Measurement of Cable System Losses using Time Domain and VLF Techniques

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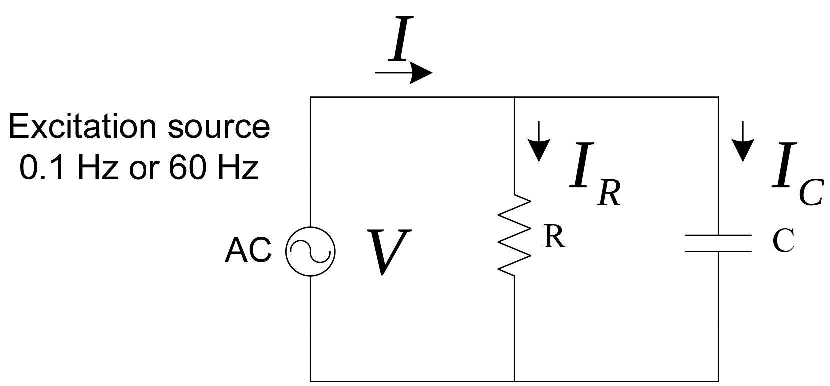
OUTLINE

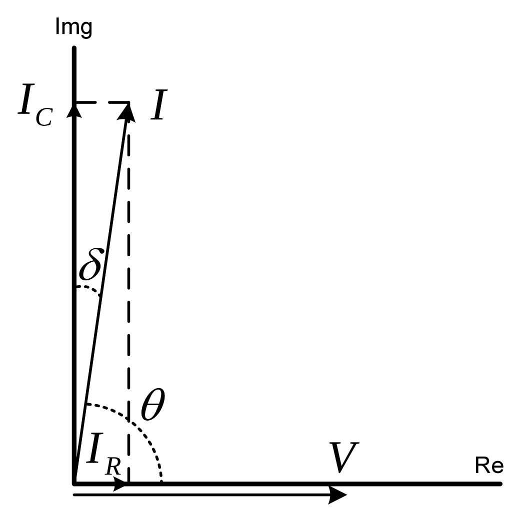
1. *VLF and TDS Principles*
2. *Correlation between Tan δ measurements at VLF and TDS*
   - *2.1 New cables*
   - *2.2 Joints*
   - *2.3 Field aged cables*
3. *Neutral issues for VLF*
4. *Effect of polluted terminations*
5. *"Arithmetic" of Tan δ at VLF and TDS (overview)*
6. *Conclusions*

1 – VLF and TDS Principles

Dielectric losses - Tan δ

- *The cable insulation system is represented by an equivalent circuit*
- *It consists of two parameters; a resistor and a capacitor [IEEE Std. 400]*
- *When voltage is applied to the cable, the total current will be the contributions of the capacitor current and the resistor current*



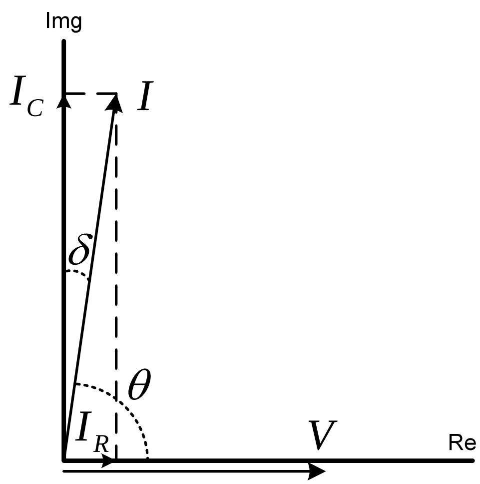


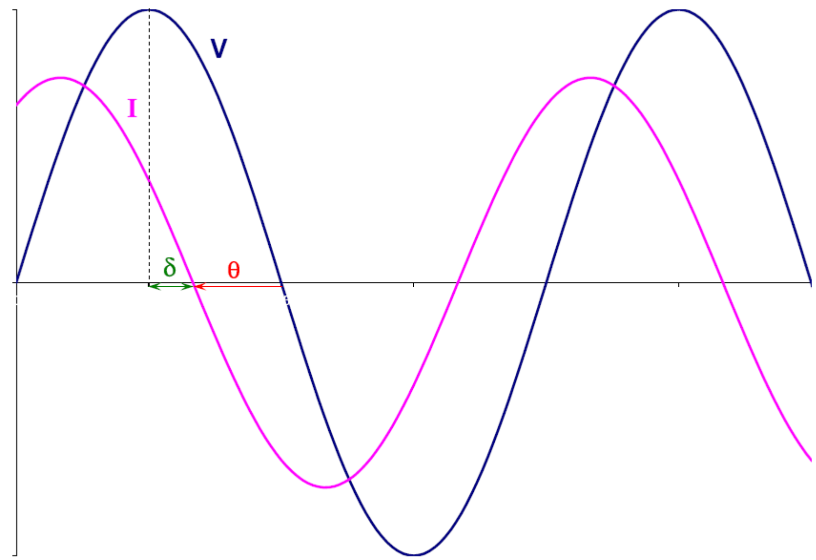
$$\tan(\delta) = DF = \frac{I_R}{I_C} = \frac{1}{\omega RC}$$

1 – VLF and TDS Principles

Dielectric losses - VLF principle

- *Frequency domain*
- *In this case, performed in AC (sine wave) "VLF" (0.1 Hz to 0.02 Hz)*
- *Derived from the phase angle difference between **I** and **V***



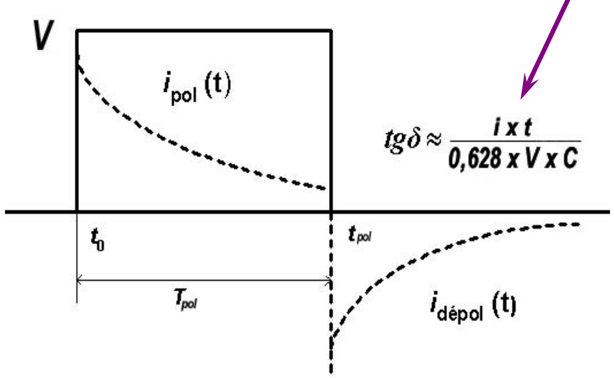


1 – VLF and TDS Principles

Dielectric losses - TDS principle

- *Time domain*
- *Based on current measurements under DC voltage*
- *Dielectric losses derived from the current contributions using Hamon approximation*

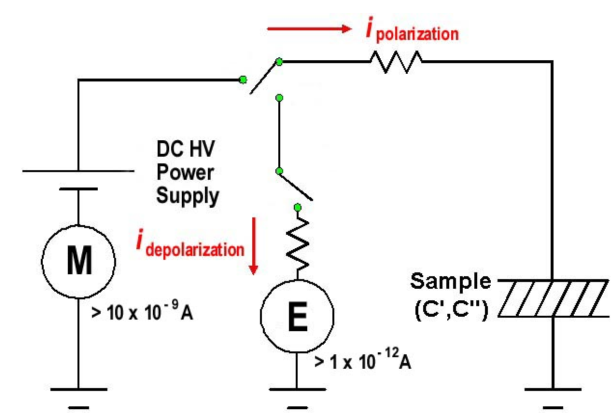
Principle



$$i_{pol}(t) = i_{cap}(t) + i_{abs}(t) + i_{qc}(t)$$
$$i_{depol}(t) = -i_{cap}(t) - i_{abs}(t)$$

Schematic of TDS device

(Grounded config.)



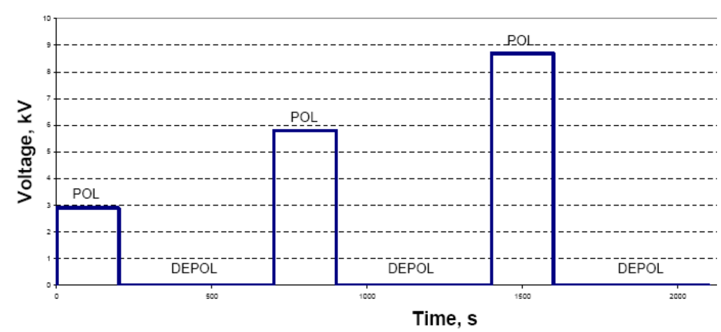
	Sensitivity
M : Multimeter	*10×10^{-9} A*
E : Electrometer	*1×10^{-12} A*

1 – VLF and TDS Principles

IREQ's TDS system

CONFIGURATION			
Grounded		Ungrounded	
Pol	Depol	Pol	Depol
Multimeter	Electrometer	Electrometer	Electrometer
Sensitivity ~ 10 X 10^{-9} A	Sensitivity ~ 1 X 10^{-12} A	Sensitivity ~ 1 X 10^{-9} A	Sensitivity ~ 1 X 10^{-12} A

