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High Voltage, Inc. designs and manufactures high voltage test equipment for testing all types of medium and high voltage equipment used for the Generation, Transmission, and Distribution of electricity: products for testing substation apparatus, cables, aerial lifts, linemen safety tools, and a multitude of other loads, including cable fault locating products.

Products range from 3 kV – 600 kV, AC or DC voltage, 1 kVA - 40 kVA, 50/60 Hz. & VLF 0.1 Hz, parallel resonant systems to 250 kVA, 150 kV & 300 kV AC/DC precision dividers, and high current neutral & ground cable resistance testers.

HVI leads the world with the finest field test equipment available, the most responsive before, during, and after sales support, and excellence in service backup, serving over 150 countries through more than 90 agents since 1997. *Always call HVI first*.

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HIGH VOLTAGE TESTING MV CABLE

Common Methods for Factory & Field Testing

So Many Options. What Should I Use?

VLF

Monitored Withstand VLF TD Test

Monitored Withstand VLF PD Test

Partial Discharge

Tan δ

Online - Offline

VLF 0.1 Hz. – 0.01 Hz. Withstand Test

50/60 Hz. Power Frequency Withstand Test

Series/Parallel Resonant Test

Diagnostic Testing

Destructive vs. Non-Destructive

Recovery Voltage

Isothermal Relaxation Current

DC Hipot

DC Leakage Current

TDR/Radar

HVI®

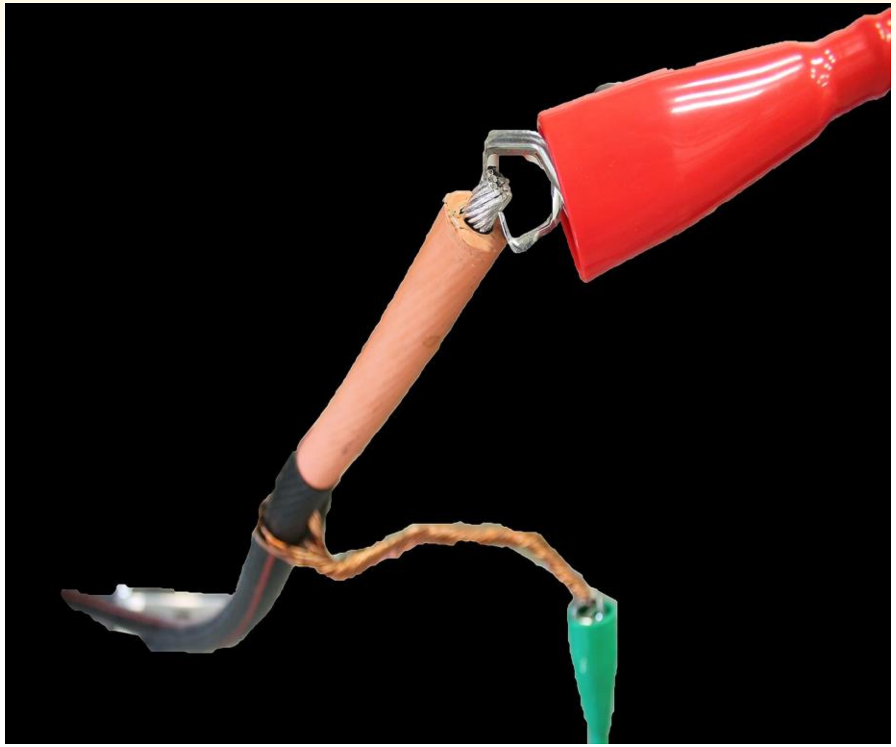
Ω-CHECK® Concentric Neutral Resistance Testing

HIGH VOLTAGE TESTING MV CABLE

FIELD & FACTORY APPLICATIONS

Time to Test

There are a multitude of methods that can be used for testing power cable to verify operational integrity and to estimate remaining life. Some are only applicable to **Factory Acceptance** testing while others are designed for **Field Acceptance, Installation, & Maintenance** testing. Some are possibly **"Destructive"** tests while many are **"Non-Destructive Diagnostic"** tests. This presentation will provide a brief look at the various methods and their technologies used.



HIGH VOLTAGE TESTING MV CABLE

Withstand/Proof & Diagnostic Testing

Withstand Tests: Destructive – Pass/Fail – Go/No-Go

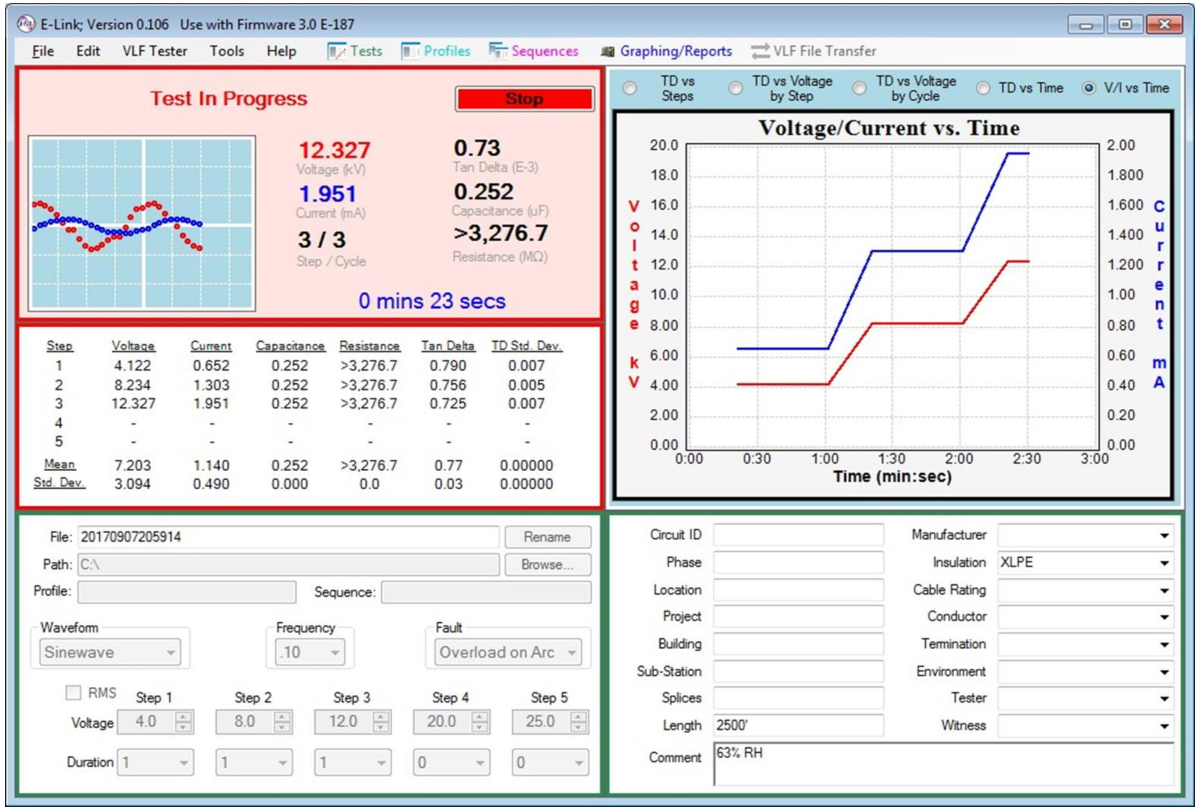
The DUT Holds the Test Voltage or Fails

- DC Hi-Pot Testing: mostly for PILC cables
- VLF Hi-Pot Testing
- AC 50/60 Hz. Hi-Pot Testing

Diagnostic Tests: Non-Destructive

Learn Something of the Insulation Quality

- DC Over Voltage Leakage Currents
- Partial Discharge Testing (PD)
- Tangent Delta Testing (TD)
- Recovery Voltage Measurement (RV)
- Iso Thermal Relaxation Current (IRC)



HIGH VOLTAGE TESTING MV CABLE

Withstand/Proof & Diagnostic Testing

TECHNOLOGIES CURRENTLY AVAILABLE

- ❑ Simple Dielectric Withstand – AC or DC Voltage
- ❑ Dielectric Loss (Tan δ & Dielectric Spectroscopy)
- ❑ Online Partial Discharge (PD)
- ❑ Offline Partial Discharge (PD)
- ❑ Isothermal Relaxation Current (IRC)
- ❑ Recovery Voltage (RV)
- ❑ Damped AC (DAC) - Oscillating Wave Test Set

HIGH VOLTAGE TESTING MV CABLE

Withstand/Proof & Diagnostic Testing

COMMON FACTORY TESTS @ 50/60 Hz: ACCEPTANCE

- Partial Discharge (PD) Test (Overvoltage) – Look for bad spots
- Tan Delta or Power Factor Test (Overvoltage) – measure overall condition
- Sheath Test – Outer jacket integrity test
- TDR/Radar Test – Check Concentric Neutral Continuity
- DC “Megger”, or Insulation Resistance (IR), Test

HIGH VOLTAGE TESTING MV CABLE

Withstand/Proof & Diagnostic Testing

COMMON FIELD TESTS: ACCEPTANCE & MAINTENANCE

- "Soak" Test
- "Megger" or IR Test
- DC Hipot Withstand
- AC Hipot Withstand - Power Frequency & Very Low Frequency (VLF)
- Tan Delta/Power Factor Test – Power Frequency & VLF @ 0.1 Hz.
- Partial Discharge (PD) Test – Power Frequency & VLF @ 0.1 Hz.
- Sheath Test – Outer jacket integrity test

HIGH VOLTAGE TESTING MV CABLE

Withstand/Proof & Diagnostic Testing

OTHER TESTING APPLICATIONS & TECHNOLOGIES

- Time Domain Reflectometry (TDR)
- **Ω-CHECK®** Concentric Neutral Corrosion Testing
- Sheath Testing
- Polarization/Depolarization Measurements
  - Recovery Voltage
  - Isothermal Relaxation Current

HIGH VOLTAGE TESTING MV CABLE

Test Types: Factory & Field Testing

- ❑ Acceptance, Installation, & Maintenance
- ❑ Withstand/Proof Verification
- ❑ Diagnostic “Non-Destructive” Methods
- ❑ Global Condition Assessment (GCA)
- ❑ Specific Defect Location & Severity
- ❑ Sheath Integrity Verification
- ❑ Concentric Neutral Resistance Measurement

Now for a brief overview of each and additional information

HIGH VOLTAGE TESTING MV CABLE

Withstand/Proof & Diagnostic Testing

IEEE STANDARDS DEFINING MV CABLE TESTS

IEEE 400, the IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems (this is the omnibus guide for other more specific guides such as these listed below.)

IEEE 400.1, the IEEE Guide for Field Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5 kV and Above With High Direct Current Voltage

IEEE 400.2, the IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)

IEEE 400.3, the IEEE Guide for Partial Discharge Testing of Power Cable Systems in a Field Environment

IEEE 400.4, the IEEE Guide for Field Testing of Shielded Power Cable Systems Rated 5 kV and Above with Damped Alternating Current (DAC) Voltage

Above are only the IEEE standards that apply to the various methods of cable testing described, other world standards exist if needed.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Overvoltage Withstand Test

Test Description

- Applies above normal operating voltage for a set time duration.
- Drives severe defects to failure during test, avoiding in service failures.
- Severe defects driven to partial discharge under the test voltage must be allowed to fail during the test. Defects that do not initiate PD lie dormant, unaffected by test.

