VERY LOW FREQUENCY AC HIPOTS

A REVIEW OF VLF TESTING & ANSWERS
TO FREQUENCY ASKED QUESTIONS

VLF-28CM
0-28 kV @ 0.4 uF

VLF-4022CM
0-40 kV @ 5.5 uF

VLF-12011CMF
0-120 kV @ 5.5 uF

Models Available

VLF-28CM	0 – 28 kVAC, load rated to 0.4 uF
VLF-4022CM	0 – 40 kVAC, load rated to 5.5 uF
VLF-50CM	0 – 50 kVAC, load rated to 50 uF
VLF-6022CM	0 – 60 kVAC, load rated to 5.5 uF
VLF-65CM	0 – 65 kVAC, load rated to 22 uF
VLF-90CM	0 – 90 kVAC, load rated to 2.75 uF
VLF-12011CMF	0 - 120 kVAC, load rated to 5.5 uF
VLF-200CMF	0 - 200 kVAC, load rated to 3.75 uF
VT33	VLF/Thumper Combination 33 kV VLF rated 1uf @ 0.1Hz Capacitor Discharge 13kV @ 760 joules

High Voltage, Inc.

31 County Rt. 7A Copake, NY 12516 Tel: 518-329-3275 Fax: 518-329-3271

Email: sales@hvinc.com Web: www.hvinc.com

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This paper is written to answer the many questions concerning VLF AC Hipots and their applications. It is not written to make the argument for VLF AC cable testing versus DC. That case has been made for over 10 years, with near unanimous worldwide consensus that DC testing is not only damaging to solid dielectric cable insulation but is also an ineffective means of determining the insulation quality of a cable. There is good reason why most utilities worldwide have stopped DC testing and are using VLF withstand and/or VLF Partial Discharge and/or VLF Tan Delta testing.

What is VLF?

VLF stands for **V**ery **L**ow **F**requency. VLF is generally considered to be 0.1 Hz and lower.

Many people assign too much mystery to VLF testing. A VLF hipot, and VLF testing, is very simple. It's just an AC hipot but with a lower frequency output. We have all used AC hipots for decades to test various types of equipment. Now they can be used for field testing cable and rotating machinery.

Where is VLF used?

VLF testing is used for any application requiring AC testing of high capacitance loads. The major application is for testing solid dielectric cable (per IEEE400.2), followed by testing large rotating machinery (per IEEE 433-1974), and occasionally for testing large insulators, arrestors, and the like.

Even if a utility doesn't adopt VLF for widespread cable testing, one of the best reasons to use VLF is to check installation quality and accessories, like splices. Many failures are due to damage during installation, improper workmanship, and/or insulation damage caused by excessive voltage fault locating - thumping. At the very least, every newly installed or repaired cable should be VLF tested before re-energizing.

What VLF hipots are available?

High Voltage, Inc. produces VLF hipots from 28 kV up to 200 kV, the widest range in the industry. Load ratings are available from 0.4 uF to 50 uF, representing approximately 3000' to 40 miles of cable.

Why 0.1 Hz?

The only way to field test high capacitance loads, like cables and motors/generators, with AC voltage, is to use a VLF AC hipot. The lower the frequency, the less current and power needed to test high capacitance loads.

X_c (capacitive reactance) = $1/2\pi fC$. A 10,000' 15 kV cable has approximately 1uF of capacitance. The capacitive reactance at 60 Hz is 2650 ohms. To apply the IEEE recommended 22kV test voltage, it would require a power supply rated for 8.3 amps, or 183kVA. Obviously not practical for field use.

At 0.1 Hz, the capacitive reactance is 1.6 megohms. The same 22kV would draw only 14mA, or only .302kVA, or 600 times less than at 60 Hz. At 0.01 Hz, a cable 6000 times longer can be tested than at 60 Hz.

Put another way, at 60Hz a cable must be charged to its test voltage every 4.2 milliseconds, 0 – 90 degrees of the waveform. It takes a lot of power to charge a cable that fast. At 0.1Hz, 2.5 seconds are available to charge the cable. It takes 600 times less power than 60Hz. 500 times less than at 50 Hz.

Is 0.1 Hz still AC?

Yes. The wave shape of the HVI VLF design is sinusoidal with polarity reversals every half cycle. Frequencies as low as 0.01 Hz are recognized in the IEEE400.2 standard.

How do you do the test?

The test is very simple. With the cable to be tested isolated, connect the high voltage output lead of the VLF to the conductor and ground the shield. Like any hipot, apply the test voltage for the required duration.

What's the test voltage and for how long?

The IEEE400.2 standard recommends testing at 3 times (3Vo) the normal line-to-ground voltage for 30 – 60 minutes. The European standard mandates 3Vo for 60 minutes. For a 15 kV cable, the maintenance test is usually performed at 22 kV peak. A 25 kV system is tested up to 33 kV and a 35 kV cable system is VLF tested up to 60 kV. Results from over 20,000 cable tests show that if a cable passes a proper VLF test, it has a better than 95% chance of avoiding an in-service failure for the next several years.

Different VLF units output different waveforms. What's best?

All High Voltage, Inc. VLF units produce a sine wave output. The original German designs, which are still offered, do not produce a sine wave output. They produce a trapezoidal waveform. They often try to claim that it's superior to the sine wave: a very tough argument to make. How can any engineer argue with a sine wave output? Their waveform does work well to VLF hipot cable, however, it is not as usable as a voltage source for Tan Delta and Partial Discharge testing. For a VLF unit to be used for diagnostic testing, either Tan Delta of Partial Discharge, it should produce a sine wave. The IEEE recognizes the sine wave output as advantageous and mandates it when the VLF unit is used for testing rotating machinery. Stick with a sine wave design to keep your future diagnostic testing options open.

