WETS D'15 2.4 Drapeau

A Study on the Effect of Performing VLF Withstand Tests on Field Aged Degraded Joints

Jean-François DRAPEAU
Researcher
Expertise Équipement électriques
IREQ

Jacques CÔTÉ, HQD
Simon BERNIER, IREQ

Jicable'11

21 June 2011

Versailles, France

Hydro Québec

OUTLINE

- Context & Introduction
- Objectives of the study
- Test Samples
- Experimental Protocol
- Results for Joints: Type A
- Results for Joints: Type B
- Results Wrap-up & Issues
- VLF Diagnostic Interpretation: Application to a Cable System Typical to HQD
- Summary

1- CONTEXT & INTRODUCTION

- **Context: Field withstand testing at HQD:**
  --> introduction of VLF considered

- **Initial assumption: --> parameters from IEEE 400.2**
  (*For 25 kV system: VLF Sine 0.1 Hz 23 kV 30 min*)

- **Question: What effect will have VLF withstand testing on degraded joints present in the MV underground system ?**

- **Before proceeding to implementation, better to collect a max. of testing data in the lab.**

2- OBJECTIVES OF THE STUDY

- **Verify and quantify the influence of performing VLF-TD withstand testing (according to IEEE 400.2)**

  on joints identified as severely degraded

  in term of dielectric loss and local temperature elevation

- **Have a "first sight" of what would be the expectable outcomes of VLF withstand tests performed in the field on HQD cable system**
  - ***--> Pass / No pass***
  - ***--> Tan δ readings from monitored withstand***
  - ***--> Interpretations on diagnostics***

2- OBJECTIVES OF THE STUDY

REMINDER: *purpose of a withstand test*

- **Application of voltage above normal operating voltage for a prescribed duration**
- ***Attempts to drive weakest location(s) within cable segment to failure while segment is not in service***

  ---> without causing any further degradation to the other components which are aged, but still in good condition

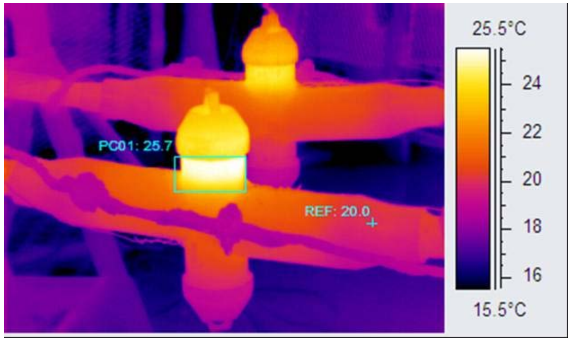
3- TEST SAMPLES

Request for targeted joint samples extraction

--> 2 types of joints know as most critical in HQD underground MV system

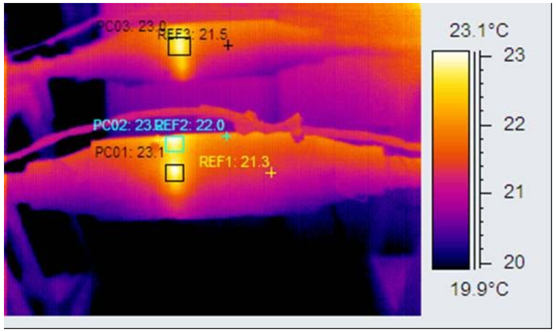
--> Joints identified with <u>thermal anomalies</u>

Type A



Disconnectable straight joint with taps design

Type B



Premolded straight joint design

4- EXPERIMENTAL PROTOCOL

- **Protocol: On a number of joints with various degradation levels:**

1. *Selection tests (30 joints out of 60)*
2. ***IR thermography (init. cond.)***
3. ***TDS characterization (init. cond.)***
4. ***VLF withstand (IEEE 400.2: 23kV - 30 min)***
   --> Monitored tan δ + IR thermography
5. ***TDS characterization (post)***
6. ***IR thermography (post)***

Pre-characterization

VLF withstand test

Post-characterization

Select. tests VLF 5 kV	Thermo #1	Loss meas. tan δ TDS #1	VLF Withstand / Thermo #2	Loss meas. tan δ TDS #2	Thermo #3
	V: 1,0 U_0	V: 1, 3, 5, 10, 15 kV t_{pol}/t_{depol} = 200/500	V: 23 kV (1,6 U_0) f: 0,1 Hz	V: 1, 3, 5, 10, 15 kV t_{pol}/t_{depol} = 200/500	V: 1,0 U_0