Field Application

- An offline test that uses:
  1. DC Voltage
  2. 50/60 Hz. AC Voltage
  3. VLF AC Voltage (0.1 Hz. – 0.01 Hz.)
  4. Damped AC Voltage (20 – 400 Hz.)
  5. Resonant Technology (50/60 Hz.)

1

2

3

4

5

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HIGH VOLTAGE TESTING MV CABLE

Test Method: Soak Test

The Soak Test is the very least that can be done to verify the integrity of a newly installed or repaired cable. Once installed and before connecting to any loads, energize the cable for a while. The easiest of all tests, but least meaningful.

Step 1: Install your cable system - open at both ends

Step 2: Connect one end to the voltage source

Step 3: Leave the other end open but safe

Step 4: Energize your cable

Step 5: Leave cable energized at operating voltage for ~ 24 - 48 hrs.

Step 6: Time's up. If no failure, call it good and connect your load

Step 7: Go home, you're done

HIGH VOLTAGE TESTING MV CABLE

Test Method: DC Hipot Test

Apply DC Voltage: Monitor the Leakage Current to Analyze or to Calculate IR

DC voltage was used from the start to test cable insulation, among other loads. Its main use was to apply a voltage of up to 8x (8Uo) normal operating voltage between two conductive surfaces and read the leakage current seeping through the insulation. The lower the better. With no absolute numbers available, nor possible with the myriad of installations and other variables, it is **essentially a learned comparative test** with users establishing their own benchmarks for Pass or Fail. Some guidelines are supplied by material vendors and IEEE/ANSI/etc.

DC testing works well on oil insulated (PILC) types of cables but **not on solid dielectric** (XLPE, TR-XLPE, EPR, PVC, etc.) cable designs. It has been largely abandoned worldwide for testing service aged solid dielectric cable due to its polarization of molecules in water trees and other effects.

DC testing can be considered a destructive overvoltage withstand test or a non-destructive diagnostic test, depending on the voltage levels reached and the testing application, or load.

HIGH VOLTAGE TESTING MV CABLE

Test Method: DC Hipot Test

Table C.1. – ICEA DC Field Test Voltages

ICEA S-97-682 Utility Shielded Power Cables Rated 5,000 - 46,000 Volts

Rated Voltage Phase-to-Phase (kV)	Conductor Size		Nominal Insulation Thickness (Insulation Level)				Maximum dc Field Test Voltages (kV)			
							During or After Installation		First 5 Years	
	AWG/kcmil	mm²	100%		133%		100%	133%	100%	133%
			mils	mm	mils	mm				
5	8 – 1000	8.4 - 507	90	2.29	115	2.92	28	36	9	11
	> 1000	> 507	140	3.56	140	3.56				
8	6 – 1000	13.3 – 507	115	2.92	140	3.56	36	44	11	14
	> 1000	> 507	175	4.45	175	4.45				
15	2 – 1000	33.6 - 507	175	4.45	220	5.59	56	64	18	20
	> 1000	> 507	220	5.59						
25	1 – 2000	42.4 – 1013	260	6.60	320	8.13	80	96	25	30
28	1 – 2000	42.4 – 1013	280	7.11	345	8.76	84	100	26	31
35	1/0 – 2000	53.5 - 1013	345	8.76	420	10.7	100	124	31	39
46	4/0 - 2000	107.2 - 1013	445	11.3	580	14.7	132	172	41	54

Example: A 15 kV class cable operating on a 13.2 kVac system has a line-ground voltage of 7.62 kVac. **Uo = 7.62**
Using the above numbers and Acceptance testing, **64 kVdc/7.62 = 8.4 Uo**. If service aged, then **20 kVdc/7.62 = 2.6 Uo**

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HIGH VOLTAGE TESTING MV CABLE

Test Method: AC Withstand Test @ 50/60 Hz.

Historically, until the advent of VLF use in the 1990’s, AC Withstand testing of cables was performed with conventional power frequency AC power supplies, or hipots. It is the best technology to use but has severe limitations to its practicality. The limitation is the AC charging current required to test a high capacitance load like a cable. A long 35 kVac cable with 3 µF of capacitance tested at 50 kVac rms, would require 3 MVA of power to test: obviously too large, heavy, expensive, difficult to transport, and too power consuming.

Although still used for shorter cable runs and other apparatus, Resonant and VLF technologies are now used in most cases.

Various 50/60 Hz. AC Hipots

60 kVac @ 3 kVA

100 kVac @ 10 kVA

120/60 kVac @ 7 kVA

400 kVac @ 10 kVA

HIGH VOLTAGE TESTING MV CABLE

Test Method: AC Withstand Test @ 50/60 Hz. vs. 0.10 Hz.

How Frequency Effects Cable Charging Current

Amps = $\omega CV = (2\pi f)CV$

C = Load Capacitance in *µF*
V = Test Voltage in *Volts*

0-50 kVac @ 3 kVA, 50/60 Hz.
Can test only **~50'** of 15 kV
cable = **.0026 µF** of load

0-50 kVac @ 250 kVA, 50/60 Hz., Parallel Resonant Set. Can test **~1.4 miles** of 15 kV cable = **.7 µF**

0-65 kVac VLF, 0.1– 0.01 Hz.
Can test **~ 2 miles** of 15 kV
cable = **1 µF** (@ 0.1 Hz.)

See the length of 15 kV cable that can be tested with the three different technologies shown above.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Series/Parallel Resonant Technology

Resonant Systems are designed to provide a variable high voltage AC source, at or near typical power frequencies, to test very high capacitance loads, like long cables, GIS, Rotating Machinery, etc. Certification and Acceptance Withstand testing and related diagnostic tests often must be performed at 50/60 Hz. To overcome the high AC charging current and power required at power frequencies, these systems are designed to compensate for the high capacitive reactance of the test loads by either altering their frequency output or by using a variable inductance reactor to “tune” out the load capacitance. There are **Variable Inductance, Parallel** and **Series, Resonant Systems** and **Variable Frequency Output (20 Hz. – 400 Hz.) Resonant** designs.

Through tuning the variable inductance of the high voltage reactor to match the capacitive reactance of the load, the apparent power required to test the load is nearly eliminated, greatly reducing the input power required from the test set and from the input power source. Depending on the nature of the load, a reduction of 10x – 40x the input current and power is achievable.

Parallel Resonant System

Output: 0-50 kVac, 5 A, 250 kVA, 50/60 Hz

Input: 230 V, 1 ph., 20 kVA, 90 A

HIGH VOLTAGE TESTING MV CABLE

Test Method: Series/Parallel Resonant Technology

Useful Formulas & Drawings

$X_C = ½\pi fC$ $X_L = 2\pi fL$ $f_{\text{resonant}} = \dfrac{1}{2\pi\sqrt{LC}}$

Capacitive Charging Current: A = 2πfCV

f = frequency (Hz), C = Capacitance (F), V = Voltage (V)

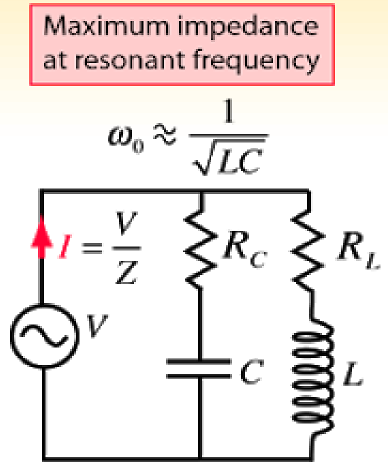
Two Resonant Designs Commonly Used – Series & Parallel

- ❑ Variable Inductance via variable gapped core transformer design
- ❑ Variable Inductance via variable frequency output ~20 Hz. - 300 Hz.

PARALLEL RESONANT CIRCUIT

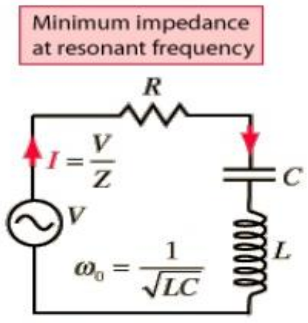
Different possible definitions of the resonant frequency for a parallel resonant circuit:

1. The frequency at which $\omega L = 1/\omega C$, i.e., the resonant frequency of the equivalent series RLC circuit. This is satisfactory if the resistances are small.
2. The frequency at which the parallel impedance is a maximum.
3. The frequency at which the current is in phase with the voltage, unity power factor.



Parallel Resonance

SERIES RESONANT CIRCUIT



Series Resonance

Since at resonance,

$X_L = X_c$

$2\pi f_r L = 1 / 2\Pi f_r C$

$f_r = 1 / 2\pi\sqrt{LC}$

$\omega_r = 1 / \sqrt{LC}$

HIGH VOLTAGE TESTING MV CABLE

Test Method: Very Low Frequency Withstand Test

VLF Models from HVI

0-35 kVac & 0-65 kVac
Load Rated to 5 & 10 uF

0-65 kV Tan Delta
0.10 Hz. – 0.01 Hz.

0-34 kVac

0-65 kVac

0-90 kVac

0-120 kVac

0.10 Hz. – 0.01 Hz. Voltages are in Peak AC & Sinusoidal

0 - 200 kVac
@ 3.75 uF

PD & TD
Equipped

HIGH VOLTAGE TESTING MV CABLE

Test Method: VLF WITHSTAND TEST 0.10 Hz – 0.01 Hz.

Advantages

- Low Cost To Implement, Easy Set-up, Many Vendors
- Minimal Training – Easier Than DC Testing
- Easy To Perform, Gather Data, & Interpret Results
- Real Time Interpretation & Trending
- IEEE 400.2-2013 Defines Test – and other Standards
- Been a Mainstream Test Since >1999

Disadvantages

- Not Power Frequency: 0.10 Hz. vs. 50/60 Hz.
- High µF Loads Require Frequencies down to 0.01 Hz, not all accepted for some diagnostic testing

HIGH VOLTAGE TESTING MV CABLE

DIAGNOSTIC NON-DESTRUCTIVE TESTING

Global Cable Assessment (GCA) Evaluation

GCA tests assess the overall health of the cable insulation. These tests include DF/tan δ/PF, PD, Dielectric Spectroscopy, Depolarization: Recovery Voltage and Isothermal Relaxation Current. Each of these tests have their place and their advantages and disadvantages. Several of the more common tests performed will be explained in the slides ahead.

Often, we just want to know the general condition of a group of cables and don't want to hipot the cables and risk failures. Non-Destructive Diagnostic Testing is what we want.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Tan δ/Loss Angle/Dissipation Factor

How Good is my Cable? What's the Condition of the Insulation and the Accessories?

