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VLF HIPOT INSTRUMENTS

World Leader in HV Testing Technology

Cable Fault Locators w/TDR

Oil/Fluid Dielectric Testers

Very Low Frequency AC Technology W/TD & PD Diagnostics

Portable AC Hipots

High kVA AC Test Sets

DC Hipots & Megohmmeters

HV Divider

Aerial Lift Testers

HVI Products Are Designed to Surpass All Others in Features, Specifications, and Ease in Use

HVI - The Source For Field HV Test Equipment

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MEDIUM & HIGH VOLTAGE CABLE TESTING

WHY YOU SHOULD BE TESTING WITH
VERY LOW FREQUENCY AC TECHNOLOGY

THREE METHODS OF CABLE TESTING NOW AVAILABLE

VLF WITHSTAND – VLF TAN DELTA – VLF PARTIAL DISCHARGE

DC voltage testing of solid dielectric cable insulation is on it's way out. It already is in much of the world. VLF AC testing is now in. Let's take a look at VLF and the present methods used for testing medium & high voltage cable.

DC USED FOR DECADES TO TEST CABLE

IT WORKED WELL FOR PILC CABLES, SHOULD WORK FOR SOLIDS, RIGHT?

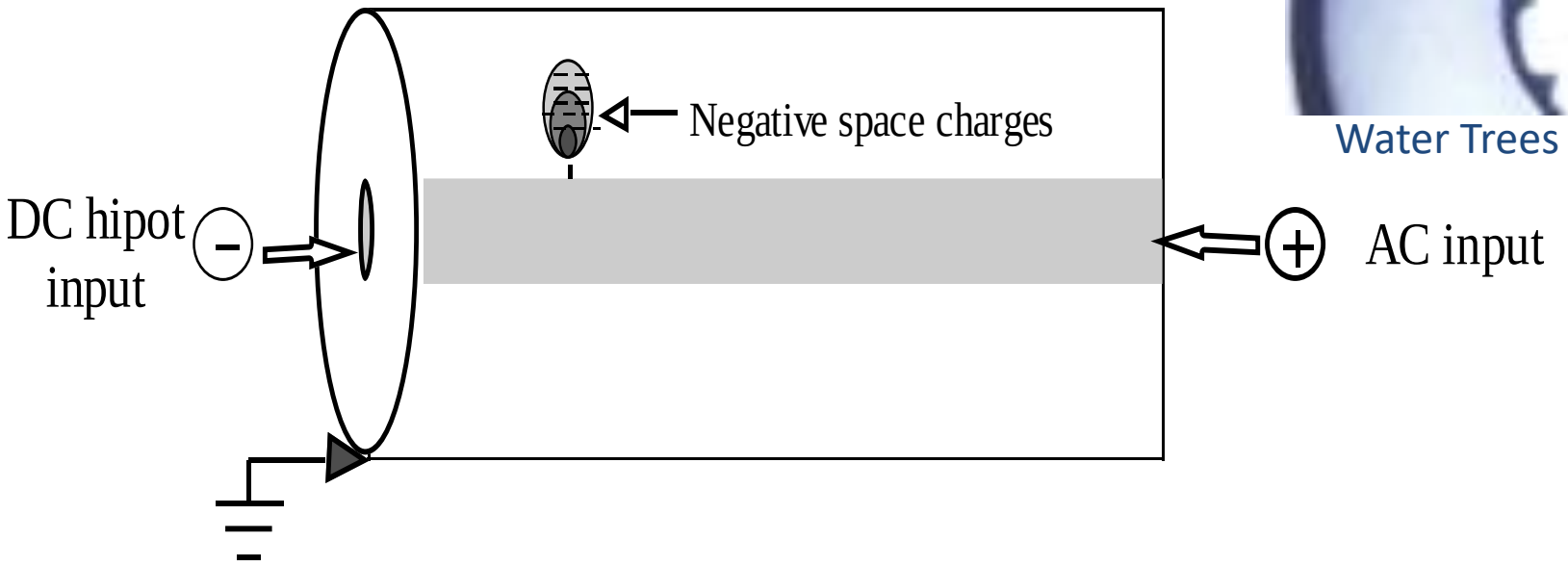
Wrong: 15 – 20 years after solid dielectric cable was installed, it started to fail prematurely. Testing, research, and field experience has shown that solid dielectric cable is prone to develop water trees and DC testing at high voltages creates "trapped space charges" within these trees that leads to failure. Also, leakage currents have been shown to mean little, especially in accessories. Let's find something better.

Q: Can't there be a good AC method for field hipoting cables, like in the factory?

A: Yes - enter VLF. Traditional 50/60 Hz AC power supplies are too big, too heavy, and too expensive, and not portable to test cable in the field. To solve the problem, work on commercial VLF began in the 80's and the use of VLF is now widespread and from many vendors. It is now well established worldwide.

WHY DC IS DAMAGING TO SOLID DIELECTRIC INSULATION

Water Trees



The 4 – 5 U_o negative output of a DC hipot test polarizes water tree areas.

Unlike oil insulated cable, in solid dielectric insulation like XLPE, these “trapped space charges” remain in place after the test.

When AC is reapplied, a high difference of potential exists across the remaining insulation. Leads to electrical trees, PD, & cable failure

WHAT WE KNOW ABOUT DC

PILC & new EPR, XLPE, etc. - DC OK – no space charges

"Service Aged" solid dielectric cable – No DC

Why? Again, "Space Charges" trapped in isolated areas of cable cause high stress points leading to failure. Also, current readings taken by DC proven to be not meaningful

IEEE and most world engineering bodies agree on issue, as well as cable manufactures and cable research labs

DC not compatible with Tan Delta and PD diagnostics

With VLF now reasonable in price and size, why not

WHY IS DC HARMFUL?