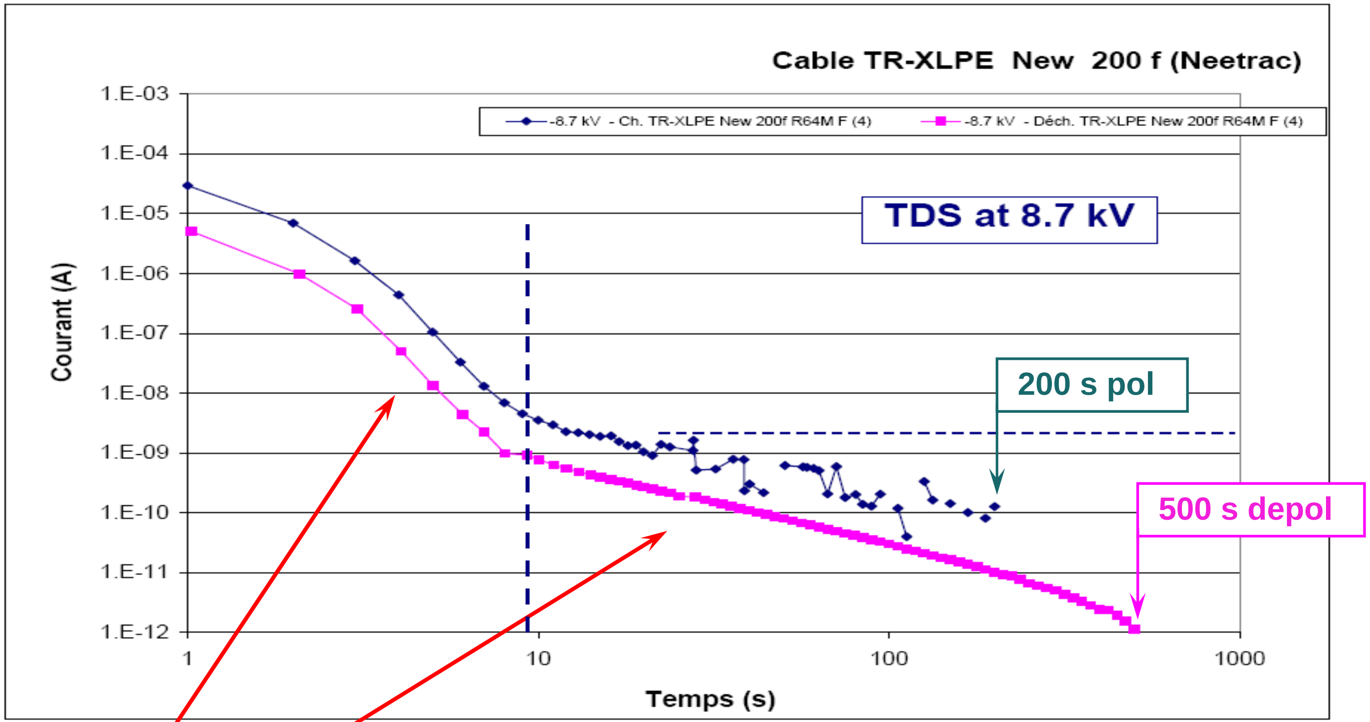
EXPERIMENTAL PROCEDURE		
DC Voltage	Time	
kV	Polarization (s)	Depolarization (s)
0	0	200
2,9 - 5,8 - 8,7	200	500



1 – VLF and TDS Principles

Dielectric losses - TDS principle

- *Example of current measurement*

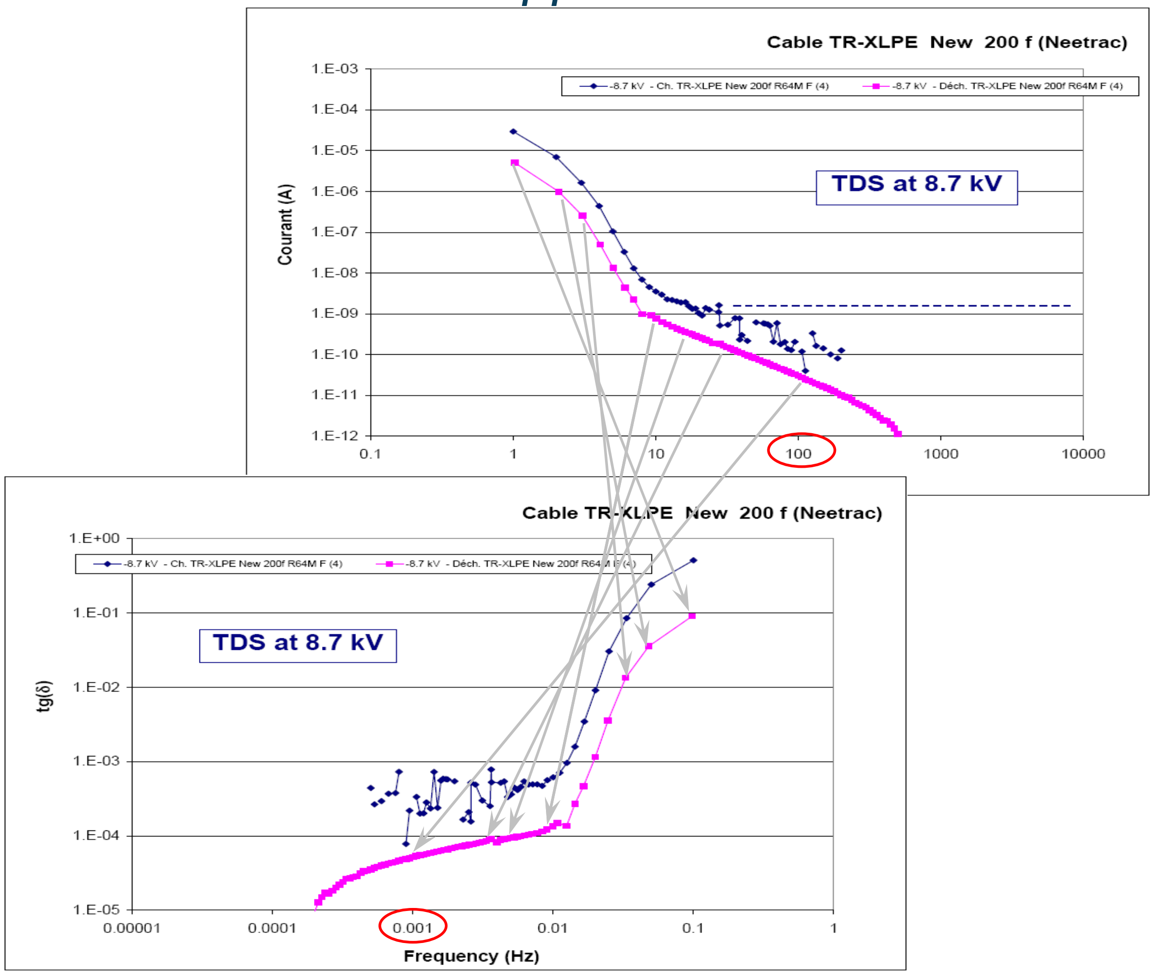


$$i_{pol}(t) = i_{cap}(t) + i_{abs}(t) + i_{qc}(t)$$
$$i_{depol}(t) = -i_{cap}(t) - i_{abs}(t)$$

1 – VLF and TDS Principles

Dielectric losses - TDS principle

- *Application of the Hamon approximation*



1 – VLF and TDS Principles

Tan δ : VLF vs TDS

VLF

- Frequency domain
- Sinusoidal waveform
- Computed from a phase difference
- Tan δ at different frequencies requires different tests
- Monitored withstand

TDS

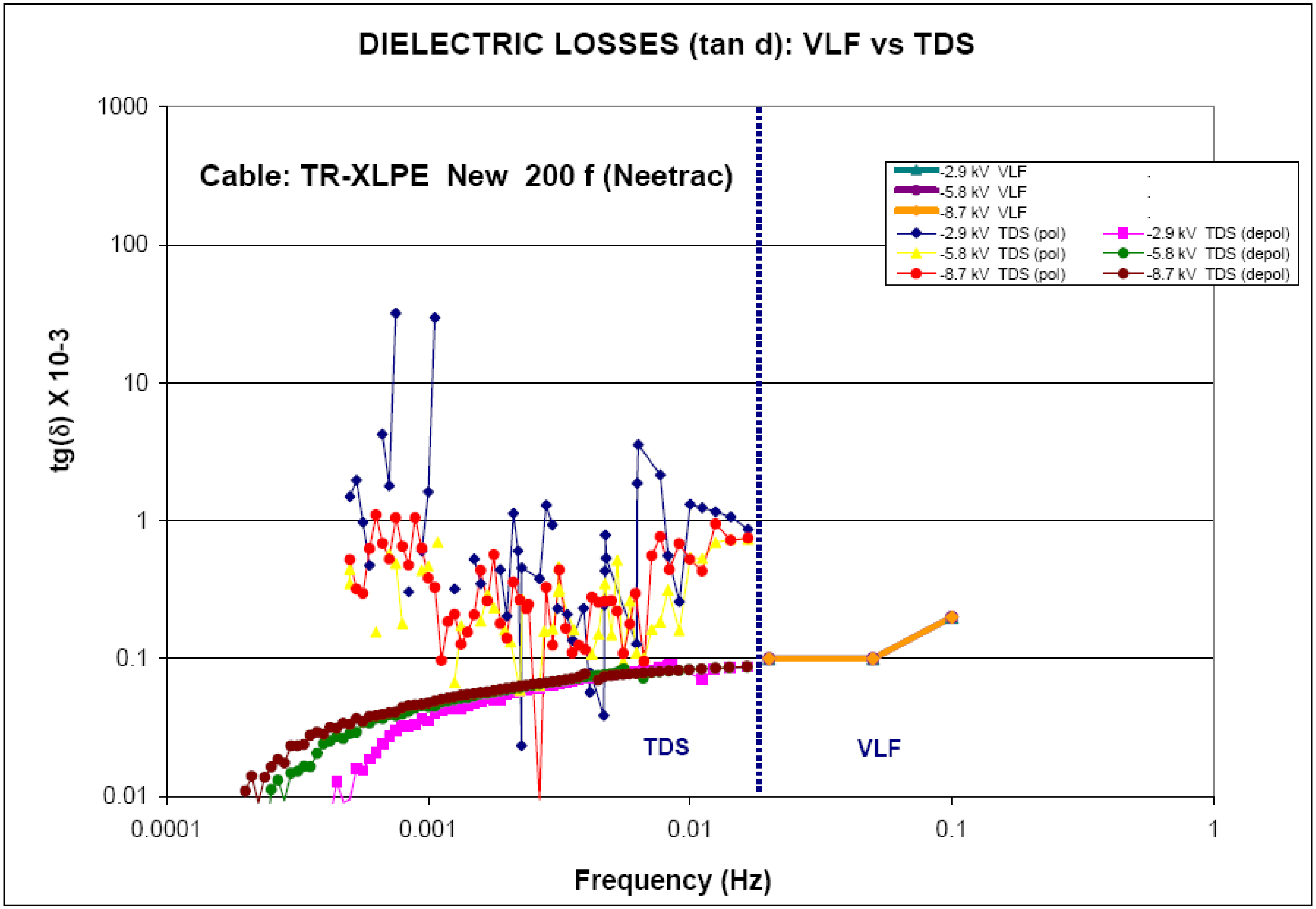
- Time domain
- DC waveform
- Estimated using the Hamon approximation
- One test at a particular test voltage provides Tan δ at different frequencies
- Monitored withstand

