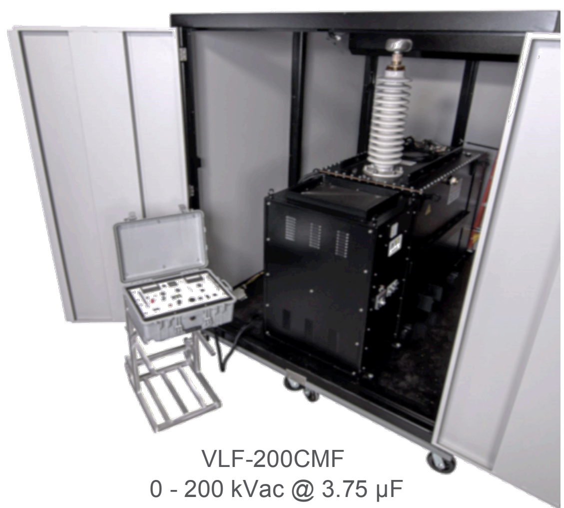
VERY LOW FREQUENCY (VLF) AC TECHNOLOGY

VLF Overview & Answers to Frequently Asked Questions

VLF-34E & VLF-65E with TD-65E
Solid State, Programmable, Wireless
0-34 kV ac and 0-65 kV ac

VLF-6022CMF VLF-90CMF VLF-12011CMF

VLF-65E Front Panel



VLF-200CMF
0 - 200 kVac @ 3.75 µF

This paper is written to answer the many questions concerning Very Low Frequency 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 20 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 and industrial/commercial applications worldwide have stopped DC testing and instead perform VLF AC Withstand, VLF Partial Discharge, and/or VLF Tan Delta testing.

What is VLF?

VLF is the abbreviation, and commonly used name, for Very Low Frequency. VLF AC hipots produce a frequency output of 0.1 Hz and lower rather than the conventional 50 Hz or 60 Hz. VLF technology was developed for a specific reason, to more easily high voltage field test certain loads of high capacitance normally requiring very high current and power to test at the traditional power frequencies of 50 Hz. or 60 Hz. The primary applications for VLF testing are MV & HV cables and rotating machinery.

Why 0.1 Hz?

When using AC high voltage to test a load, the lower the frequency of the applied voltage the lower the current and power required. The easiest and most economical way to AC high voltage field test high capacitance loads, like cables and motors/generators, is to use a VLF AC hipot. A frequency of 0.1 Hz. was selected long ago as the standard frequency to be used for VLF testing. World standards permit, and most VLF instruments deliver, output frequencies of 0.1 Hz. - 0.01 Hz. For cable testing, 0.1 Hz – 0.01 Hz. is permitted, although 0.1 Hz. and 0.05 Hz. are preferred for use. For motor and generator coil testing, 0.1 Hz. is required.

What is the math behind VLF testing?

There is no mystery to VLF technology. It conforms to basic physics and established principles of electricity. The most elemental equation governing the laws of electricity is Ohm's Law: I = V/R. The higher the denominator R (resistance), the lower the I (current) when a V (voltage) is applied. In AC circuits, the load is mostly capacitive. That means that the R of a circuit is directly proportional to its operating frequency. R is the Capacitive Reactance Xc, and calculated using 1/□C, □ = 2πf and C is the fixed capacitance of the load. Xc (capacitive reactance) = 1/2πfC.

Example: A 15 kV cable 5,000' (1500 m) long has approximately 0.5 μF of capacitance. At 60 Hz. the capacitive reactance is 5300 ohms. At a common test voltage of 22 kVac rms, it would require a power supply rated for 4.2 amps, or 91 kVA. A very large and expensive test set; not very practical for field use.

At 0.1 Hz. the capacitive reactance is 3.2 megohms. The same 22 kV rms test would draw 7 mA, or .154 kVA, 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 60 Hz. a cable must be charged to its test voltage every 4.2 milliseconds: 0 – 90° (the peak) of the waveform. At 0.1 Hz, 0 – 90° takes 2.5 seconds, permitting 600x more time to charge the cable, requiring a far less powerful voltage source.

Is 0.1 Hz still AC?