A cable is a capacitor. In a perfect capacitor, the current is 90° phase shifted from the applied voltage. (In a resistor they are in phase). The more deteriorated the insulation is, the less it exhibits the properties of a perfect capacitor. The ideal phase shift of 90° decreases to perhaps 89.8° – 89.5°. The TD number is the tangent of the angle Delta, as shown in the drawing. It is easily measured at VLF frequencies and very useful at determining the health of the cable.

TD testing will help to **prioritize where to start** cable replacement efforts, injection or rejuvenation upgrades, additional tests that may be beneficial, data benchmarks for future comparison, and other information useful for sustaining a healthy distribution system.

Tan Delta, like Power Factor, testing provides an **overall assessment** of the condition of the load tested, in this case cable systems. What is the dielectric health of my cable from point A to point B? If cables are to be replaced if faulty, the goal is to test hundreds of similar cables, rate their health by several criteria, compare all the results, and develop a prioritized “hit” list of where we go next with cable system improvement efforts.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Tan δ/Loss Angle/Dissipation Factor

Test Description - Measures total cable system loss (cable, elbows, splices, etc.)

The cable is isolated from its load with the ends open and insulated from ground. An AC voltage source, usually from a VLF hipot, is applied to the cable in several step voltages, typically 0.5 Uo, 0.75 Uo, 1.0 Uo, 1.25 Uo, 1.7 Uo, 1.8 Uo, 2 Uo. The TD results are monitored during the test to watch for a “tip-up” situation possibly requiring the test to be ended, and/or continued and recorded for condition assessment.

- Excellent method for measuring water tree content
- May be performed at one or more frequencies (dielectric spectroscopy)
- Can be performed at multiple voltage levels
- Monitoring may be conducted on the spot or for long durations

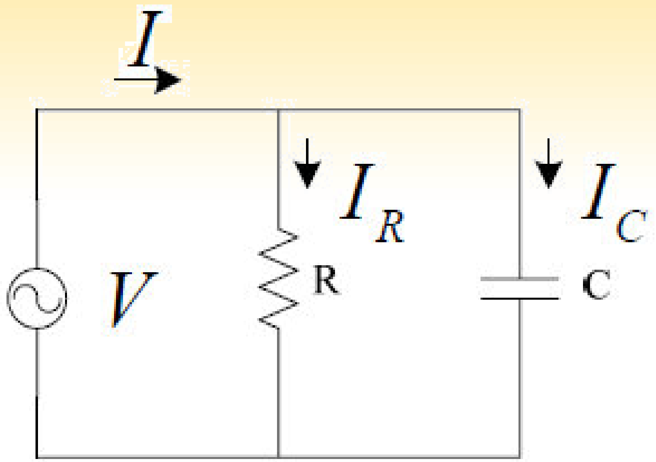
Various Voltage Sources Possible

VLF @ 0.10 Hz or 0.05 Hz. is normally used for TD testing, although use other AC voltage sources can be used, with interpolation of the results required since frequency dependent:

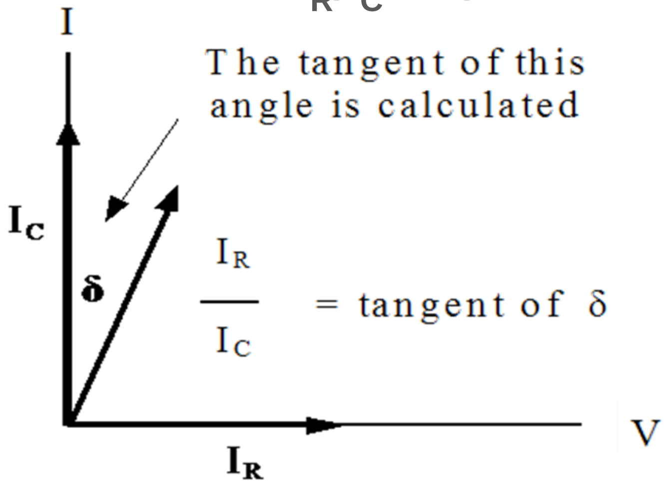
50/60 Hz. AC **Serious or Resonant Systems** **Damped AC OWTS**

HIGH VOLTAGE TESTING MV CABLE

Test Method: Tan δ/Loss Angle/Dissipation Factor



Tan δ = $I_R/I_C = 1/\omega RC$



Example of Test: 15 kV (rms) System Voltage

System KV (RMS)	15	Peak Voltage (kV)	RMS Voltage (kV)
First Test Point	$U_0/2$	6	4
Second Test Point	U_0	12	9
Third Test Point	$1.5(U_0)$	18	13
Fourth Test Point	$1.8(U_0)$	22	16

VLF-TD Interpretation

TD Stability - TD vs. Voltage - Absolute Value - Trend

Condition Assessment	VLF-TD Time Stability (VLF-TDTS measured by standard deviation at U_0 $[10^{-3}]$		Differential VLF-TD (VLF-DTD) (difference in mean VLF-TD) between 0.5 U_0 and 1.5 U_0 $[10^{-3}]$		Mean VLF-TD at U_0 $[10^{-3}]$
No Action Required	<0.1	and	<5	and	<4
Further Study Advised	0.1 to 0.5	or	5 to 80	or	4 to 50
Action Required	>0.5	or	>80	or	>50

HIGH VOLTAGE TESTING MV CABLE

Test Method: Tan δ/Loss Angle/Dissipation Factor

Advantages

- Low Cost To Implement & Easy Set-up
- Simple & Quick Test Easily Interpreted
- Minimal Training with established Data Interpretation Available
- Data at Voltages from .5 Uo - 2 Uo
- Been A Common Test Since >1999
- Cable Conditions Graded and Compared
- Establish History of Cables for Trending
- IEEE 400.2-2013 Defines Test

Disadvantages

- Off-line Test With Cable Out of Service
- Singular Defects not Found
- Tests at 0.10 Hz. – 0.05 Hz. vs. 50/60 Hz.
- Not exactly comparable with factory tests
- Not Best for Mixed Insulation Types

Tan Delta Module VLF Unit

HIGH VOLTAGE TESTING MV CABLE

Test Method: Partial Discharge

Partial Discharge (PD) testing is a “diagnostic” test used to assess the condition of a cable's insulation system, searching for any problems or defects within insulation itself, terminations, joints, splices, etc. It attempts **to locate and measure** the severity of any PD event in the cable. PD testing can be performed both **“on-line”** during a U_0 Soak Test or while load energized, or **“off-line”** during an overvoltage AC Hipot test at various frequencies, usually VLF when field testing.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Partial Discharge - Offline

Test Description

An over voltage test to stress cable system to look for PD producing defects. Measurement and interpretation of partial discharge signals below and above normal operating voltages are made. Magnitude, location, and inception & extinction voltages are all important indictors of cable condition.

Field Application

Apply high voltage to de-energized and disconnected cable up to pre-determined level while observing the results, to stop test or voltage increase if necessary, to prevent failure if PD is present. Record test data for later analysis. It is an Off-line test that can use:

- ❑ 50/60 Hz. AC, conventional hipot or resonant
- ❑ VLF AC @ 0.10 Hz. – 0.05 Hz.
- ❑ Damped AC @ 20 Hz. – 500 Hz.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Partial Discharge Offline Setup

Your Pre-Test List of Items & Actions Needed

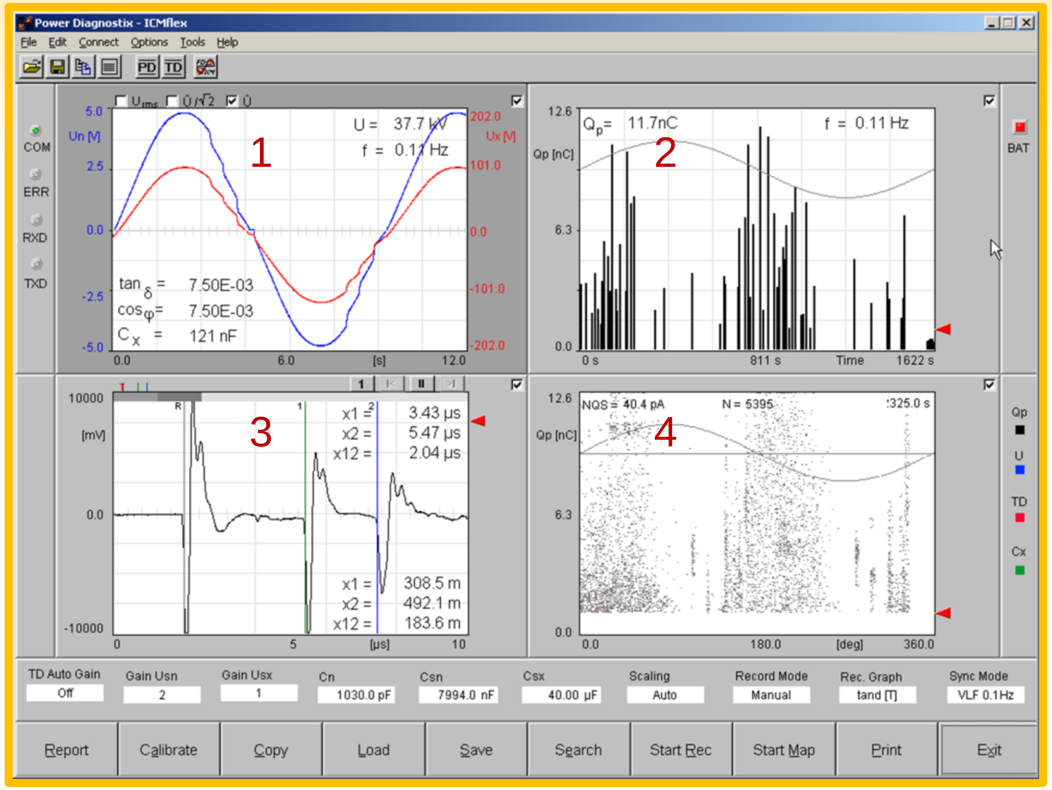
- ❑ A Cable Map
- ❑ A TDR/Radar to Map Out Cable
- ❑ Know your Cable Lengths
- ❑ Know the Splice Locations
- ❑ Know Cable's Propagation Velocity
- ❑ Perform a Sensitivity Check by Injecting a 0.5, 1, or 2 nC signal
- ❑ Verify TDR info

HIGH VOLTAGE TESTING MV CABLE

Test Method: Partial Discharge Offline Data

Test is Over – Analyze Data

- ❑ Voltage Levels of Test
- ❑ PD Inception Voltages (PDIV)
- ❑ PD Extinction Voltages (PDEV)
- ❑ PD Levels Measured
- ❑ Frequency of Noise
- ❑ Locations of Noise
- ❑ Discharge Patterns (phase resolved)
- ❑ Phase to Phase Comparisons
- ❑ Year to Year Comparisons



