HVI - The World's Source for High Voltage Test Equipment

Advanced test equipment for high voltage proof and preventive maintenance testing of electrical apparatus hvinc.com

MOTOR & GENERATOR VOLTAGE AC TESTING

Elevated Voltage Coil Testing: Withstand & Diagnostic Methods

Introducing 0.1 Hz VLF Technology

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Rotors Wound, Stator Bars Mounted, LV Tests Performed, Now Ready To HV Test. What's Best?

After routine low voltage testing, how best to verify the design, insulation materials, varnishing process, and workmanship all hold up to over voltage stress?

- Elevated Voltage Testing of Some Sort -

- **Hipot It? AC or DC Voltage? mA readings?**
- **AC Withstand Test? pass/fail, go/no-go, ..**
- **Diagnostic Tests? IR, Power Factor, Tan Delta, Partial Discharge, DC Ramp….?**
- **To what voltages, Standards, …?**

What is the Industry Standard? What Should I Be Doing?

- Many use DC voltage, even for Withstand testing
- Some use AC voltage, depending on kVA needed
- Many perform no over voltage testing ($>U_0$)

Question: How best to verify the AC dielectric breakdown strength of a coil, bushing, cable, etc?

Answer: Although there are useful tests performed with DC voltage, for the final acceptance test of most electrical apparatus, there is no substitute for an over voltage test using a sine wave producing AC voltage source.

Answer Too Often Heard:

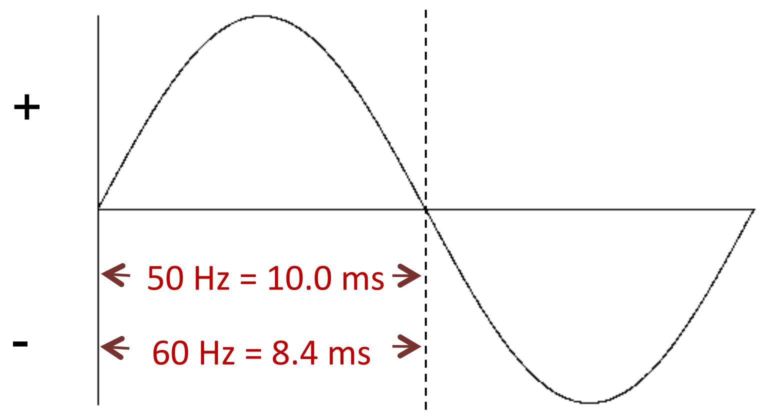
"DC… *Because That's The Way We've Always Done It.*"
or….*"Oh, We Just Megger It."*

The above two methods, often improperly used for testing all types of high voltage apparatus and power cable, *are not derived from a sound engineering analysis based on physics and facts*. These methods may be easier, quicker, and less expensive, but they *lack the ability to measure the AC integrity of the insulation* within an acceptable degree of certainty.

DC is fine for several tests, but not for all, and never for some.

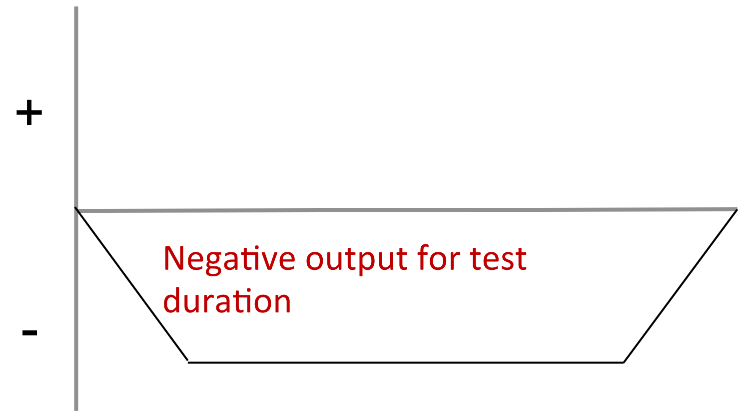
AC or DC VOLTAGE? DIFFERENCES?

