VLF AC Testing

High Voltage, Inc.
Copake, NY USA

www.hvinc.com

Major Cable Components

Conductor

Conductor or Strand Shield

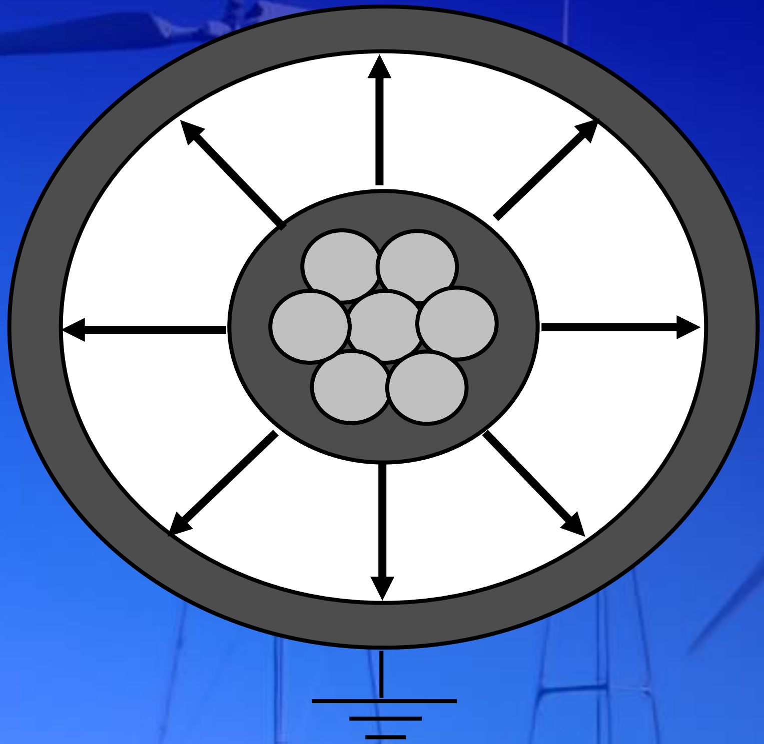
Insulation

Insulation Shield

Metallic Shield/Neutral

Jacket (Recommended)

Good Cable = Uniform electric field

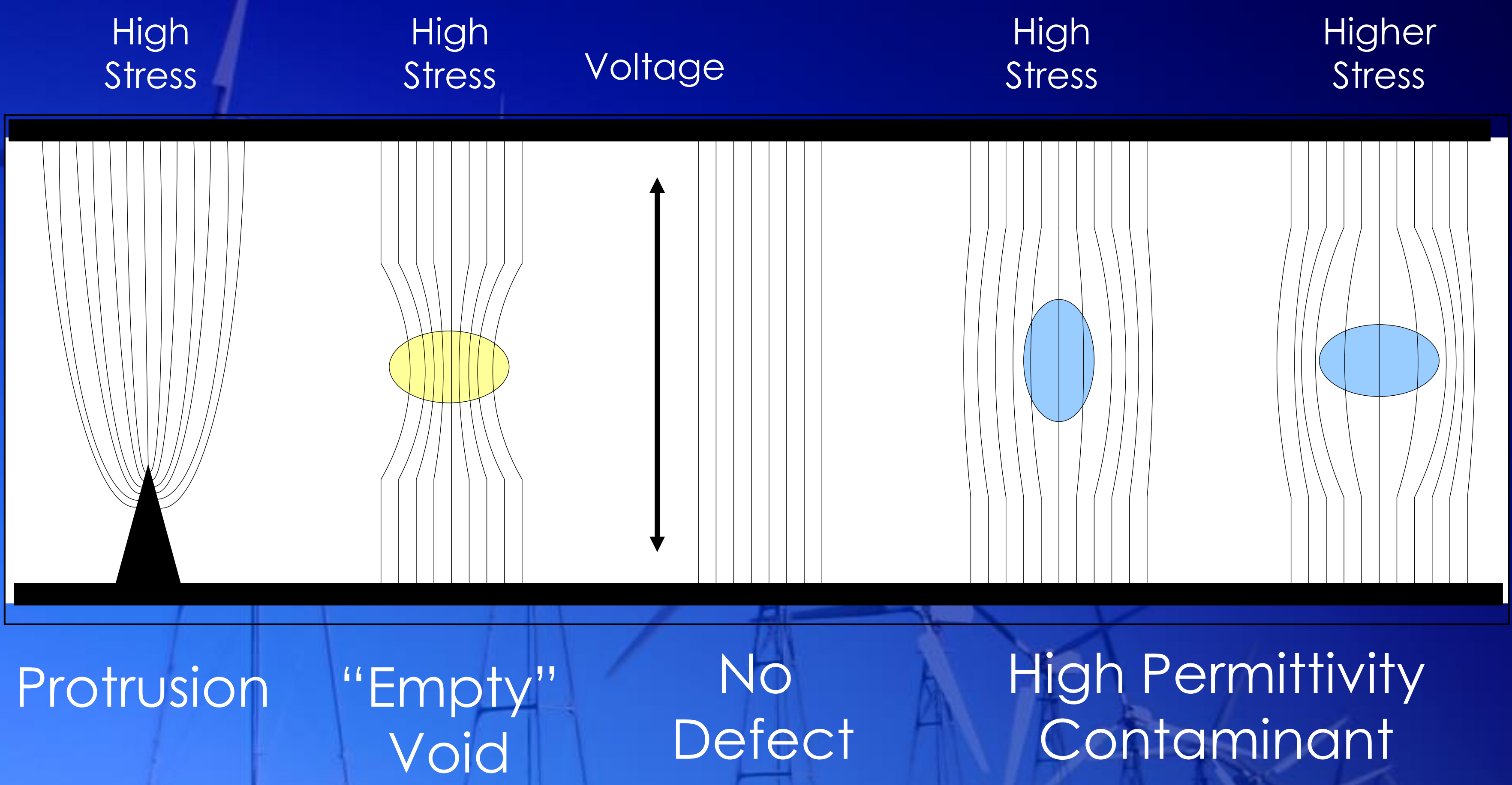


When both shields are:

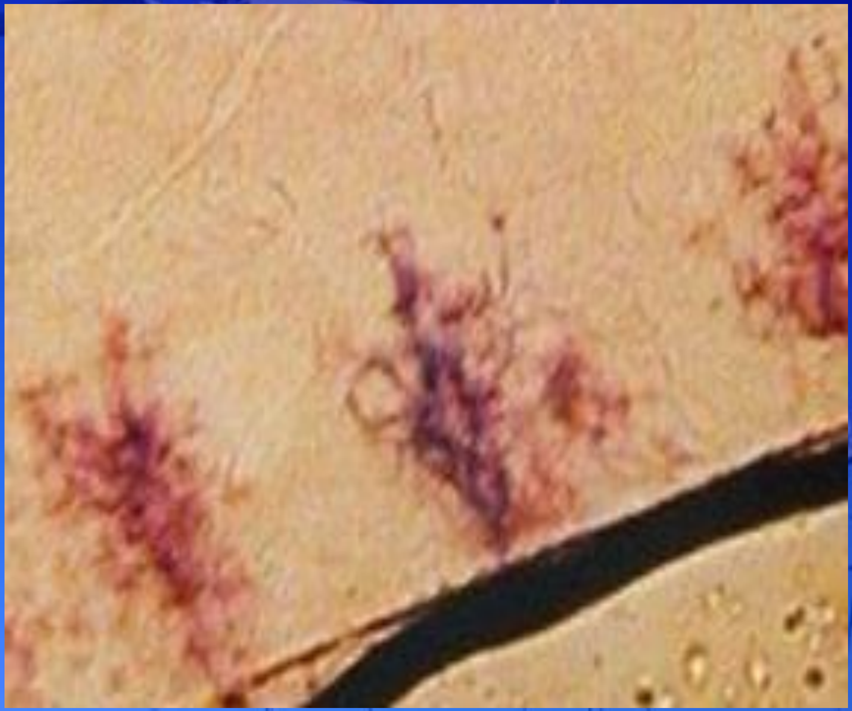
- Smooth
- Intact

Electric field lines are uniform, with a controlled electrical stress distribution.

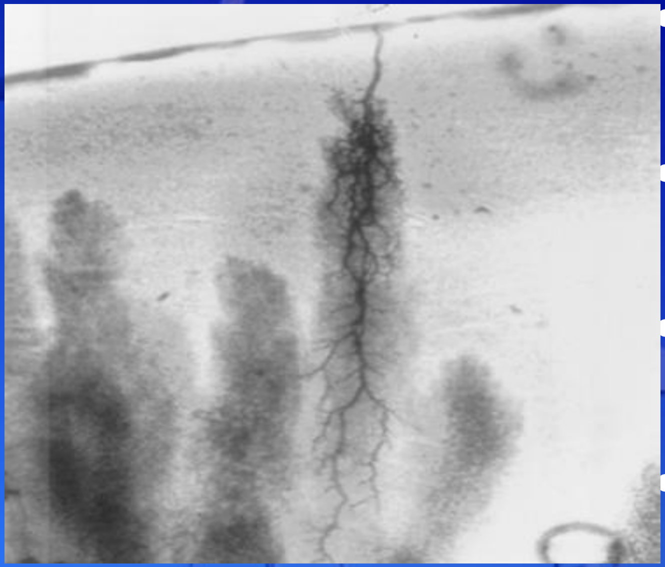
Basic stress enhancements



Tree effect



Conversion of water to electrical trees



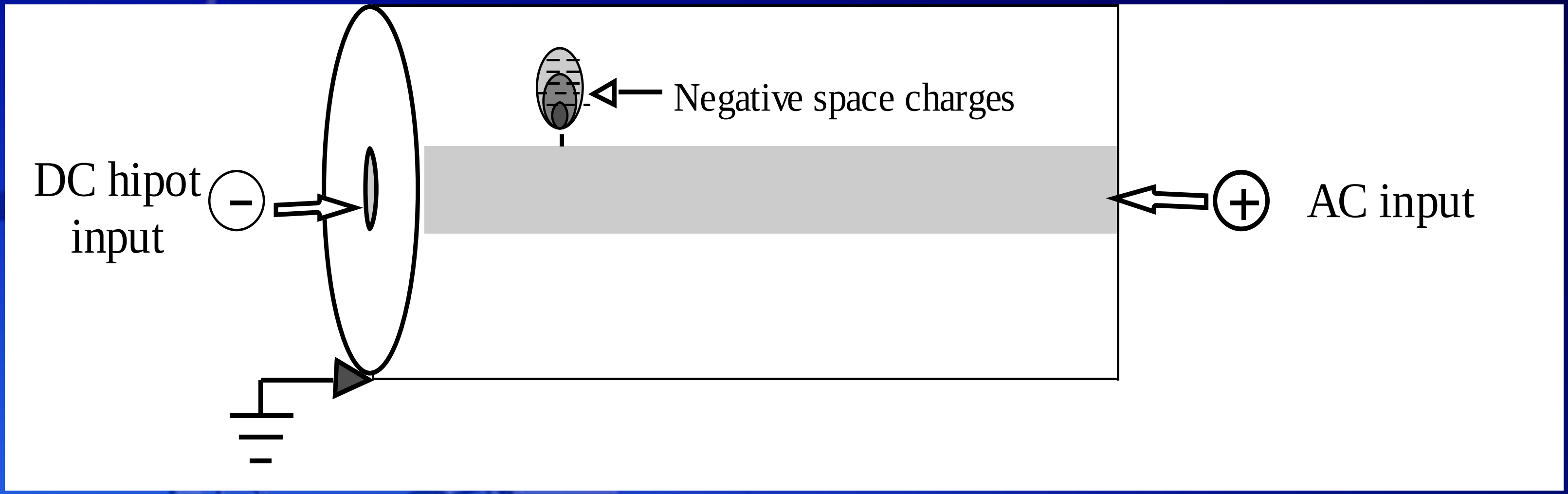
Electrical tree growing from water tree

- Acts as a stress enhancement or protrusion (non-conducting)
- Water tree increases local electric field
- Water tree also creates local mechanical stresses
- **If** electrical and mechanical stresses high enough ⇒ electrical tree initiates
- Electrical tree completes the failure path – rapid growth