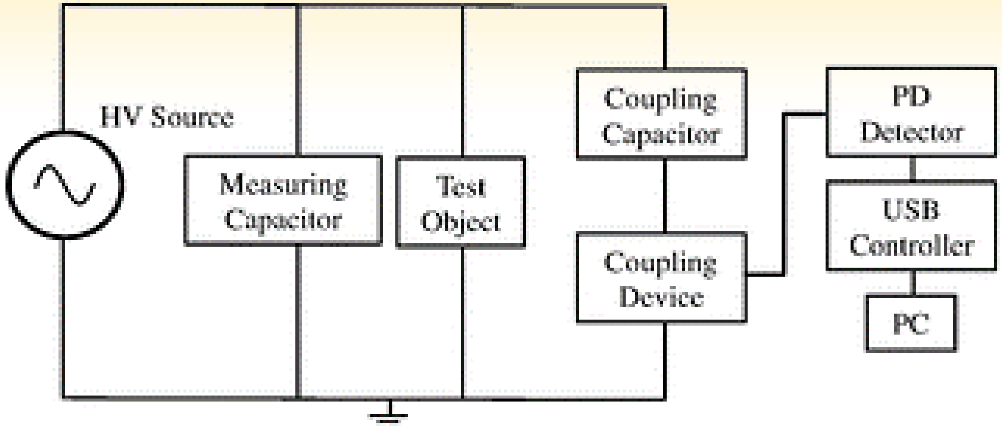
PD Graph Explanations – One of Several Graphs

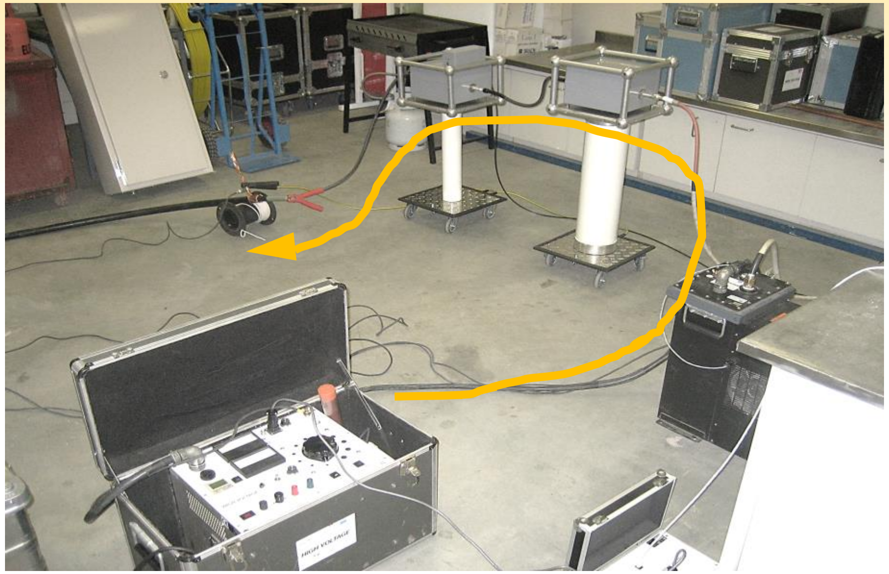
1. Voltage Divider: Blue Reference, Red Test Object
2. PD Activity & PD Peak Measurement
3. PD Site Locations per TDR
4. Phase Resolved PD: # of Pulses & Magnitude

HIGH VOLTAGE TESTING MV CABLE

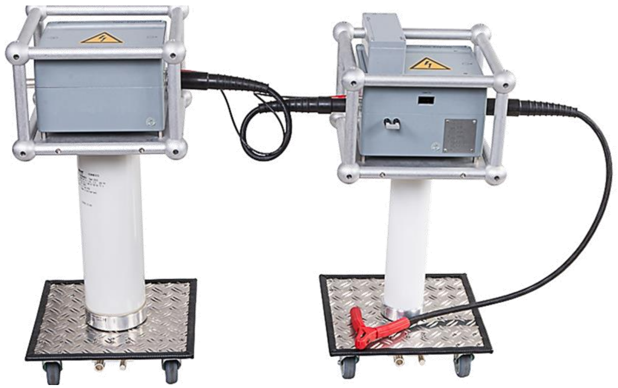
Test Method: Partial Discharge Offline Data

The Equipment Needed & the Setup





VLF Hipot



PD/TD Filtering/Measurement Capacitors & Detectors

Cable Load Tested

Signal Input & Interpretation & Laptop w/Operating Software & Data Logging

HIGH VOLTAGE TESTING MV CABLE

Test Method: Partial Discharge Offline Evaluation

PD off-line diagnostic evaluations are generally considered to be efficient and reliable in discovering defects, their locations, and assessing their severity. Offline PD testing has the benefit over online by providing a controlled over voltage to detect defects that initiate PD at levels above nominal.

Pros:

- Operates above nominal line voltage
- Can Discover Electrical Trees & Others
- Measures PD Severity and Location
- Can Examine ~ 2 To 3 Miles of Cable
- Finds All Defects From One Cable End
- Can Be Quickly Compared to Factory Tests
- Gives Onsite Report of The Test Results
- Records All Data For Later Analysis

Cons:

- Expensive, Difficult to Set-up & Operate
- Skilled Operator & Data Interpreter Required
- What's Acceptable PD? What's Not?
- Not Effective at Detecting Water Trees
- Outside Influences Affect Readings
- Mixed Cables Make Location Siting Difficult
- Can cause cable failure f voltage too high

HIGH VOLTAGE TESTING MV CABLE

Test Method: Monitored Withstand TD & PD

How does the word "Monitor" in the name fit in?

While we are performing a 30 - 60 minute VLF Withstand test, let's do something more while we wait. What other tests can we do during that time that would be valuable for diagnosing the cable quality?

Since we have 2 – 3 times normal operating voltage on the cable for the hipot test, let's also measure and record the Tan Delta numbers and/or the Partial Discharge activity. The TD and PD data saved over a long test period is valuable information in diagnosing the insulation and accessories quality.

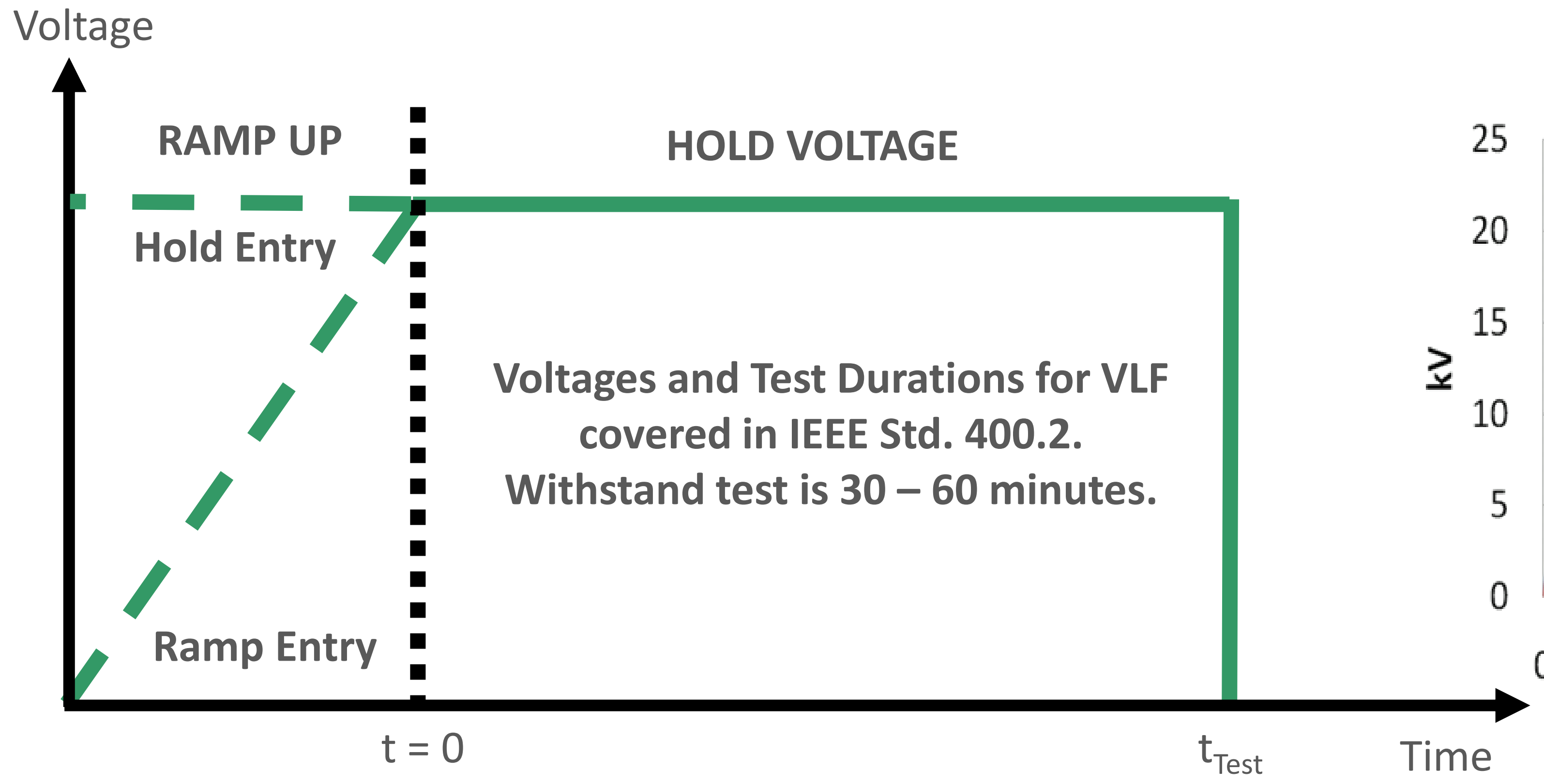
Since the intent of TD and PD testing is to be non-destructive (no failed cables during the test) then an important part of the test is to **"Monitor"** the numbers of each as we increase the test voltage in steps from zero to maximum while we observe the TD and PD data along the way. If all looks good at step 1, then we will advance to step 2, and so on. We will Monitor the data this way until we reach the maximum test voltage set by the Standards for VLF Withstand testing (which is higher than the normal levels for TD and PD). If we see dangerous PD levels or severe "tip-ups" to the TD numbers, then **we can stop the test to avoid a failure**. We have learned what we came for about the cable.