AC: Alternating Current



- Identical to operating conditions
- Polarity reversals every half cycle
- No polarization of molecules
- No residual space charges
- Load charges/discharges every 16 ms
- No stored energy in load
- Voltage field stress divides more evenly across coils by X_c of turns
- AC Sine Wave needed for diagnostics: Tan Delta and Partial Discharge

DC: Direct Current



- Very unlike operating conditions
- No polarity reversals – always negative
- Polarization of molecules – dipole effect
- Residual space charges may result
- Load charges depending on capacitance
- Stored energy in load possible
- Voltage field stress divides across coils and materials by resistance, not Xc.
- Leakage currents more measure surface tracking than inner dielectric properties

but. . . DC is *NON-DESTRUCTIVE*
AC is DESTRUCTIVE

ITS NOT THAT SIMPLE

Theoretically, DC does not cause failure during the test - non destructive, if tester closely watches the current meter for tip-up and turns off the voltage in time.

But, DC can cause material degradation that hastens future failure - destructive. Also, DC leakage currents are often meaningless, always changing and with no established benchmarks. They don't always measure what you think.

AC is destructive *to defects triggered into PD under the test voltage* and stressed till failure - a successful test. Same materials are factory tested at $4U_0$ - $5U_0$ and ~$3U_0$ for field Acceptance. *AC is non-destructive to materials that are healthy or contain only minor defects not affected by test voltage.*

AC Elevated Voltage Testing

THREE COMMON METHODS - 50/60 Hz or 0.1 Hz

AC WITHSTAND TEST (Also known as PROOF, GO/NO-GO, HIPOT, PASS/FAIL, STRESS, or PRESSURE TEST.)

- **Apply the test voltage, usually for 60 seconds, coil holds/passes or fails.**

TANGENT DELTA (TD or TAN δ) MEASUREMENT

POWER FACTOR (PF or COS Θ) MEASUREMENT

DIAGNOSTIC TESTS. TD also known as Dissipation Factor or Loss Angle Test

- **Both measure the overall level of insulation degradation.**

PARTIAL DISCHARGE (PD) TESTING

DIAGNOSTIC TEST. Measures the location and severity of electric noise from PD. PD Inception Voltage (PDIV) & PD Extinction Voltage (PDEV) measured.

- **Where are the bad spots and how bad are they?**

AC Elevated Voltage Testing

AC WITHSTAND TEST ***Apply the voltage - load holds or fails***

Plug in the hipot, connect the HV output to the motor leads and ground to ground, turn on the hipot, turn up the voltage, wait 60 seconds, turn it off.

This test is the easiest of all to perform. No current readings to monitor, no stored energy in the load, less pretest preparation, and it takes only one minute. This test provides complete certainty of results. No DC leakage currents to read and try to interpret. Can the load withstand the necessary AC overvoltage it must to provide reliable service for years?

Typical Acceptance test voltage is 2x line-line voltage plus 1000 volts. Often a maintenance test on older equipment will be at 80% of this level.

$2U_0$ + Ik = Test V. 6600 volt motor = 6600 x 2 + 1000 = 14,200 volts.

AC Elevated Voltage Testing

TANGENT DELTA (TD or TAN δ) MEASUREMENT

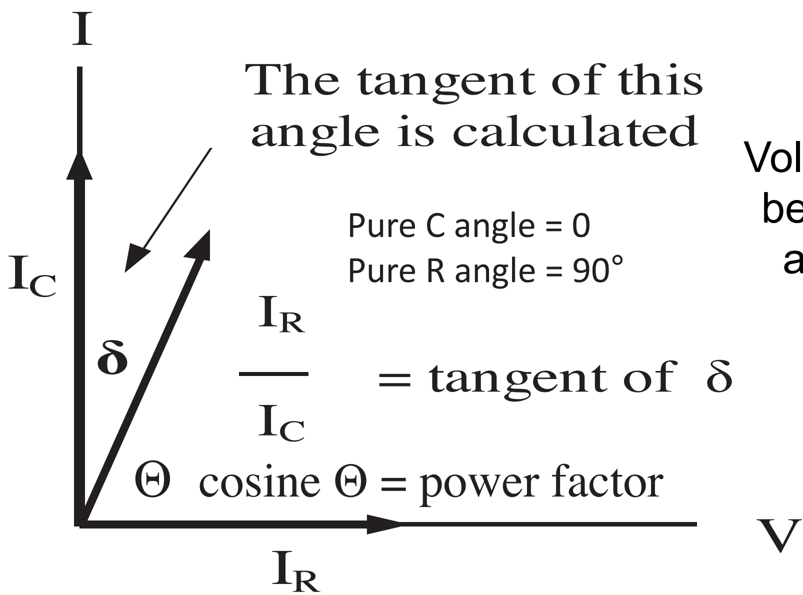
Also known as DISSIPATION FACTOR or LOSS ANGLE TEST

