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Investigation of Cracking on 35-kV Post Insulators Removed from Service

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Technical Update, December 2008

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Cosponsors

We Energies

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PRODUCT DESCRIPTION

We Energies recently experienced numerous failures of 35-kV porcelain post insulators. The majority of failures have manifested as a fracture causing the energized (phase) end of the insulator to separate from the insulator body. We Energies removed several insulators from service for inspection and investigation, including seven insulators that were shipped to EPRI for further investigation.

Severe cracking was observed between the top shed and metal trunnion cap on the energized (phase) end of three of the seven samples.

Results and Findings

Destructive testing of two of the samples that exhibited severe cracking showed that the internal porcelain material did not fully vitrify during the kiln-firing process when they were manufactured. Incomplete vitrification of the porcelain material can lead to weakened structural integrity of the porcelain material and premature failure during service in the field.

Challenges and Objective(s)

Design and manufacturing issues can take many years to emerge since distribution line hardware is often designed for a useful life of thirty or more years. The intended longevity of line hardware means that failures occurring even twenty years after installation can still be considered premature. However, even though this timeframe is considered short in terms of insulator life, many other changes can occur during these years. For example, manufacturers go out of business or are acquired by other companies, manufacturing processes change, material formulations are altered, and so forth. Most of these changes result in lost information. People retire, documents are lost or discarded, and "old" manufacturing methods are replaced and forgotten. This loss of information complicates hardware failure investigations.

The primary objective of this work was to determine the cause of the insulator failures under investigation. In the process of investigating the failures, the project team also hoped to provide information that could be applied in a general fashion to a wider range of porcelain hardware failures.

Applications, Values, and Use

Utilities can use the information in this report to better understand the structure and manufacturing of porcelain post insulators. This report also will be useful for any utility investigating similar failures on a variety of porcelain hardware.

EPRI Perspective

Although a particular insulator model may meet design standards at the time of its production, that does not guarantee that a design flaw or manufacturing defect will not manifest itself as a failure many years later. When failures of a particular component begin to amass, particularly before the perceived end of its useful life, it is important to examine the failures to determine an appropriate response.

EPRI is well suited to perform this type of forensic investigation. In addition to industry-leading researchers, EPRI also has the ability to readily partner with other experts when warranted. The EPRI high-voltage laboratory in Lenox, Massachusetts, also provides a wide range of test capabilities well suited for forensic investigations.

Approach

EPRI researchers partnered with Ed Cherney, a recognized industry expert on porcelain insulating materials, to examine several of the insulators removed from service by We Energies. Together, the investigation team used a variety of destructive and non-destructive test methods to examine the insulators.

Keywords

Line post insulator
Porcelain
Vitrification

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1
INTRODUCTION

We Energies experienced an elevated occurrence of failures of 34.5-kV porcelain post insulators on their distribution system during spring 2008. The insulators are used in an armless overbuilt circuit design as shown in Figure 1-1. The top circuit is operated at 24.9 kV and the bottom circuit is operated at 8 kV. The insulators in question are used on the top (24.9 kV) circuit.

Figure 1-1
Example of the Armless Construction Design Employed on the We Energies Distribution System

We Energies removed 7 insulators from field service and sent them to EPRI for further analysis. The condition of the samples ranged from not having any deficiencies to cracked porcelain and missing cement as indicated in Table 1-1. We Energies numbered the samples 1 through 7 and performed the initial visual inspection before sending the samples to EPRI.

It should be noted that upon opening the shipping crate, sample #1 was found to have broken into two pieces with the energized end cap breaking away from the insulator body as shown in Figure 1-2. This fracture is believed to have occurred during shipping.

Table 1-1
Inventory of Insulator Samples as Compiled by We Energies

Sample Number	Manufacturer	Year Manufactured	Condition
1	AB Chance	1979	Porcelain is cracked around top endcap in two locations. Cracking in cement around top endcap.
2	AB Chance	1979	Porcelain is cracked around top endcap in one location. Some cement missing from around top endcap; minor cracking in cement around bottom endcap.
3	AB Chance	1979	Lightning damage on top and bottom porcelain skirts. Some cement missing from around both endcaps; no cracks. Lightning flashed from endcap to endcap.
4	AB Chance	1979	Porcelain – good. Cement – good.
5	AB Chance	1979	Porcelain – good. Some cracking in cement seals around end castings.
6	Lapp	1979	Porcelain – good. Cement – good. (Note: Inspection by EPRI staff found that this insulator had also flashed over but was otherwise in good physical condition.)
7	Lapp	1979	Porcelain – good. Section of cement missing from around base.
Photo Only	AB Chance	1979	Porcelain is severely cracked around top endcap; also penetrated top skirt.