1 – VLF and TDS Principles

VLF & TDS Laboratory Setups

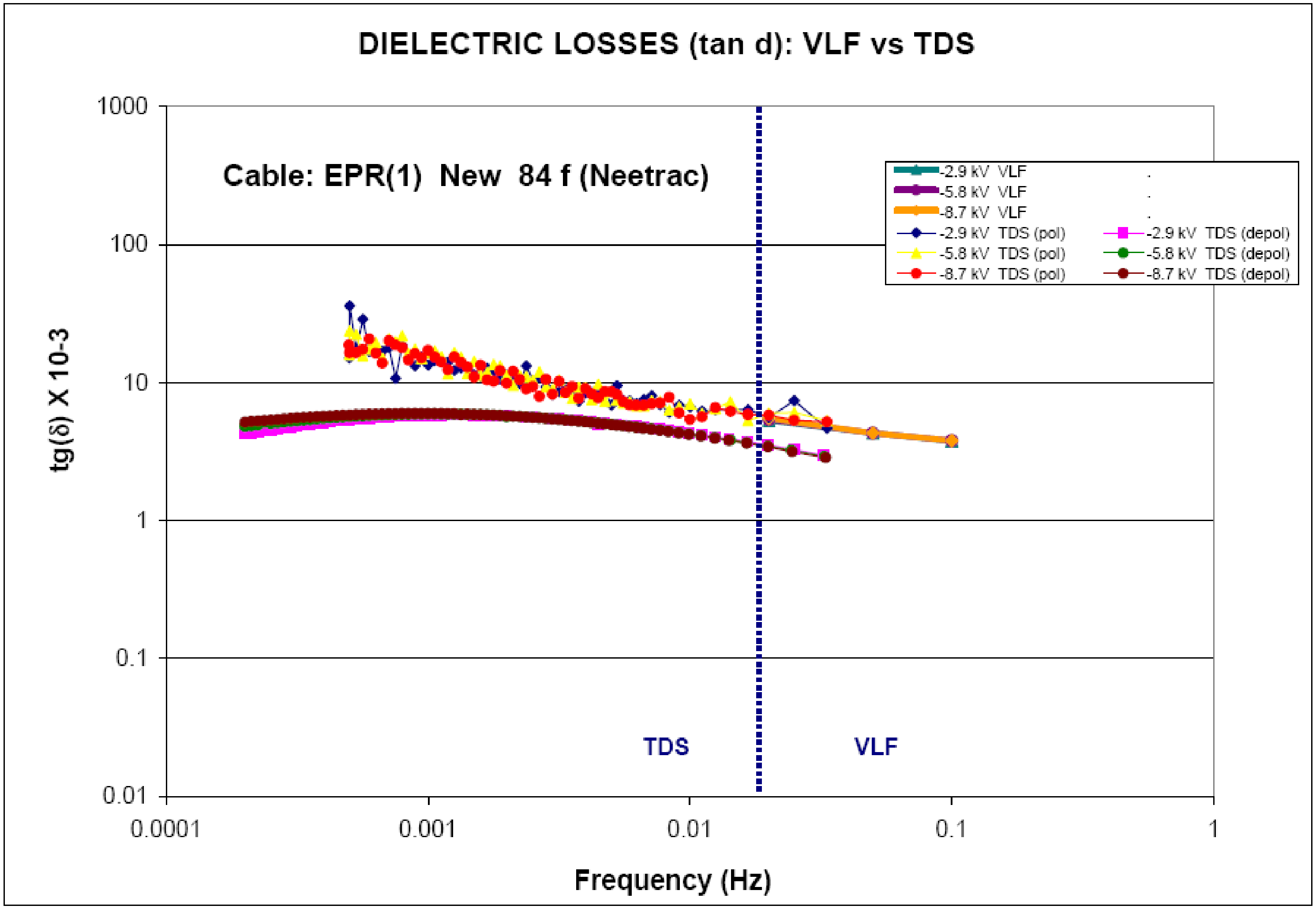
2 – Correlation between Tan δ measurements at VLF and TDS

2.1 New cables - TR-XLPE



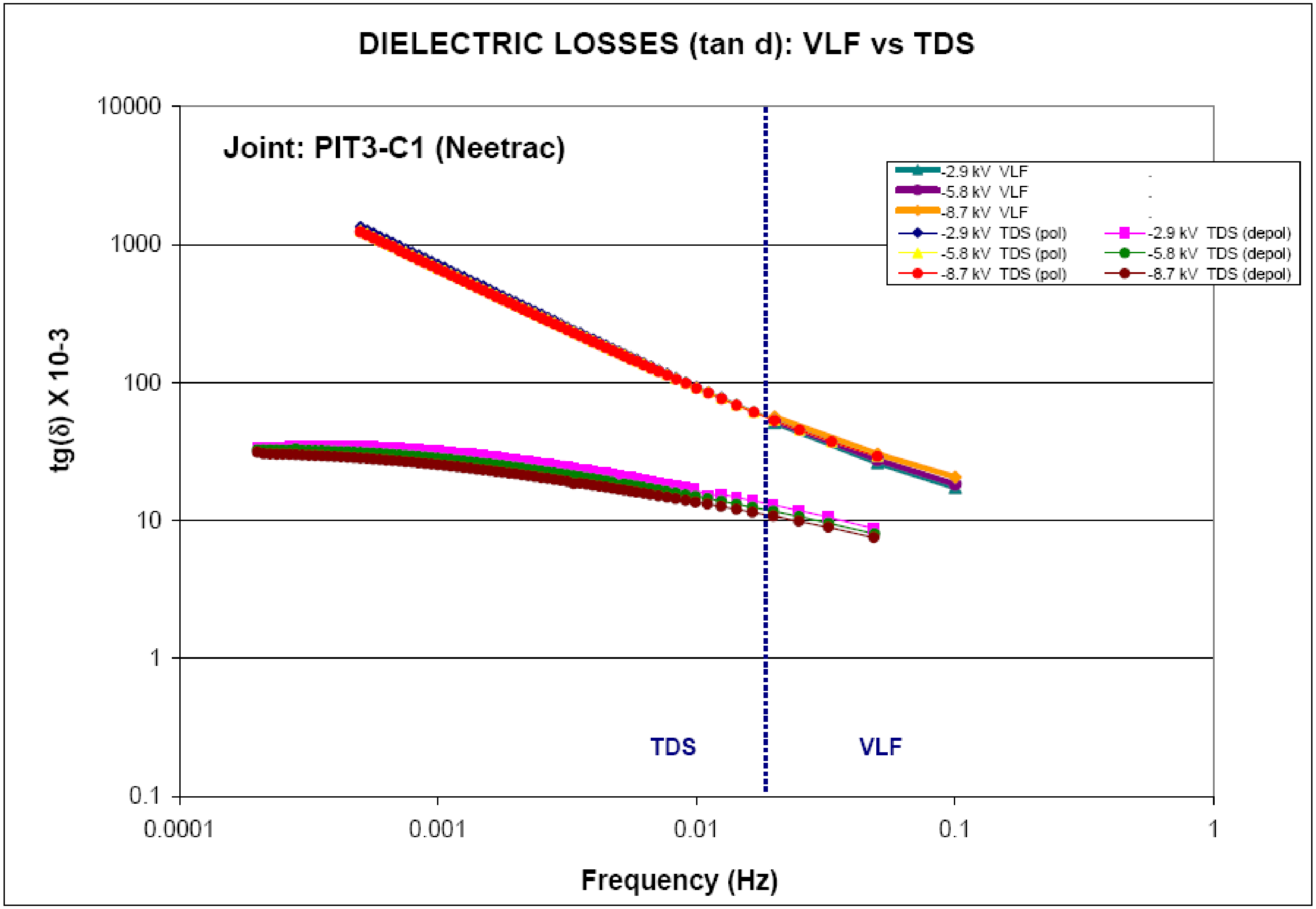
2 – Correlation between Tan δ measurements at VLF and TDS