WATER TREES ARE CHARGED BY DC

- Tree shaped channels are found within the insulation of operating cables resulting from the presence of defects & moisture in electrical fields.
- Prevalent in solid dielectric cables.
- Eventually leads to PD and the creation of electrical trees.
- Leads to insulation failure.
- DC testing hastens failures.
- **A change was needed**

VERY LOW FREQUENCY AC HIPOT

A VLF HIPOT IS SIMPLY AN AC HIGH VOLTAGE INSTRUMENT BUT WITH A FREQUENCY OUTPUT OF 0.1 Hz AND LOWER.

THE LOWER THE FREQUENCY, THE LOWER THE CURRENT AND POWER REQUIRED TO TEST HIGH CAPACITANCE LOADS LIKE CABLES AND ROTATING MACHINERY.

DON'T OVERCOMPLICATE IT.
IT'S A SIMPLE AC WITHSTAND TEST.

VLF IS THE EASIEST, LEAST EXPENSIVE, MOST CERTAIN WAY OF TESTING THE AC INTEGRITY OF A CABLE.

WHAT IS VLF TECHNOLOGY?

VLF stands for Very Low Frequency. A VLF hipot has an output of 0.1 Hz and lower, rather than 50/60 Hz. In all other respects, it is just like any AC hipot, and similar to most AC high voltage testing, it is used to provide a go/no-go stress test, or withstand/proof test. Does you load hold the test voltage or fail? Sine wave producing VLF instruments can also be used for the voltage source for off-line diagnostic testing. VLF products are rated by their output voltage and their uF rating, or how much capacitance they can test. They permit us to AC test high capacitance loads in the field, like long cables, with portable and affordable equipment.

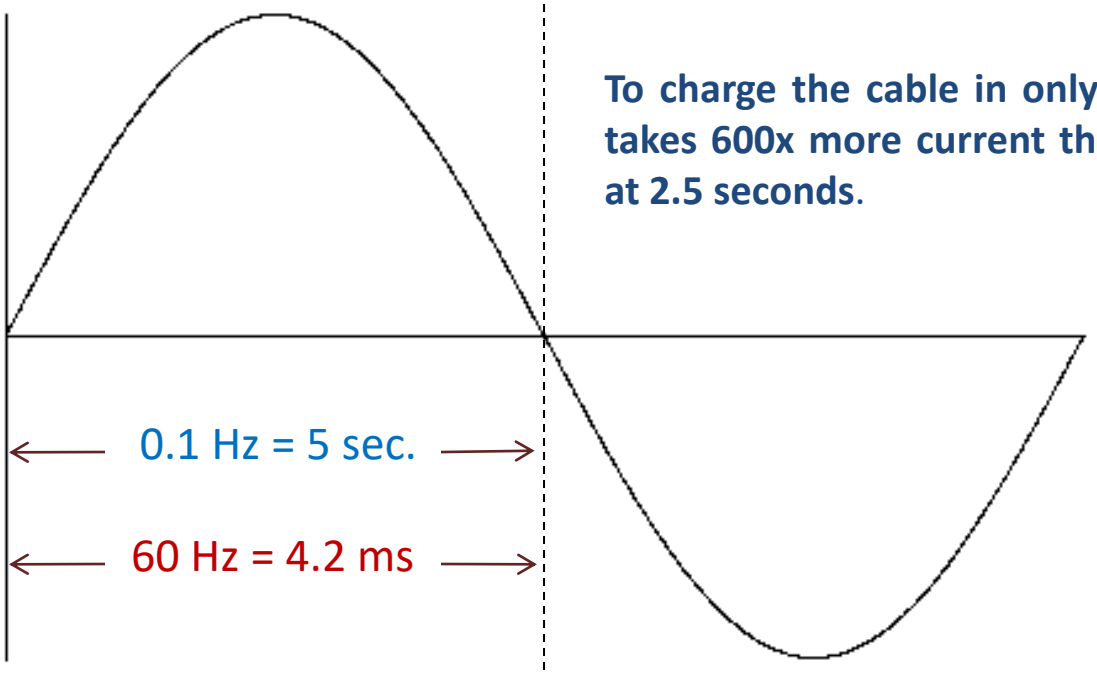
DROP THE FREQUENCY TO DROP THE POWER NEEDED

Very **L**ow **F**requency: 0.1 Hz and lower.
By decreasing the frequency, it is possible to test miles of cable with a small and affordable unit.

Output frequencies range from 0.1 – 0.01 Hz.
IEEE400.2 recognizes frequencies as low as 0.01Hz.

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 with the same power consumption. Basic physics, nothing mysterious.

0.1 Hz vs. 60 Hz Waveform



To charge the cable in only 4.2 ms, it takes 600x more current than it takes at 2.5 seconds.

0.1 Hz = 10 sec. period

60 Hz = 17 msec. period

600x diff.

At 0.1 Hz the charging time to max. voltage is 2.5 seconds.

At 60 Hz the charging time to max. voltage is only .0042 seconds.

WHAT A DIFFERENCE THE FREQ. MAKES

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

At 22 kV peak, 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 power supply needed is only .304 kVA.

(22 kV is the typical test voltage for 15 kV cable)

60 Hz vs. 0.1 Hz

60 Hz Hipot

0 - 50 kVac @ 3 kVA
Can test ~ *50' of cable*

Great for switchgear testing
No good for cables

0.1 – 0.02 Hz VLF

0 - 44 kVac @ 1.2 kV
Can test ~ *5 miles of cable*

Ideal for cables per IEEE 400.2 and motors/generators per IEEE 433.