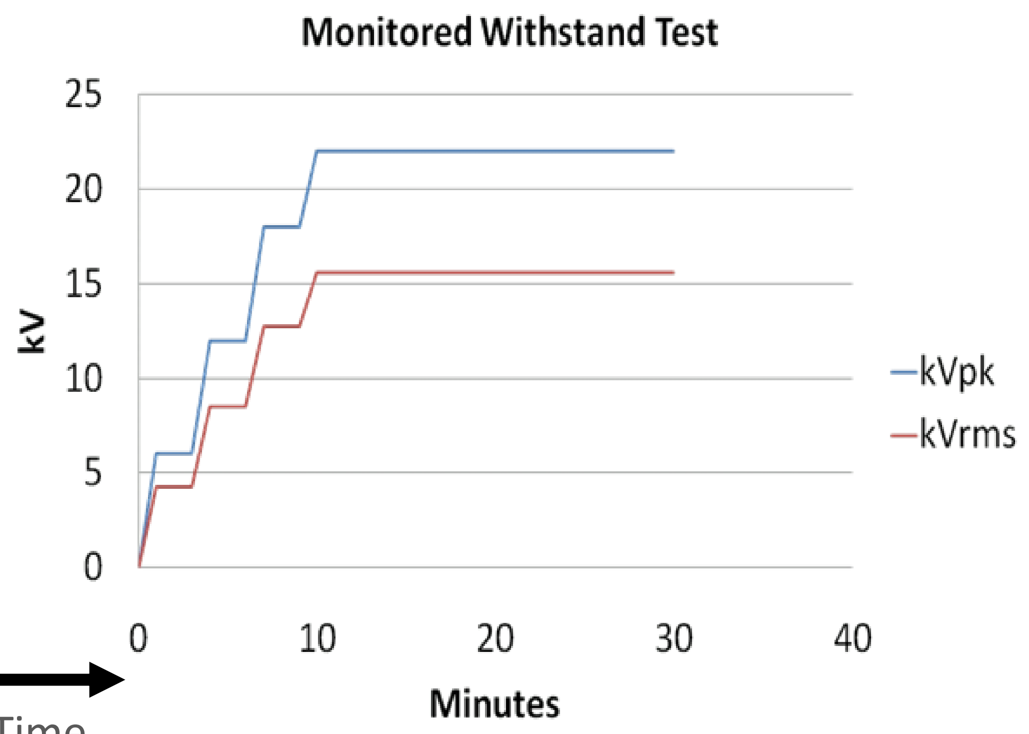
HIGH VOLTAGE TESTING MV CABLE

Test Method: Monitored Withstand Testing

Monitor One or More Parameters During VLF AC Withstand Test

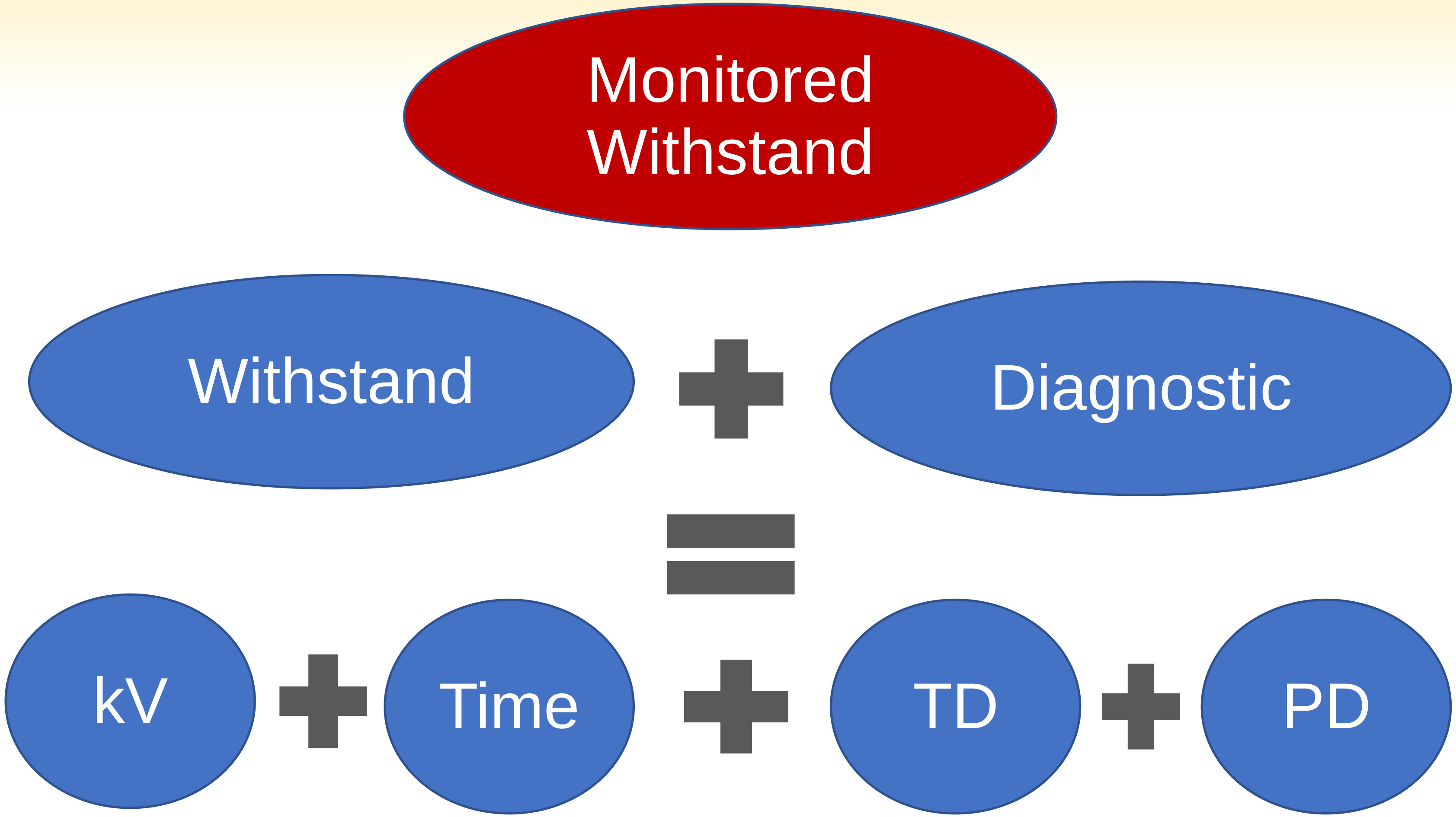
VLF Withstand Test + TD & PD Diagnostic Tests Simultaneously





HIGH VOLTAGE TESTING MV CABLE

Test Method: Monitored Withstand TD & PD

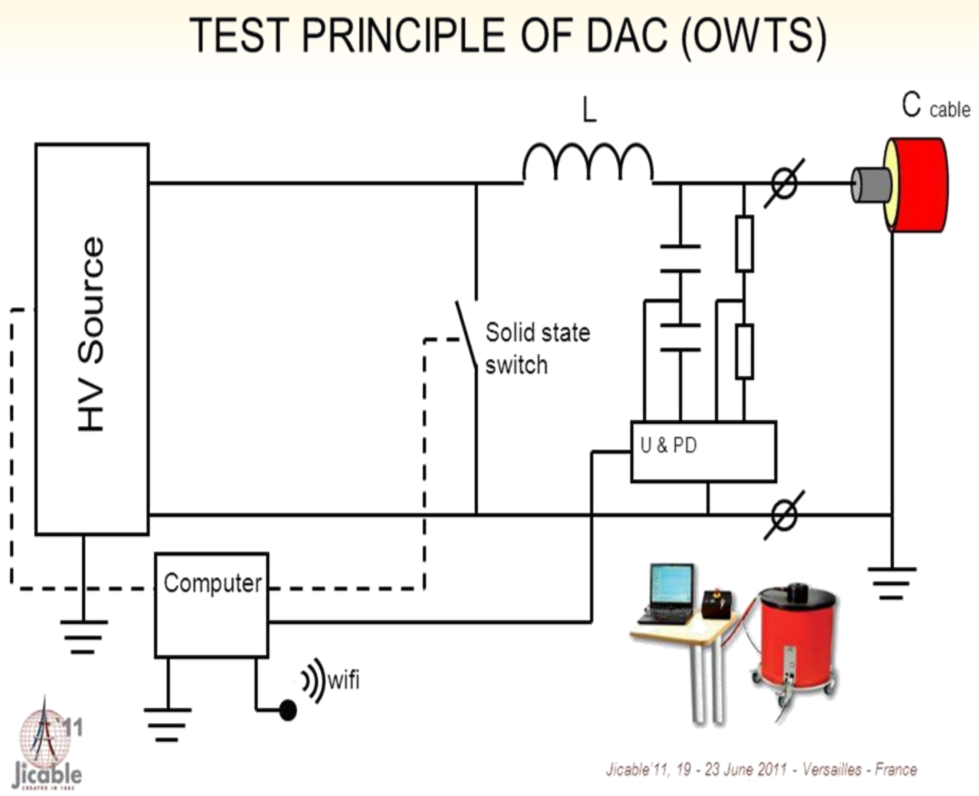


HIGH VOLTAGE TESTING MV CABLE

Test Method: Damped AC PD Measurement (OWTS)

AC Testing at Uo with Oscillating Waves

The OWTS® method charges the test object using a DC supply. After a few seconds, the nominal Uo service voltage is reached. A solid-state switch with fast closure time closes to create a series resonant circuit between the cable and an air-cored inductor. This circuit begins to oscillate at the resonant frequency of $f = 1/(2\pi\sqrt{LC})$. The inductance of the air core is selected such that the resonant frequency is similar to the power frequency of the service voltage (within the range 50 to 1000 Hz). MV cable insulation usually has a low dissipation factor. This combines with the low loss factor of the air-core inductor to produce a high Q (30 to 100) resonant circuit. **The result is an oscillating wave at the resonant frequency f with a decay time of 0.3 to 1 second.** This produces a few dozen cycles to energize the test object. PD is initiated, where is exists, in a similar fashion to 50/60 Hz inception conditions.



HIGH VOLTAGE TESTING MV CABLE

Test Method: Damped AC PD Measurement (OWTS)

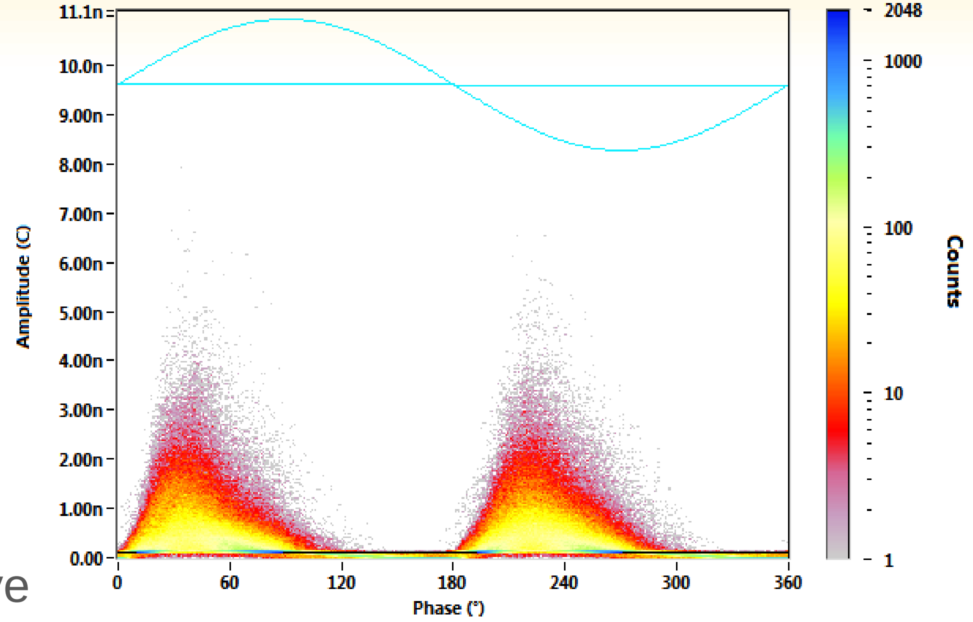
OWTS Features & Test Results

- PD diagnosis under oscillating wave test voltage – electrical field distribution as in nominal service conditions
- PD level measurement according to IEC 270 at a bandwidth of 150 … 650 kHz
- Automatic Calibration and Joint location facility
- Semi and fully automatic PD analyzing software for defect location with mapping feature
- Calculation of the **cable capacitance** and the **tan delta** value of the test object from the characteristic decrease of the voltage wave shape
- Simple to use and easy to handle menu-driven unit for operation of the test sequence
- Compact design, low weight

HIGH VOLTAGE TESTING MV CABLE

Test Method: Partial Discharge - Online

PD on-line diagnostic evaluations are generally considered to be efficient and reliable in discovering defects and assessing their severity in shielded power cables **when in service at operating voltage**. Defects with PD above Uo cannot be determined.