Yes. The wave shape of the HVI VLF design is sinusoidal with polarity reversals every half cycle, only at a slower rate than 60 Hz. Frequencies as low as 0.01 Hz are recognized in the IEEE 400.2-2013 standard as useable for cable testing, although typically 0.1 Hz. – 0.05 Hz. are preferred. VLF is not DC, where a monopolar negative polarity is applied to the load for long periods of time, which causes space charges to develop within the insulation through a polarizing dipole effect on the molecules and a stored energy to develop within the load. Again, VLF is an AC (alternating current) voltage, sinusoidal with conventional polarity reversals every half cycle.

Where is VLF used?

VLF testing is principally used for two applications: AC field testing medium and high voltage cable and testing rotating machinery - motor and generator coils. These two applications are defined and sanctioned by several world standards, including IEEE 400.2-2013 for cable testing and IEEE 433-2012 for testing rotating machinery. VLF can be used for testing other high capacitance loads like large insulators, arrestors, bus duct, etc. but no recognized standards yet exist.

One of the best applications for the use of VLF is to check installation quality of cable and accessories. Many in-service failures are due to damage to cable during its installation, improper workmanship, faulty materials, etc. These in-service failures can be prevented by VLF Acceptance testing after installation and after every cable fault repaired. For motors and generators, producers of these products must factory test their coils with 50/60 Hz. power frequency AC Dielectric test sets, or hipots. However, rewind and repair shops and field maintenance testing can use VLF, and should, due to the size, weight, and price advantage over the use of prohibitively large, heavy, expensive, and difficult to set up 50/60 Hz. hipots.

What VLF hipots are available?

HVI produces VLF hipots that produce from 30 kVac up to 200 kVac with load ratings from 0.4 μF to 50 μF, the equivalent capacitance ratings of cable approximately 3000' (914 m) to 40 miles (64 km) in length and can test the largest of generator coils. Both manual controlled, conventional oil cooled designs with analog controls (knobs, meters, switches, etc.), and fully programmable, automatic, wireless, PC controlled solid state designs are available.

How do you do the test?

The test is very simple. With the cable to be tested isolated from any voltage source, connect the high voltage output lead of the VLF to the conductor and a common ground to the shield. Like any hipot, apply the test voltage for the required duration. A basic withstand test is that easy. Other diagnostic tests, yet to be described, are a little more complicated.

What's the test voltage and for how long?

The IEEE 400.2-2013 standard offers precise test voltages for medium voltage and some high voltage cable. (Generally, the test voltages are approximately 1.7 - 3 times (1.7 Uo - 3 Uo) the normal line-to-ground voltage for 30 – 60 minutes, with the multiple number depending on the voltage rating and thickness of the cable insulation.) A chart of the test voltages is below. The European standard mandates 3 Uo rms for 60 minutes for any cable. This test voltage standard is a holdover from the earlier standards when testing at 50 Hz with a sinusoidal waveform. It does not account for the cosine-rectangular waveform, where rms and peak are equal, of the VLF design of the time. It should be adjusted to recognize the differences between rms and peak voltages.) Other countries have also written VLF standards.

For a 15 kV cable, the Maintenance test is usually performed at 22 kVac peak and the Acceptance test voltage is 30 kVac peak. A 35 kV cable is Maintenance tested at 47 kVac peak and Acceptance tested at 62 kVac. The standard includes cables rated to 69 kV, although 200 kVac peak VLF units are available for testing cables rated up to 150 kVac.

IEEE Std. 400.2-2013 VLF Test Voltage for Sinusoidal Waveform

CABLE RATING phase to phase kV rms voltage	INSTALLATION phase to ground peak voltage	ACCEPTANCE phase to ground peak voltage	MAINTENANCE phase to ground peak voltage
5	13	14	10
8	16	18	14
15	27	30	22
25	41	45	34
35	55	62	47
46	72	81	61
69	106	119	89

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

All HVI VLF units, and most others, produce a sine wave output. The original European designs, which are still offered, do not produce a sine wave output. They produce a trapezoidal, or cosine-rectangular, waveform. The cosine-rectangular waveform works well to VLF hipot cable; however, it is not as usable as a sinusoidal design 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 VLF 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 DC voltage testing. Using VLF does not cause degradation of good insulation nor aggravate defects too small to be triggered into PD under the test voltage. It does cause existing cable defects that are severe enough to be triggered into partial discharge under the test voltage, to break through, or fail, 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 operating voltage, it is not a reliable cable. 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 levels.