Is the VLF test destructive?

VLF hipoting is not destructive to good insulation and does not lead to premature failures like with DC voltage testing. Using VLF does not cause degradation of the insulation. It does cause existing cable defects, like water trees and weak splices that are severe enough to be triggered into partial discharge under the test voltage, to break through during the test. Minor defects that are not triggered into pd from the test voltage are unaffected. If a cable can't hold 2 – 3 times normal voltage, it is not a good situation. Cause failure at defect locations during a controlled outage or prior to energizing newly installed or repaired cables, find the fault, make the repair, and be left with a good cable. It is AC voltage; what the cable is designed for and experiences during service. Cable is factory tested with AC voltage at levels far higher than the field test.

When people talk of VLF testing being destructive, it is only destructive in that a defective cable or splice may fail under test, which is the intent of the test. It is not destructive to good insulation or defects small enough to be unaffected by the test voltage. How can any engineer doubt the efficacy and effectiveness of testing a cable designed to carry AC voltage with AC voltage?

But my cable might fail during the test

Precisely. That is the point of VLF testing. It is not a diagnostic test. It is an AC stress test. There are no leakage current readings to take. (DC leakage currents tell little about the cable quality.) A cable either holds the test voltage or fails. If a cable can't hold 2 – 3 times normal voltage, it's not going to last long. You want it to fail during the test, when you are ready to repair or replace it.

Who endorses VLF?

Nearly every applicable engineering body in the world, cable producers, and the hundreds of utilities worldwide that use the over 1000 VLF units shipped by HVI and others over the past 10 years. EPRI, IEEE, CEA, other country's engineering organizations, nearly every cable manufacturer, and many utilities throughout the world have embraced the effectiveness of VLF testing. German VLF test standards (DIN-VDE Standard 0276-620 & 0276-1001) have existed for many years and the IEEE has released a VLF specific cable testing standard - IEEE 400.2. IEEE433 for VLF testing of rotating machinery has existed for over 30 years.

Why hasn't VLF been more widely used?

VLF is not new. It dates back to the 60's for generator testing. The reason it has not been widely used for more than 7 - 8 years is because only in the last 8 – 10 years has it been confirmed that DC voltage testing damages solid dielectric cable and is an ineffective means of determining insulation quality. Also, the original and current European designed VLF units were and are large, heavy, expensive, and some do not produce the desired sine wave output. It was not until High Voltage, Inc. developed the first line of truly portable, inexpensive, and sine wave producing units that it became feasible and economical to VLF test in the field. Over 800 HVI VLF units have been shipped worldwide since 1998, with thousands to follow.

What are the alternatives to VLF testing cables?

Not much when you consider the available technologies and weigh the costs of each. DC should no longer be used since it damages cable insulation and tells little about the cable insulation quality. Recognizing the problems associated with DC testing, many utilities have reduced their test voltages from 45 – 50 kVDC to 15 kVDC on 15 kV cable. 15 kVDC is barely above the peak AC stress a cable experiences in service and far below the twice normal voltage frequently experienced due to transients. The test is not meaningful. Even less meaningful is a megohmmeter test or a 24 hour soak test. Some testing should be done; it's just a matter of balancing the cost of equipment, ease in use, and definitiveness in the results.

Some have developed off-line partial discharge detection methods for field-testing cable insulation, with the goal being to determine the insulation quality and location of defects without risking failure during the test. This method can work well in some circumstances but is very expensive and often interpretive in its results. HVI intends to offer this method of cable diagnostic as well as other methods. Some offer on-line partial discharge detection. Although this method does work when done properly, it misses those instances where the pd inception voltage is above the nominal operating voltage while the pd extinction voltage is below; a common occurrence.

Tan Delta, or dissipation factor (analogous to power factor), testing is performed, where a VLF unit is used to energize the cable and loss readings are measured. This method works well, so long as there are few splices, joints, etc. along the cable run and there is only one type of cable under test, which is usually not the case since many cable runs are of mixed cable types, all with a different loss factor. This method is easy to perform with minimal training and allows users to grade their cables' level of deterioration. If done properly, it is a non-destructive diagnostic test. Tan Delta testing is an excellent method for prioritizing cable replacement or injection. High Voltage, Inc. does offer Tan Delta.

DC, VLF, PD, TD, and other more esoteric methods all have their place. The best route is to use a combination of VLF, PD, and TD testing. However, the PD is very expensive and limited in its accuracy. The Tan Delta is easy to perform but limited in its applications. The VLF is a go/no-go test, not diagnostic, but there is no better way to verify a cable's AC integrity and locate the faults for repair.

The surest way to weed out bad cables and accessories is to just perform a simple AC hipot test, just like we do with vacuum bottles, arrestors, hot sticks, switchgear bus and insulators, etc. Yes the cable may fail under test if it has a severe defect, but that's the point of the test. If a cable can't withstand two to three times normal voltage for 30+ minutes, it's bound to soon fail. Fail it when convenient, rather than waiting for it to fail on its own, often at the worst possible time.

Summary

A utility faces the choice of how to test their underground cable. Many do nothing and let cables fail, resulting in necessary emergency repairs, adjacent cables damaged, annoyed customers, and loss of consumption revenue: not a good practice. Many have embraced VLF testing to weed out bad cables and accessories with great results. Hundreds more will over the coming years. **At the very least, every utility should test their important feeder runs, substation cables, cables to critical customers, and everything newly installed or repaired.** Add partial discharge and tan delta to your VLF package and cover all the bases.