Dc testing

- **Advantages:**
  - - DC hipots are small, portable, and economical
  - - Easy to operate
  - - Considered non-destructive
- **Disadvantages:**
  - - DC has been found to damage solid dielectric insulation
  - - DC leakage currents ineffective at determining cable life
  - - No diagnostic tools available

Why DC is damaging



- DC hipot output negatively charges up water tree areas.
- These "trapped space charges" remain after test.
- When AC is reapplied, there's a high difference of potential across very little of the insulation. Leads to electrical trees – cable fails.

No testing

- **Advantages:**
  - \- Easy to operate
  - \- No expensive equipment

- **Disadvantages:**
  - \- Unplanned outages
  - \- Loss of revenue
  - \- No feel for the health of your system
  - \- Reactive" mentality, not proactive

Power frequency testing

- **Advantages:**
  - - Same profile as service conditions
  - - Correlates to factory testing
  - - Allows diagnostic testing
- **Disadvantages:**
  - - Very Large and Expensive equipment
  - - Difficult to operate

VLF testing

- **Advantages:**
  - - Stress similar to service conditions
  - - Light weight, low cost
  - - Easy to use
  - - Easy to interpret results, Go-No Go test
  - - Sine wave output can be used with diagnostic equipment
- **Disadvantages:**
  - - Voltage waveform in some designs (trapezoidal) don't allow diagnostics of PD or Tan Delta.
  - - Destructive – cable may fail under test

What is vlf?

A VLF instrument is just an AC hipot with an output frequency lower than 50/60 Hz.

Very Low Frequency: 0.1 Hz and lower

By decreasing the frequency, it is possible to test miles of cable with a small and affordable unit.

Models range from 0.1 – 0.01 Hz.

Vlf explained

$$X_C = \frac{1}{2 \times \pi \times \underline{\mathbf{f}} \times C}$$

The lower the frequency, the higher X_C (capacitive reactance).

The higher X_C (or resistance across the power supply output),

the lower the current/power needed to apply a desired voltage.

At 0.1 Hz, it takes 600 times less power to test a cable, or any other high capacitance load, than at 60 Hz. At 0.01 Hz, 6000 times higher capacitive loads can be tested than at 60 Hz.

60 Hz vs. 0.1 Hz

At 60 Hz. a 1 µF cable has an X_C of 2.65 kOhms.

At 22 kV, it requires 8.3 amps of current to test.

Total power supply rating must be 183 kVA.

At 0.1 Hz, the X_C is 1.59 megohms.

At 22 kV, the current needed is 14 mA.

Total supply power needed is .304 kVA.

VLF rapidly grows defects to failure.

VLF is non-destructive to good insulation.

VLF exposes existing defects in insulation and accessories that can be excited by the applied voltage.

VLF with Tan Delta or PD offers an excellent non-destructive diagnostic test.

IEEE 400.2 Field Test Voltages
For Shielded Power Cable Systems
Using Sine Wave Output VLF

Waveform	Cable system rating (phase to phase) [kV]	Installation (phase to ground)		Acceptance (phase to ground)		Maintenance[2] (phase to ground) (see Note 2)	
		[kV rms]	[kV peak]	[kV rms]	[kV peak]	[kV rms]	[kV peak]
Sinusoidal	5	9	13	10	14	7	10
	8	11	16	13	18	10	14
	15	19	27	21	30	16	22
	20	24 (Note 3)	34 (Note 3)	26	37	20	28
	25	29 (Note 3)	41 (Note 3)	32	45	24 (Note 3)	34 (Note 3)
	28	32	45	36 (Note 3)	51 (Note 3)	27	38
	30	34	48	38	54	29 (Note 3)	41 (Note 3)
	35	39	55	44	62	33	47
	46	51	72	57	81	43	61
	69	75	106	84	119	63	89

XLPE tree growth rate

Test voltage factor (V/V_o)	Growth rate at 0.1-Hz sinusoidal test voltage (mm/h)
2	2.3
3	10.9-12.6
4	58.3-64.2
5	336

A 15kV 133% cable has an insulation thickness of 5.9 mm.

In a 30 minute test, nearly all defects will grow to failure.

XPLE Testing statistics

TNB in Malaysia 3 V_0 @ 60 minutes

- 17,435 VLF tests performed –
  - 2,179 cable failures

Minutes to failure	Failures	% of total
0 - 12	1472	67.62
13 - 30	469	21.54
31 - 45	129	5.93
46 - 60	107	4.92

89.16 % (67.62 + 21.54)

2.78% of tested cables failed later in service.

(Many cables were PILC)

