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Condition Assessment and Reliability Analysis of Porcelain and Toughened Glass Cap and Pin Insulators

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SUMMARY

This paper presents the condition assessment and reliability analysis methodology developed by Powertech Labs for porcelain and toughened glass cap and pin insulators. Using the methodology, approximately 4,000 porcelain and toughened glass cap and pin insulator samples taken from 74 BC Hydro AC transmission line circuits operating at voltages 69 kV and above were tested and assessed. Some of the insulator samples had been 70+ years in-service. The following tests and studies are included in the methodology: 1) Cost-effective sampling method, 2) Visual inspection in the lab, 3) Determination of insulator condition rating, 4) Mechanical and electrical (M&E) testing on selected samples, 5) Reliability analysis (Weibull analysis) to quantify the probability of exceeding the rated strength and 6) Life data analysis to determine the end of life of an insulator population if data is sufficient

Based on the assessment and analysis' results, the asset management engineer would be able to determine the insulator health by summarizing the results in terms of brand, strength rating, year of manufacturer and voltage. Thus, more effective corrective actions can be taken to prioritize replacements and mitigate the risk of failure.

KEYWORDS

Insulators, sampling, testing, condition assessment, risk assessment, Weibull analysis.

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1. INTRODUCTION

Some BC Hydro transmission overhead lines have reached, or are close to reach the end of their design life. If well maintained, their life can be extended to defer the capital expenditures required to replace or refurbish them while achieving reliability performance indicators. Moreover, the reliability of a transmission line depends on long-term performance of components including insulators which are line's components that deserve special attention due to their critical role in keeping the line electrically and mechanically reliable.

Therefore, there is a need to determine the health of in-service insulators and identify those near their end of life. Furthermore, if sufficient end of life test data is available, the probability of failure or mean time to failure can be quantified through statistical analysis.

Since 2007, BC Hydro initiated a multi-year porcelain and glass cap and pin sampling program to assess the condition of BC Hydro Transmission system's insulators. Upon request of BC Hydro, Powertech developed the methodology and conducted the assessment on over 4,000 porcelain and toughened glass cap & pin insulators. The methodology included: 1) Sampling of insulators from the field 2) Visual inspection of as-received insulator samples in the lab, 3) Determination of insulator overall condition rating, 4) Mechanical and electrical (M&E) testing on selected sample, 5) Reliability analysis (Weibull analysis) to quantify the probability of exceeding the rated strength and 6) Life data analysis to determine the end of life if data is sufficient.

Over the course of the program an insulator fabricator expressed interest in performing testing on a few samples it fabricated many years ago. This allowed BC Hydro to validate Powertech's laboratory test results on the insulators samples tested by that insulator manufacturer. A description of the insulator test results' validation is also included in this paper.

2. SAMPLING PROGRAM

An effective approach to know the condition of insulators and understand how they age is to sample in-service transmission line insulators and conduct tests and examination in the laboratory environment.

At the beginning of the program, sampling by opportunity, the least expensive option, was chosen to acquire insulator samples from the field. Using this sampling approach samples were obtained as part of transmission line maintenance, upgrades, modifications, or de-commissioning activities. For example, when a crossarm of a transmission structure needed to be replaced, line crews kept removed insulators and sent the components to Powertech for assessment.

The samples were labelled with circuit and structure number and other asset information. Over the last 12 years, BC Hydro transmission line crews collected approximately 4,000 porcelain and toughened glass cap & pin insulator units across the entire BC Hydro Transmission system through the opportunity sampling program.

3. VISUAL INSPECTION

Each of the as-received insulator samples was examined and classified by insulator type, brand, vintage and strength rating.

The following items were covered by the visual inspection:

- Top & bottom shell contamination
- Top & bottom shell flashover damage
- Shell radial cracking
- Grout radial cracking, spalling and loss of filling
- Cap and pin corrosion

Figure 1 exhibits the examples of insulator defects on as-received insulators.

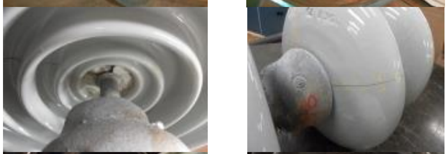
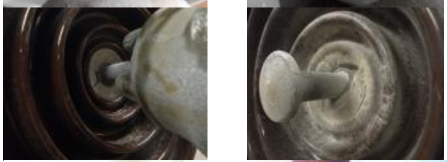
Insulator Defect	
Top & bottom shell contamination:	
Top & bottom shell flashover damage:	
Shell radial cracking:	
Grout radial cracking, spalling, an, lack or loss of filling:	
Cap & pin corrosion:	

Figure 1. Insulator defect types

4. CONDITION RATING

The following rating system was used for the visual inspection.