POWER FACTOR (PF or COS Θ) MEASUREMENT

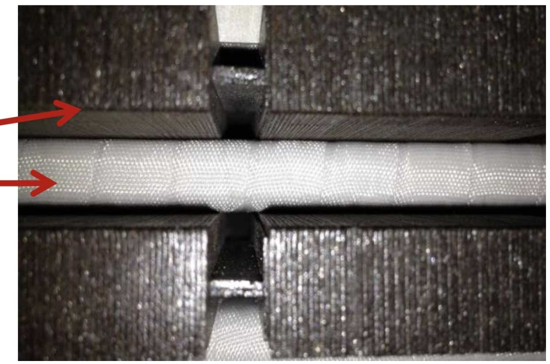
Both are very similar **Diagnostic Tests** used to measure the overall level of insulation degradation. Over time, all insulation deteriorates due to many factors. These tests measure the change from new, perfect insulation to something less as it degrades. Absolute numbers, readings versus increasing voltage, and trends over time are all important factors indicating the level of insulation decay. Helpful for comparative testing.

TD Simplified Model And Phasor

Tan Delta = $I_R/I_C = 1/(2\pi fCR)$ Similar to Power Factor



Stator winding insulation and core



Similar model to a shielded cable

If the insulation material is perfect, the pictured insulated stator bar and adjacent grounded core appear as a capacitor with the current Ic 90° phase shifted from applied voltage V, making the angle δ = 0°. The more degraded the material due to moisture, impurities, voids, water trees, typical ageing mechanisms, etc, the more resistive leakage current flows and the greater the angle 5, indicating a measureable level of insulation degradation.

AC Elevated Voltage Testing

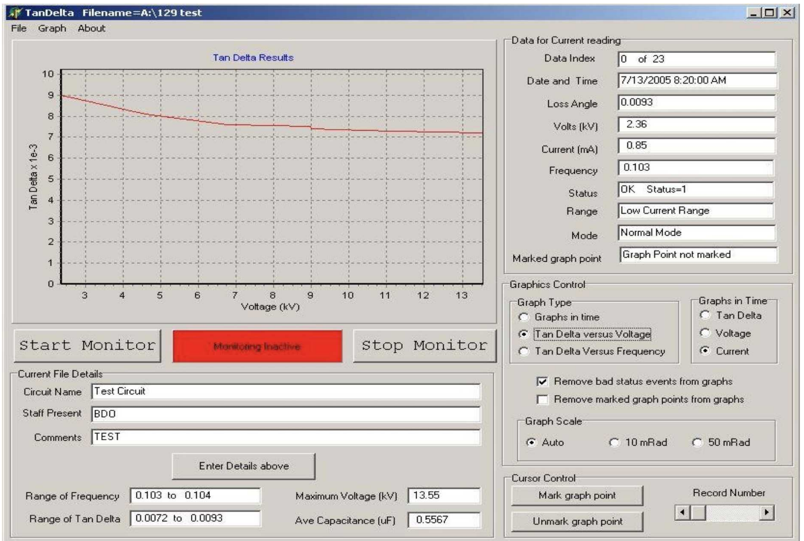
PARTIAL DISCHARGE (PD) TESTING

DIAGNOSTIC TEST. Measures the location and severity of electric noise from PD.
PD Inception Voltage (PDIV) & *PD Extinction Voltage* (PDEV) measured.