Figure 1-2
Sample #1 Arrived at the Test Facility with the Energized End Broken-Off

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EVALUATION OF SAMPLES

Sample #1

Sample #1 was identified as a CHANCE horizontal line post insulator manufactured in 1979. This unit, bearing the identification number 80-03658WΦ, arrived at the EPRI test facility with the line end trunnion cap broken off (energized end). The line end trunnion cap showed an extremely rough porcelain fracture surface as evident in Figure 2-1.

Figure 2-1
Fracture Surface where the Energized End Broke Away from Sample #1: Endcap (left) and Insulator Body (right)

The first and second sheds from the energized end were broken via sledge hammer impact in order to observe how the porcelain material fractured further down the insulator body. Breaking the sheds below the energized end showed progressively less “roughness” of the fractured surface as seen in Figure 2-2. Figure 2-3 shows that sample #1 was also broken closer to the ground end fitting and exhibited a very smooth fracture surface in that area.

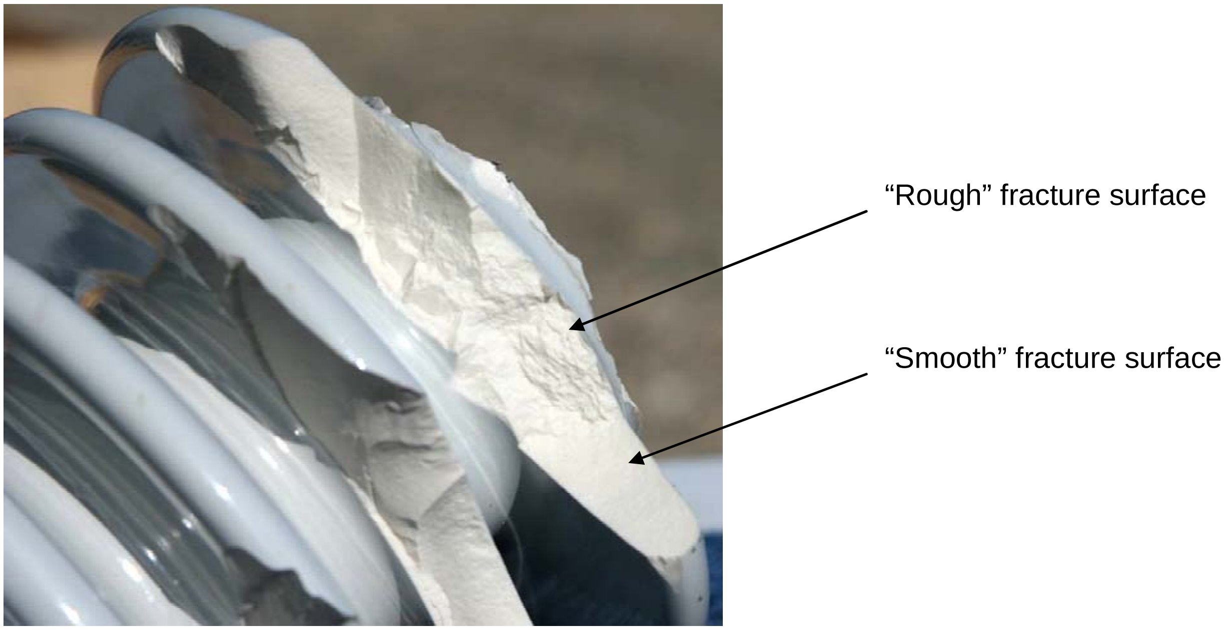

Figure 2-2
Fracture Surfaces of First and Second Sheds Below the Energized Trunnion Cap of Sample #1

Figure 2-3
Fracture Surface at the Ground End of Sample #1

Sample #2

Sample #2 was identified as a 1979 A CHANCE horizontal line post insulator which showed a region of finely divided cracks in the glaze just below the line end trunnion cap as shown in Figure 2-4 and Figure 2-5.