	Rating
No defect and damages	1
Minor defect and damages	2
Moderate defects and damages	3
Severe defects and damages	4

Table 1. Insulator condition ratings scheme

The definition of the abovementioned condition ratings was determined based on BC Hydro's Transmission Line Maintenance Standards and Powertech's Overhead Inspection Procedures.

Then, weighting was assigned to each insulator defect shown in Figure 1. For the condition rating of the insulators, greater weightings were assigned to the grout lack or loss of filling and the pin corrosion defect type. Regarding the other insulator defects, weightings were spread among the other insulator defect types and the sum of all weightings was equal to one.

Consequently, the overall condition rating was calculated for each of the insulator samples. Table 2 summarizes the condition rating results of BC Hydro transmission line insulators based on the visual examination of the 4,000 porcelain and glass cap and pin insulator samples.

Insulator Type	No defect	Minor Defect	Moderate Defect	Severe Defect	Total
Glass	2.0%	10.0%	0.4%	0.4%	12.8%
Porcelain	8.0%	75.0%	2.1%	2.1%	87.3%
Total	10.0%	85.0%	2.5%	2.5%	**100.0%**

Table 2. BC Hydro transmission line insulators' condition based on visual inspection

5. M&E TESTING

The visual inspection has limitations as it cannot tell the remaining M&E strength and determine how an insulator ages.

To quantify the remaining strength, the combined mechanical and electrical strength test (M&E test) was conducted on selected samples in accordance with ANSI C29.2 (1999)-Clause 8.3.4 and ANSI C29.1 (1988)-Clause 5.2. The samples selected for M&E test usually represent a homogeneous population such as a brand with the same vintage and strength rating.

6. RELIABILITY ANALYSIS

For each of the homogeneous group, a Weibull analysis was performed to establish the probabilistic description (statistical model) of the insulator population. Hence, the probability of exceeding the rated M&E strength can be estimated. Table 3 shows some of the results for demonstration purpose.

Rated Strength (lbs)	Year of Manufacture	Reliability with respect to Rated M&E Strength (%)
15,000	1966	92.80
20,000	1988	97.00
18,000	1956	76.27
18,000	1962	99.99
18,000	1963	100.00
18,000	1964	87.90
18,000	1965	100.00
18,000	1966	99.20

Table 3. M&E test reliability results

A statistical model can be used to predict the probability of exceeding any given mechanical load. It can also be used to estimate the risk of failure of the entire insulator string.

Thus, Weibull analysis is shown in Section 7 to quantify the probability of exceeding the rated strength.

7. LIFE DATA ANALYSIS

For one of the insulator brands, a life data analysis was conducted based on M&E test results and insulator age to estimate the mean time to failure. The end of life was defined as the remaining M&E strength less than the rated strength. Figure 2 shows the statistical analysis results. It can be seem that the Mean time to failure = 68 years and the actual life span is within 40 to 115 years with 95% confidence level.