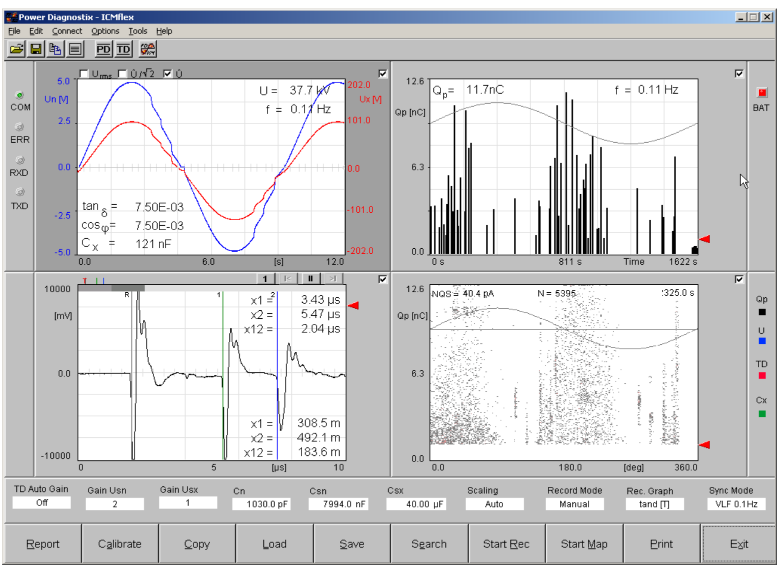
Where are the bad spots and how bad are they?

- Where are the PD locations?
- What is the PDIV as the test voltage is raised? Starts?
- What is the PDEV when the voltage is lowered? Stops?
- What are the IV & EV relative to operating voltage?
  Does it start at only 10% over normal or 80%?
  Once PD ignites, does it extinguish below or above normal?
- How severe is the PD? Very localized or widespread?
- Is the PD location accessible for a repair or buried?
- Is the PD in the insulation or in terminations?

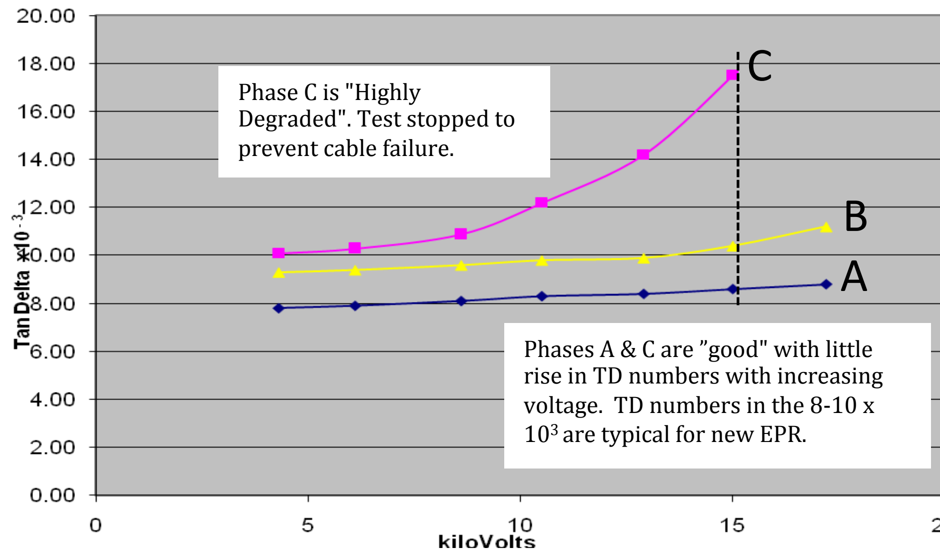
Tan Delta & Partial Discharge



Sample Graphs



Tan Delta I5kV EPR



AC High Voltage Sources
Three Technologies Available

Choice of tester design depends on:

- Test type (factory cert. @ 60 Hz. or field maint.)
- Current or Power needed (load capacitance?)
- Withstand Test only or TD and/or PD testing?
- Partial Discharge free output for PD testing?
- Input power available?
- Portability required - size & weight limits?
- Economic constraints

The Choices:

1. 50/60 Hz Power Frequency Dielectric Test Sets
2. Series/Parallel Resonant or Variable Frequency Supply
3. Very Low Frequency (VLF) AC Technology

AC High Voltage Sources

50/60 Hz AC Dielectric Test Set

This is a conventional AC hipot/test set designed to operate at the power frequency of 50 or 60 Hz. Typically a conventional two winding transformer to step-up the input line voltage to the high voltage needed, likely in an oil filled steel tank or porcelain/fiberglass tube.