Tests conducted 2001 – 2002

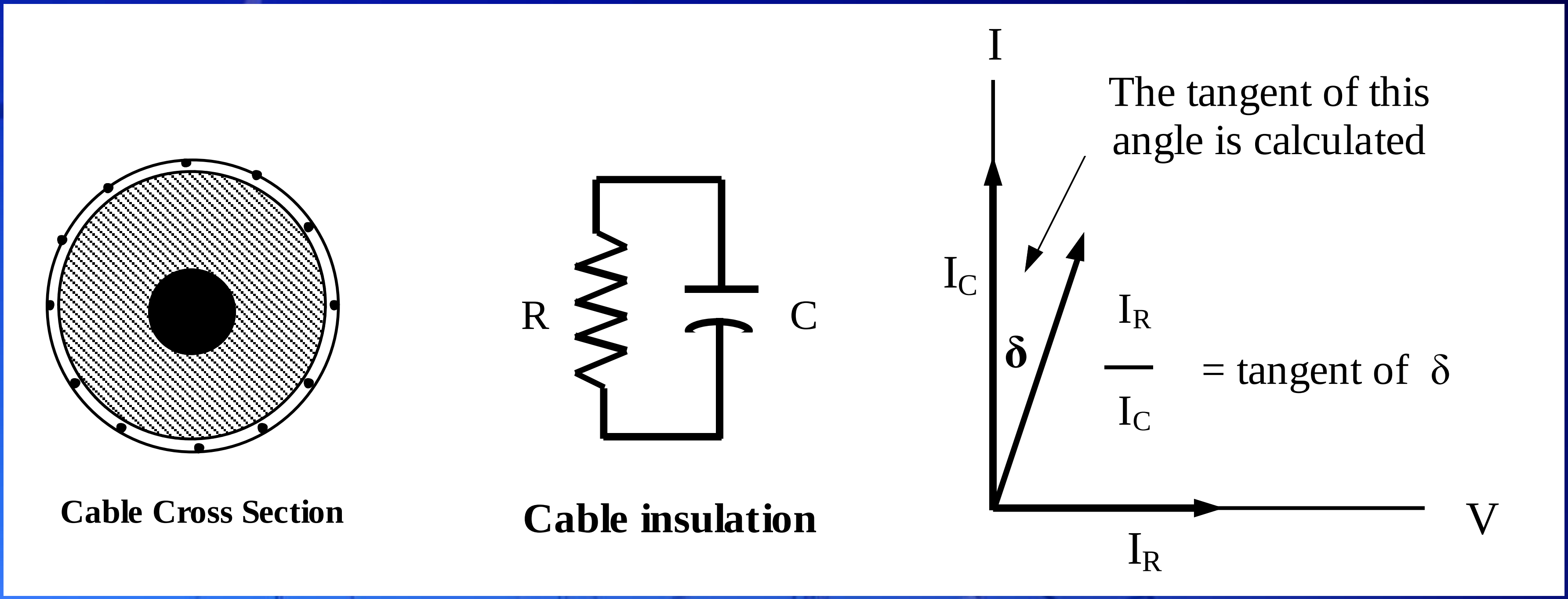
- Diagnostic Cable Test Methods

  Partial Discharge

  Tan Delta

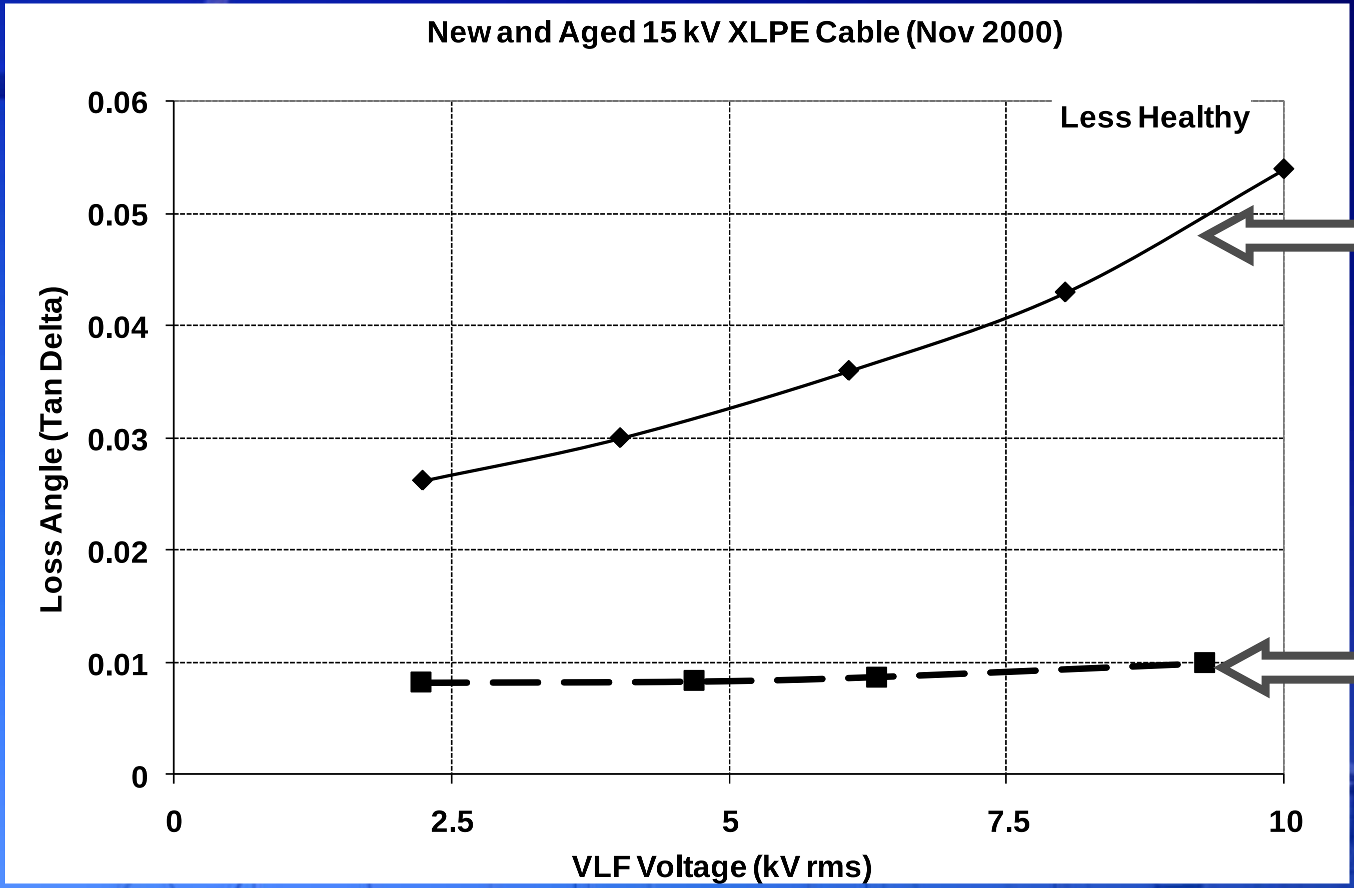
Simplified Cable Model and Phasor Drawing

Tan Delta = I_R / I_C - measured in radians



- With perfect insulation, a cable is a near perfect capacitor, with a 90° phase shift between voltage and current. Less than 90° indicates insulation degradation. Cables can be rated good, marginal, or bad.