Pros:

- ❑ Finds *some* cable and accessory defects
- ❑ Done while circuit is energized/on-line
- ❑ Does not need an external voltage source
- ❑ Can continuously monitor PD activity

Cons:

- ❑ Cannot be applied to long directly buried power cables
- ❑ Cannot be cross compared to completed factory test
- ❑ Not a calibrated test, hence the test results are not objective
- ❑ Finds only 3% or less of cable insulation defects in extruded cable
- ❑ Needs access to the cable every few hundred feet depending on the cable type
- ❑ Demands that manholes are pumped to access cable conduits and joints

HIGH VOLTAGE TESTING MV CABLE

Test Method: Dielectric Response Analysis

Polarization and Depolarization Currents Measurement

A cable is essentially a capacitor; the conductor is one plate and the neutral is the other, with the insulation acting as the dielectric material. The charging and discharging characteristics of a capacitor are well known, under both AC and DC voltage environments. The more imperfect the cable insulation, the more its behavior deviates from a pure capacitor. By measuring, grading, and comparing test results vs. ideal data, the quality of the insulation can be determined. Several methods employing this principle provide an overall, or global, assessment of the insulation over the entire cable length, detecting the presence of water trees, physical defects, and any conductive types of defects.

There are several methods of looking at the response of the insulation during its discharge. These tests all examine the polarization behavior of the insulation, due primarily to moisture content. However, since all three current modes (absorbtion, capacitive charging, & leakage) are present during the charging phase of an insulation test, the measure of absorption current is difficult since masked by the presence of the higher capacitive and leakage currents. The discharge phase of the test can more rapidly remove these effects, giving the possibility of interpreting the degree of polarization of the insulation and relating this to moisture and other polarization effects.

HIGH VOLTAGE TESTING MV CABLE

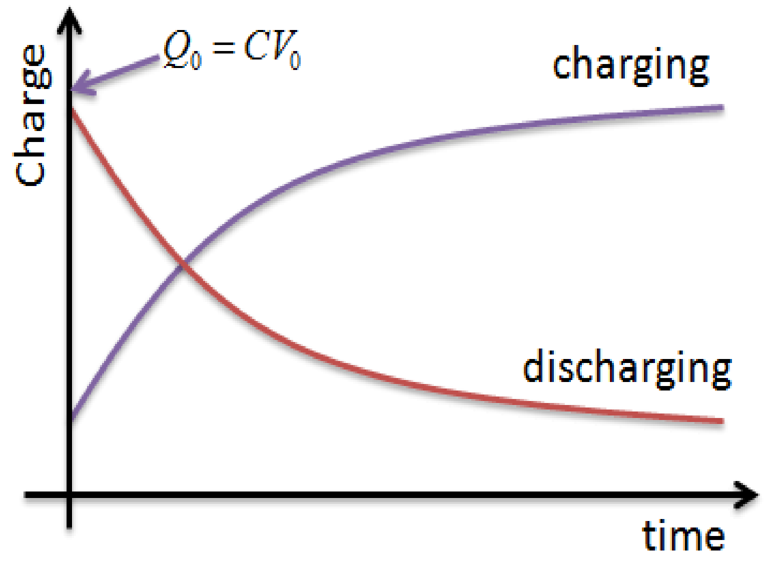
Test Method: Dielectric Response Analysis

Polarization/Depolarization – How good is the insulation?

- Measures and records polarizing and depolarizing current vs. time
- Compares the actual collected data with ideal data
- Also can be used to calculate **Polarization Index (PI)**
- Can compare new and aged insulation and trending over time
- Absolute values and time-based trending of data valuable

Various Methods Used

- Tan Delta/Dissipation Factor (*already covered*)
- Recovery Voltage
- Isothermal Relaxation Current (IRC)
- DC Leakage Current



HIGH VOLTAGE TESTING MV CABLE

Test Method: Dielectric Response Analysis

Recovery Voltage Method

This test is used to determine the level of water tree degradation and other impurities in extruded insulation. Like other cable insulation diagnostic tests, it relies on the known principles of the charging and discharging characteristics of capacitance, comparing the ideal behavior versus that of the tested cable.

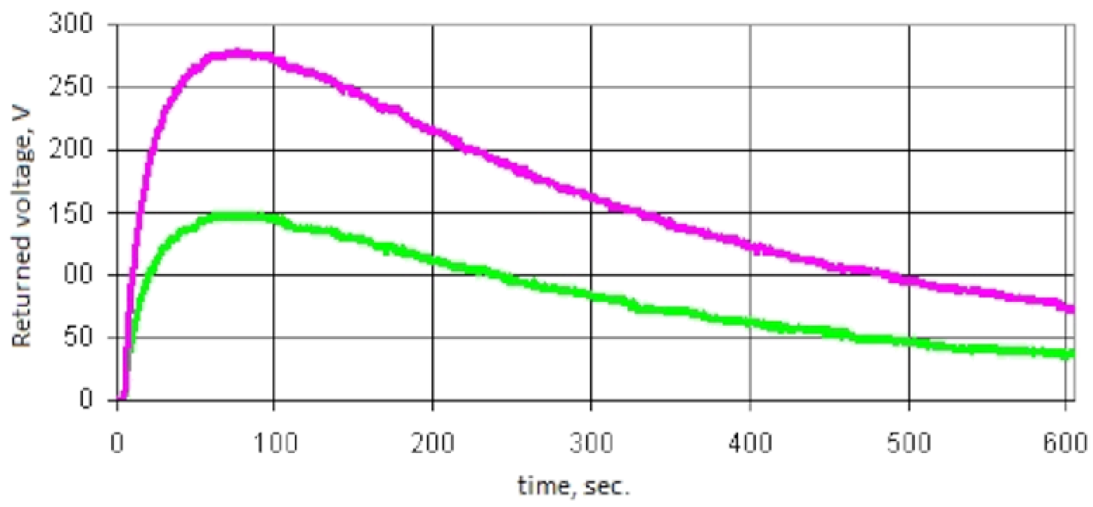
DC voltage is used to charge the cable. The cable is then discharged to ground through a resistor. The ground is lifted, and the cable rebuilds a charge. This rising open circuit voltage is recorded, graphed against time, and then compared to the charging wave shape of a perfect capacitor. The more imperfections in the insulation the more it will deviate from the ideal.

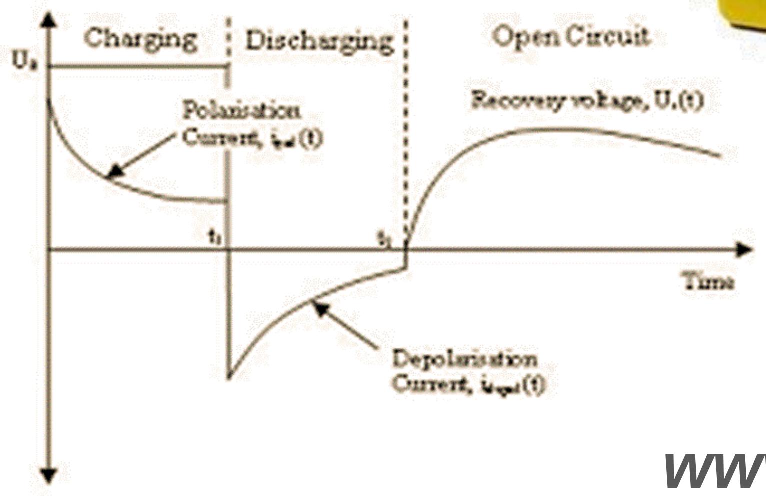
HIGH VOLTAGE TESTING MV CABLE

Test Method: Dielectric Response Analysis

Recovery Voltage Method

- Cable is charged with DC voltage for a short time
- Cable discharged with ground resistor then ground removed
- Open circuit voltage climb recorded & mapped versus time
- Curve shape data indicates moisture in PILC cables
- Curve shape data indicates water tree extent in solid dielectric





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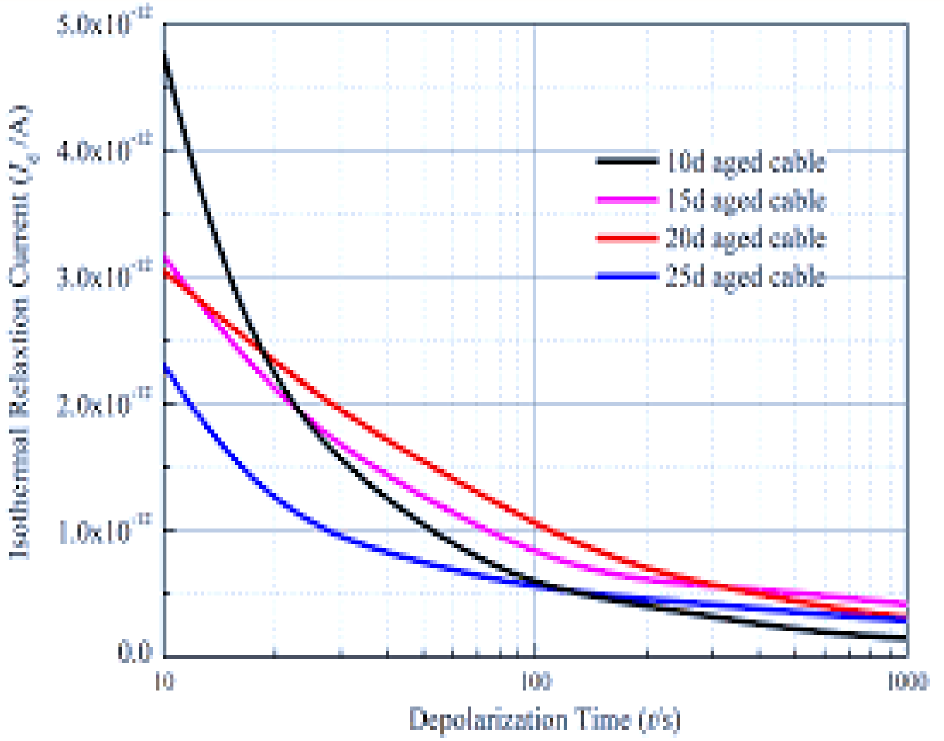
HIGH VOLTAGE TESTING MV CABLE

Test Method: Dielectric Response Analysis

Isothermal Relaxation Current IRC

IRC Analysis offers a non-destructive method of measuring and analyzing the degradation processes of polymeric composites. This diagnostic method provides a global statement about the quality of the insulation. It is based on the measurement of the depolarization current after previous charging with DC voltage. Different rates of relaxation current with respect to time are determined and represented in an IRC-Diagram. For the best results, it requires a reference value from the past to show the changes in the condition of the insulation.