4- EXPERIMENTAL PROTOCOL

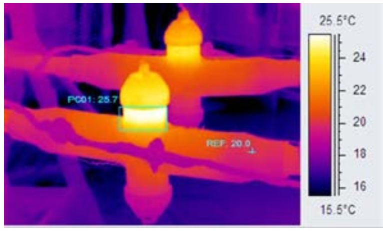
CLASSIFICATION: "Effect of VLF withstand" on joints

Level | **Thermal anomaly evolution** | **Dielectric loss evolution**

Prevailing parameter

JOINT CONDITION EVOLUTION IMPACT IS :	Criteria for "thermal anomaly" evolutions Value of "Δ [ΔT]" Sum for all the hot spots (HS) occurring on the same joint (°C)	(%)	Max for individual hot spots (%)	Criteria for TDS loss evolutions Δ [tan δ_{mean}] (%)
STRONG (=FAILURE)	Criteria for $\Delta[\Delta T]$ & $\Delta[\tan \delta_{mean}]$ t.b. determined or Failure occurrence			
SIGNIFICANT	$\Delta[\Delta T] > 0.5$ or [$\Delta[\Delta T] > (0{,}1 \, X nb_{HS})$	and $\Delta[\Delta T] > 50\%$]		and $\Delta TD \geq 200\%$.
SOME	$(0.1 X nb_{HS}) < \Delta[\Delta T] \leq 0.5$	and $\Delta[\Delta T] > 20\%$	or $\Delta[\Delta T] > 40\%$	and $100\% \leq \Delta TD \leq 200\%$
VERY LIGHT	$(0.1 X nb_{HS}) < \Delta[\Delta T] \leq 0.5$	and $\Delta[\Delta T] \leq 20\%$		or $20\% \leq \Delta TD \leq 100\%$
NONE	$\lvert\Delta[\Delta T]\rvert \leq 0.1 \, (X nb_{HS})$			and $\lvert\Delta TD\rvert < 20\%$
REDUCED SIGNS OF DEGRADATION	Evolutions showing negative values : e.g. -0,4°C, -25%, etc. $\lvert\Delta[\Delta T]\rvert > (0.1 X nb_{HS})$	and $\lvert\Delta[\Delta T]\rvert > 20\%$		and $\lvert\Delta TD\rvert \geq 20\%$

5- RESULTS FOR JOINTS - TYPE A



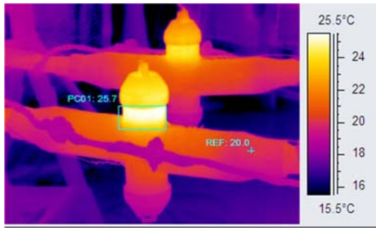
JOINT SAMPLE	Initial cond. VLF Tan δ @ 5 kV(X 10^{-3})	ΔT variation Δ(ΔT)	TDS Loss Variation (%)	EVOLUTION Impact is :
06-A	7932	+1.3°C / +27%	+20%	Significant
16-X	4329	+0.3°C / +11%	+149%	Some
20-X	3239	-1.6°C / -59%	+8%	Reduced signs of degradation
20-Z	2738	+1.2°C / +133%	+109%	Significant
20-Y	2705	+3.2°C / +168%	+182%	Significant
14-X	2014	-0.8°C / -57%	+47%	Reduced signs of degradation
19-X	1597	-0.6°C / -38%	+6%	Reduced signs of degradation
18-Y	1036	+0.3°C / +21%	+27%	Some
14-Z	918	0.0°C / 0%	+40%	Very light
18-Z	784	-0.1°C / -16%	+35%	Very light
14-Y	743	-0.1°C / -16%	+52%	Very light
13-Y	358	-0.2°C / -33%	+13%	None
18-X	295	0.0°C / 0%	+71%	Very light
19-Y	128	N/A	+50%	Very light
06-C	58	+0.4°C / +67%	+601%	Significant
16-Y	7	N/A	+10%	None

Impact of VLF withstand

Observations: (General)

- NO failure
- Impact level of VLF withstand show an evolution consistent with initial condition of the joint
- --> varies rather "smoothly" from "significant" down to "none"
- When initial condition of the joint is good
  ---> No significant impact