2.1 New cables - EPR



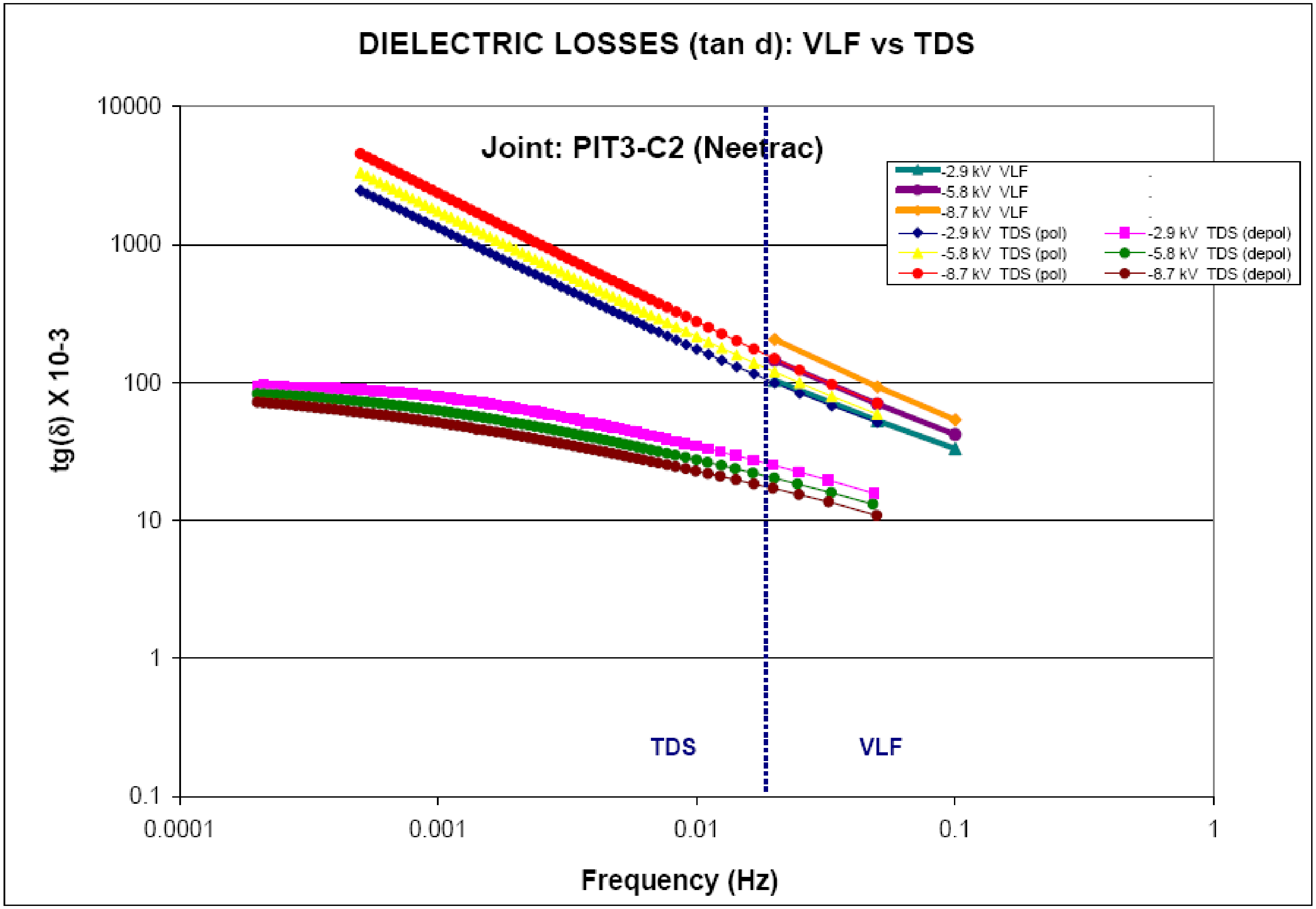
2 – Correlation between Tan δ measurements at VLF and TDS

2.2 Joints - PIT3-C1



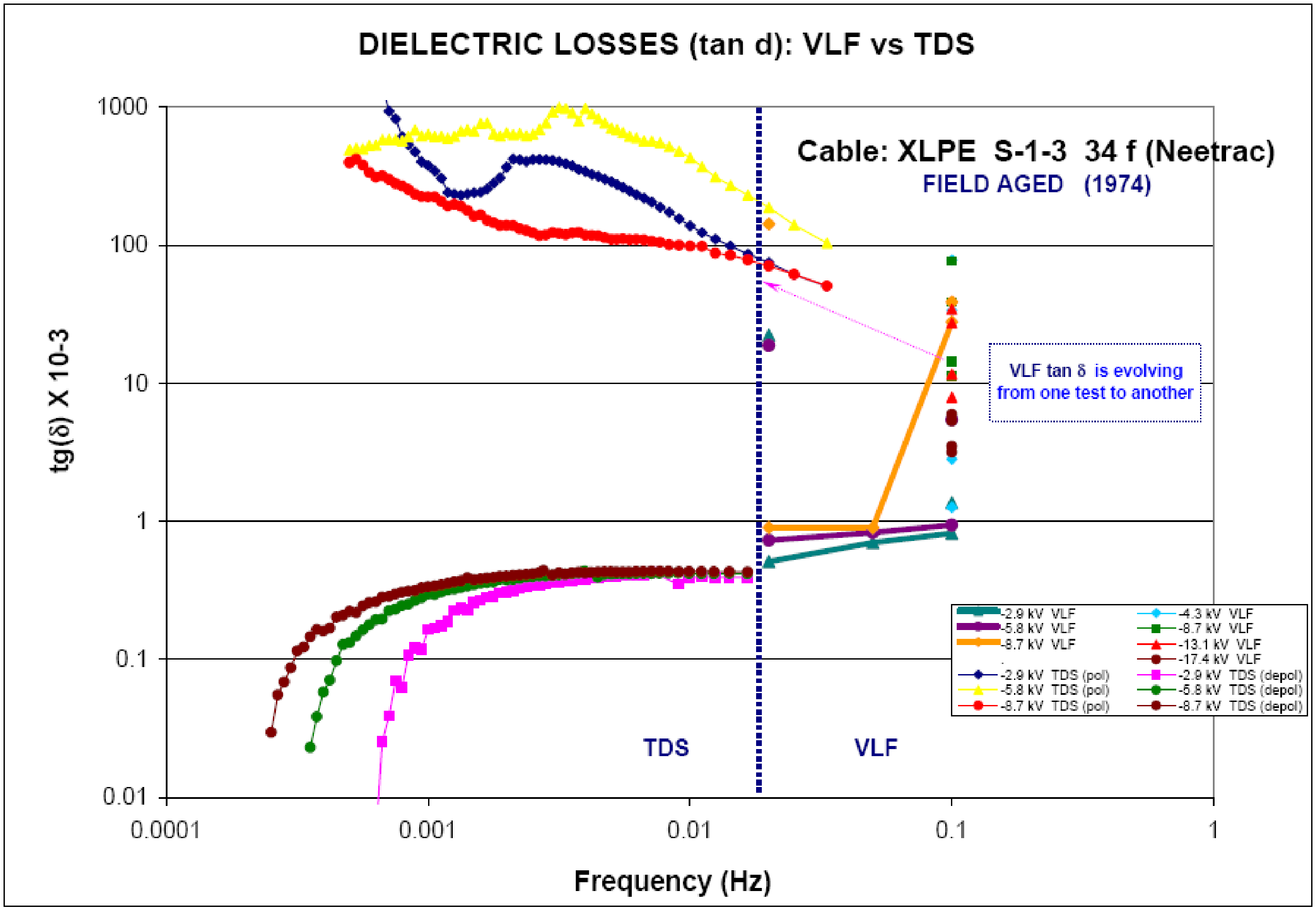
2 – Correlation between Tan δ measurements at VLF and TDS

2.2 Joints - PIT3-C2



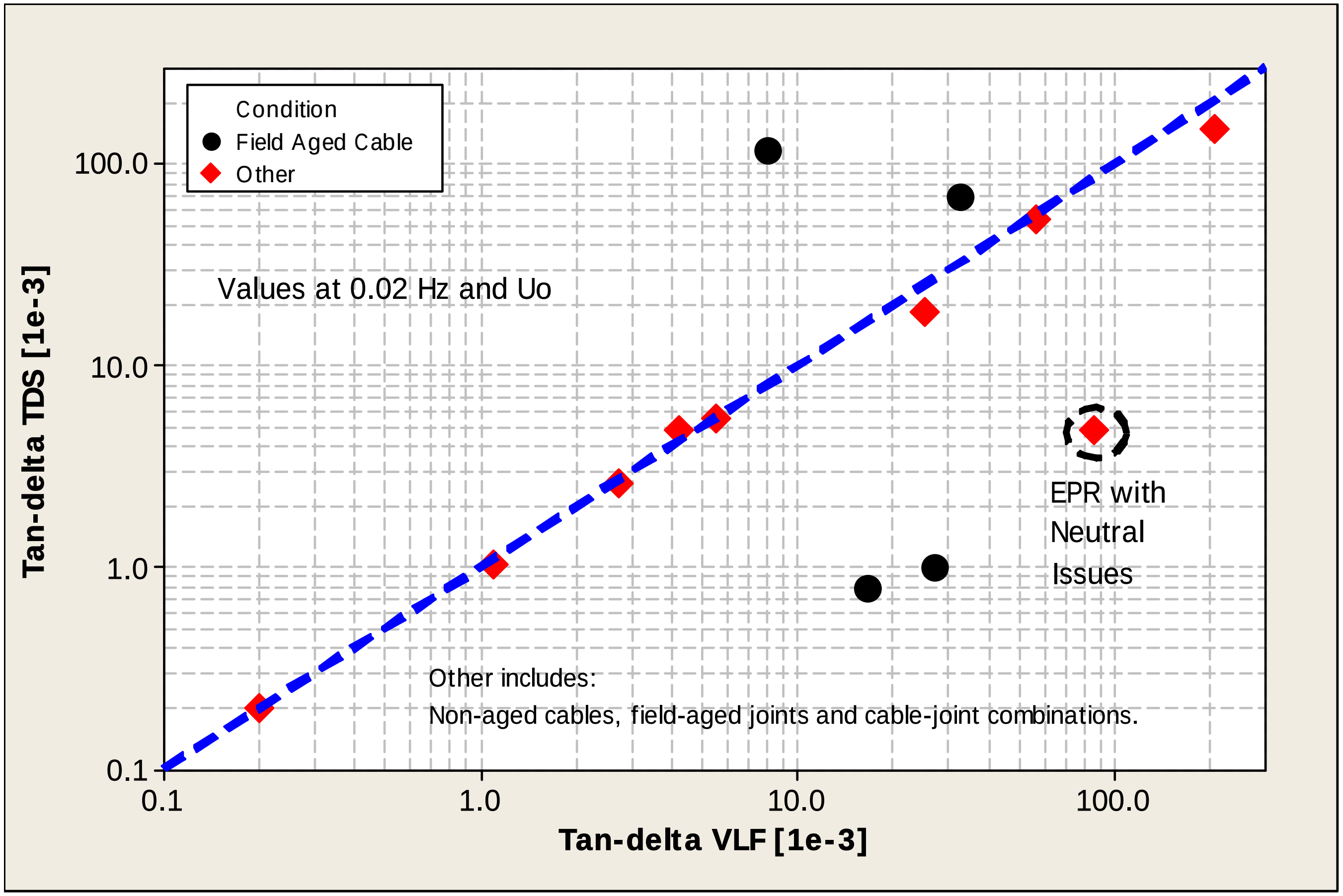
2 – Correlation between Tan δ measurements at VLF and TDS