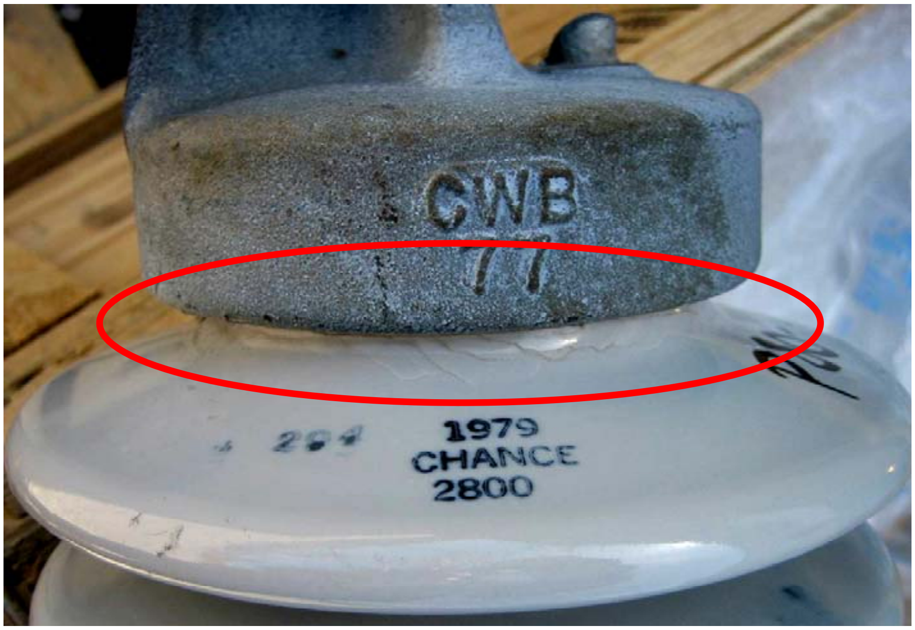

Figure 2-4
Sample #2 Showed a Region of Finely Divided Cracks Just Below the Trunnion Cap

Figure 2-5
Close-Up View of Cracks Just Below the Energized Trunnion Cap of Sample #2

The trunnion cap on the energized end was cut from sample #2 (Figure 2-6) using a band saw equipped with a diamond coated blade. Cutting revealed a multitude of small cracks in the vicinity of the circumference of the post as shown in Figure 2-7. The cracks can be difficult to see in the photograph since the cutting action polishes the surface.

Figure 2-6
The Trunnion Cap was Cut from the Energized End of Sample #2

Figure 2-7
Cut Surface of Sample #2 Showing Cracks Near the Circumference of the Insulator

The porcelain sheds of sample #2 were broken with a sledge hammer to observe the fracture surface along the breaks. Sample #2 exhibited a small area of “rough” fracture on the energized end near where the trunnion cap connects to the insulator body as shown in Figure 2-8.

Figure 2-8
Fracture Surfaces of First and Second Sheds Below the Energized Trunnion Cap of Sample #2

Sample #4

Sample #4 was identified as a CHANCE unit with a date marking of August 12, 1977 on the first shed as shown in Figure 2-9. Sample #4 was also marked 80-03593 WΦ. Sample #4 was chosen for evaluation because it did not show any outward signs of cracking or crazing.

Sample #4 was broken via sledge hammer impact in order to observe how the porcelain material fractured. The initial hammer blow broke the energized end trunnion cap away from the insulator body as shown in Figure 2-10. The bulk of the insulator body was then broken as shown in Figure 2-11. Finally, the base end cap was broken from the insulator body (Figure 2-12). All fracture surfaces appeared smooth and the insulator body appeared to be uniform in texture from end-to-end with no signs of underfired porcelain.

Figure 2-9
Energized End of Sample #4 Showing a Manufacturing Date of "Aug 12 1977"

Figure 2-10
Fracture Surface of Sample #4 where the Energized End Trunnion Cap was Broken from the Sample

Figure 2-11
Fracture Surface of Sample #4 along the Insulator Body

Figure 2-12
Fracture Surface of Sample #4 where the Base Cap was Broken from the Insulator Body

Sample #7

Sample #7 was identified as a 1979 Lapp insulator with the marking P80-03595. Sample #7 did not show any outward signs of cracking or crazing. There was a small section of cement missing from around the pole-end cap but this was deemed inconsequential. Sample #7 also showed several marks of undetermined origin on the base end cap as shown in Figure 2-13. These marks were not evident on the energized-end trunnion cap.