5- RESULTS FOR JOINTS - TYPE A



JOINT SAMPLE	Initial cond. VLF Tan δ @ 5 kV(X 10^{-3})	ΔT variation Δ(ΔT)	TDS Loss Variation (%)	EVOLUTION Impact is :
06-A	7932	+1.3°C / +27%	+20%	Significant
16-X	4329	+0.3°C / +11%	+149%	Some
20-X	3239	-1.6°C / -59%	+8%	Reduced signs of degradation
20-Z	2738	+1.2°C / +133%	+109%	Significant
20-Y	2705	+3.2°C / +168%	+182%	Significant
14-X	2014	-0.8°C / -57%	+47%	Reduced signs of degradation
19-X	1597	-0.6°C / -38%	+6%	Reduced signs of degradation
18-Y	1036	+0.3°C / +21%	+27%	Some
14-Z	918	0.0°C / 0%	+40%	Very light
18-Z	784	-0.1°C / -16%	+35%	Very light
14-Y	743	-0.1°C / -16%	+52%	Very light
13-Y	358	-0.2°C / -33%	+13%	None
18-X	295	0.0°C / 0%	+71%	Very light
19-Y	128	N/A	+50%	Very light
06-C	58	+0.4°C / +67%	+601%	Significant
16-Y	7	N/A	+10%	None

Impact of VLF withstand

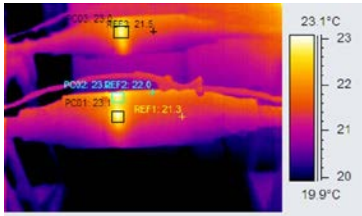
Observations: (Particular)

- 3 samples showing "reduced signs of degradation"
- Anomaly = localized "spot" in the "tap"

- Anomaly = localized "spot" in the insulation body

- Localised anomalies are associated with "significant" impact

6- RESULTS FOR JOINTS - TYPE B



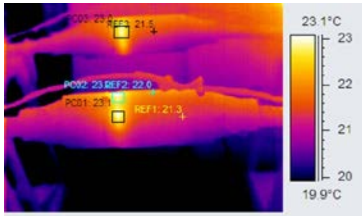
Impact of VLF withstand

JOINT SAMPLE	Initial cond. VLF Tan δ @ 5 kV(X 10^{-3})	ΔT variation $\Delta(\Delta T)$	TDS Loss Variation (%)	EVOLUTION Impact is :
02-X	6165	-	-	Strong (=failure)
01-Z	359	-	-	Strong (=failure)
21-Z	241	-6.9°C / -100%	-51%	Reduced signs of degradation
02-Y	63	+0.6 °C / +15%	-46%	Strong (=failure)
04-X	19	+0.1°C / +4%	+355%	Some
07-C	19	+0.2°C / +100%	+399%	Strong (=failure)
21-Y	9.6	-	+2%	None
04-Y	7.7	+0.0°C / +0%	+4%	None
01-X	6.5	-	+13%	None
03-Z	6.4	-	-22%	None
01-Y	6.0	-	+13%	None
07-X	5.9	-	+10%	None
07-B	5.9	-	+10%	None
03-X	4.7	-	+12%	None

Observations: (General)

- **Two distinc groups: "bad" (6) vs "good" (8)**
- **Among 6 "bad", there are 4 failures**
- **When initial condition of the joint is good**
  ---> No measurable impact

6- RESULTS FOR JOINTS - TYPE B



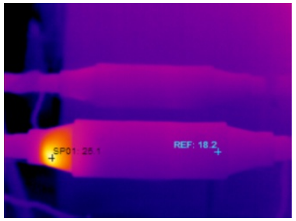
JOINT SAMPLE	Initial cond. VLF Tan δ @ 5 kV(X 10^{-3})	ΔT variation Δ(ΔT)	TDS Loss Variation (%)	EVOLUTION Impact is :
02-X	6165	-	-	Strong (=failure)
01-Z	359	-	-	Strong (=failure)
21-Z	241	-6.9°C / -100%	-51%	Reduced signs of degradation
02-Y	63	+0.6 °C / +15%	-46%	Strong (=failure)
04-X	19	+0.1°C / +4%	+355%	Some
07-C	19	+0.2°C / +100%	+399%	Strong (=failure)
21-Y	9.6	-	+2%	None
04-Y	7.7	+0.0°C / +0%	+4%	None
01-X	6.5	-	+13%	None
03-Z	6.4	-	-22%	None
01-Y	6.0	-	+13%	None
07-X	5.9	-	+10%	None
07-B	5.9	-	+10%	None
03-X	4.7	-	+12%	None