VLF FOR CABLE TESTING - REVIEW

- Original cables were PILC - many oil filled - DC worked well
- Solid Dielectrics introduced in ’60’s. DC use just continued
- Forty year insulation failing after 15 – 20 years. Why?
- Water trees charged up by DC test, programming cable for future failure & DC leakage currents are not very meaningful
- We want to test cables in the field with AC, just like in the factory
- VLF permits us to AC field test cables with ease for the first time. Also makes AC diagnostic testing possible
- 0.1Hz allows testing of miles of cable with portable unit
- Distribution systems reliability improving with VLF use

WHERE IS VLF USED TODAY?

Medium and high voltage cable is probably 90% of the application for VLF, followed by ***motor/generator*** *testing*. Long cables with high capacitance need the VLF to test them. It is used by hundreds of utilities, testing contractors, & large industrials. VLF satisfies the need for proof testing newly installed, newly repaired, & any critical application cables. It's also a great splice and termination checker.

Small 30 kV models are used to check the integrity of 15 kV cables up to 200 kV models to test HV cables. VLF generators are also used to provide the variable voltage used for off-line diagnostic testing, like Tan Delta and Partial Discharge.

Users have many choices from 4 - 5 vendors, and all the major rental houses in the country carry many models.

VLF AC CABLE TESTING TECHNOLOGY
WITHSTAND & DIAGNOSTIC APPLICATIONS

There are three commonly used methods for field testing medium and high voltage cable using VLF technology. We'll take them one at a time, although often all three are used on the same cable.

- **VLF Withstand** Proof/hipot testing
- **VLF – TD** Tan Delta Diagnostic testing
- **VLF – PD** Partial Discharge Diagnostic testing

DEFINING THE VLF WITHSTAND TEST

The most basic VLF test is a withstand, or proof, test. Apply the voltage for some length of time. If there are severe defects that initiate partial discharge, the test forces their growth to failure. Minor defects unaffected by the test voltage remain as is. The cable either holds the voltage or fails. If it fails, repair or replace and retest. If it passes, the cable is assumed to be good for at least another ~5 years. If it fails again, further thought must be given to decide future steps.

The premise of the test is this: if the cable passes a 2 – 3 times normal voltage test, don't worry about. It's good for years. Quite often, the test exposes bad accessories, where poor workmanship comes into play.

We perform AC hipot tests on a go/no-go basis to many loads, now we can do it to cable.

APPLICATIONS FOR USE OF VLF

There are several obvious and common reasons to use VLF.

1. **Test after installation.** Cable is already de-energized. Guarantee no damage occurred to cable during installation and prove workmanship on accessories is good. Most faults are in terminations, splices, etc.
2. **Test after repair.** Initial fault may have damaged more cable. Over voltage thumping may have created more faults. Avoid the need for another repair in two months. Often rapid repairs are not properly done, causing future, possibly near term failure.
3. **Test critical cables** on a regular basis. Cause failures when convenient and not during service. VLF failure causes very little damage to cable.
4. **Safe to re-energize?** Some use VLF to perform a **quick check of repaired cables** to verify safe to re-energize. Not a full VLF test but a better check than all other methods: DC, megohm test, hot stick adaptor, soak test, etc.
5. **Diagnostic testing** using the VLF as the voltage source is possible to perform **Tan Delta and Partial Discharge** testing.

IEEE 400.2-2004 STANDARD

(STANDARD NOW UNDER REVIEW AND WILL BE REISSUED SOON.)

The IEEE 400.2 VLF test standard defines the required test voltages. The time duration for the test is suggested to be 30+ minutes, which has shown to eliminate up to 95% of defects. A 60 minute test may be performed to be nearly 100% assured that no defects nearing failure remain. The voltages specified are generally 2 – 3 times the normal operating voltage. The actual values are determined by the insulation thickness and the desired kV/mm of test voltage stress.

Note: Perform the test properly or do not test at all. Suggested time and voltage are necessary to allow electrical trees started to grow to failure. An abbreviated test or too low a voltage test may only aggravate defects and lead to future in-service failures. Like with most tests, let the technology work.

IEEE400.2 FIELD TEST VOLTAGES

For Shielded Power Cable Systems Using Sine Wave Output VLF

	0.1 Hz Test Voltage		
System Voltage phase to phase	Installation phase to ground	Acceptance phase to ground	Maintenance phase to ground
kVrms	kVrms/kVpeak	kVrms/kVpeak	kVrms/kVpeak
5	9/12	10/14	7/10
15	18/25	20/28	16/22
25	27/38	31/44	23/33
35	39/55	44/62	33/47
46 *	51/72	57/81	43/61
69 *	75/106	85/119	63/89

Test voltages are generally 2 – 3 time the line-to-ground system voltage.

* Proposed for next version of standard.

VLF MODEL SIZES AVAILABLE

There are many models from the 4 or 5 major vendors.

Models are designed for a voltage output and a capacitance (uF) load rating at several specific frequencies from 0.1 Hz – 0.01 Hz.

Voltage ratings range from 20 kVac – 200 kVac with capacitive load ratings from 0.4 uF – 50 uF

Example: For a 15 kV cable test of 22 kVac peak l-g, a 0.1 Hz @ 0.5 uF VLF can test up to 4000’ depending on cable diameter. Lengths up to 30 miles can be tested by some VLF units.

SELECTING A VLF MODEL

Specs to know before model selection

Must know the cable voltage and test specs to select voltage.
Ex: the Maintenance test on a 15kV cable is 22kV peak.

Must know the cable load capacitance: the uF rating.

Must know the required frequency of test.

Will it be used to Tan Delta and Partial Discharge testing?

