FIELD CASE STUDY OF MEDIUM-VOLTAGE CABLE ACCESSORIES WITH PARTIAL DISCHARGES IN THE HYDRO-QUEBEC UNDERGROUND DISTRIBUTION NETWORK

Daniel FOURNIER
Hydro-Québec Distribution-Canada
fournier.daniel.3@hydro.qc.ca

Sylvain POIRIER
Hydro-Québec IREQ-Canada
poirier.sylvain@ireq.ca

Jacques FRATE
Hydro-Québec IREQ-Canada
frate.jacques@ireq.ca

ABSTRACT

Most of the power failures in Hydro-Québec's underground distribution network occur at cable joints. Some are due to partial discharges inside these joints and the corresponding degradation of their electrical insulation. The network consists mainly of XLPE cable with EPDM rubber premolded accessories. Since 2004, Hydro-Québec has been using its new on-line portable partial-discharge analyzer (PDA) for the detection, location and interpretation of PDs in its distribution network [1]. The analyzer is used both to ensure safety and to perform predictive maintenance by removing defective accessories before they fail.

The scope of this study is to establish the relationship between the diagnosis based on PD measurements in the field and the seriousness of defects in cable accessories. To do this, many cable joints plagued with partial discharges and dielectric hotspots were withdrawn from the field for testing and analysis in our laboratory. Correlations with Hydro-Québec's infrared diagnosis [1-2] for cable joints will also be made. Finally, we will try to estimate the remaining field life of cable joints with defects.

INTRODUCTION

Hydro-Québec has 34 laboratory trucks dedicated to PD and infrared field measurements in its distribution network vaults. Inspections are performed on a regular basis and are part of a safety and predictive-maintenance program. Recently, field statistics showed that a specific straight-joint model (type A) had more problems than other equivalent cable joints. Indeed, even though type A represents ~32% (~50,000) of the joints in our network, it presently accounts for ~65% of those diagnosed to be in the red condition (needing immediate replacement) based on infrared and PD measurements. Both workers and management wanted to know if our diagnosis allows Hydro-Québec to be in control of this situation by replacing the defective joints in good time, without exposing workers to safety hazards. To answer this question, 37 type A joints were withdrawn from the field and analyzed in our laboratory. The withdrawal criterion was that at least one phase of a line had a joint with a PD and/or a dielectric hotspot. In that case, all three phases were withdrawn with 1 m of cable on each side of the joints. This procedure allowed us to investigate joints both in the normal and the "red" condition.

EXPERIMENTAL STEPS

The experimental protocol following joint withdrawal is illustrated in Figure 1. Joints were first x-rayed in order to evaluate any electrical insulation damage related to PD and/or dielectric hotspot defects and to locate them inside the joint. Joints were then installed on our special high-voltage (HV) lab test bench.

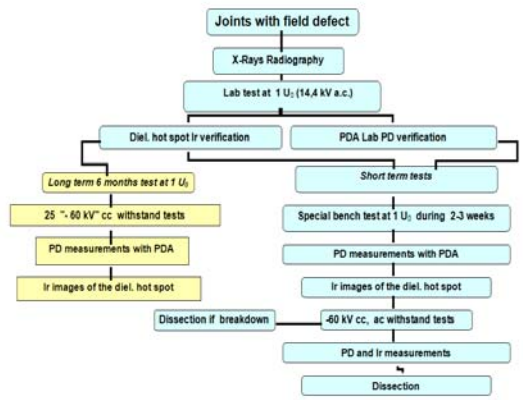

Figure 1. Experimental protocol for joints withdrawn from the network. The procedures in yellow are long-term tests.

Field conditions were faithfully reproduced using our special cable splice which allows us to add cable lengths on both sides of joints without any change in cable impedance (~ 35 ohms), up to ~500 MHz. Classification of the defects was made at that point. The next step consisted in confirming the PDs and dielectric hotspots measured in the field. The same equipment (PDA and infrared camera) was used to measure both PDs and dielectric hotspots at 1 U_0 in the lab. At that point, four joints were subjected to long-term testing to verify whether or not the "- 60 kV DC" withstand test could induce or aggravate PD or dielectric hot-spot defects. The other 33 joints were used directly for short-term tests whose purpose is to evaluate the seriousness of defects by establishing the relationship between the defects and HV withstand tests. Joint dissections were done after each dielectric breakdown occurring during AC or DC HV withstand tests.

Finally, the results were analyzed and conclusions drawn with emphasis on the nature of insulation degradation, its rate of degradation and the link between PDs, infrared measurements and joint-condition assessment.

RESULTS AND DISCUSSION

All defects were reconfirmed in the laboratory. In fact, the same ΔT (joint temp. – ambient temp.) were obtained for all joints with dielectric hotspot defects. Also, PD activity resumed after a few hours of conditioning on the test bench, which consisted of a gradual increase of the high voltage up to 2 U_0 or until reappearance of the PD activity. All joints with defects were subsequently put on the test bench at 1 U_0 for 2-3 weeks. Then, PD and infrared measurements were taken prior to the final HV DC withstand test. No defects, degradation or particular changes were observed at that point. In fact, the PD signals and dielectric hotspots were similar to the field measurements. The PD signals were recorded and a classification of dielectric hotspots was made (see Fig. 2).

