



VLF AC Withstand Testing of Cable

Test Voltages & Time Durations for VLF Cable Testing per IEEE 400.2-2023

No Testing “Rules of Thumb” to use. Below numbers result from decades of research & field use

Testing Methodology: When VLF Withstand testing cable, the proper test voltage and time duration are critical for the success of the test. If a VLF test is too low in voltage and/or too short in duration, more harm than good may result. **Test as the standards dictate to make best use of VLF technology.** If the test voltage initiates partial discharge in a defect, enough time must pass to permit the PD created electrical tree to grow to failure. The test voltage and time duration are both critical to causing failures at **defect locations severe enough to be triggered into PD** during the test. **Lesser defects are not affected, as they remain dormant and not aggravated by the test voltage.** VLF Withstand and Diagnostic testing does not harm “good” insulation.

The following information is taken directly from the IEEE 400.2-2023 Standard. Shading of some columns was added, indicating the **peak** values of the VLF test voltage, the most commonly used unit of measure.

IEEE Std. 400.2-2023

IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

Table 3 - VLF withstand test voltages for sinusoidal and cosine-rectangular waveforms (see Note 1)

WAVEFORM	Cable system rating (phase to phase) [kV]	Installation (phase to ground)		Acceptance (phase to ground)		Maintenance2 (phase to ground) (see Note 2)	
		[kV RMS]	[kV PEAK]	[kV RMS]	[kV PEAK]	[kV RMS]	[kV PEAK]
Sinusoidal	5	9	13	10	14	7	10
	8	11	16	13	18	10	14
	15	19	27	21	30	16	22
	20	24 (Note 3)	34 (Note 3)	26	37	20	28
	25	29 (Note 3)	41 (Note 3)	32	45	24 (Note 3)	34 (Note 3)
	28	32	45	36 (Note 3)	51 (Note 3)	27	38
	30	34	48	38	54	29 (Note 3)	41
	35	39	55	44	62	33	47
	46	51	72	57	81	43	61
	69	75	106	84	119	63	89
	115	125 (Note 4)	176 (Note 4)	140 (Note 4)	198 (Note 4)	105 (Note 4)	148 (Note 4)
	138	150 (Note 4)	212 (Note 4)	168 (Note 4)	238 (Note 4)	126 (Note 4)	178 (Note 4)

NOTE 1 - If the operating voltage is a voltage class lower than the rated voltage of the cable, it is recommended that the **maintenance** test voltages should be those corresponding to the operating voltage class.

NOTE 2 - The maintenance voltage is about 75% of the acceptance test voltage magnitude.

NOTE 3 - Some existing test sets have a maximum voltage that is up to 5% below the values listed in the table. These test sets are acceptable to be used. However, there is a risk that the cable may be “undertested” due to a combination of lower test voltage and allowed uncertainty of the measuring circuit.

NOTE 4 - Voltage Levels are based upon current practice where the relative test voltages decrease as the cable rating increases to compensate for the changes in design stress for HV vs MV cables. Considering typical cable designs the stresses at test voltages for HV cables are more than twice those for MV cables. Lower voltages levels may be used upon agreement with the circuit owner.



5.1 General VLF ac withstand voltage testing

5.1.1 VLF ac withstand voltage test parameters

The purpose of a withstand test is to verify the integrity of the cable under test. If the test cable has a defect severe enough at the withstand test voltage, an electrical tree will initiate and grow in the insulation. Inception of an electrical tree and channel growth time are functions of several factors including test voltage, source frequency and amplitude, and the geometry of the defect. For an electrical tree from the tip of a needle in PE insulation in laboratory conditions to completely penetrate the insulation during the test duration, VLF ac voltage test levels and testing time durations have been established for the two most commonly used test voltage sources, the cosine-rectangular and the sinusoidal wave shapes. However, the time to failure will vary according to the type of insulation such as PE, paper, and rubber. Thus the electrical tree growth rate is not the same for all materials and defects.

The voltage levels (installation and acceptance) are based on the most used, worldwide practices of from less than $2 U_0$ to $3 U_0$, where U_0 is the rated rms phase to ground voltage, for cables rated between 5 kV and 69 kV. The maintenance test level is about 75% of the acceptance test level. One can reduce the test voltage by another 20% if the voltage is applied for longer times (Bach [B2]; Baur, Mohaupt, and Schlick, [B6]; Krefter [B27]). Evidence (Hernandez-Mejía, et al. [B21]) indicates that increasing the voltage above $3 U_0$ to compensate for reduced test cycles (time) does not replicate performance either on test or in service as compared to the lower voltage, longer time tests.

Table 3 lists voltage levels for VLF withstand testing of shielded power cable systems using cosine-rectangular and sinusoidal waveforms (Bach [B2]; Eager, et al. [B9]; Krefter [B27]; Moh [B28]). For a sinusoidal waveform the rms is 0.707 of the peak value, assuming the harmonic distortion is less than 5%. The rms and peak values of the cosine-rectangular waveform are assumed to be equal.

It should be noted that terminations may need to be added to avoid flashover for installation tests on cables rated above 35 kV.

Regarding the test times:

- The recommended minimum testing time for a simple withstand test on aged cable circuits is 30 min at 0.1 Hz (Goodwin, Oetjen, and Peschel [B13]). If a circuit is considered as important, e.g., feeder circuits, then consideration should be given to extending the testing time to 60 min at 0.1 Hz (Hampton, et al. [B19]).
- The recommended minimum testing time for an installation and/or acceptance withstand test on new cable circuits is 60 min at 0.1 Hz.
- A test time within the range 15–30 min may be considered if the monitored characteristic remains stable for at least 15 min and no failure occurs. **It should be noted that the recommended test time for a withstand test is 30 min.**

If the circuit fails during the test, it should be repaired or replaced and then retested using a complete 30-minute test, preferably a monitored withstand test. It is recommended to retest each section with VLF-TD, VLF-DTD, VLF-TDTS, or VLF-PD before the repair to get an assessment of the cable before repair. It is also recommended to retest with VLF-TD, VLF-DTD, VLF-TDTS, or VLF-PD after repair to assess the workmanship of the repair. Monitoring cannot be used to reduce the tests as the cable system has already been shown to be potentially weak by the prior failure. *End of IEEE reference.*

Summary: The above information describes VLF Withstand testing, where the intent of the test is to apply a sufficient test voltage for a long enough time to permit any severe defects driven into partial discharge to fail within the test duration. If a defect can't withstand the test voltage, let it fail and make the repair or replacement. If the cable holds, the operator has a high assurance that the cable should not fail in service for many years.

Diagnostic Testing: If a pass/fail AC Withstand test is not desired, there are several qualitative Diagnostic Tests available. Using the VLF as the over voltage source, **Tangent Delta (δ)** measurements and **Partial Discharge** detection and location tests can be performed with accessories added; available from HVI.

Consult HVI for further information on VLF testing and any other high voltage testing application.