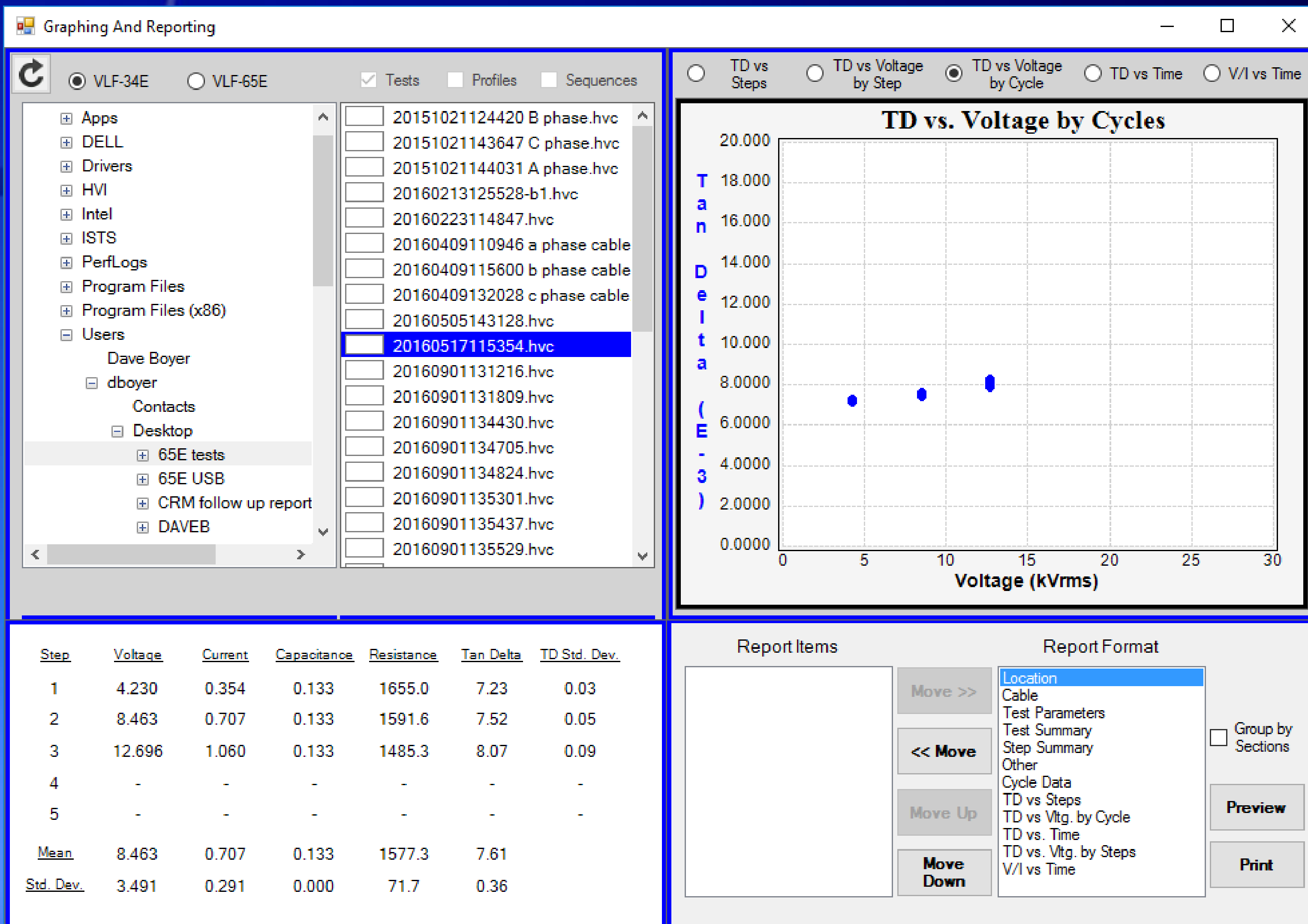
Tan Delta vs. Voltage for New and Aged XLPE Cables