Impact of VLF withstand

Observations:
(Particular)

- 1 sample showing "reduced signs of degradation"

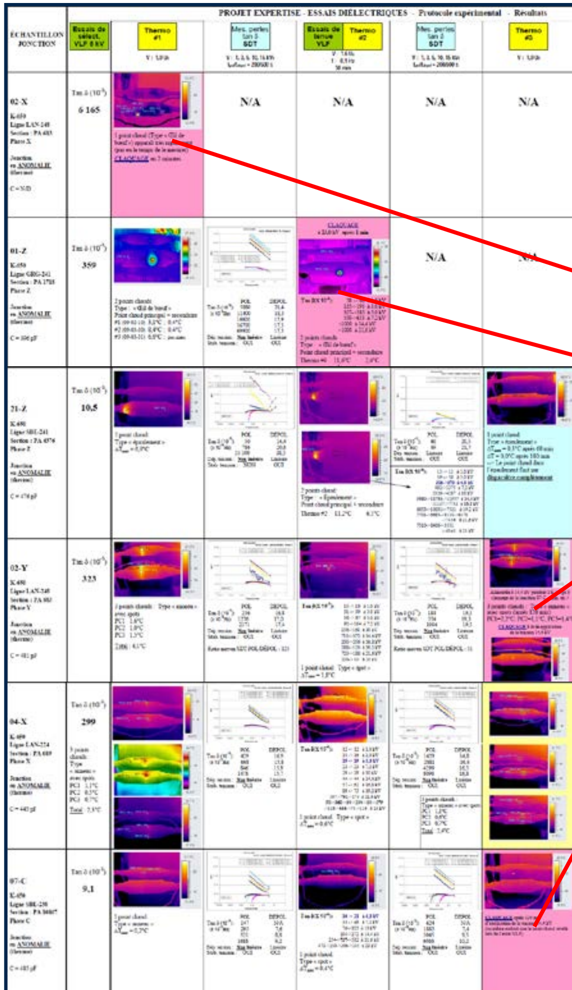
  This sample had a particular "heat signature"
  --> localized hot spot in the "shoulder"



- Failures occurred at different steps in the procedure

6- RESULTS FOR JOINTS - TYPE B

Impact of VLF withstand



Observations:
(Particular)