Pros: Operates at power frequency like motor/generator
Testing simulates real world stresses. Most realistic
Best option for power needs up to ~ 60 -100 kVA
Sine wave output can/is used for TD and PD testing

Cons: Requires the highest input power to operate
Heaviest, largest, usually most expensive option

Power Frequency AC Test Sets

30 kVac @ 3 kVA

100 kVac @10kVA

5 kVac @ 5 kVA

120/60 kVac @ 7 kVA

60 kVac (a), 5 kVA

50 kVac @ 3 kVA

10 kVac @ 10 kVA

200 kVac @ 20 kVA

AC High Voltage Sources

SERIES/PARALLEL RESONANT &

VARIABLE FREQUENCY SYSTEMS

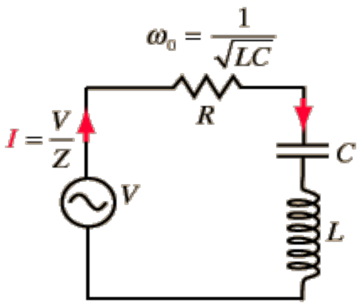
A Series Resonant transformer system is designed to test very high capacitance loads at high voltages while minimizing the amount of real power pulled from the input line. Compared to a conventional 60 Hz test set, the input power required can be 10-30 times less depending on the pf of the load.

A HV reactor with a variably adjustable air gap in the steel core is used. The internal *"inductance - L"* of the SR supply is *"tuned"* by adjusting the core's air gap to match the load *"capacitance - C".* At resonance, the load appears mostly resistive, requiring little power to apply high voltage.

A Variable Frequency tester reduces the effective Xc of the capacitive load by lowering the frequency of the output, down to as a low as 30 Hz.

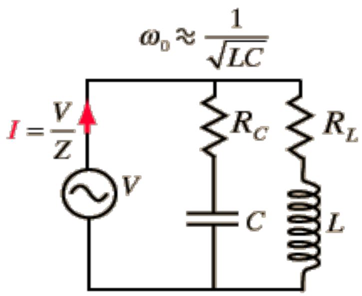
Series/Parallel Resonant & Variable Frequency Systems

Minimum impedance at resonant frequency



Series Resonance

Maximum impedance at resonant frequency



Parallel Resonance

$$F_R = \frac{1}{2\pi\sqrt{LC}}$$

Parallel Resonant
50 kVac @ 200 kVA

Series Resonant HV Tank
~ 500 kVac @ 500 kVA

Series Resonant - Modular
~ 1200 kVac

AC High Voltage Sources

Very Low Frequency AC Technology

A VLF hipot is simply an AC high voltage instrument but with a *frequency output of 0.1 Hz and lower rather than 50/60 Hz.*

Basics Physics: the lower the frequency of the applied voltage, the lower the current and power required to test high capacitance loads like rotating machinery and cables. VLF technology permits the field testing of high uF loads with AC voltage.

The technology was developed to offer an alternative to using DC to test solid dielectric power cables. What better method than to use AC, and by dropping the frequency, portable and affordable products could be produced for field use. DC is not recommended for testing service aged cable.