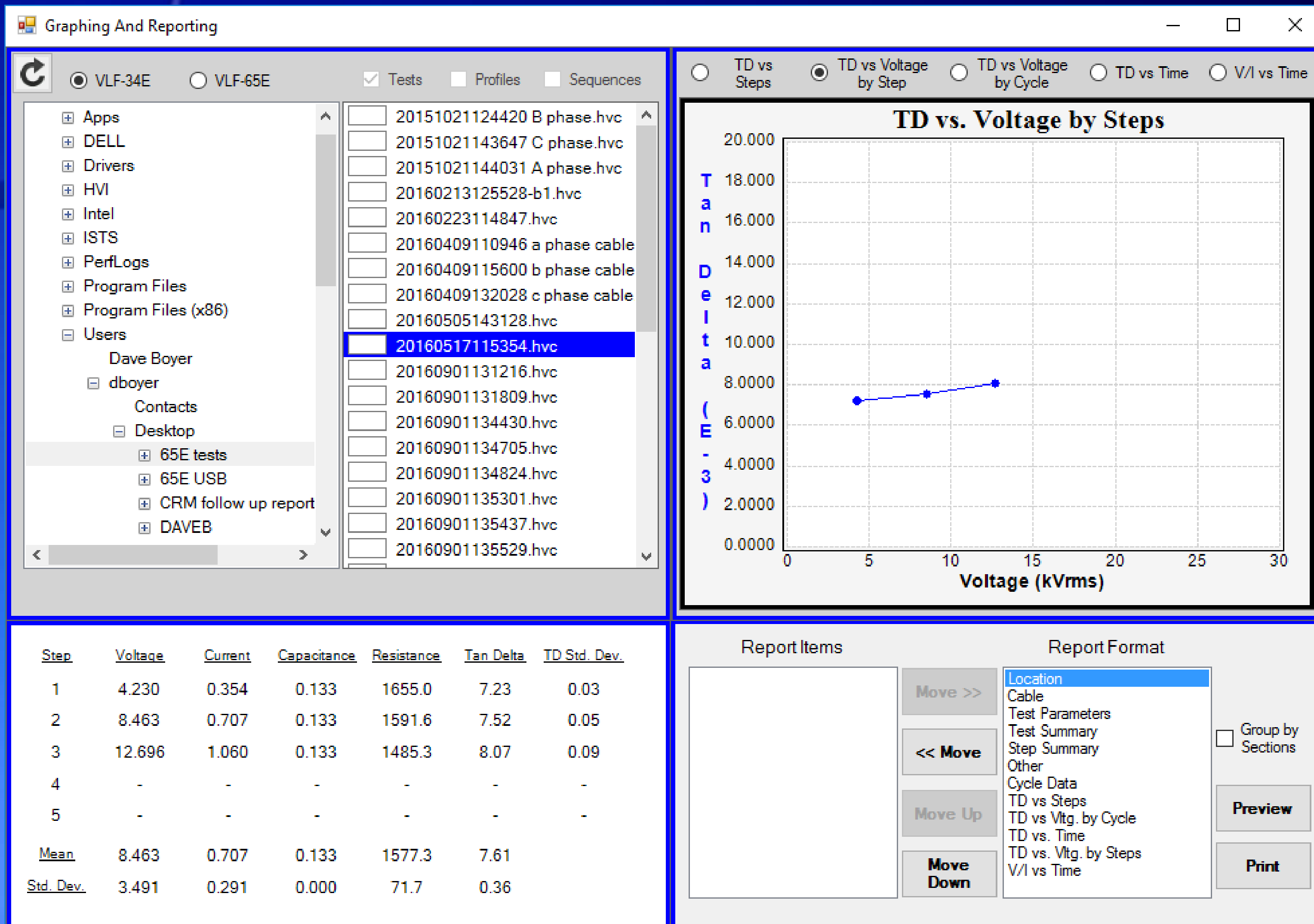
Aged cable non-linear tan delta #s versus voltage

healthy cable linear tan delta #s versus voltage

Tan delta stability

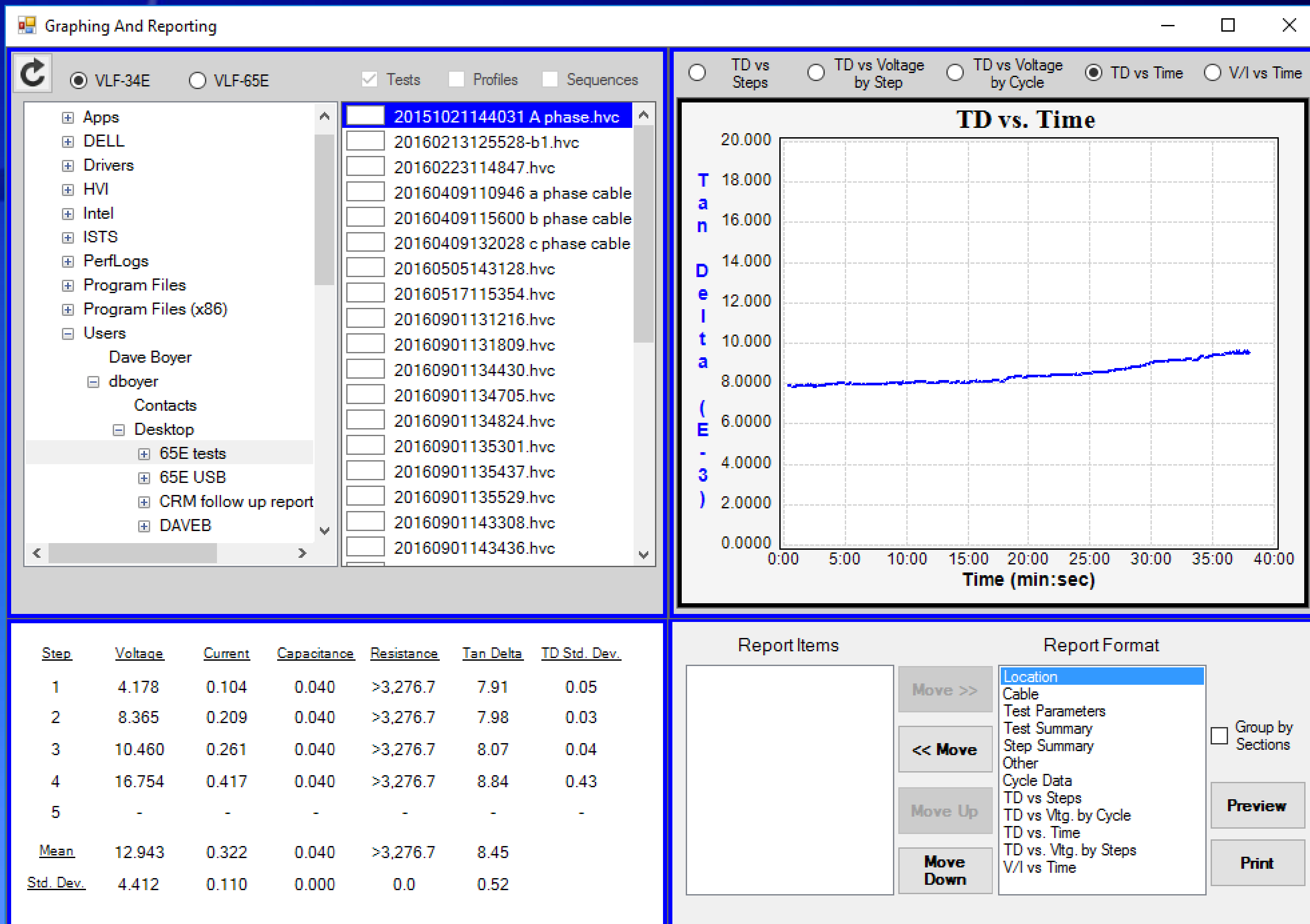


Tan delta tip up



Step	Voltage	Current	Capacitance	Resistance	Tan Delta	TD Std. Dev.
1	4.230	0.354	0.133	1655.0	7.23	0.03
2	8.463	0.707	0.133	1591.6	7.52	0.05
3	12.696	1.060	0.133	1485.3	8.07	0.09
4	-	-	-	-	-	-
5	-	-	-	-	-	-
Mean	8.463	0.707	0.133	1577.3	7.61	
Std. Dev.	3.491	0.291	0.000	71.7	0.36	