OCCURENCES OF FAILURES

Failure 1: 1st time energized @ 1Uo

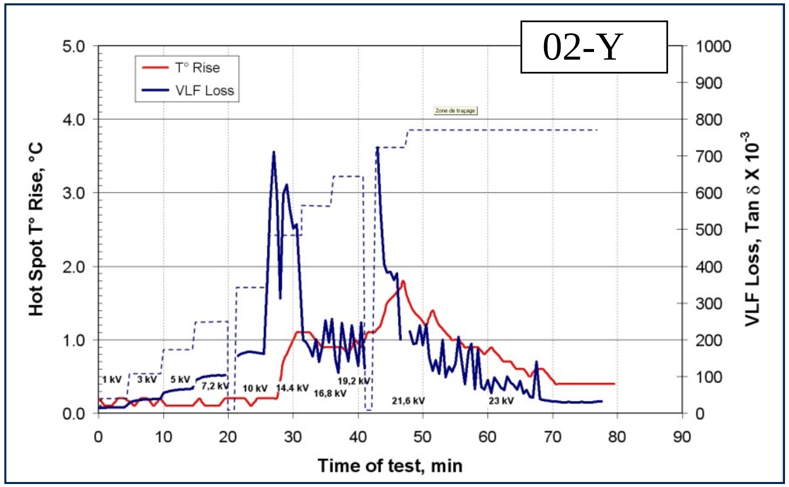
Failure 2: During VLF withstand

Failure 3: When re-energized @ 1Uo

Failure 4: When re-energized @ 1Uo

6- RESULTS FOR JOINTS - TYPE B

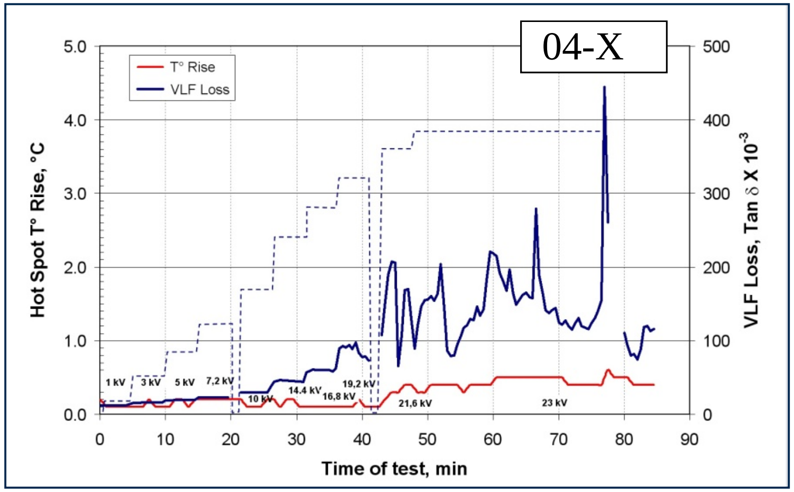
Impact of VLF withstand

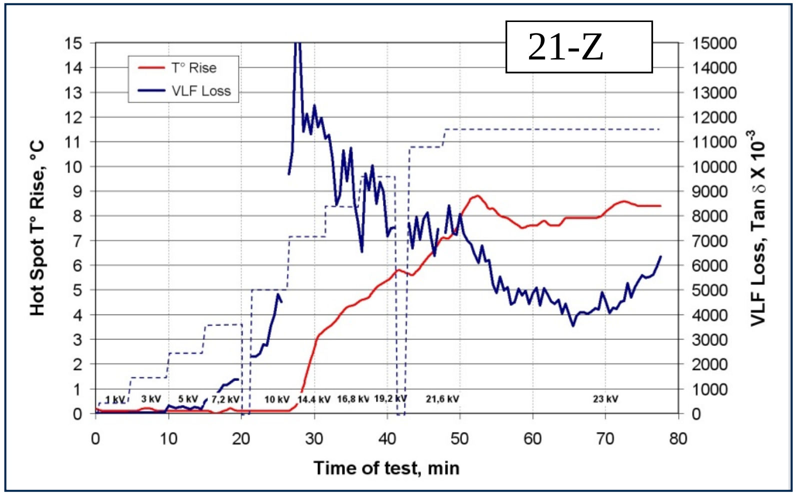


Observations:
(Particular)

UNEXPECTED LOSS BEHAVIOR DURING VLF MONITORED WITHSTAND

Dielectric loss show several huge quasi-instantaneous variations (increase or decrease)





7- RESULTS WRAP-UP & ISSUES

IMPACT OF PERFORMING VLF WITHSTAND TESTS...

- **On joints in good condition:**
  --> No measurable effect

- **On degraded joints of type A**
  --> Some effect, but not that much

- **On degraded joints of type B**
  --> Significant effect: - Occurrence of failures
  - Erratic behavior of losses

ISSUES:

- **"Spot" type anomalies appear particularly vulnerable**

- **Clear indications that presence of water has a strong influence on joint insulation behavior**

8- VLF DIAGNOSTIC INTERPRETATION: Application to a Cable System typical to HQD

DIELECTRIC LOSS FEATURES FOR SINGLE JOINTS:

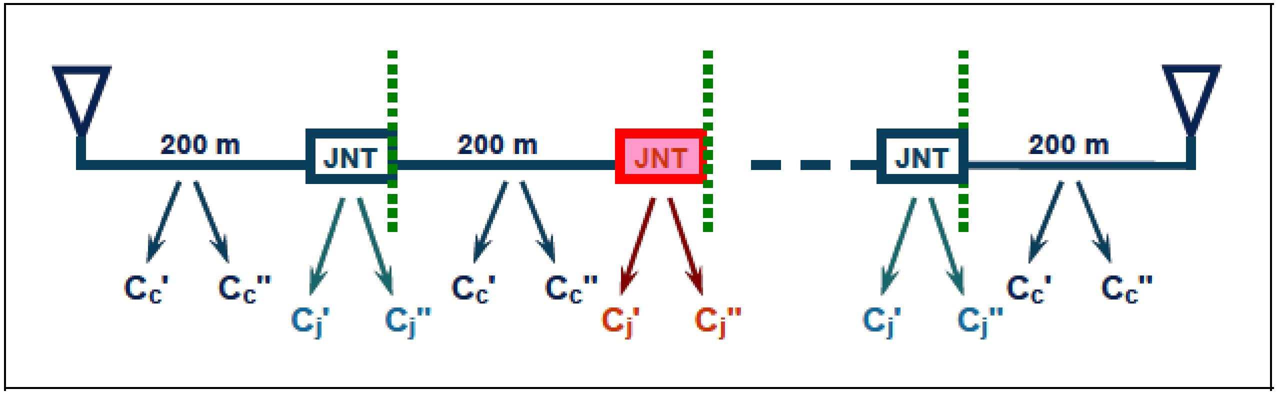
JOINT SAMPLE	Mean Tan δ (X 10^{-3}) at each step -------- RAMP-UP --------			HOLD	Differential TD (Tip-Up)
	$0.5\ U_0$	$1\ U_0$	$1.5\ U_0$	$1.6\ U_0$	$[1.5U_0 - 0.5U_0]$
A - 06-A	8768	11265	16170	21294	7402
B - 02-Y	100	532	370	90	270