2.3 Field aged cables - S-1-3



2 – Correlation between Tan δ measurements at VLF and TDS

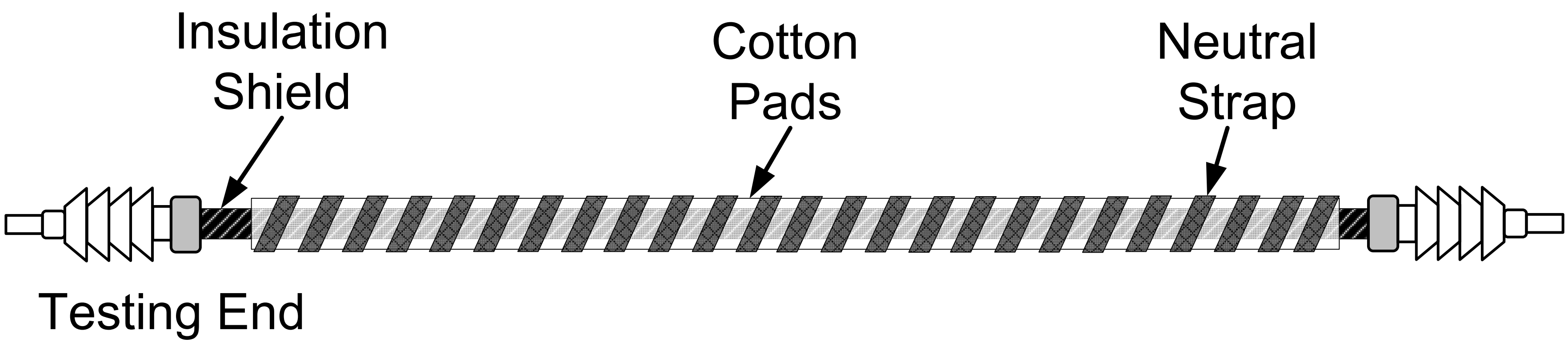
Correlation Tan δ - VLF vs TDS



2 – Correlation between Tan δ measurements at VLF and TDS – Interim Conclusions

- Good correlation between Tan δ from VLF and Tan δ from TDS for samples not evolving during test.
- Spectrums seem to complement each other.

3 – Neutral Issues for VLF



3 – Neutral Issues for VLF

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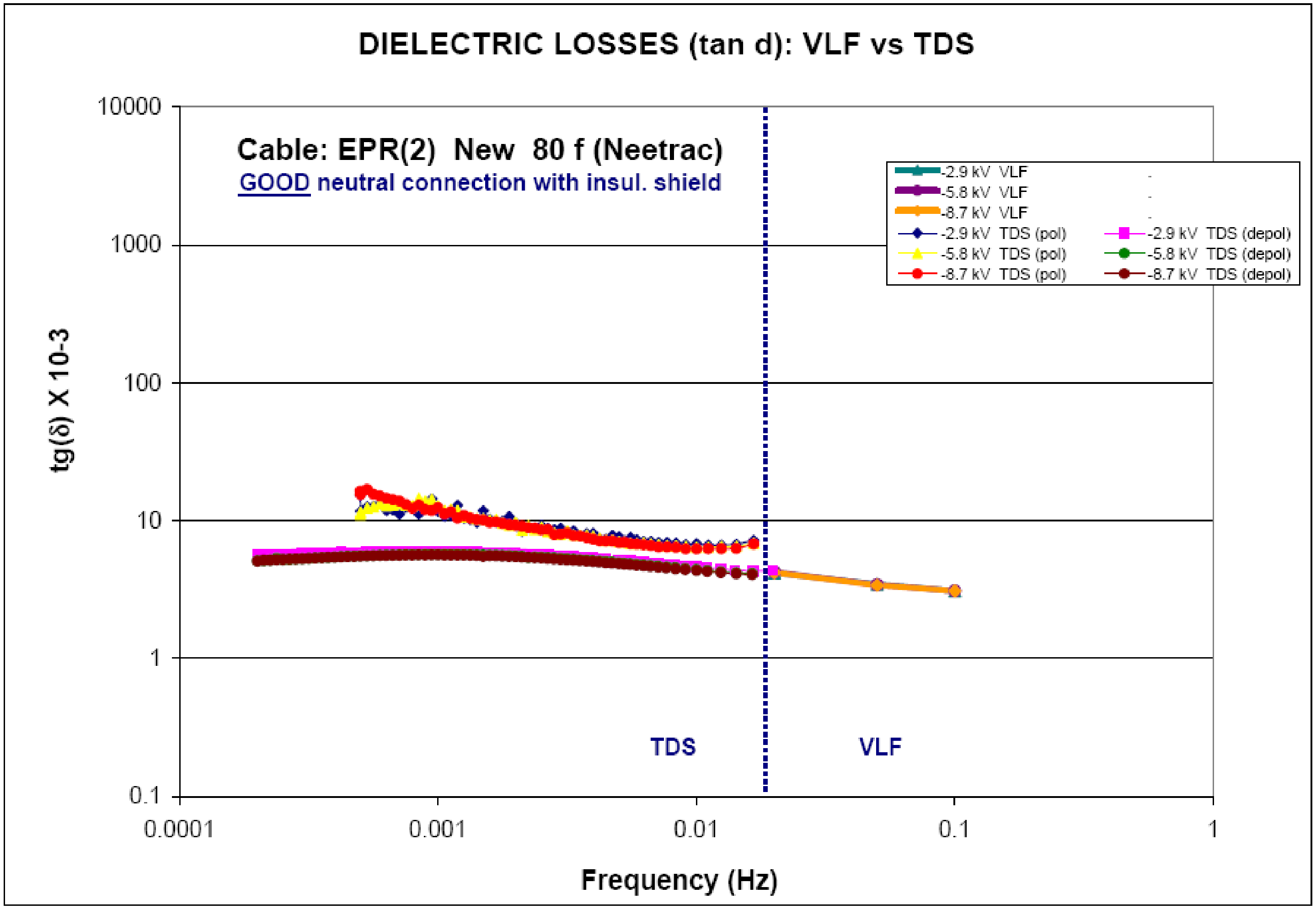
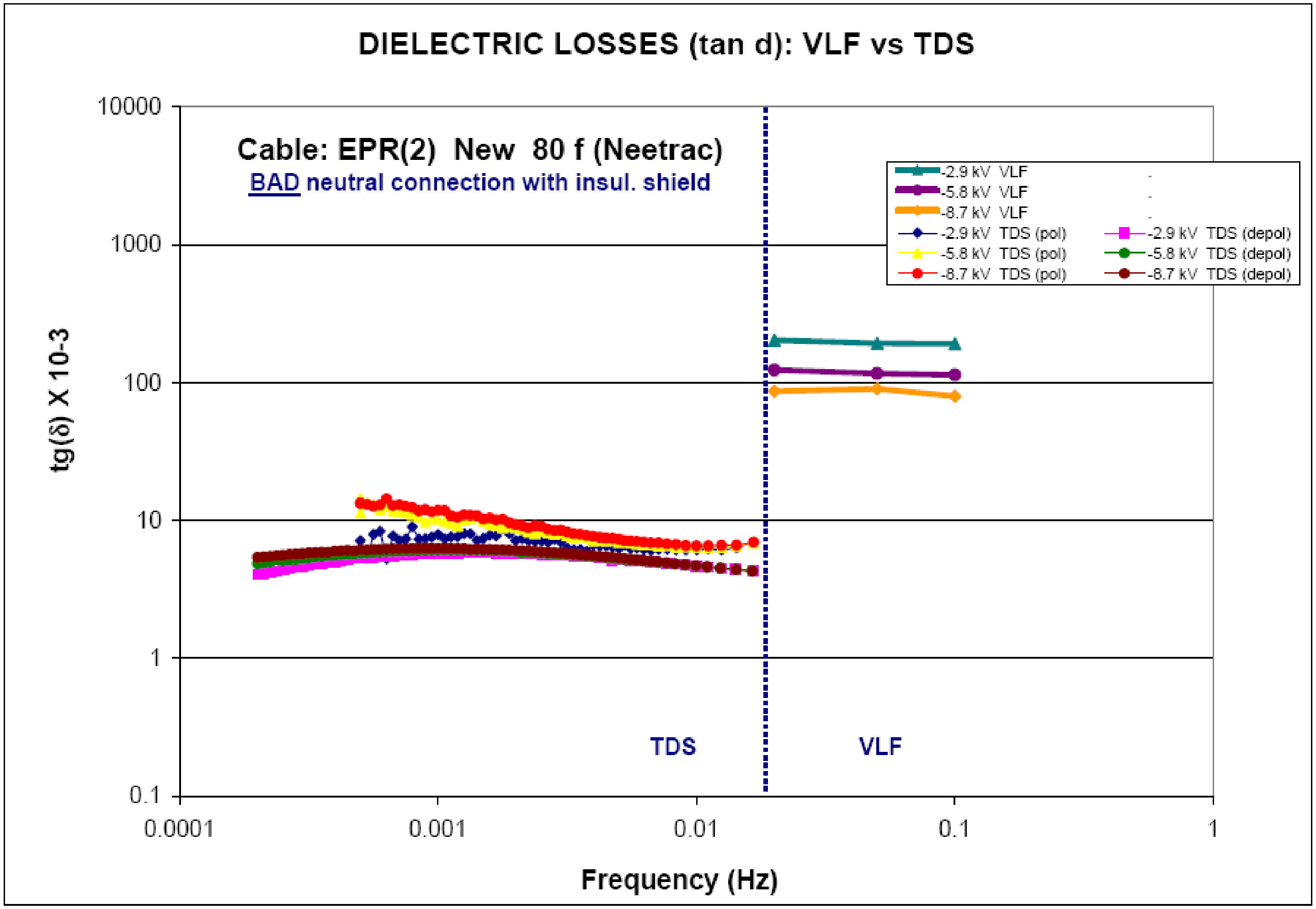
EPR with Good neutral connection