Typical VLF Output Spec

Output Volt.:	0 - 60 kVac Peak
Output Load:	0.10 Hz @ 1.1 µF
	0.05 Hz @ 2.2 µF
	0.02 Hz @ 5.5 µF
	0.01 Hz @ 11.0 µF

VLF ratings and selection

VLFs are sized from 20 kV – 200 kV. Peak and rms specs.

Models are rated by the uF of load they can test. Ratings from 0.4 – 50 uF.

Most are variable frequency of 0.1 – 0.01 Hz: does spec allow frequencies below 0.1 Hz for withstand testing? For TD & PD testing, 0.1 Hz is used. Get a VLF rated at 0.1 Hz for the uF rating needed.

Lower frequencies permit higher uF testing. 0.05 Hz can test twice 0.1 Hz. IEEE 400.2 allows the use of 0.1 Hz – 0.01 Hz, so should testing specifications.

VLF MODELS FROM VARIOUS VENDORS – MANY MODELS NOT SHOWN

High Voltage, Inc. - NY

28kV

60kV

90kV

200kV

Baur - Austria

34kV

60kV

56kV W/PD & TD

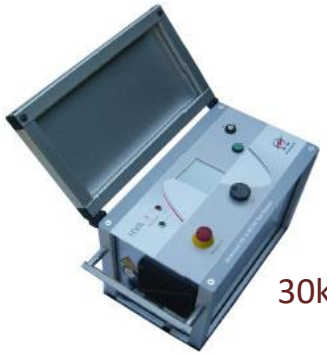
Seba – Germany

28kV

60kV

54kV

HV Diagnostics Switzerland



30kV

60kV

Voltages are in peak.
Load ratings from
0.4 uF – 50 uF

VLF AC CABLE TESTING TECHNOLOGY
WITHSTAND & DIAGNOSTIC APPLICATIONS

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VLF – TD DIAGNOSTIC CABLE TESTING

VLF TANGENT DELTA (TAN δ) MEASUREMENT

Also called Dissipation Factor or Loss Angle

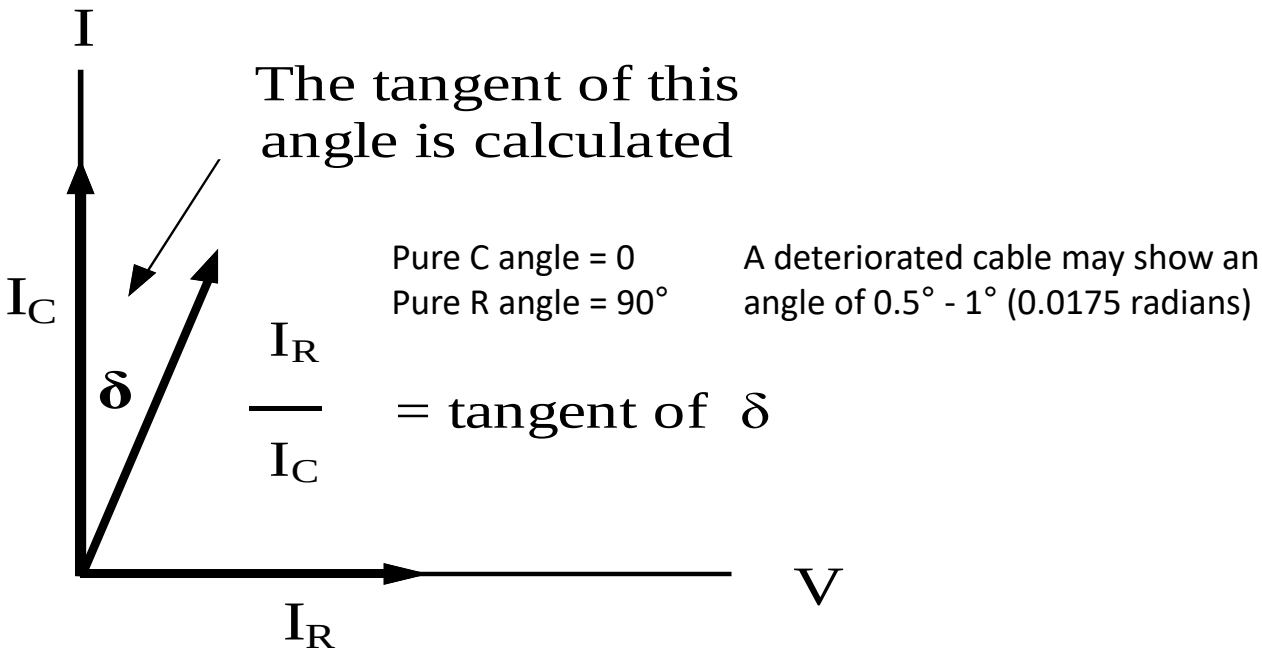
Over time, cable insulation degrades due to thermal, chemical, mechanical, and atmospheric conditions, as well as physical damage during installation. Accessories degrade for the same reasons and often from improper workmanship. ***TD testing is a non-destructive method to determine the extent of insulation and accessory degradation over the entire cable length measured*.**

Find out which of your cables are

Highly Degraded, ***Slightly Degraded***, or ***Good***?

SIMPLIFIED CABLE MODEL AND PHASOR

Tan Delta = $I_R/I_C = 1/(2\pi fCR)$



Pure C angle = 0
Pure R angle = 90°

A deteriorated cable may show an angle of 0.5° - 1° (0.0175 radians)

In a perfect cable, characteristics are similar to a capacitor. Current I_c is 90° phase shifted from voltage V, making the angle δ = 0°. The more deteriorated the insulation is, the more the angle δ grows, to maybe 0.5°. The greater the angle, the more resistive the cable appears, or the more deteriorated the cable's insulation and accessories are. Test many cables, grade and compare them to replace and/or inject the weakest first.