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HIGH VOLTAGE TESTING MV CABLE

Test Method: Dielectric Response Analysis

Product of SebaKMT GMBH
Now owned by Megger

RVM & IRC COMBINED SYSTEM

The portable, combined system is used as a universal dielectric diagnostic system on PE/XLPE/EPR insulated cables and paper insulated cables. It combines the known methods of **Isothermal Relaxation Current** measurement (IRC-Analysis) and **Voltage Return Method** (RVM-Analysis) for aging and deterioration diagnostics. Due to the low charging voltage of the measurements, the system offers a non-destructive condition assessment valuation.

HIGH VOLTAGE TESTING MV CABLE

Test Method: Concentric Neutral Corrosion Testing

Tests While Cables Energized

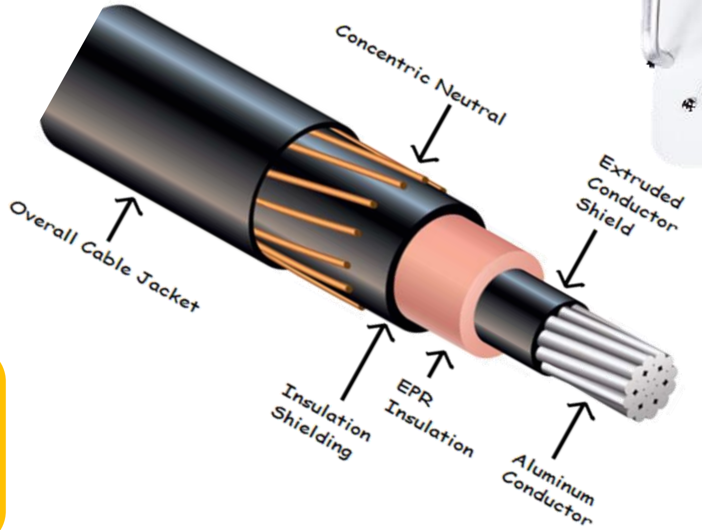
How are your Neutrals?

Measures Neutral Corrosion

Easy to Set Up

Easy to Operate

Easy to Interpret

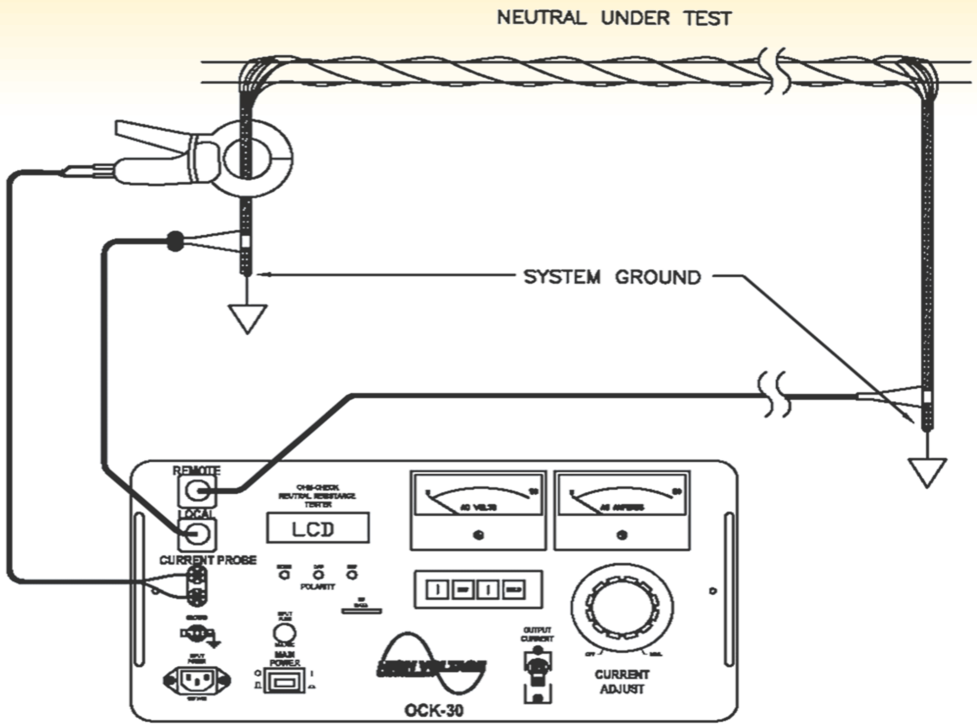


Ω-Check® Concentric Neutral Resistance Tester

Also Tests Substation Ground Cables
0 – 48 V up to 30 A

CONCENTRIC NEUTRAL CORROSION TESTING

How Many Neutral Strands Do You Have Left?



The HVI **Ω-CHECK®**

Test Neutrals With Cable Energized

Can you answer these questions?

How many neutral strands are open? Where is my return current going? Where is my fault current going? Why is my ground at elevated voltage?

Healthy neutrals are vital to the stability, reliability, and safety of any distribution or transmission system. All the above are definite problems if much of the concentric neutral is missing. Here are some of the potential problems if neutrals corrode:

- **Injecting or rejuvenating cables?** First measure the neutrals to insure enough remain before the effort & expense of injecting**.**
- **Partial Discharge or Tan Delta testing your cables?** What good are the results if your neutral is missing?
- **Unexplained voltage fluctuations and shock hazards** on metal fixtures or in swimming pools?
- **URD return currents paths** not going where they should, causing relay protection and control problems**?**
- **Severe shock hazards, fires, or explosions**? Fault currents jumping to other utilities or pipes?

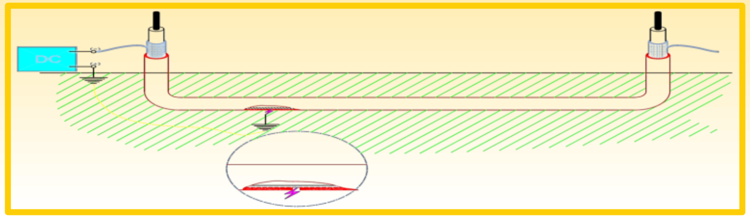
Don’t ignore the health of your neutrals. There is a way to conveniently measure the resistance of the neutral, compare it to what it should be, and display and store the results. It’s easy, quick, and economical.

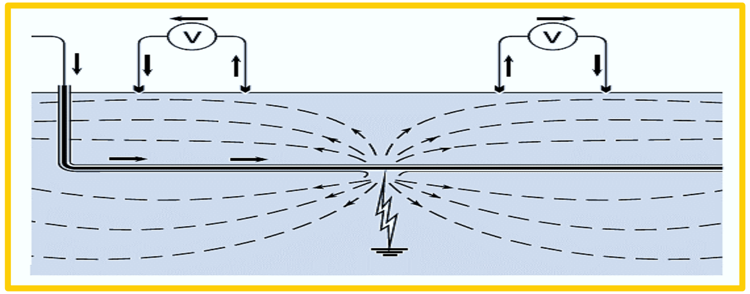
HIGH VOLTAGE TESTING MV CABLE

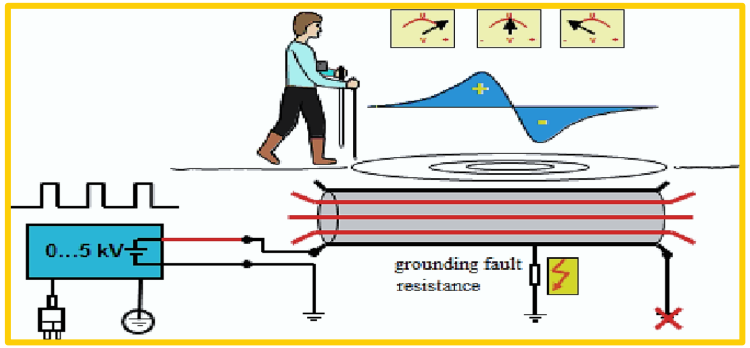
Test Method: SHEATH TESTING

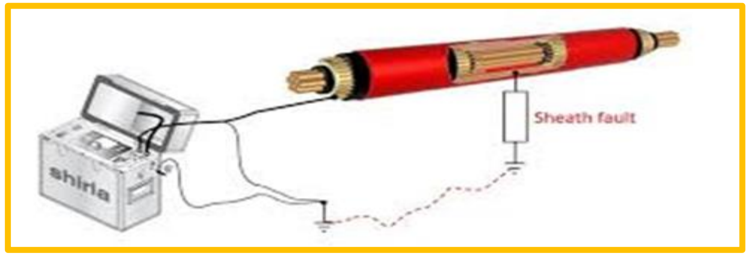
Sheath Testing is a high voltage test of the most outer Jacket, or Sheath, of the cable. This is the PE, PVC, or other material that protects the cable from water intrusion and other physical damage. It is needed to protect the metallic neutral shield from corrosion and is vital to the long-term health of the cable. Test it following installation to find any holes needing repairs.

Test Procedure: High voltage, usually up to 10 kVdc, is connected to the metallic shield of the cable. The Return and/or Ground of the tester is connected to earth ground near the cable. The voltage is applied. The leakage current meter is observed to monitor the mAdc level. If higher than expected, a possible opening in the sheath may exist. Any breach in the outer sheath will permit an electro-magnetic field to be discharged from the opening through the earth to the surface. Using above ground "pinpointing" or electro-magnetic detection devices, walk the cable to find the location where the stray E-M field is located.









HIGH VOLTAGE TESTING MV CABLE

Test Method: TIME DOMAIN REFLECTOMETRY (TDR)

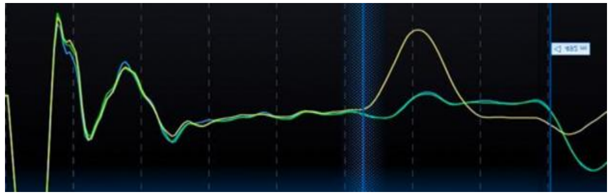
Used for Fault Location and Concentric Neutral Testing

Test Description

- Measures changes in the cable impedance as a function of circuit length by observing the pattern of wave reflections.
- Used to identify locations of accessories, faults, etc.

Field Application

- Offline test that uses a low voltage, high frequency pulse generator to send a “blip” down a cable and looks for reflections from impedance changes in the insulation.
- Used with “Thumper” to reflect signal off created arc to show location of fault.
- Used to examine continuity of concentric neutrals.



