MOBILE SYSTEM FOR DIAGNOSIS OF HIGH VOLTAGE CABLES (132KV/220KV)
VLF-200 HVCD
VERY LOW FREQUENCY (VLF) - PARTIAL DISCHARGES AND TANGENT DELTA
HV/EHV POWER CABLES DIAGNOSTIC AND ON-SITE FIELD TESTING WITH VLF+PD+TD

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SUMMARY

The advantages of the utilization of VLF *(Very Low Frequency)* technology have positioned this testing mode to be the most efficient alternative for installation/maintenance tests and diagnosis of underground cables with thermo-plastic insulation. More than a dozen international regulations in force in Europe and the USA encompass and govern testing procedures in VLF.

Presented here is the first Mobile System with VLF (0.1 Hz) technology, for testing of applied voltage and of diagnosis by Partial Discharges/Tangent Delta, in HV and EHV cables (HV/EHV), known as **VLF-200 HVCD.** (HIGH VOLTAGE CABLE DIAGNOSTIX).

Developed and assembled in Argentina by **INDUCOR INGENIERIA S.A.,** in conjunction with its technology partners: **HIGH VOLTAGE Inc.** (USA), & **POWER DIAGNOSTIX SYSTEM** (Germany), the system has the capacity to perform diagnostic tests on the state of HV cables of up to 20 km of length, (3.75 uf of load), occasionally identifying, the laying sites which produce partial discharges (discharge map).

KEYWORDS

VLF Very Low Frequency - PD Partial Discharges - Outline (map) of PD - Tangent Delta.

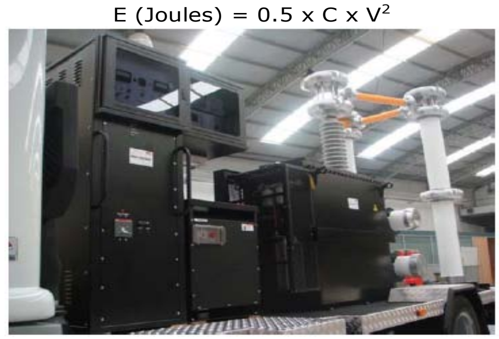
VLF TECHNOLOGY IN THE VLF-200 HVCD SYSTEM:

According to the definition of the IEEE, test equipment under the VLF system is any that can generate an alternating current signal, of a frequency on the order of 0.01Hz to 1Hz.

The principle of operation is achieved from a direct current, which, after being conditioned by an electromechanical/electronic system, goes on to form an alternation through a systematic process of loading and unloading of the cable under test.

It is clear that loading a cable with direct current is very easy and requires a low power source, but the main problem is in the intervals of discharge of substantial energy accumulated in said cable, according to the equation:

$$E \text{ (Joules)} = 0.5 \times C \times V^2$$



220 kv VLF-200 HVCD mobile unit, with Tangent Delta/Partial Discharge test capacity (INDUCOR INGENEIRIA S.A.)

This high energy variable at play, which must be dissipated two times per cycle, was one of the more complex parts to solve, especially when given such high voltages (220 kV), and large capacities, as those of extremely long cables(up to 20 km).
Taking the previous example, the maximum energy to be dissipated in a full cycle would be nothing less than:

$$E = 2 \times 0.5 \times 3.75 \times 10^{-6} \times 220{,}000^2 = 150 \text{ K Joules.}$$

INNOVATION OF THE VLF-200 HVCD SYSTEM:

The advantage of VLF test equipment, is that of approximating as far as possible a test performed with alternating current at the network frequency, but the substantial difference lies in the low power that is required in 0.1 Hz VLF mode, compared to the 50 Hz or 60 Hz. At 50 Hz, a cable of 3.75uf, tested at 220 kV of test voltage, would require 57 MVA of power (259 A), while at 0.1 Hz it would only require 0.52A. (114 KVA). The variable at play is the capacitive reactance.

Many breakdowns in underground cables are due to an inefficient execution of their splices, and for these cases, VLF has been shown to be an easy and safe method for maintaining confidence in the energy distribution systems.

Beyond detecting flaws, nowadays, the worldwide trend is based on early anticipation of an electrical accident, through the application of diagnostic techniques for cables and accessories , allowing control starting from their installation, the type of failure that they will have in the future, when they constitute an integral part of an underground layout, allowing for the analysis meter by meter of the state of degradation, whether it be increasing or stable.

