These technical issues include fault current problems, insecure system operation, voltage regulation problems, as well as lifetime and breakdown problems. The lifetime and breakdown of the 154 kV transmission lines are related to the performance of suspension-type porcelain insulators contained throughout. Suspension-type insulators face several problems such as pin corrosion, coronal discharge and short lifetimes due to variable temperature and moisture conditions, contamination, electrical stress and mechanical vibrations. These factors not only reduce the lifetime of the suspension-type insulators but also cause failure or breakdown of electric transmission. The lifetime of suspension-type insulators also depends on their material characteristics [7-12, 15-18].

In this paper, we investigated material characteristics such as alumina addition, X-ray diffraction (XRD) crystal structures and relative density of suspension-type porcelain insulators manufactured in 1989, 1995 and 2001 for 154 kV transmission lines. Various failure modes of suspension-type porcelain insulators reported in the past are also discussed.

2. RESULTS AND DISCUSSION

Fig. 1. A suspension-type porcelain insulator used for 154 kV power transmission lines in South Korea by KRI company.

Fig. 2. Suspension-type porcelain insulator used for 154 kV and 345 kV power transmission lines in South Korea.

A suspension-type porcelain insulator used for 154 kV power transmission lines is shown in Fig. 1. These suspension-type insulators are mostly made of cement that facilitates the assembly of magnetic and metal caps and pins, along with metal and magnetic fittings. Suspension-type insulators consist of a number of interconnected porcelain discs with each individual unit designed to support a particular voltage [7-9].

Organic materials (polymers) and inorganic materials (glass and porcelain) are widely used in HV insulation [10-13]. Porcelain and glass type suspension insulators were the first to be introduced for power transmission lines. These insulators offer benefits such as high mechanical strength under pressure, increased hardness and can operate in dust, high moisture and other non-ideal environments [13-15]. Due to these benefits, porcelain insulators are still in use around the world, including in South Korea, as shown in Fig. 2.

Figure 3 shows the components of the porcelain insulators manufactured by KRI Company, Korea in 1989, 1995 and 2001 and their proportions within the insulator. For the purpose of comparison, we included the component abundance for the porcelain insulator manufactured by NGK Company, Japan in 2000. The crystal structure of porcelain insulators (K-1989, K-1995, K-2001 and N-2000) manufactured in various years were calculated from XRD analysis. It was observed from the XRD analysis that the porcelain insulators contain various crystals such as mullite ($3Al_2O_3 \cdot 2SiO_2$), quartz (SiO_2), cristobalite (SiO_2), and corundum (Al_2O_3) as reported by Choi et al. [17]. The electrical and mechanical characteristics of the porcelain-type insulators are greatly influenced by the XRD crystals contained within. The cristobalite crystal, which is vulnerable to thermal shock, made up 4.0% and 5.74% of the porcelain insulators K-1989 and K-1995, respectively, but was reduced to 0.5% for K-2001. The amount of corundum crystal in the porcelain material is directly related to alumina addition, therefore the insulators manufactured in 2001 had the maximum proportion of corundum amount at 16.4%. The quartz crystal was gradually decreased between 1989 and 2001 for the porcelain insulators. The lowest percentage of quartz crystal was 3.3% in the porcelain insulators manufactured in 2001. A very high current (72 kA/cycle) was generated during the arc test and this caused cracks in the porcelain insulators with low alumina content. Therefore, an increase in alumina content was proposed from 8 wt% in K-1989 to 12 wt% in K-1995 and later on 17 wt% in K-2001 which helped porcelain insulators withstand the high arc. The porcelain insulator N-2000 was comprised of 17 wt% alumina [9,10,13,14, 16-19].