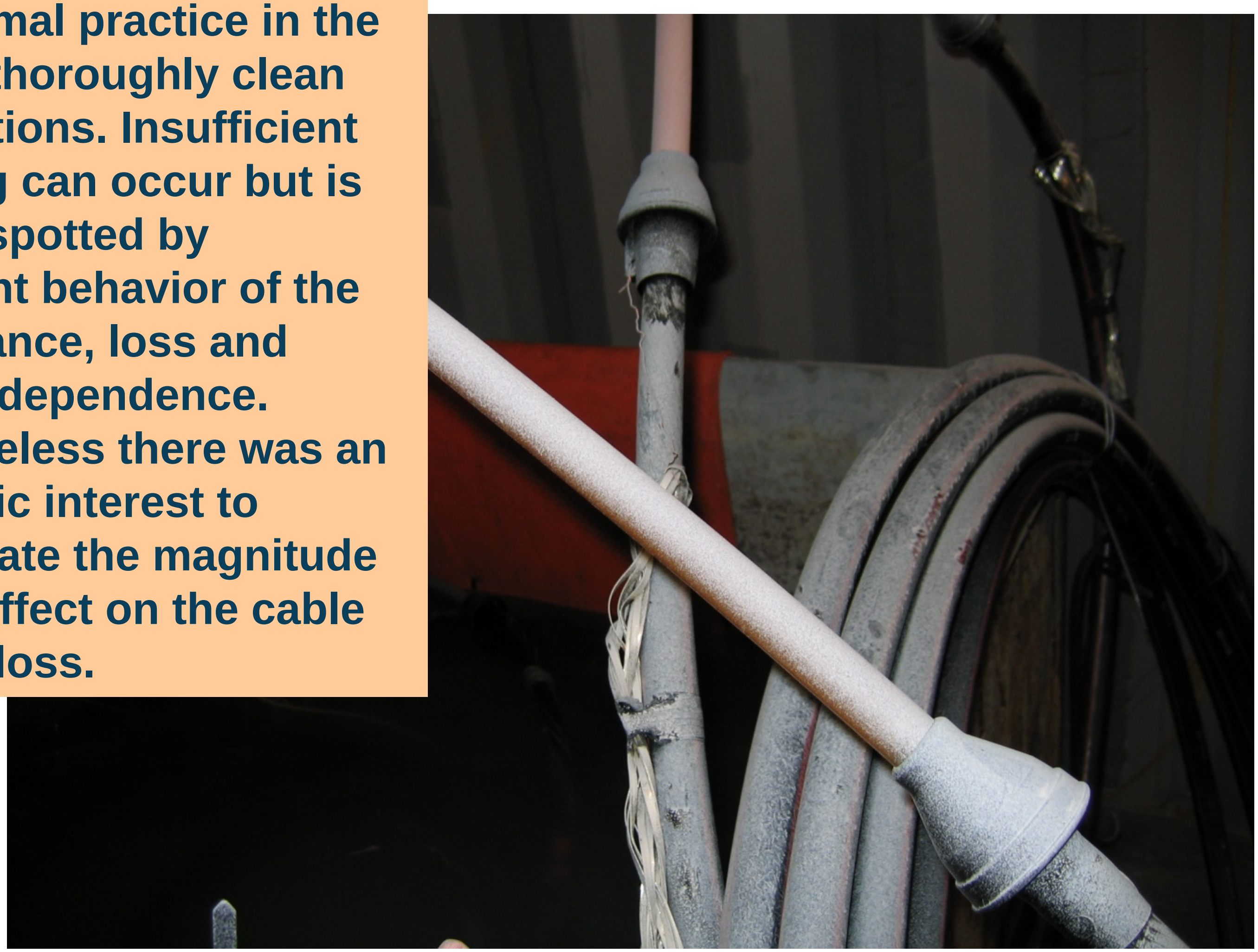
3 – Neutral Issues for VLF

EPR with Bad neutral connection



4 – Effect of highly polluted terminations

It is normal practice in the field to thoroughly clean terminations. Insufficient cleaning can occur but is readily spotted by divergent behavior of the capacitance, loss and voltage dependence. Nevertheless there was an academic interest to investigate the magnitude of this effect on the cable system loss.