VERSATILITY OF THE VLF-200 HVCD SYSTEM:

The new **VLF-200 HVCD** Mobile System allows for the testing series of applied voltage (withstand voltage//Withstand Test), in accordance with point 5.3 *VLF testing with sinusoidal waveform;* established according to:

IEEE Std 400.3™-2006
IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment.

As well as the diagnostic testing of the state (degradation), according to the provisions of:

IEEE Std 400.2™-2004
IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)

The latter include the partial discharge tests, in overall form, as well as in the tracing of the "Discharge Map," and those of Tangent Delta or Dissipation Factor.

1- APPLIED VOLTAGE TEST (Withstand Test)

The IEEE/EPRI/CEA agencies, and other worldwide engineering and standardization entities set test levels for cable dielectrics, from 1.5 to 3 times the Uo voltage, for a minimum of 15 minutes.

The update of the traditional IEC-60840-2004 rules, for A.C. testing, states in its *TEST VOLTAGE* section, that the level of test voltage for new cable systems must be between 1.7 Uo and 2 Uo, for cables between 30 kV and 150 kV nominal voltage.

While for higher voltage cables, the test voltage decreases from 1.4 Uo for those of (220-230 kV), to 1.3 Uo (275-345 kV), 1.2 Uo for (380-500 KV), and to only 1 Uo for those of 500 kV.

VLF-200 HVCD voltage/current control panel

Additionally, IEC-62067 specifies tests at 1.7 Uo/1 hour for all types of cables greater than 150 kV.
Both IEC standards accept tests at 1Uo/24hr. According to the rule, the user and the manufacturer of the cables may agree upon the test voltage and the testing procedure.

ACCORDING TO IEC, THE HIGHER THE NOMINAL VOLTAGE OF THE CABLE SYSTEM TO BE TESTED, THE LOWER THE COEFFICIENT OF THE VOLTAGE TEST

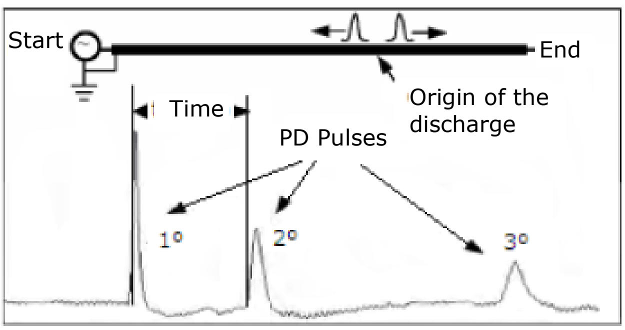
The **VLF-200 HVCD** Mobile System, enables alternating current testing of up to 20km of cables, with only 20 KVA of network power, and with a selectable frequency of 0.02 - 0.05 and 0.1 Hz.

2 – PARTIAL DISCHARGE TEST AND MAPPING

(Partial Discharge Test & Mapping)

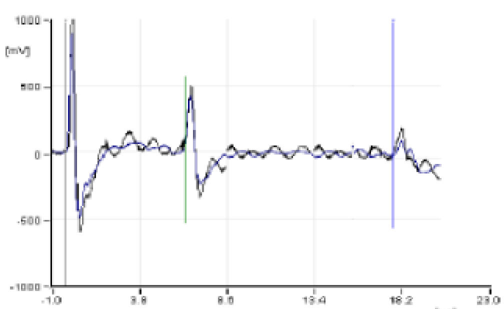
The new **VLF-200 HVCD** Mobile System, in its “DIAGNOSTIC” mode, goes beyond being able to quantify an “overall” value of the partial discharges of high-voltage wiring, according to IEC-60270, which would be of very little use because it could not identify which would be the accessory, splice, terminal or cable section that produces more of them, it also allows a tracing or mapping of partial discharges characteristic of a system of installed cables according to its length in meters (Coulombs-Peak vs. meter map).

The measurement principle for the tracing of this map, is based on SIGNAL REFLECTOMETRY. Once the PDs have been produced through the application of a test voltage (VLF in this case), they will travel toward both ends of the cable; being reflected in the terminals and producing a typical trace of three impulses for each discharge event.