ISSUE: **How such VLF feature values would translate in the field, considering cable circuits with various lengths ?**

8- VLF DIAGNOSTIC INTERPRETATION: Application to a Cable System typical to HQD

Configurations considered for the simulations:

One "bad" joint in a cable system



Overall loss calculation:

$$Tan\,\delta_{line} = \frac{\sum C''_{cable\ \ i} + \sum C''_{jct\ \ i}}{\sum C'_{cable\ \ i} + \sum C'_{jct\ \ i}}$$

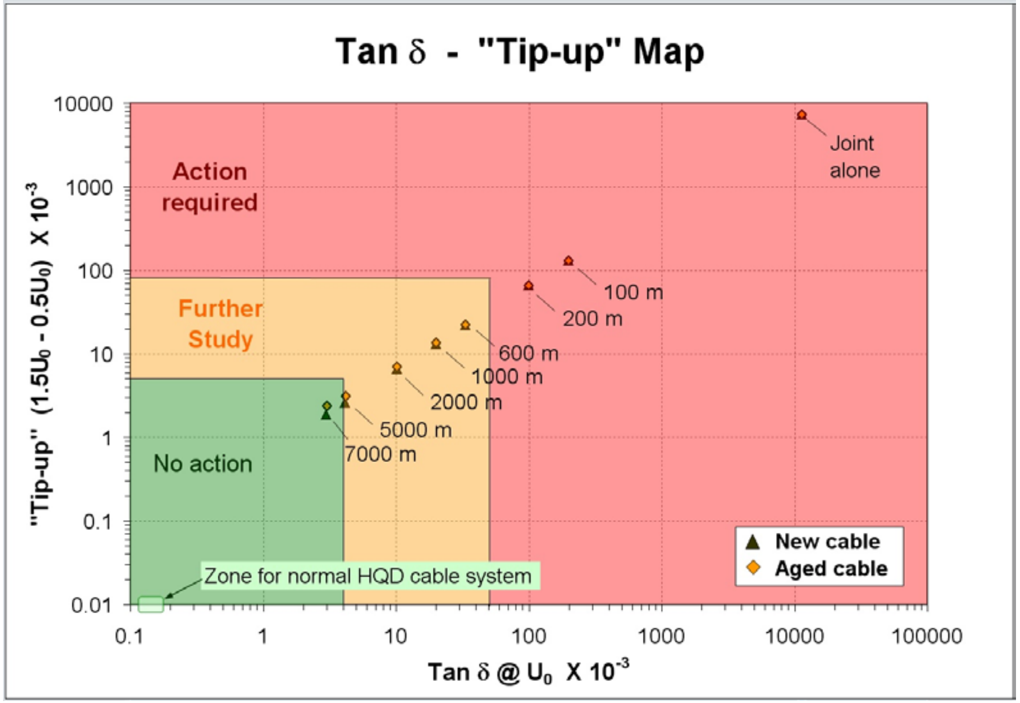
Loss contributions

Direct capacitances

8- VLF DIAGNOSTIC INTERPRETATION: Application to a Cable System typical to HQD

Simulation results for joint type A:

(Diagnostic criteria defined in IEEE 400.2[1] for PE-based insulation)



--> Cable length has a significant impact on VLF diagnostic outcome

(1) According to latest draft D9

9- SUMMARY

- **Effect of performing VLF withstand tests is strongly dependant to the type (design) of joint and to the type of defect (e.g. heat anomaly pattern)**

- **Expected outcomes on joints are not straightforward --> multiple and complex phenomena are involved (e.g. effect of water)**

- **Further studies are required in order to allow a better understanding of these issues**