TAN DELTA (δ) MEASUREMENT

Using VLF @ 0.1 Hz

- Excellent predictive tool for determining the integrity of cable
- Absolute values, variations, and trending of values are of interest for predicting insulation and accessory integrity
- Evaluates over all condition of cable (rather than local as with PD measurement)
- Tan Delta is more easily measured at VLF (magnitude increases as frequency decreases)
- Requires VLF sinusoidal applied test voltage
- Excellent method to evaluate Water Trees
- Easy to use and interpret measurements
- Comparative test to prioritize cable replacement, injection, or to determine what other tests may be useful

CHARACTERISTICS OF WATER TREES

Typical Water Tree in XLPE →

Addition of a new parallel R- C component

The R component is Voltage Dependent (non – linear)

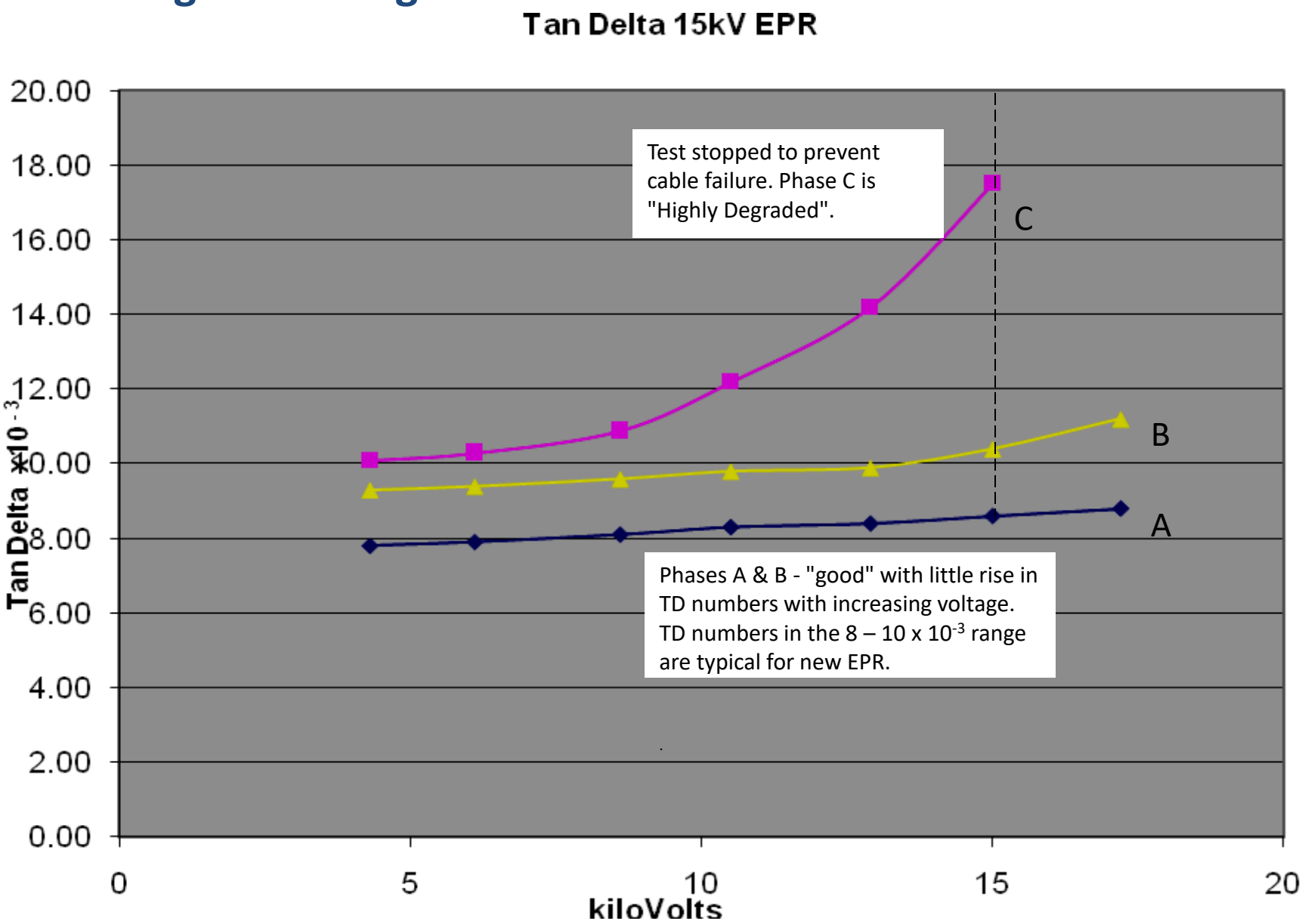
Tan Delta numbers trend upward with increasing voltage

WATER TREES ADD RESISTIVE ELELMENT

Cable is no longer purely capacitive

- TD can measure the extent of water tree damage
- Tree shaped channels are found within the insulation of operating cables resulting from the presence of moisture in voids within an electrical field
- Most prevalent in aged XLPE and PE cables
- Water tress eventually grow to become electrical trees and emit partial discharge
- PD activity leads to in-service failures

Typical TD graph
TD # vs. rising test voltage



TAN DELTA MEASUREMENT DEVICES

Devices available up to 200 kV peak

Tan Delta

60 kV model

HV divider Signal analyzer

M & B Systems - England

Tan Delta & Partial Discharge

70 kV model

Power Diagnostix – Germany

TAN DELTA TESTING

Advantages

- Less destructive than VLF or 60 Hz testing
- Measures overall condition of cable and accessories
- Aids in prioritization of cable replacement/repair
- Test easily performed and interpreted

Disadvantages

- Can be destructive if test voltage is too high
- Gives overall condition of cable, not singularities
- Not best for mixed type cable runs
- More useful with historical data

Conclusion

TD testing is an easy method to evaluate many cables for comparison to help determine where replacement or injection efforts are best spent. It also helps to determine what other tests may be useful.