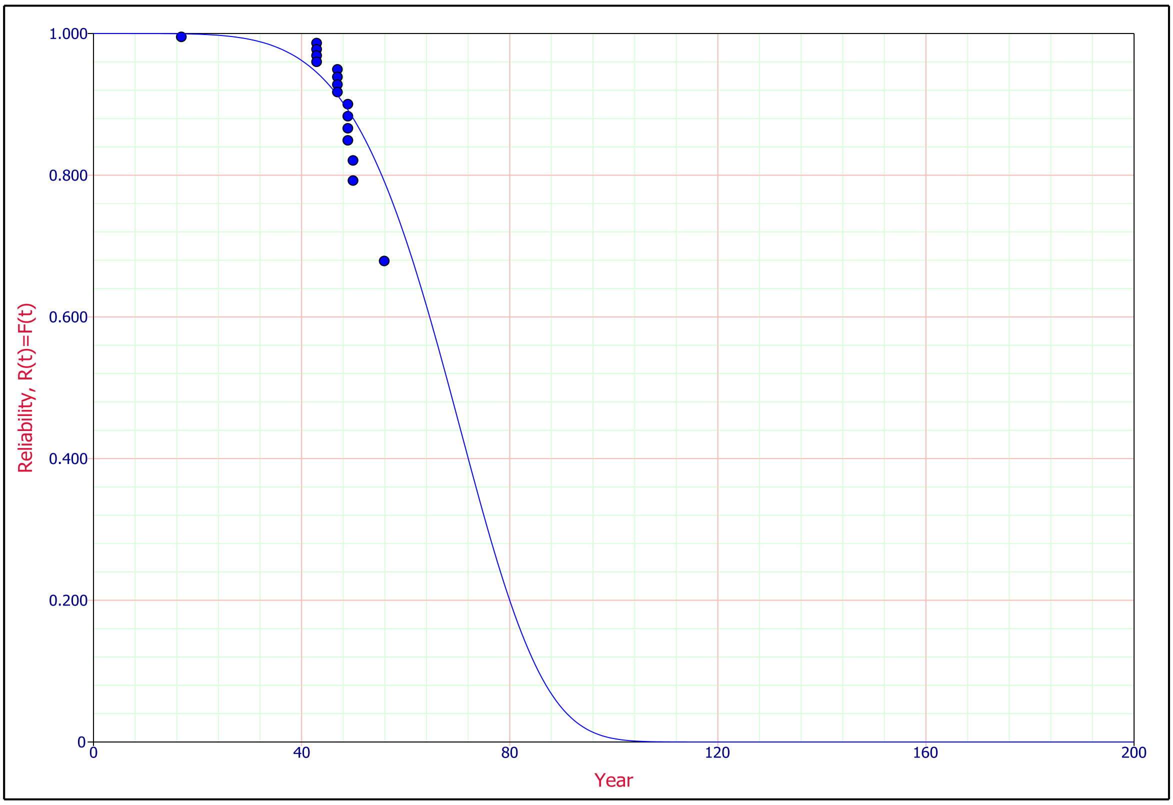


Figure 2. Life data analysis for one insulator brand

8. VALIDATION OF TEST RESULTS

Validation of Powertech's test results was carried out by an insulator fabricator whose product was sampled and tested. The insulator fabricator was interested in assessing the performance of its product after being in service for 40+ years. This assessment took place at the insulator manufacturer's testing facility.

The scope of the manufacturer's testing was the following:

- Visual observation
- Measurement of insulator resistance
- Electromechanical failing load test
- Power frequency puncture test in oil
- Porosity test

Table 4 presents the test objects' data.

	69 kV Dead-end Structure	69 kV Tangent Structure
# of insulator samples	2 units	2 units
Environmental	10 km from coastline	100 km from coastline
Condition	no pollution source	no pollution source
Manufacture year	1964	1971
Year of removal	2015	2015
Years in service	51 years	44 years
Rated mechanical strength	18 kips (80 kN)	18 kips (80 kN)

Table 4. Insulator test specimens' data

Figure 3 presents a mosaic of the insulator samples' visual inspection. Moreover, Figure 4 depicts the results of the electromechanical test and porosity test.

Insulator Sample	Upper side	Bottom side	Cap	Pin	Close-up
Sample 1: 1964 vintage insulator					
Sample 2: 1964 vintage insulator					
Sample 3: 1971 vintage insulator					
Sample 4: 1971 vintage insulator					

Figure 3. Visual examination results

	Electromechanical Failing Load Test	Porosity Test
Sample 3: 1971 vintage insulator		
Remarks:	Broken socket	No dye penetration

Figure 4. Electromechanical failing load and porosity test results

The manufacturer's test results are shown in Table 5. The results illustrate that the insulator samples passed all tests in the manufacturer's test program.

	No. of Insulator Samples		Test Purpose	Relevant Standard	Result	Pass/Fail
	Dead-end	Tangent				
Visual observation	2	2	Cracks, corrosion, other defects	Visual inspection	Slight corrosion	***Pass***
Measurement of insulator resistance	2	2	Insulation resistance	1,000 V-mega ohmmeter	> 2,000 MΩ	***Pass***
Electromechanical failing load test	1	1	Mechanical performance	ANSI C29.2	> 23,700 lbs	***Pass***
Power frequency puncture test in oil	1	1	Electrical puncture performance	ANSI C29.2	> 170 kV	***Pass***
Porosity test	1	1	Porosity of porcelain	ANSI C29.2	No dye penetration	***Pass***

Table 5. Validation of test results

The evidence demonstrates that, after 40+ years in-service, the insulator samples have minor defects and their electromechanical performance exceeds the design values. Therefore, the manufacturer's test results are consistent with Powertech's test results.

9. CONCLUSIONS

- The condition assessment study determined that the majority of BC Hydro transmission line insulators are still in good condition after many years in-service.
- The results of the condition assessment and risk analysis can be utilized by asset managers to design their maintenance programs.
- M&E testing on selected insulators showed that a few brands and vintages of insulators reached end of life criteria.
- The test results validation demonstrated that Powertech's condition assessment was consistent with the fabricator's methodology.
- Powertech's methodology allows prediction of cap & pin insulators' end of life if enough data is collected (Weibull analysis).

10. BIBLIOGRAPHY

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[2] ANSI C29.2-1992, American National Standard for Insulators - Wet-Process Porcelain and Toughened Glass - Suspension Type.