The physical characteristics of the suspension-type porcelain insulators also depend on the size and shape of the pores created

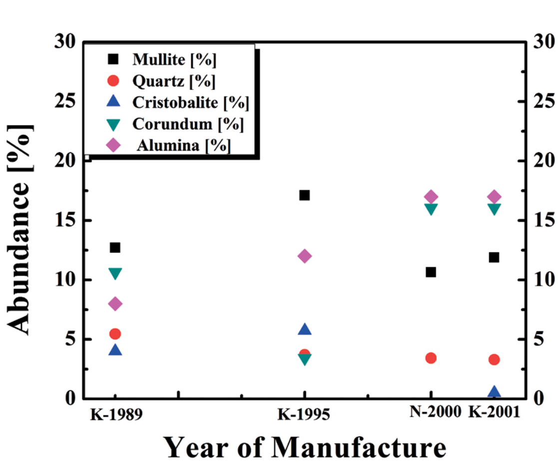

Fig. 3. Crystal components of suspension-type porcelain insulators and their abundance according to their year of manufacture.

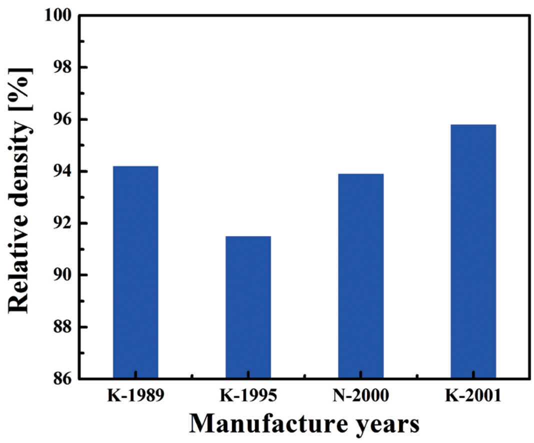

Fig. 4. The relative density of suspension-type porcelain insulators manufactured during various years.

during the sintering process. Due to its high sintering density, the porcelain insulator K-2001 showed better mechanical characteristics when compared with K-1989 and K-1995 [15-19].

The relative density of the porcelain insulators (K-1989, K-1995, K-2001 and N-2000) is shown in Fig. 4. The suspension-type porcelain insulators (K-1989) manufactured in 1989 showed a relative density of 94.2% whereas those manufactured in 1995 (K-1995) showed the lowest relative density of 91.5%. The porcelain insulators manufactured in 2001 (K-2001) showed the maximum relative density of 95.8% and similarly, those manufactured in 2000 (N-2000) by NGK had a relative density of 93.9%. It can be concluded that the suspension-type porcelain insulators K-1995 had inferior electrical and mechanical characteristics due to their decreased sintering density when compared to the K-1989 and K-2001 models [17,18,21,22].

The electrical and mechanical strength, stability and lifetime of suspension-type insulators are critically important for smooth operation and long lifetimes. There are various factors which affect the surface/interface properties of suspension-type porcelain insulators. These factors include temperature, moisture, contamination, mechanical vibration and electrical stress. These main factors have been implicated as major causes of flashover or failure in suspension-type insulators. Modes of failure include pin corrosion, external flashover, internal puncture, mechanical separation and radial cracking, which have been observed over the past decades for these insulators. These failures can be prevented by modifying the material characteristics of suspension-type insulators to give the materials greater stress resistance. The amount of alumina in the porcelain is directly related to the amount of cristobalite crystal present, which is vulnerable to thermal shock. A very high current is generated during the arc test so the alumina content was increased for the insulators K-1995 and K-2001 to withstand the high arc current. Using an optimized proportion of alumina not only enhances the performance and strength of suspension insulators but also prevents various types of failure [23,24].

3. CONCLUSION

In this paper, the material characteristics of porcelain suspension-type insulators were investigated. Properties such as alumina content, XRD crystal structure and relative density were determined for insulators manufactured in 1989, 1995, 2001 by the KRI Company and in 2000 by the NGK company for 154 kV transmission lines. The electrical and mechanical strength of the suspension-type porcelain insulators were examined by arc and flashover tests. The amount of SiO_2 was decreased and the alumina content was increased in order to prevent the production of cristobalite which is prone to thermal shock. It was noted that the increased alumina content (17 wt%) for the porcelain insulators manufactured in 2001 was the major cause of their thermal shock resistance and subsequent performance. The porcelain insulator K-2001 also showed the highest relative density of 95.8% as compared to other insulators tested. Various failures can be avoided and lifetimes of the insulators can be extended by optimizing the material characteristics.

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