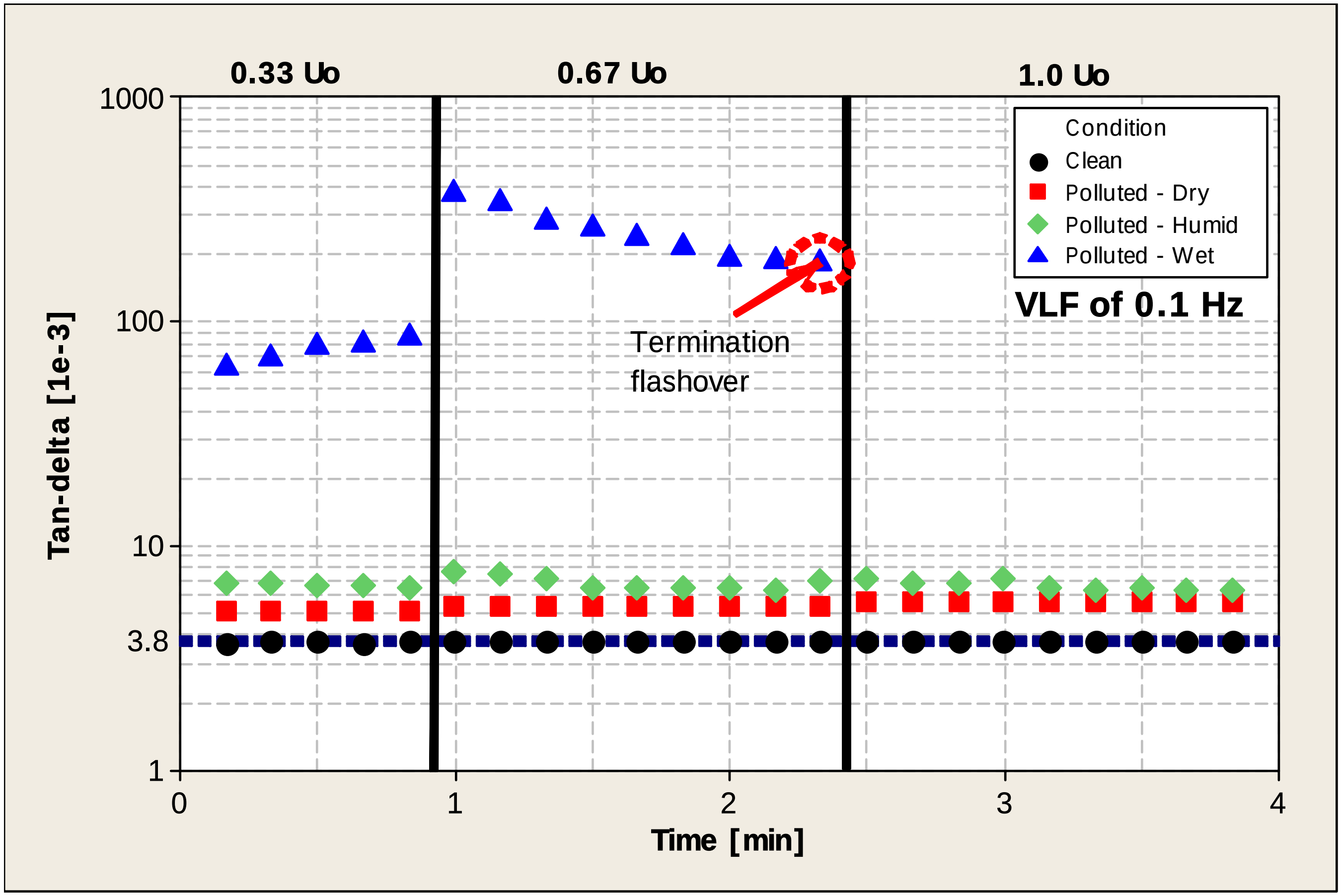


4 – Effect of highly polluted terminations

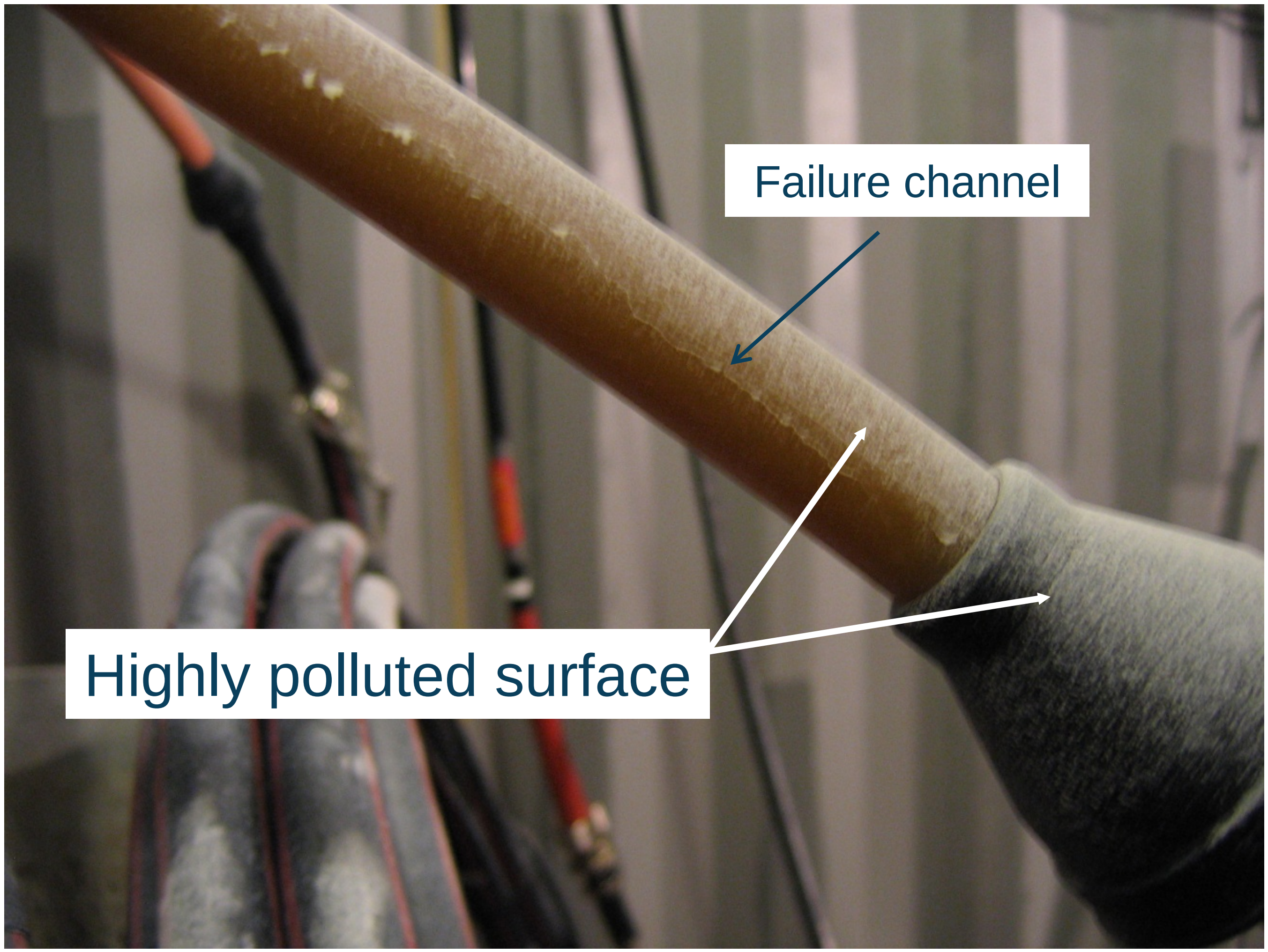
Normal clean test terminations prior to pollution

Polluted test terminations

4 – Effect of polluted terminations

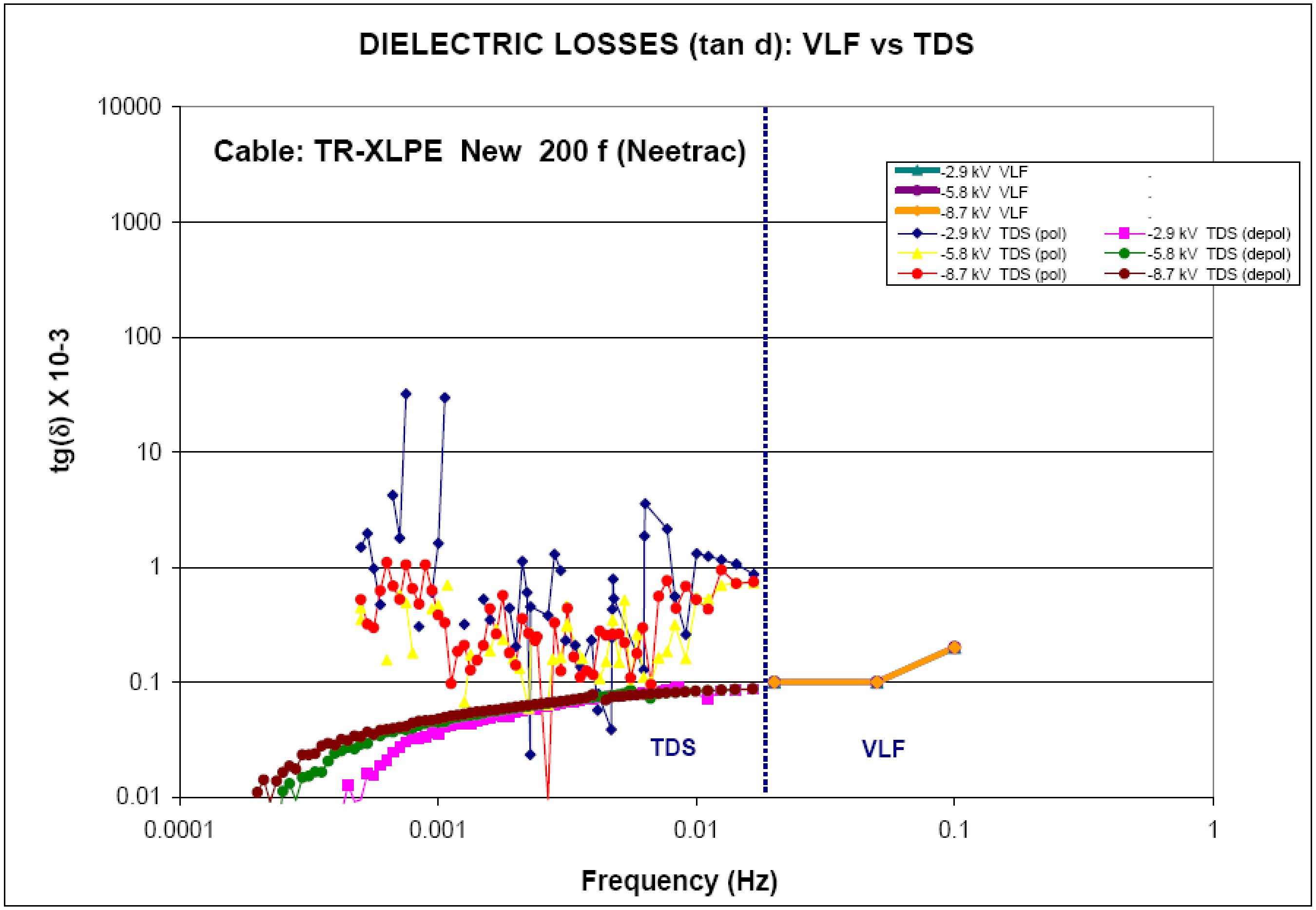


4 – Effect of polluted terminations



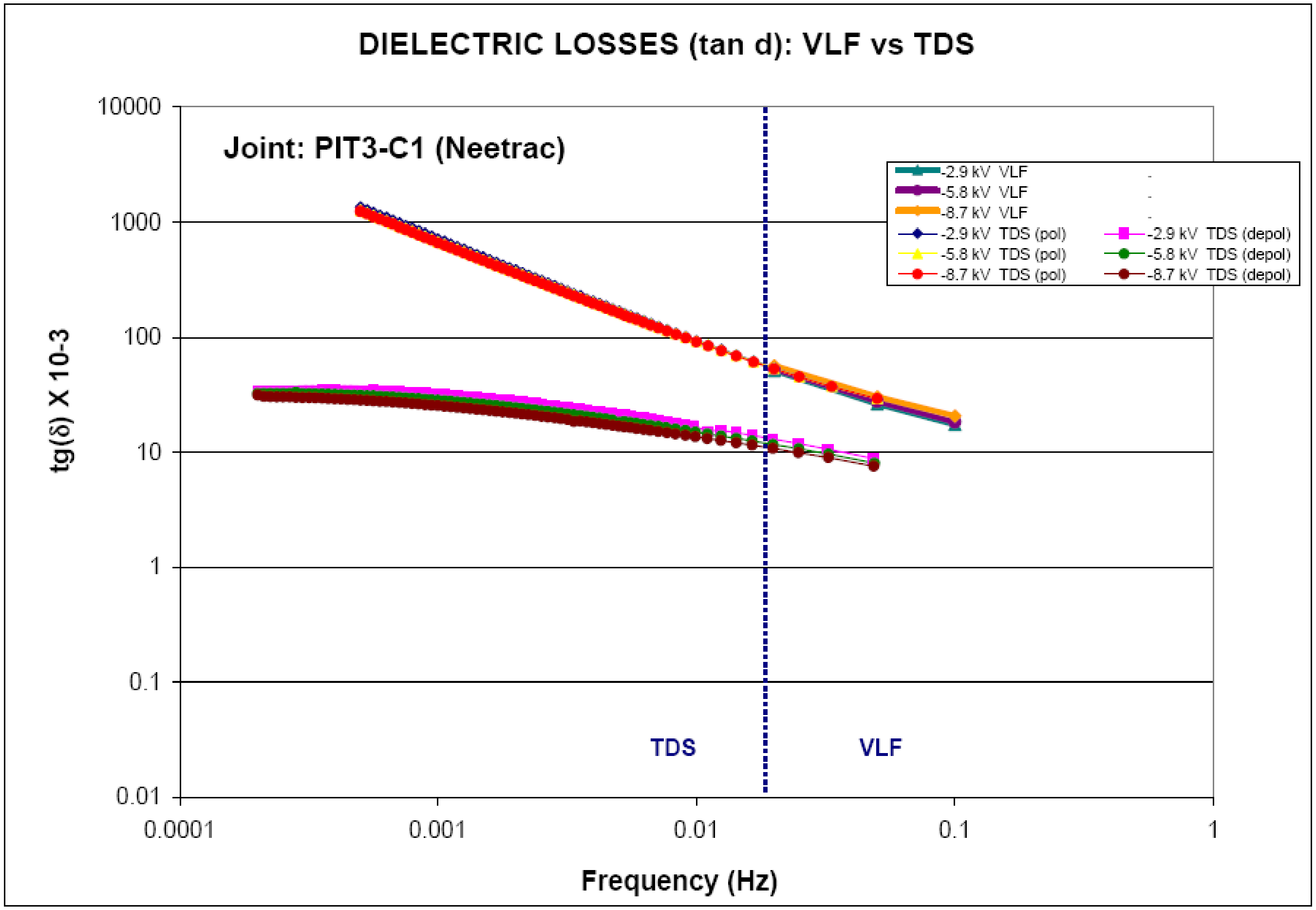
5 – "Arithmetic" of Tan δ at VLF and TDS (Overvue)