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HIGH VOLTAGE TESTING MV CABLE

REVIEW: DIAGNOSTIC TESTS PRESENTED

TECHNOLOGIES CURRENTLY CONSIDERED

- ❑ Dielectric Loss (Tan δ & Dielectric Spectroscopy)
- ❑ DC Voltage Hipot
- ❑ Insulation Resistance (IR) Test
- ❑ Online Partial Discharge (PD)
- ❑ Offline Partial Discharge (PD)
- ❑ VLF Monitored Withstand Tan Delta (MWTD)
- ❑ VLF Monitored Withstand Partial Discharge (MWPD)
- ❑ Isothermal Relaxation Current (IRC)
- ❑ Recovery Voltage (RV)
- ❑ Damped AC (DAC) – Oscillating Wave Tester
- ❑ Time Domain Reflectometry (TDR)

WIND FARM 35kV CABLES ARE IDEAL FOR VLF WITHSTAND TESTING

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!

HIGH VOLTAGE TESTING MV CABLE

Test Method: Cable Fault Locating

....and then come the cable faults, many cable faults!

What to do?

1. ID the faulted cable or cables
2. Find the faults: insulation & accessories
3. Fix the faults or replace what's bad
4. Over voltage test the repaired cable
5. Verify no other faults were created
6. Verify the adjacent cables are not harmed
7. Re-energize and maybe perform on-line tests
8. Clean and pull maintenance on the equipment

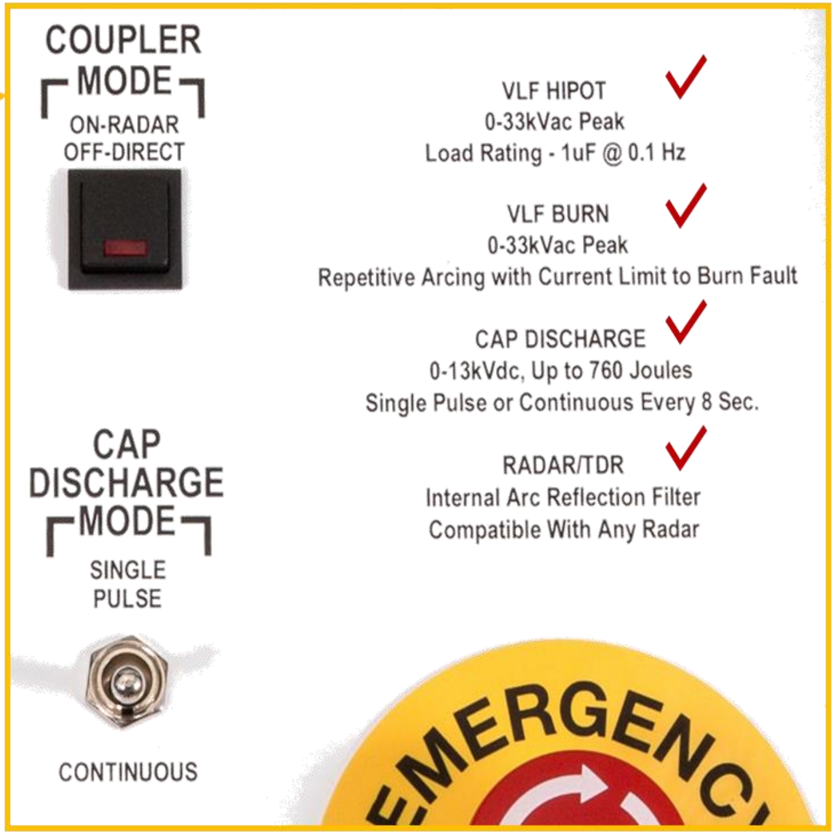
HIGH VOLTAGE TESTING MV CABLE

Test Method: Cable Fault Locating

Cable Fault Locating Equipment Often Doubles as Test Equipment

VLF/Thumper Combination – TDR/Radar Ready

All the Features Needed – Including **VLF Hipot** & **VLF Burn** ✓



Custom Made Van Package

Fault Locating & VLF Testing

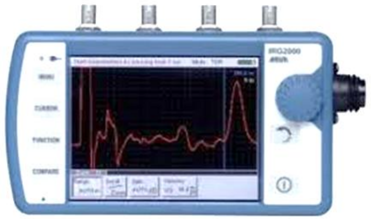
Includes

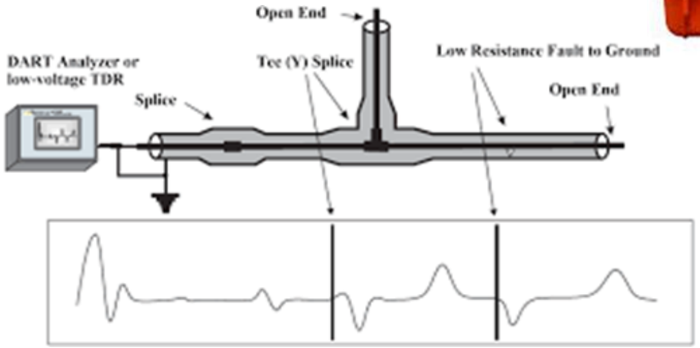
- Thumper: 36kV, 3200J
- TDR/Radar
- Listening Device
- VLF: 62 kV @ 5.5 uF
- Data Logger
- 2 Cable Reels, 100’
- Ready Mount Skid

HIGH VOLTAGE TESTING MV CABLE

Test Method: Cable Fault Locating

A few examples of Cable Fault Locators - TDRs - Pinpointing/Listening Devices





It's Your Fault – Fix It!

HIGH VOLTAGE TESTING MV CABLE

Test Method: Murray Loop/Wheatstone Bridge

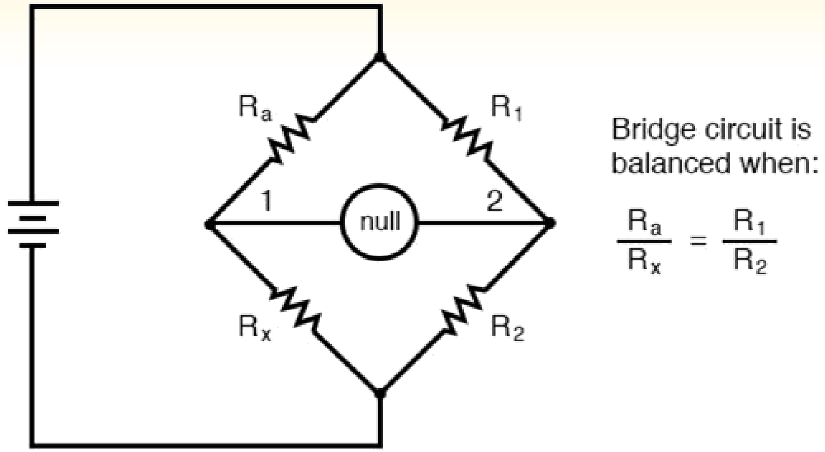
Test at Low Voltage for Shorts or High Voltage for Impedance Faults

The Murray loop test is a common and accurate method for locating underground cable faults. This employs the principle of a **Wheatstone Bridge** for fault location.

For **earth resistance faults**, a DC high voltage is applied to cause an arc at the faulted location, allowing sufficient current to flow to complete the circuit. The variable resistor is altered until the bridge is “balanced”, permitting the resistance ratios to be calculated and figure the distance to the fault.

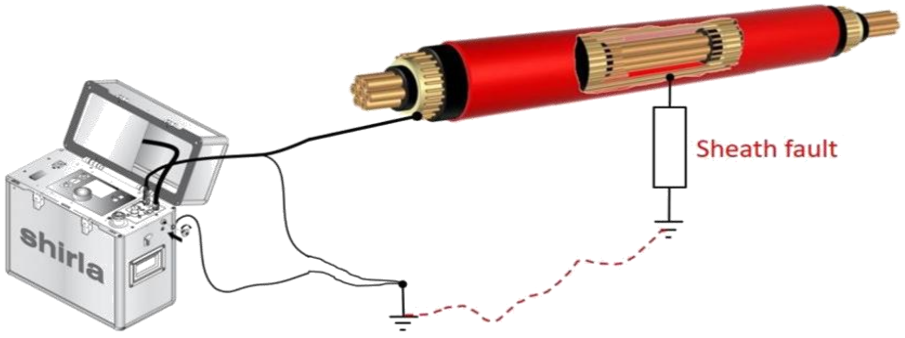
For **“dead shorts”,** low voltage output instruments can be used to provide adequate current flow to accurately measure the resistances needed to calculate the fault location.

Wheatstone Bridge Circuit

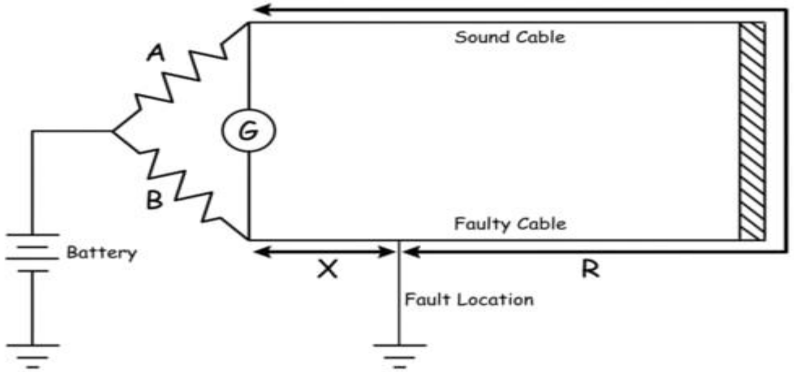


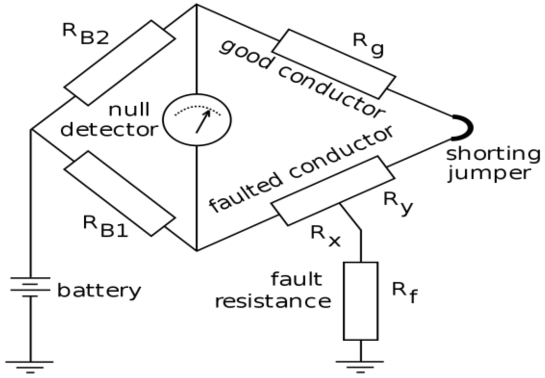
$$\frac{R_a}{R_x} = \frac{R_1}{R_2}$$

The *Shirla Sheath Test and Fault Location Device* from **Baur** uses the measuring bridge principle according to Murray and Glaser.



Two different representations





HIGH VOLTAGE TESTING MV CABLE

Common Methods for Factory & Field Testing

Most of the information presented here was original material prepared by HVI. Some of the technical descriptions were a composite of HVI material and that of others presented in the public domain. Many photos were of HVI products and from other vendors of high voltage test equipment. If you require additional information, please contact HVI. We are ready to help in any way we can.

Perhaps the best source for information covering all types of cable testing, especially VLF and related diagnostic testing of cables, is NEETRAC at Georgia Tech. http://www.neet rac.gatech.edu

Georgia Tech

NEETRAC

National Electric Energy Testing, Research and Applications Center

http://www.neetrac.gatech.edu

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High Voltage, Inc. • hvinc.com • p. 518.329.3275 • f. 518.329.3271 • 31 County Route 7A • Copake, NY 12516 USA