Lower Frequency = Lower Power

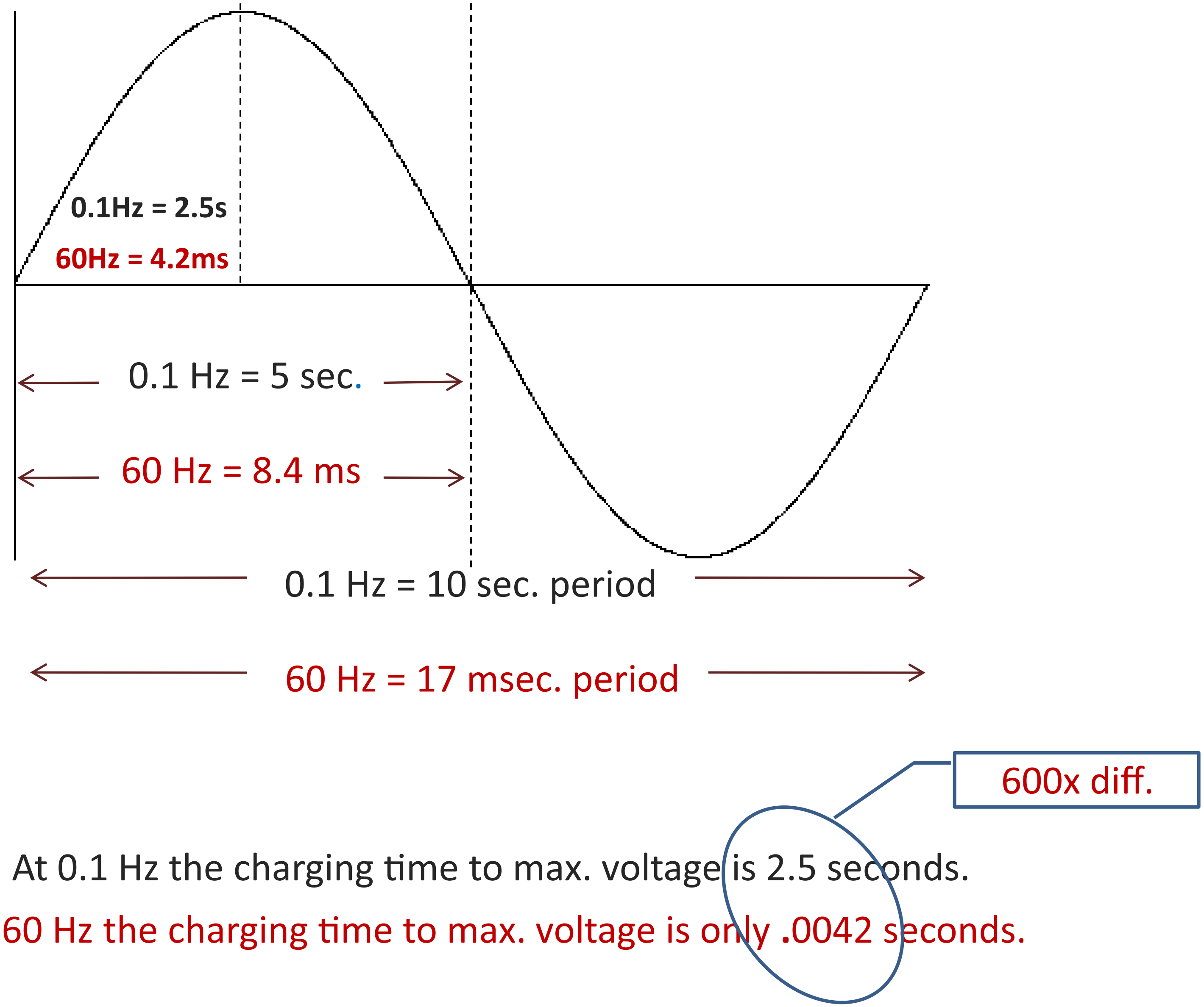
Very Low Frequency: 0.1 Hz and lower. By decreasing the frequency, it is possible to test very large and highly capacitive generators and motors and to test miles of cable with a small, portable, and affordable power supply compared to a 60 Hz or Series Resonant system.

IEEE 433-2009 defines and sanctions the use of 0.1 Hz for testing rotating machinery. (Original standard published in 1974)

IEEE 400.2-2013 is the standard for testing MV & HV cable. In both cases, 0.1 Hz is allowed for use for TD, PF, and PD diagnostic testing.
(Original standard published in 2004)

At 0.1 Hz it takes 600 times less power to test a motor or cable than at 60 Hz. For Withstand testing, frequencies from 0.1 Hz - 0.01 Hz are permitted, offering even greater advantage.

VLF Difference: 0.1 HZ Vs. 60 Hz



At 0.1 Hz the charging time to max. voltage is 2.5 seconds.

At 60 Hz the charging time to max. voltage is only .0042 seconds.

VLF Explained – Calculating Xc

$$X_c = \frac{1}{2 \times pi \times \underline{\mathbf{f}} \times C}$$

The lower the frequency, the higher the capacitive reactance, or X_c. The higher X_c , or resistance across the power supply's voltage output, the lower the current and power needed to apply that voltage.

Lower frequency = higher resistance = less current

What A Difference The Freq. Makes

At 60 Hz. a .4 µF coil has an X_c of 6.6 kOhms.

At 28 kV rms *, it requires 4.3 amps of current to test.

Total power supply rating must be **120 kVA**

At 0.1 Hz, the X_c is 3.98 megohms.

At 28 kV rms x 1.63 for VLF peak,

the current needed is only 12 mA.