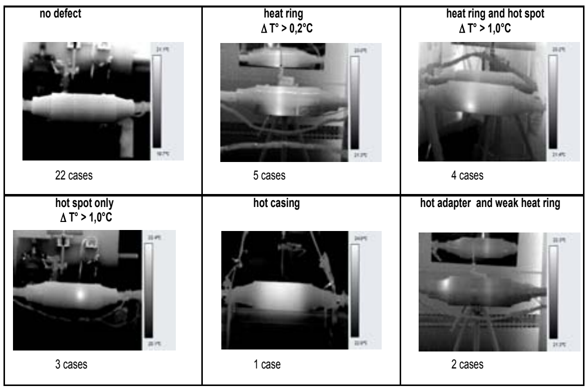

Figure 2. Infrared images (at 1 U_0, no current load) of 37 type A straight joints removed from the field. Classification of dielectric hotspot defects according to their shape and ΔT.

Table 1 summarizes all PD and infrared measurements along with the withstand test results. All cases in the green portion (top 22 cases) had either no dielectric hotspots or very faint ones (ΔT < 0.1°C) and all passed the HV withstand tests even though three cases had some PD signals.

All seven cases in the red part of Table 1 failed to pass either the AC or the DC withstand tests. In fact, dielectric breakdown occurred at fairly low values (21-23 kV AC and 30-48 kV DC). Live infrared recordings and dissections showed that all breakdowns occurred exactly at the hottest dielectric spot observed on joints (see Fig. 3). Moreover, these recordings showed that the same dielectric hotspots observed at 1 U_0 were also present during DC withstand tests. They also showed that the ΔT of dielectric hotspots was directly proportional to the voltage during the HV withstand tests. These observations lead to the conclusion that joint defects consist in a direct conduction path through the rubber insulation, as confirmed by the specific PD pattern associated with these defects (see Fig. 4.). Therefore, AC or DC dielectric breakdown occurred as the result of excessive heat (ohmic losses) in the conduction path.

Age years	diel. hot spot	diel. hot spot Δ °C	PD	PD quadrant	Withstand test cc	Withstand test ac	Comments
21	n/o	n/a	no	n/a	n/a	passed	
21	n/o	n/a	no	n/a	n/a	passed	
24	n/o	n/a	no	n/a	n/a	passed	
26	n/o	n/a	no	n/a	n/a	passed	
21	n/o	n/a	no	n/a	n/a	passed	
21	n/o	n/a	no	n/a	n/a	passed	
23	n/o	n/a	no	n/a	n/a	passed	
24	n/o	n/a	no	n/a	n/a	passed	
22	n/o	n/a	no	n/a	n/a	passed	
21	n/o	n/a	yes	1 & 3	n/a	n/a	Sniffer PD measurements
21	n/o	n/a	yes	1 & 3	n/a	n/a	Sniffer PD measurements
24	n/o	n/a	no	n/a	n/a	passed	
21	n/o	n/a	no	n/a	n/a	passed	
21	n/o	n/a	no	n/a	passed	passed	6 months, 1 U_0, 25 "-60kV" cc tests
21	n/o	n/a	yes	max. 3	passed	passed	corona discharges
21	n/o	n/a	no	n/a	n/a	passed	
23	n/o	n/a	no	n/a	n/a	passed	
31	n/o	n/a	no	n/a	n/a	passed	
24	ring	< 0,1	no	n/a	n/a	passed	
28	ring	< 0,1	no	n/a	n/a	passed	
23	ring	< 0,1	no	n/a	n/a	passed	
22	ring	< 0,1	no	n/a	n/a	passed	
26	ring	0,2	no	n/a	passed	passed	6 months @ 1 U_0, 25 "-60kV" cc tests
24	ring	0,2	no	n/a	passed	passed	
22	ring	0,3	no	n/a	n/a	passed	
23	ring	0,3	no	n/a	passed	passed	6 months @ 1 U_0, 25 "-60kV" cc tests
23	spot+ring	0,4	no	n/a	passed	passed	
31	spot+ring	0,4	no	n/a	passed	passed	
24	spot+ring	0,6	no	n/a	passed	passed	6 months @ 1 U_0, 25 "-60kV" cc tests
23	spot+ring	1,2	yes	2 & 4	breakdown	n/a	breakdown (bdn) at -35kV cc
21	casing	1,3	yes	4	breakdown	n/a	breakdown (bdn) at -35kV cc
23	spot+ring	2,0	yes	2 & 4	breakdown	n/a	breakdown at -48kV cc
24	spot	2,1	yes	1&3, 2&4	breakdown	n/a	breakdown at -37kV cc
21	ring	2,2	yes	2 & 4	n/a	breakdown	bdn. during PD measu. at 23kV ac
23	spot+ring	2,6	yes	max. 1	breakdown	n/a	bdn. at -30kV cc
24	n/a	n/a	yes	n/a	n/a	breakdown	bdn PD measu. 21kV ac, no IR image

n/o = not observed
PD = Partial Discharges
n/a = not applicable

Table 1. Summary of results for the 37 type A joints.