Monitored withstand test



VLF-tan delta report

Print Preview

Zoom 1 of 1 Close

HVI VLF-34E

VLF Tan-Delta Report

Parameters - **20160517115354.hvc**

Waveform: Sinewave **Frequency:** .1 (hz) **Fault:** Overload

File Name: C:\Users\dboyer\Desktop\65E tests\20160517115354.hvc

Date/Time: 5/17/2016 11:53:55 AM **Phase:** A

Step Summary - **20160517115354.hvc**

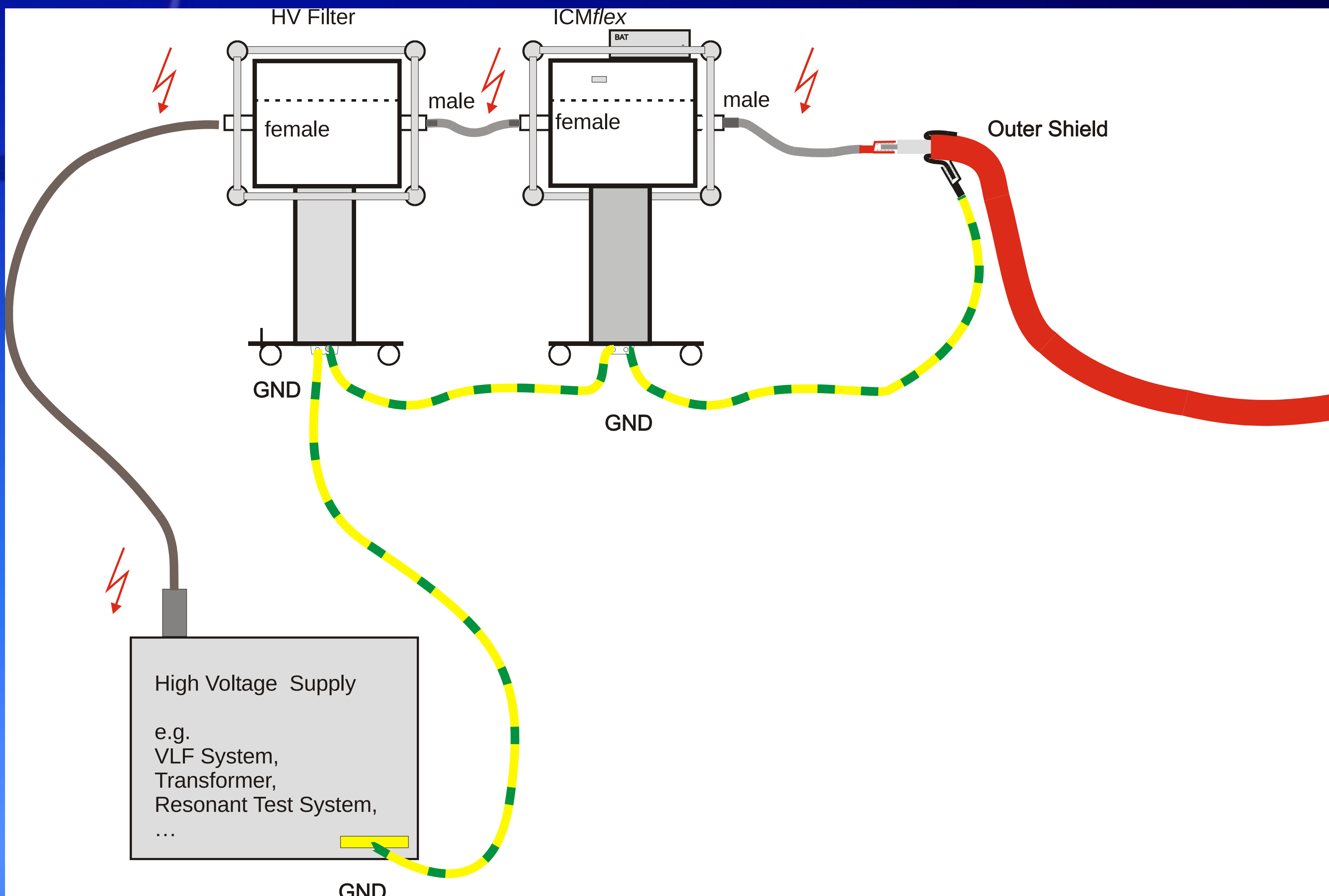
Step	Cycles	Source (kV)	Duration (min)	Voltage (kV)	Current (mA)	Tan Delta (E-3)	Capacitance (uF)	Resistance (MOhm)	Event
1	18	4.0	3	4.230	0.354	7.229	0.133	1654.978	0
			Std. Dev.	0.000	0.000	0.031	0.000	7.009	
2	18	8.0	3	8.463	0.707	7.520	0.133	1591.632	0
			Std. Dev.	0.002	0.000	0.053	0.000	11.115	
3	18	12.0	3	12.696	1.060	8.066	0.133	1485.253	0
			Std. Dev.	0.006	0.000	0.089	0.000	16.012	

Assessment of Unidentified Filled insulations

Condition Assessment $[10^{-3}]$	No Action Required	Further Study Advised	Action Required
Stability for TD_{U_0} (standard deviation)	<0.1	0.1 to 1.3	>1.3
	&	or	
Tip Up $(TD_{1.5U_0} - TD_{0.5U_0})$	<5	5 to 100	>100
	&	or	
Tip Up Tip Up $\{(TD_{1.5U_0} - TD_{U_0})$ - $(TD_{U_0} - TD_{0.5U_0})\}$	<0.5	0.5 to 30	>30
	&	or	
Mean TD at U_0	<35	35 to 120	>120