Schematic reflectometry of a partial discharge signal

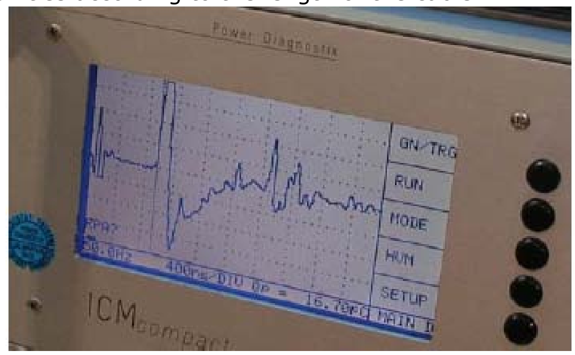
In this trace, the time between the first and the second impulse corresponds to the distance between the origin of the PD (location), and the final end of the cable; likewise, the time between the first and the third impulse reflects the time to move twice through the cable.



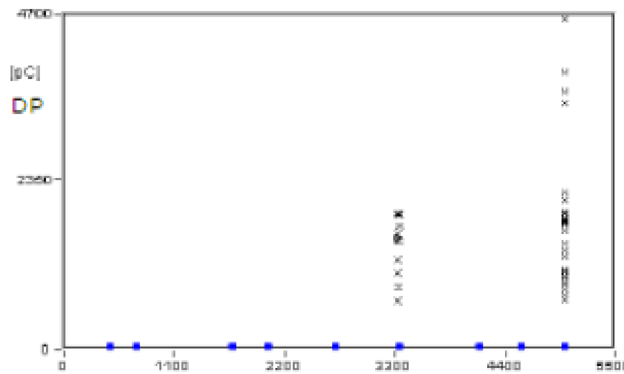
Schematic reflectometry of a partial discharge signal

A simple calculation determines the position (origin) of the discharge according to the length of the cable.

Based on the results of the location, the diagram of the PDs is that shown in the figure, which details the activities according to the length of the cable.



Comparing this diagram with the cable installation plan, and with positions of the existing splices (verified during the calibration), the defective points of the system can be identified.

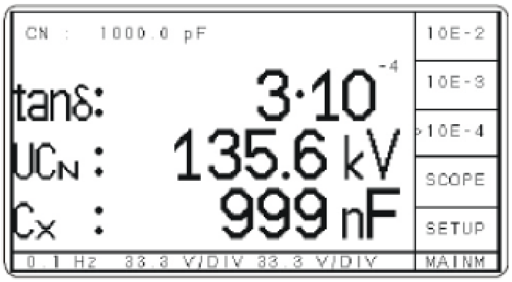


Map of the discharges

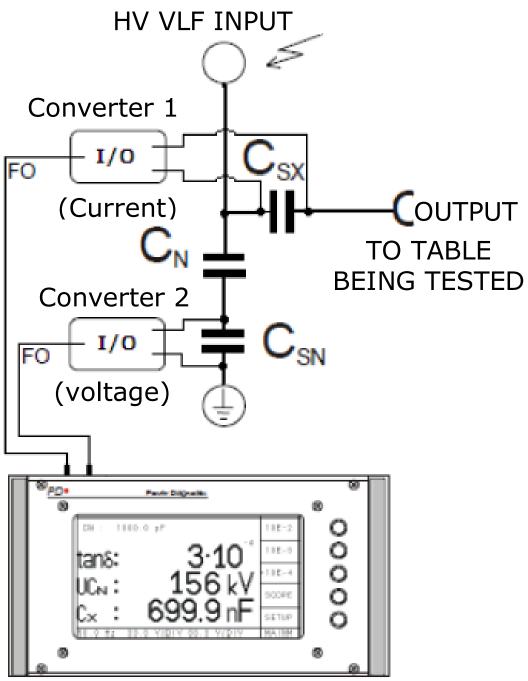
PD measurement panel of the **VLF-200 HVCD** system

3 - TANGENT DELTA TEST *(Dissipation Factor)*

In its “DIAGNOSTIC” mode, the new **VLF-200 HVCD** Mobile System also enables a Tangent Delta (Dissipation Factor) test, with a resolution of 1X10-$^{4.}$ according to IEEE Std 400.2™-2004.
Its LCD type screen graphically shows voltage and current waveforms The screen variables are C: Capacity; V: Applied Voltage, and the Cos φ of the display.



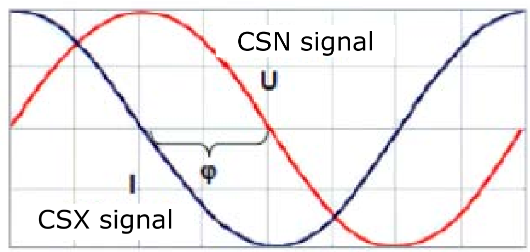
The Tangent Delta measurement system simultaneously accepts two current signals, one by means of a capacitive shunt in series with the sample **(CSX),** and another by means of a reference capacitor **(CN),** forming a voltage divider **(CSN)** , in parallel with the sample.