Sample #7 was broken via sledge hammer impact in order to observe how the porcelain material fractured. The initial hammer blow broke the energized end trunnion cap away from the insulator body as shown in Figure 2-14. The bulk of the insulator body was then broken as shown in Figure 2-15. Finally, the base end cap was broken from the insulator body (Figure 2-16). All fracture surfaces appeared smooth and the insulator body appeared to be uniform in texture from end-to-end with no signs of underfired porcelain.

Note that the polystyrene cube visible in the chucking hole in Figure 2-16 is a normal part of the manufacturing process. This configuration is used to prevent cement expansion from exerting a hoop stress on the porcelain body that could result in fracture.

Figure 2-13
Sample #7 Showing Marks on Base End Cap and Small Section of Missing Cement around Base End Cap

Figure 2-14
Fracture Surface of Sample #7 where the Energized End Trunnion Cap was Broken from the Sample

Figure 2-15
Fracture Surface of Sample #7 along the Insulator Body

Figure 2-16
Fracture Surface of Sample #7 where the Base End Cap was Broken from the Insulator Body (note that the polystyrene cube in the chucking hole is a normal part of the manufacturing process)

Samples #3, #5, and #6

Since it was unlikely that destructive testing of the remaining insulators would provide further useful information, the remaining samples were visually inspected but not broken. The results of the visual inspections are as follows:

- Sample #3 was identified as a 1979 CHANCE horizontal line post insulator that had flashed over. There was evidence of a region of finely divided cracks just below the line end trunnion cap similar to those observed on Sample #2.
- Sample #5 was identified as a 1979 CHANCE horizontal line post insulator bearing the identification number P79-01606WΦ which showed a crack resembling a large chip at the base end.
- Sample #6 was identified as a 1979 LAPP vertical line post insulator that had flashed over but otherwise there was no evidence of cracking at either end of the post.

3
ANALYSIS

A Brief Overview of Insulator Firing

The body of porcelain insulators starts out as greenware (unfired clay). The greenware is then formed into the final body shape and fired in a kiln. Multiple greenware pieces are placed on a “kiln cart” which is then rolled into the kiln. Inside the kiln, the greenware material undergoes vitrification (heat fusion) during the heat soak transforming it into the hard porcelain material familiar to us as the insulator body.

The vitrification process is dependent on the temperature inside the kiln as well as the time duration of the heat soak. The temperature inside the kiln is not always uniform. This was especially true during the late 1970’s when the insulators under examination were manufactured. If the insulators are placed too close together on the kiln cart then pockets of cooler air can develop near the center of the kiln cart due to thermal shadowing from the samples located along the perimeter. Stacking of greenware on a kiln cart is done to maximize the number of pieces in firing and the smaller pieces are positioned between larger ones. Kiln operation during the late 1970’s was as much of an art as a science and it was not uncommon for insulators to leave the kiln without fully vitrifying. Incomplete vitrification can reduce the strength and durability of the final insulator.

Analysis of Findings

Both sample #1 and sample #2 exhibit incomplete vitrification in their internal structure near the energized (phase) end of the insulators. This is the same area where the insulators have cracked and fractured. Samples #4 and #7 did not show any outward signs of cracking and their internal structure appeared to be uniform from end-to-end without any signs of underfired porcelain.

Sample #1 (1979 CHANCE) exhibits complete vitrification (heat fusion) of the porcelain at the base end with an abrupt transition to incomplete vitrification or underfired porcelain at the line end where the separation failure occurred. This underfired porcelain likely would not pass the dye penetration test for porosity in ANSI C29.1.

Sample #2 (1979 CHANCE) was cut between the energized line-end trunnion cap and the first shed. Cutting this sample for inspection revealed a multitude of small cracks and fissures penetrating into the insulator. The cutting process polishes the cut surface making underfired porcelain less evident. However, the small cracks and fissures present in the sample are indicative of a layered structure and consistent with underfired porcelain. The sheds adjacent to the energized end of the insulator were subsequently broken to examine the fracture surfaces. The broken surfaces revealed a small area of incomplete vitrification near the energized end.