TR-XLPE cable system without splive



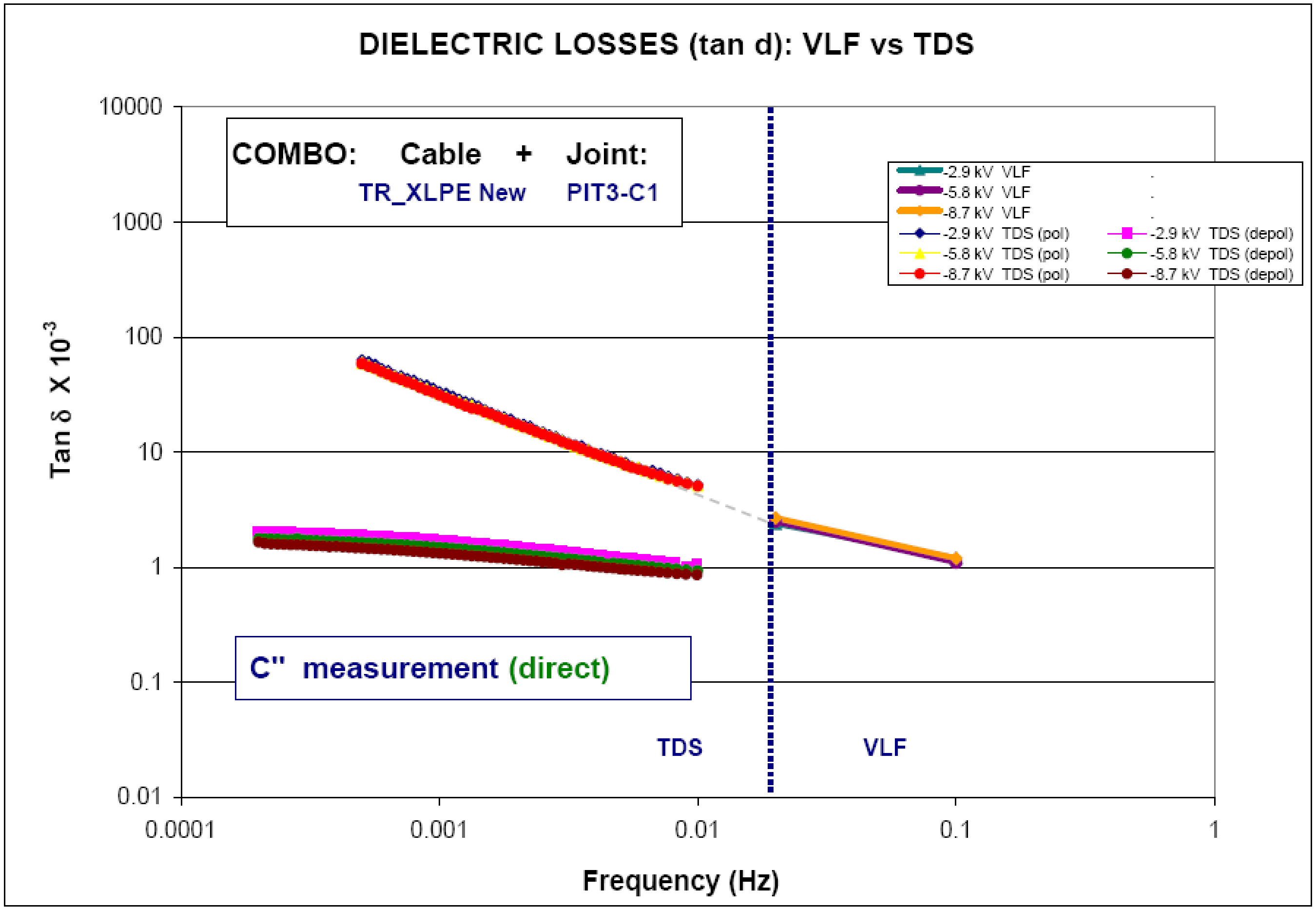
5 – "Arithmetic" of Tan δ at VLF and TDS (Overvue)

Joint PIT3-C1 alone



5 – "Arithmetic" of Tan δ at VLF and TDS (Overvue)

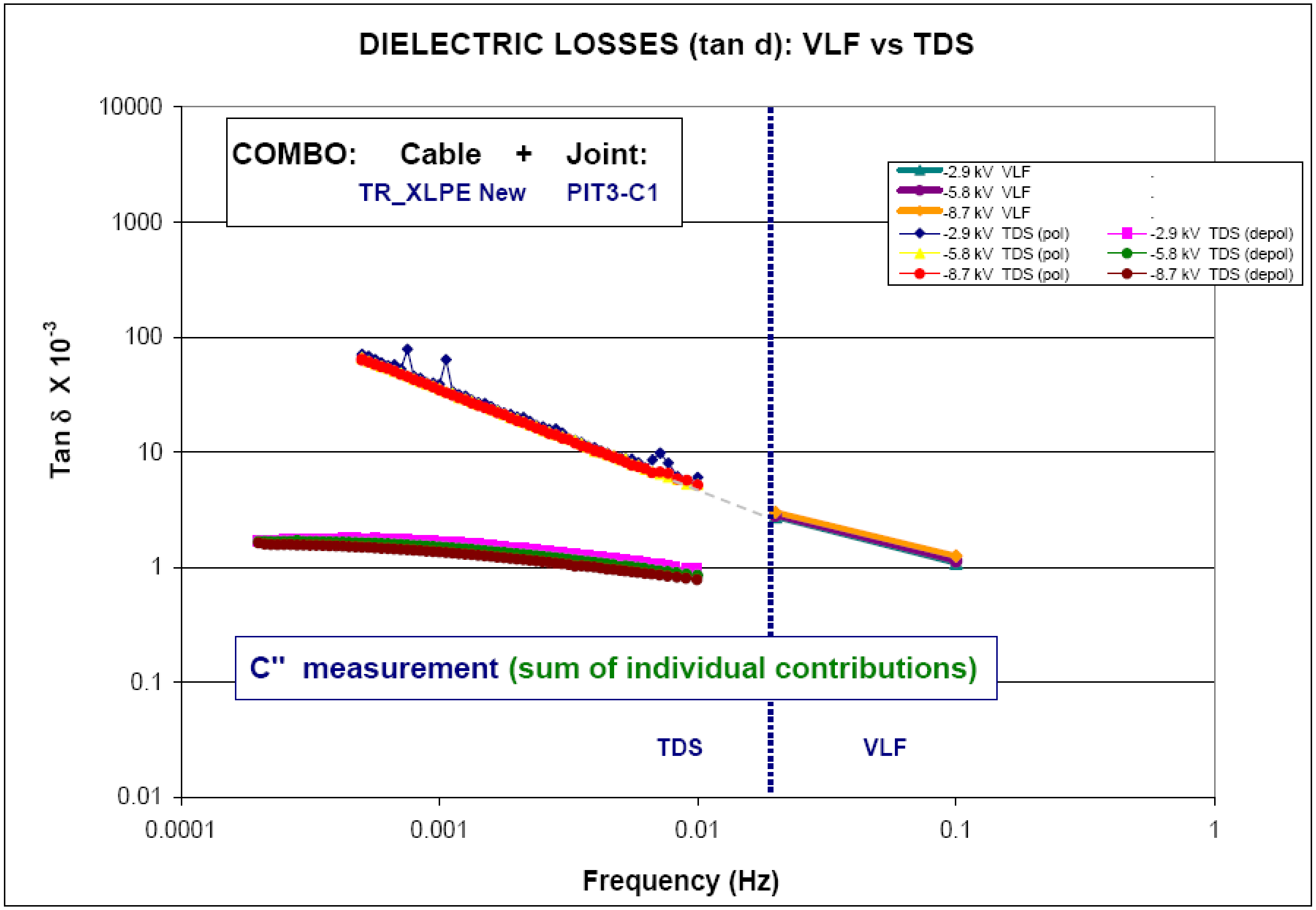
TR-XLPE system cable PLUS Joint PIT3-C1
As measured directly:



5 – "Arithmetic" of Tan δ at VLF and TDS (Overvue)

TR-XLPE system cable PLUS Joint PIT3-C1

As calculated by sum of individual contributions:



6 – Conclusions

- Good correlation between Tan δ from VLF and Tan δ from TDS for samples not evolving during test.
- Spectrums seem to complement each other.
- Polluted terminations influence cable system loss measurements.
- TDS seems less perturbed by neutral issues then VLF.
- “Arithmetic” of cable system loss works for TDS as well as for VLF.