Could my cable fail during the test?

Yes, that is the point of AC Withstand testing. It is not a diagnostic test. It is an over voltage AC stress test, or proof/pressure test. There are no leakage current readings to measure. A cable either holds the test voltage or fails. If this method of testing is not acceptable, there are diagnostic tests that can be performed that nearly eliminate the chance of cable failure during the test. These tests allow the user to learn something of the cable insulation rather than possibly cause a failure during the test. See the Tan Delta and Partial Discharge sections of this FAQ.

Who endorses VLF?

Nearly every applicable engineering body in the world, cable producers, and the hundreds of utilities worldwide that use the over 6000 VLF units shipped by HVI and others over the past 20 years. EPRI, IEEE, IEC, CEA, VDE, other countries 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 an updated VLF specific cable testing standard - IEEE 400.2-2013. IEEE 433-2012 for VLF testing of rotating machinery has existed for over 40 years, originally released in 1974.

What are the alternatives to VLF Withstand testing cables?

Not many, when you consider the available technologies and weigh the costs, effectiveness, ease of use, and other factors. A 50/60 Hz. power frequency AC Withstand test is not usually an option, as described earlier. Certainly DC should no longer be used since it leads to future cable failures and tells little about the cables insulation and accessories quality. (One can reduce the DC test voltage, but then the test is even less meaningful. A 5 kVdc megohmmeter IR test on a 15 kV cable that operates at over 10 kVac peak stress when in service reveals little or nothing about a cable's quality, nor does a 24 hour no load on-line soak test.) There are several "diagnostic" tests possible, but many are experimental, esoteric in their theory and design, and not economically feasible; except for off-line Tan Delta and Partial Discharge testing, described below.

What are some VLF Diagnostic testing methods?

There are times when a go/no-go, or pass/fail Withstand test is not suitable. We would rather learn something about the health of the cable system without risk of failure during the test; a test that measures the quality, or integrity, of the insulation and its expected life is preferred. A VLF hipot can be, and often is, used as a variable voltage source to apply an overvoltage to the test object while various measurements and observations are made about the insulation quality.

Two common methods of using VLF technology to perform off-line elevated voltage diagnostic, or non-destructive, testing on cables and rotating machinery are Tangent Delta and Partial Discharge. Both use a VLF instrument to apply a variable voltage to the load while diagnostic measurements are taken. Based on these measurements, the voltage can be raised up to perhaps 1.7 Uo to 2.0 Uo the normal operating voltage, but only for very brief periods, perhaps only seconds. From the data gathered, judgments can be made as to the integrity and expected life of the insulation.

Tan Delta, or Tan δ, Dissipation Factor (analogous to power factor), testing is performed to provide an overall assessment of the integrity of the insulation, usually compared to the ideal or to many other tests to prioritize where replacement, repair, or rejuvenation money should be spent. This method works well, is easy to perform with minimal training, and is relatively easy to interpret results. TD testing is a very common test performed by many.

Partial Discharge testing exposes specific locations and severity of troublesome electrical discharges along a cable path or the overall electrical noise (PD) within a coil. PD testing is more difficult to perform and interpret than Tan Delta and is more expensive. However, both are valid but reveal very different data sets. PD testing is commonly performed on cables, substation apparatus, and other gear but at 50/60 Hz. PD testing cables and generator coils using 0.1 Hz. is a newer technology but no less possible or reliable than at power frequency.

The surest way to weed out bad cables and accessories is to perform a simple, over voltage AC hipot test, just like we do with vacuum bottles, arrestors, hot sticks, switchgear bus, 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 2 - 3 times its normal voltage for 30+ minutes, it's bound to soon fail. Cause failure when convenient to repair, rather than waiting for an in-service failure to occur at the worst possible time. If preferred, VLF voltage sources can be used to perform non-destructive diagnostic testing, like the Tan Delta/Power Factor and Partial Discharge methods described earlier.

Summary

Very Low Frequency technology is readily available and has been used for decades to AC voltage test cables and rotating machinery in the field, never before practical, nor even possible in many cases. IEEE, IEC, and other Standards exist to define the testing and interpretation of results. Overvoltage AC Withstand and Diagnostic testing methods are readily available in voltages up to 200 kVac peak from several vendors worldwide.

Still have questions? Please contact High Voltage, Inc.

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