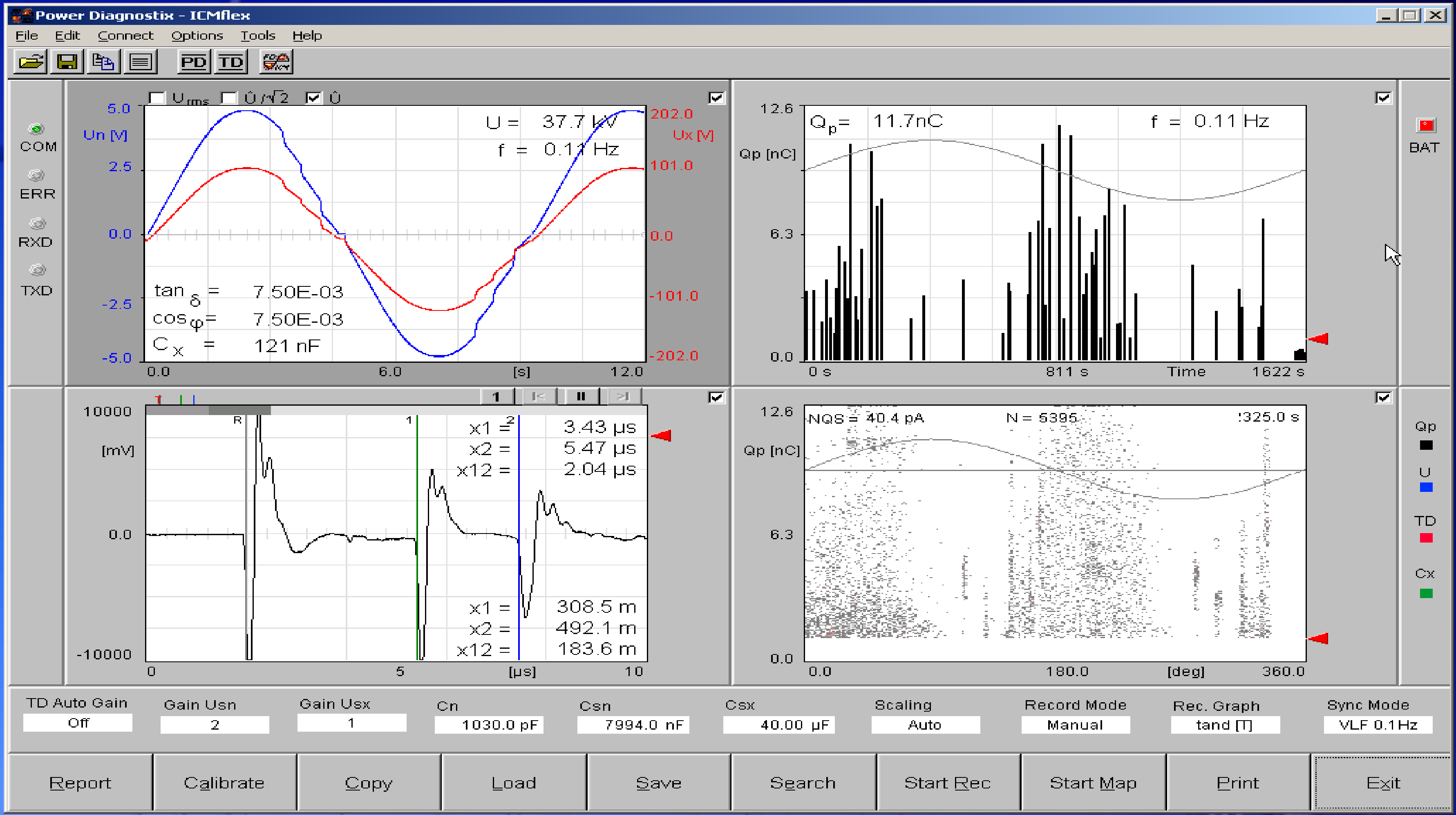
Step	Cycles	Source (kV)	Duration (min)	Voltage (kV)	Current (mA)	Tan Delta (E-3)	Capacitance (uF)	Resistance (MOhm)	Event
1	18	4.0	3	4.230	0.354	7.229	0.133	1654.978	0
			Std. Dev.	0.000	0.000	0.031	0.000	7.009	
2	18	8.0	3	8.463	0.707	7.520	0.133	1591.632	0
			Std. Dev.	0.002	0.000	0.053	0.000	11.115	
3	18	12.0	3	12.696	1.060	8.066	0.133	1485.253	0
			Std. Dev.	0.006	0.000	0.089	0.000	16.012	

Partial discharge (PD) setup



PD and TD field test

PD Info



Power Diagnostix - ICMflex
File
Edit
Connect
Options
Tools
Help
U = 37.7 kV
f = 0.11 Hz
tan δ = 7.50E-03
cos φ = 7.50E-03
Cx = 121 nF
Un [V]
Ux [V]
Qp = 11.7nC
f = 0.11 Hz
Qp [nC]
Time
NQS = 40.4 pA
N = 5395
x1 = 3.43 µs
x2 = 5.47 µs
x12 = 2.04 µs
x1 = 308.5 m
x2 = 492.1 m
x12 = 183.6 m
COM
ERR
RXD
TXD
BAT
TD Auto Gain
Off
Gain Usn
2
Gain Usx
1
Cn
1030.0 pF
Csn
7994.0 nF
Csx
40.00 µF
Scaling
Auto
Record Mode
Manual
Rec. Graph
tand [T]
Sync Mode
VLF 0.1Hz
Report
Calibrate
Copy
Load
Save
Search
Start Rec
Start Map
Print
Exit

Thank You

High Voltage, Inc.
www.hvinc.com