One possible explanation for the abrupt transition in porcelain vitrification is due to positioning of the greenware (unfired clay) on the kiln cart. Not all greenware on a kiln cart experiences the same soak (temperature-time profile). The insulators placed along the perimeter of the kiln cart can create a thermal shadow resulting in lower temperatures near the center of the cart. In addition, the surface of the kiln cart is fitted with a refractory in order to protect the kiln cart from the high temperatures present inside the kiln. Because of the refractory, the kiln cart surface is at a lower temperature than areas higher up in the kiln. To remedy this, refractory pedestals are often used to raise greenware above the floor of the kiln cart for a more uniform soak. It is possible that the insulators under consideration were fired while inverted (energized end pointed down) and placed directly onto the refractory floor of the kiln cart resulting in incomplete vitrification.

The failure of these 1979 AB Chance line post insulators is attributed to aging of underfired porcelain at the energized end of the insulator. Although initially glazed over, small cracks and fissures developed in service and propagated with time leading to a complete fracture.

4
SUMMARY AND NEXT STEPS

Summary

We Energies recently experienced numerous failures of 35-kV porcelain post insulators. The majority of the failures have manifested as a fracture causing the energized (phase) end of the insulator to separate from the insulator body. We Energies removed several insulators from service for inspection and investigation including seven insulators which were shipped to EPRI for further investigation.

EPRI researchers worked with Ed Cherney, a recognized industry expert on porcelain insulating materials, to examine several of the insulators removed from service by We Energies. Severe cracking was observed between the top shed and metal trunnion cap on the energized (phase) end of three of the seven samples. We Energies reported that an eighth sample, which was not sent to EPRI, exhibited similar cracking.

Destructive testing of two of the samples that exhibited severe cracking, samples #1 (1979 CHANCE) and #2 (1979 CHANCE), showed that the internal porcelain material did not fully vitrify during the kiln-firing process when they were manufactured. Incomplete vitrification of the porcelain material can lead to weakened structural integrity of the porcelain material and premature failure during service in the field.

Sample #4 (1977 CHANCE) and sample #7 (1979 Lapp) did not show any outward signs of cracking and their internal structure appeared to be uniform from end-to-end without any signs of underfired porcelain.

Next Steps

These insulators are clearly causing an operational difficulty for We Energies as evidenced by the fact that they are being considered for complete replacement. Unfortunately, underfired porcelain in overhead distribution applications is not uncommon and is a random problem. No specific recommendation can be given as there is not enough data to determine to what extent other post insulators of similar vintages are affected by the deficiencies found in these samples. Not all 1979 CHANCE line posts will have underfired porcelain and there is no information indicating what percentage of the post insulators on the We Energies distribution system have similar deficiencies.

We Energies line crews who work on or near similar post insulators have been alerted to the possibility that these insulators may fail unexpectedly due to weakened structural properties resulting from aging of underfired porcelain.

Dye Penetration (Porosity) Testing

ANSI C29.1-1988 (R2002), "Test Methods for Electrical Power Insulators," describes a method of porosity testing. The test method calls for freshly broken pieces of the insulator to be soaked in a solution of fuchsine dye in alcohol at a pressure of 4,000 or 10,000 pounds per square inch for 5 hours and 2 hours respectively. Porosity is indicated by penetration of the dye into the broken porcelain pieces to an extent visible to the unaided eye.

The extent of underfiring in samples #1 and #2 leads to the conclusion that the dye would be visible to the unaided eye, even if the test was performed at normal atmospheric pressure. Therefore, such a test would not contribute additional information to the findings at hand.

Vibration Analysis

EPRI is currently developing a vibration analysis tool to detect structural defects in porcelain and polymer insulators. The system has shown promising success in detecting even small cracks in porcelain disc (bell) insulators used in high voltage transmission systems. It is yet unclear if the same technique can be applied to detect cracks in post insulators.

As part of the examination process for these insulators, EPRI researchers recorded vibration analysis data. This data is not likely to yield any definitive answers in the short-term but will help contribute to developing a successful inspection technique over the next two to five years.

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