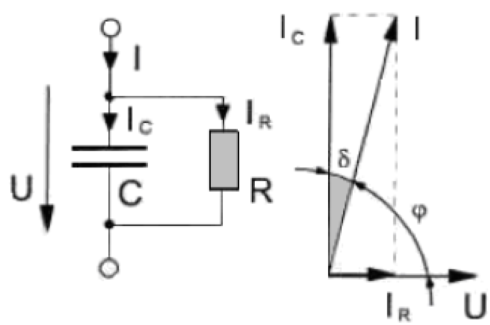
TD measurement diagram in the VLF200-HVCD system

Both signals are captured directly on the high voltage circuit. Then, two I/O converters transform these analog signals into optic signals and send them to the measurement hardware, to be evaluated by means of a microprocessor, finally obtaining the capacity/tangent/Cos φ results, all in relation to the applied VLF voltage.

During the graphic analysis, the current angular phase-shift between the voltage and the current waveforms corresponds to the angle φ situated as a complement of δ.



Technically, an insulating system is constructed with low loss materials, resulting in a small current Ir, in phase with the applied voltage. This current can be interpreted as a resistor **R i**n parallel with a capacity **C.**



Tang δ dissipation factor = IR / IC

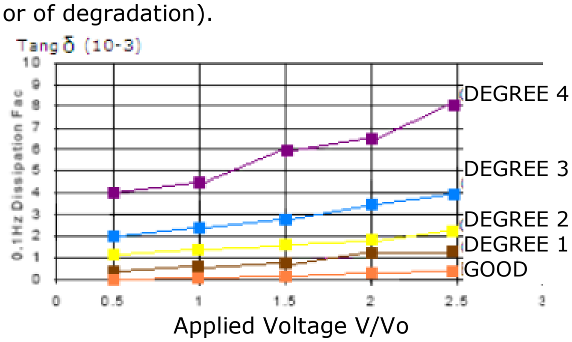
The phase difference between actual current **I,** and the ideal current **Ic,** is described as the angle δ. Given that P = Q - tang δ, the losses are therefore proportional to the tang δ, and yield an expression of the quality of the insulating material.
The angle δ is described as the loss angle, and the tan δ as the loss factor.

Applied particularly to a system of HV cables, the tang δ refers to the quality and evolution of the installed material as a whole (sole system composed of cable /terminals/splices).
As there are no prior tangent delta values establishing comparative initial parameters, (evolution of defects), the analysis of the result will be taken into consideration in the following two variables:
1- Comparison of results between the different phases of the same triad.
2- Stability of the tangent value in the face of increasing test voltage.

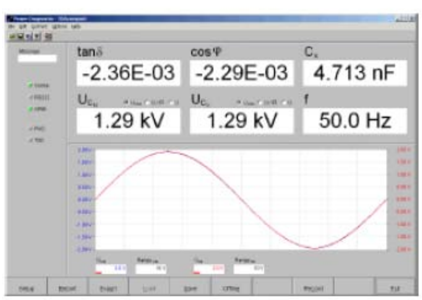
Acceptance criterion:
T δ @ 2 Uo < 1.2 ‰
T δ @2Uo -T δ @ Uo <≥ 0.6 ‰.

Rejection Criterion:
T δ @ 2 Uo ≥ 2.2 ‰
T δ @2Uo -T δ @ Uo ≥ 1.0 ‰

Degrees 1 to 4 indicate the aging *(aged condition)* of the cable system in ascending order (degree of deterioration or of degradation).



Then, powerful software makes it possible to graph and keep on the screen all the measured variables , both in real time and simultaneously.



VLF-200 HVCD mobile system during the conformance testing

Presentation of the VLF-200 HVCD mobile system at the BIEL 2009 show – Buenos Aires

CONCLUSIONS:

The **VLF-200 HVCD** Mobile System**,** with VLF sinusoidal technology, now makes it possible to perform installation and diagnostic tests on the state of HV / EHV underground cables, enabling precise measurements of the longest cable lays.

Given the need to forego direct current tests, due to the adverse effects that this produces on XLPE type insulation, the versatility of the **VLF-200 HVCD** Mobile System compared to conventional resonant equipment marks a fundamental difference in both dynamism and in diagnostic capacity.

SOURCE: **INDUCOR INGENIERIA S.A.**

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