The next seven cases, in the yellow part of Table 1, had dielectric hotspots with ΔT ranging from 0.2 to 0.6 °C.

Figure 3. Dissection of a type A joint. The inner Al sleeve is sometimes not connected to the cable connector, which is at high voltage. Note also that the inner semi-conducting material (at the tip of the pen) is not in close contact with the sleeve. Dielectric breakdown occurred through the insulation, to the left of the pen.

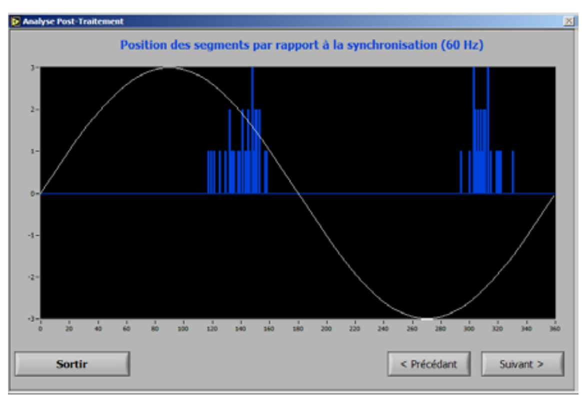

Figure 4. Phase resolved detection for the defective cable joints shows that PD activity shifts by 90°. Most PD pulses occurred in the 2nd and 4th quadrants [1].

Finally, Table 1 shows that joint breakdown occurred only in the presence of 1) a dielectric hotspot whose $\Delta T \geq 1.2°C$ and 2) PDs that occur mostly in the second and fourth 60-Hz quadrants.
Three joints with PDs did not fail during the HV withstand tests. According to our x-ray images and dissections (see Fig. 3), the PDs in these cases occurred between the inner Al sleeve, which is at an unknown potential, and the crimped cable connector at HV potential. Moreover, PD activity for these cases occurred in the first and third quadrants. They did not show the special pattern (see Fig. 4) associated with "direct conduction" defects. None had any dielectric hotspots or rings although one case had a specific heat pattern (hot casing).
So, what is responsible for PD and dielectric hotspot defects in type A cable joints? First, the Al sleeve must be in direct contact with the cable connector in order to be at the same HV potential. Second, a tight contact of the semiconductor onto the Al sleeve is of prime importance to assure a smooth distribution of the equipotential lines inside the type A joints.
X-ray images and dissections were very helpful in finding an answer. They showed that every joint with a defect had air gaps between the inner semiconductor (EPDM rubber doped with carbon black) and the Al sleeve. We also observed that, in some cases, Al sleeves were not in contact with the cable connector, i.e. they were not at the HV potential. This situation is due to a time- and heat-related mechanical relaxation mechanism affecting joint semiconductor and EPDM materials [3-4]. Dissections also showed us that, in some cases, corrosion of Al sleeves had seriously deteriorated the sleeve/connector contact.
We conclude from the above observations that mechanical relaxation of materials and corrosion of the Al sleeves prevent good contact of the semiconductor with the HV parts inside some aged (~23 years in service) type A joints. Thus the semiconductor cannot smooth out the equipotential lines, probably generating high electrical stress at some points (see Fig. 3) and, eventually, leakage currents with ohmic losses through the insulation. The final degradation step is characterized by the presence of PD activity.

CONCLUSION

This field case study of the type A joint demonstrated the usefulness of our PD device. First of all, good correlation with infrared diagnosis and laboratory tests proved that the PD diagnosis was correct. Moreover, PD patterns allow us to have an estimate of the remaining field life of defective type A joints. In fact, we can conclude from our work that any joint with PD activity related to a direct conduction defect and located in the second and fourth 60 Hz quadrants will have a short remaining life since any HV surge (~ 2 U_0) associated with network switching operations might induce a final dielectric breakdown. These joints must be replaced as soon as possible. On the other hand, according to our laboratory and field records, joints with PD activity in the first and third 60-Hz quadrants (not related to a dielectric hotspot) should have a longer remaining life.
Infrared diagnosis proved to be very effective in the field detection of defective joints. The only problem with this diagnosis is that joint dielectric hotspots can be hidden by a nearby joint or a concrete wall. Fortunately, the most serious cases, which needed replacement, were always detected and rightly diagnosed by our PD device.
Finally, some 50,000 A type joints are presently in service in our distribution network. Some of them seem to develop problems after ~23 years in service. Now, with its PD diagnosis, Hydro-Québec is able to replace the troublesome ones in good time and spread the replacement costs over many years. This preventive maintenance program also helps reduce worker safety hazards.

ACKNOWLEDGMENT

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