VLF AC CABLE TESTING TECHNOLOGY
WITHSTAND & DIAGNOSTIC APPLICATIONS

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VLF – PD DIAGNOSTIC CABLE TESTING

VLF PARTIAL DISCHARGE TESTING

Over time, cable insulation degrades due to thermal, chemical, mechanical, and atmospheric conditions, as well as physical damage during installation. Accessories degrade for the same reasons and often from improper workmanship. *PD testing is a non-destructive method to determine the locations and severity of electrical discharges (PD) within your cable system. Where are the bad spots?*

Don’t you want to know where and how severely your cable is degraded, and without risking failure during the test?

OFF-LINE PARTIAL DISCHARGE TESTING

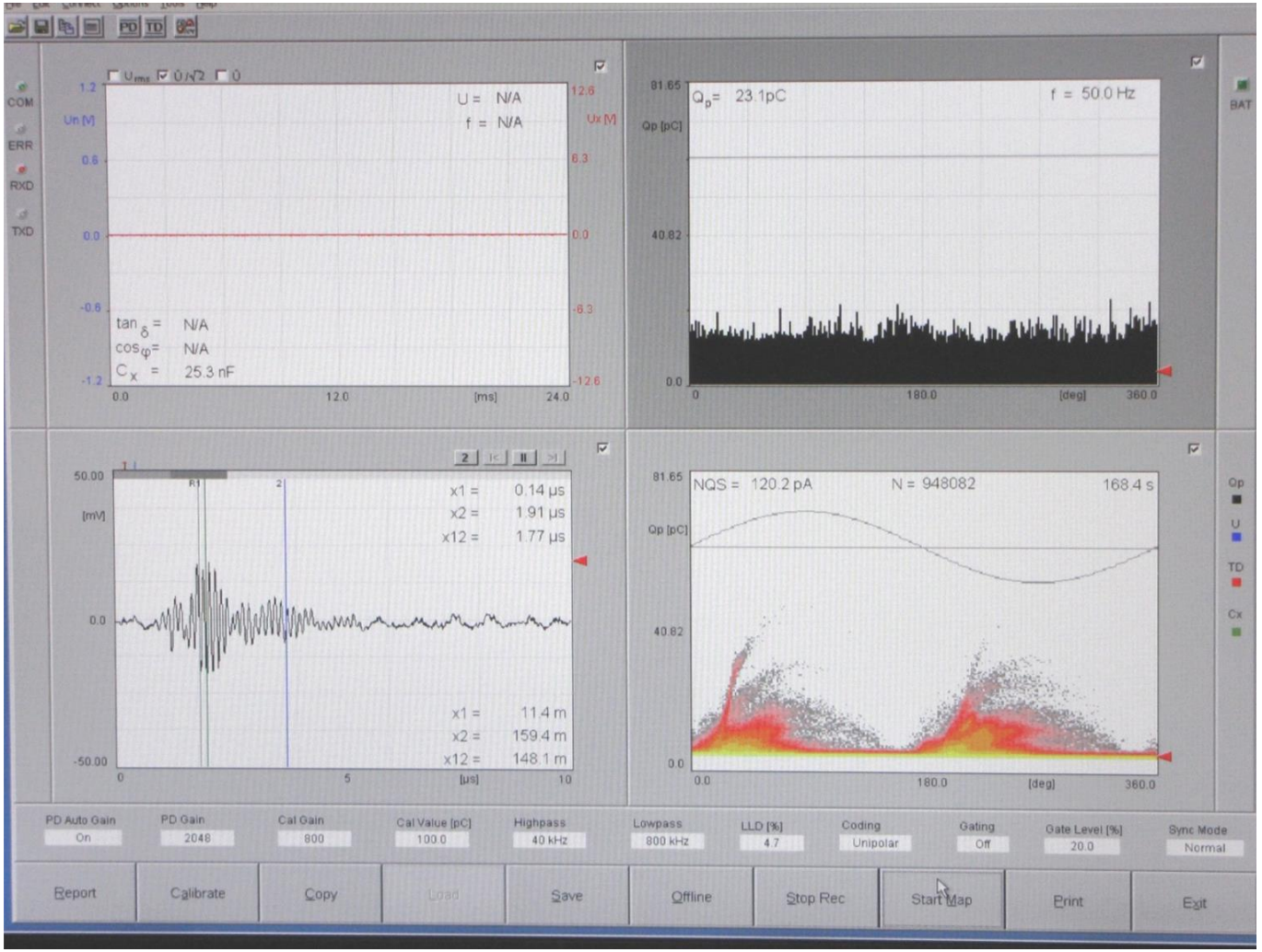
Off-Line PD testing is a method of evaluating a cable to locate and measure the severity of defects. If performed properly, it is a non-destructive test. This can be performed with power frequency or VLF equipment. Readily available and portable VLF products bring PD testing to the field, with equipment within the economic reach and ease in use for most to purchase and perform their own testing.

OFF-LINE PARTIAL DISCHARGE TESTING

Pd testing locates areas of pd and their magnitude. We measure the Pd inception voltage, or PDIV (at what voltage does it start) and the Pd extinction voltage, PDEV (at what voltage does it extinguish). With this known, an educated decision can be made as to the action required. Some levels of pd are acceptable while others are not. Generally, any pd in the insulation is not acceptable, however, splices and terminations can live for years with high Pd. For example, PD that starts in the insulation at say 1.7 – 1.8 U_o is acceptable. If it starts at only 1.1 – 1.5 U_o, it is worrisome.