Total power supply needed is only .531 kVA

* 28 kV rms @ 60 Hz if a 13.8 kV input coil

28 kV rms x 1.63 for equivalent VLF test voltage = 45.6 kV VLF peak

Very Low Frequency AC Testers

0.1 – 0.05 Hz VLF AC Technology

High Voltage, Inc. models

28 kVac @ .4 uF

34 kVac @ 5 uF

40 & 60 kVac @ 5.5 uF

65 kVac @ 10.0 uF

120 kVac @ 5.5 uF

200 kVac @ 3.75 uF

Selecting An AC Dielectric Test Set

THE VOLTAGE NEEDED IS KNOWN; HOW MUCH CURRENT?

AC ≠ DC. While a small 5 mA DC hipot is adequate to test a coil or cable of high capacitance, an AC hipot operating at 60 Hz must charge the load every ½ cycle in just 4.2 ms, from 0 – 90°. Far more AC power is needed than DC. To calculate the AC current needed:

AC Amps Required = 2πfCV

C = load capacitance in Farads   V = test voltage in Volts

Example: a .2 uF @ 6000V coil tested at 13 kVac ($2U_o$ + 1k) will need a 60 Hz. test set rated for the following current and kVA:

A = ***2πfCV = 377 x (.2 x 10^{-6}) x 13,000 = .98 amps***

Power supply rating = 13 kVac x 1 A for 13 kVA of power.

Call it a 0 – 15 kVac @ 1A model. Cost ~ $ 20,000.00 USD

Hipot Comparison Of 60 Hz Vs. 0.1 Hz

60 Hz Hipot

0 - 50 kVac @ 3 kVA

Can test ~ 3.5 nF

Test ~ 10m of 15kV cable

Both cost $9,000

0.1 Hz VLF

0 - 28 kVac peak, .4 uF load @ 0.1Hz

Can test ~ 400 nF equiv. 60 Hz load

Can test ~ 1500m of 15 kV cable

Ideal for motors/generators per IEEE 433 and cables per IEEE 400.2

VLF Models From Various Vendors

High Voltage, Inc. - NY

Baur - Austria

Seba – Germany

HV Diagnostics Switzerland

Voltages are in peak. Load ratings from 0.4 uF - 50 uF

Test Example & Equipment Sizing

<u>Stator Winding Under Repair</u>

4000 V, 400 hp 3 Ph., 60 Hz.

66 coils/ph. x 3 = 198 coils Test: 9

kVac (4 kV x 2 + 1000V)

Each coil draws ~ 3.3 mA @ 9 kVac

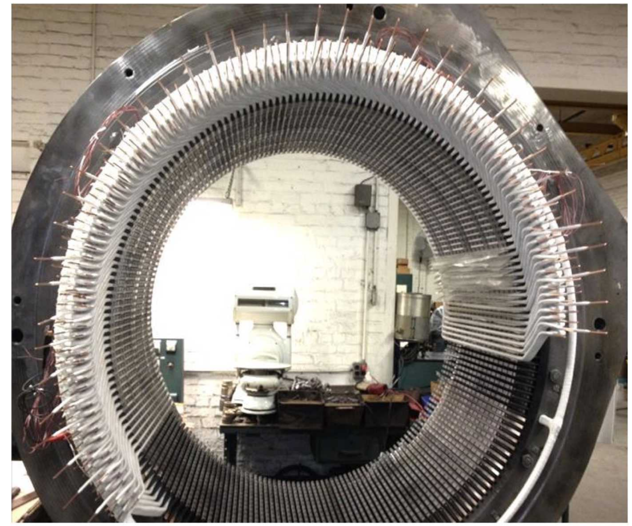
To test all 3 ph. = 660 mAac

A10 kVac @ 1A supply is needed to test all three phases at once.

AC Hipot Needed
10 kVac @ 10 kVA

Example Coil Size with the AC & DC Hipots needed

If **DC Hipot** used 20 kVdc @ 5 or 10 mA



Motors & Generators, like most other types of electrical apparatus, should be tested in the best manner possible to verify their AC voltage operating integrity. Other tests, even with DC voltage are fine and needed, but none are a substitute for a proper AC Withstand test and AC Voltage Diagnostic testing.

Thank You, Michael T. Peschel

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