Performed properly with the right equipment and interpretation, locations of PD can be accurately measured.

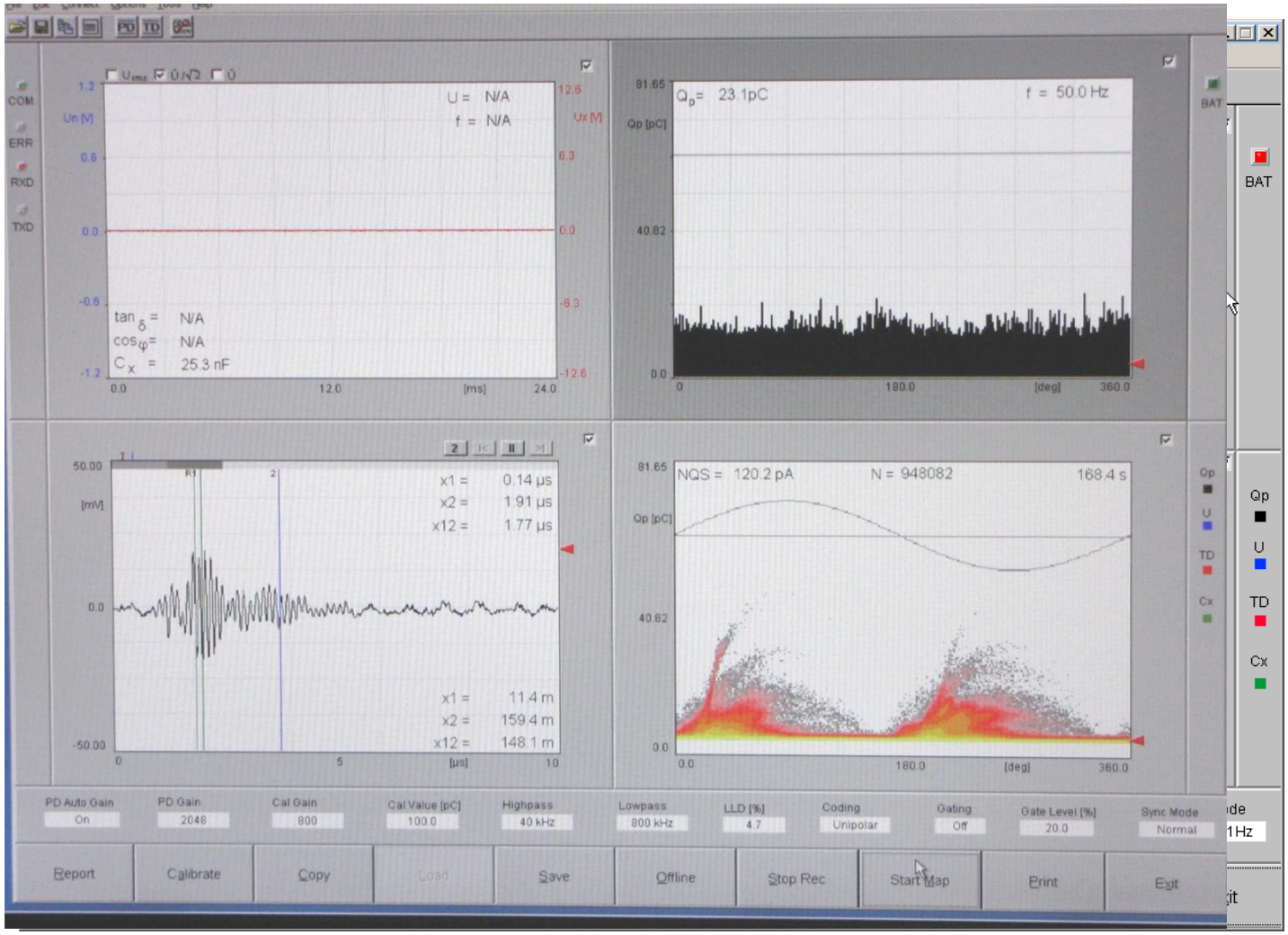
TYPICAL TD/PD SCREEN SHOT



Shows PD magnitude and location – From Power Diagnostix Systems GMBH

Takes some training and data interpretation

TYPICAL TD/PD SCREEN SHOT



Location and amplitude of PD measured.

VLF AC CABLE TESTING TECHNOLOGY
WITHSTAND & DIAGNOSTIC APPLICATIONS

We have described the three commonly used methods for field testing cable using VLF technology. Which ones are right for your application depend on many variables. Not all will be practical or even prudent for your situation. Know the differences in results, availability, ease of use, and cost.

- **VLF Withstand** Proof/hipot testing
- **VLF – TD** Tan Delta testing
- **VLF – PD** Partial Discharge testing

DEFINE THE GOALS OF YOUR TESTING?

What test data are you after and what will you do with it?

- Verify new installation – fail, find, and fix?
- Verify repaired cable before re-energizing?
- Verify critical cables during downtime?
- Compare many cables to prioritize replacement or injection and/or to determine if other tests are needed?
- Is cable direct buried requiring exact fault location, or is it in conduit and easily replaceable?
- Cost of equipment, availability, ease in use, ease in analysis, etc.. all must be weighed against the usefulness of the data gathered.

Match the test methods to your situation

SUMMARY & CONCLUSION

No one test method can do it all. Use one or all three to learn the most about your cables

Before selecting the approach, know what data you need and what you are going to do with it

Match the test technology with the desired results, weighed against cost, availability, ease of test, etc.

Years of experience, standards, and results verify VLF

Now VLF-TD and VLF-PD are available for field testing

You test everything else with multiple methods. There's no reason to not test your cables the same.

SUMMARY & CONCLUSION

VLF Withstand testing is the most effective method of exposing cable and accessory defects. With the Tan Delta and Partial Discharge options, both hipot and diagnostic tests are possible.

Suitable for use on cables and rotating machinery.

Worldwide standards exist for VLF testing.

Hundreds of users worldwide have embraced VLF with more joining the ranks every week.

VLF It! It's fast, easy, and sure.

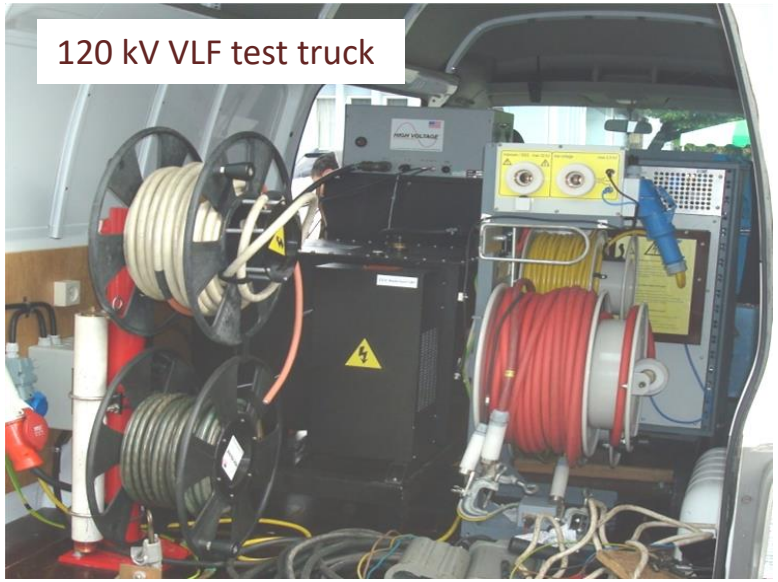
VARIOUS APPLICATION PHOTOS

200 kV VLF Trans. Test

TD Test 15 kV XLPE

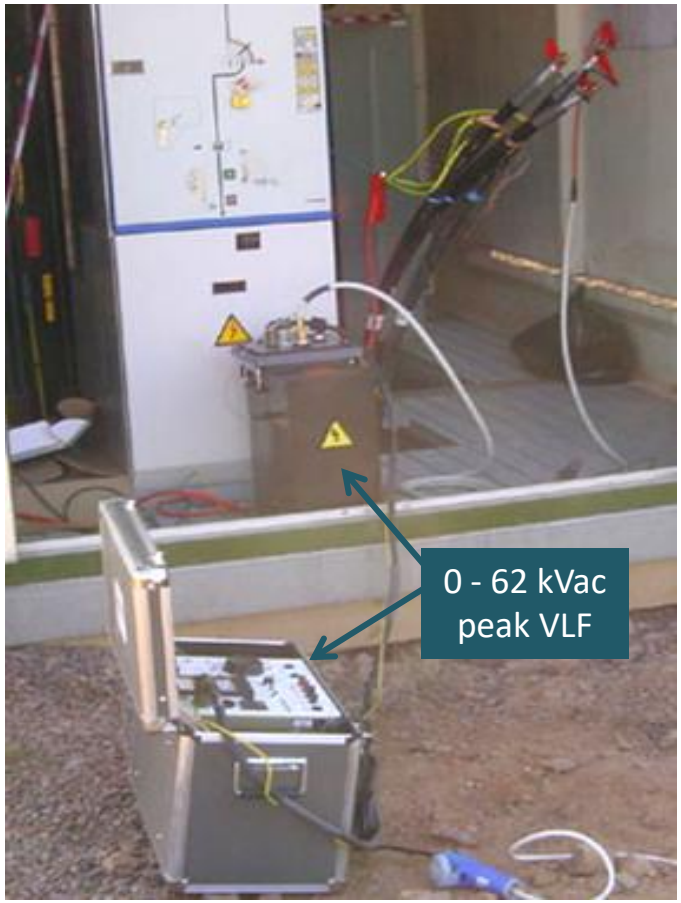
VLF TD & PD test 22 kV cable

200 kV VLF - VLF TD - VLF PD test truck



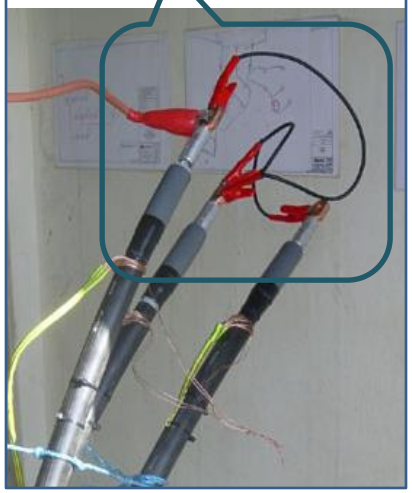
120 kV VLF test truck

WIND FARM 35kV CABLES ARE IDEAL FOR VLF WITHSTAND TESTING



VLF Acceptance Test
per IEEE 400.2

VLF Hipot testing
3 phases at once
@ 62 kVac peak for
30 - 60 mins.



Cable system is new but needs **VLF Withstand** test to find faulty workmanship on splices and terminations and possible cable installation damage.
Tan Delta and Partial Discharge testing are not needed. VLF It!

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THANK YOU

MIKE PESCHEL - CHAIRMAN & EXECUTIVE VP

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