



Voltage Regulator Testing and Standards

Voltage regulators need to comply with strict Quality Standards:

Standard	Focus on	Applicable to
<u>IEEE Std C57.12.80</u>	Standard Terminology	for Power and Distribution Transformers
<u>IEEE Std C57.12.00</u>	Standard for General Requirements	for Liquid-Immersed Distribution, Power, and Regulating Transformers
<u>IEEE Std C57.12.90</u>	Standard Test Code	for Liquid-Immersed Distribution, Power, and Regulating Transformers
IEEE Std C57.15	Standard requirements, terminology, and test code	for step-voltage regulators
<u>IEEE Std C57.131</u>	Standard Requirements	for Tap Changers
IEEE C57.12.31	Standard	for Pole-Mounted Equipment–Enclosure Integrity
ASTM D3487	Standard Specification	for Mineral Insulating Oil used in Electrical Apparatus

+ Prolec GE Internal Quality Standards and customer specifications.

Per IEEE Std C57.15 sec 6.10.2 the routine tests required are:

Preliminary

- **Ratio test**
- **Resistance** measurements
- **Insulation resistance**
- **Insulation power factor test**

Losses

- **No-load loss (core loss) and excitation current at rated voltage and rated frequency**
- **Load loss and impedance at rated current and rated frequency**
- **Applied-voltage test**

Dielectric

- **Induced-voltage test**
- **Lightning impulse test**

Additional

- **Leak test**
- **OLTC test**
- **Control system test: applied voltage and operation**

Routine tests – Preliminary tests:

Test	Description of the test	Purpose
Ratio	<ul style="list-style-type: none"> • Test is conducted from 16L to 16R, covering the entire series winding. • Includes ratio test of instrument transformers like PT, CT and utility winding if any. • Per IEEE Std C57.15 SEC 9.4.5, the tolerance for ratio is 0.5% from the design value. 	<ul style="list-style-type: none"> • Verify that the correct turns were wound. • Verify that ratio values exist throughout each winding and are per design.
Resistance	<ul style="list-style-type: none"> • The test is performed at the specific taps where load losses were requested by the customer (typically 16R, 15R, 15L & 16L). 	<ul style="list-style-type: none"> • Resistance is measured for internal quality purposes, is not a guaranteed value. • Values are used later on the load loss test to breakdown the winding and stray losses.
Insulation resistance	<ul style="list-style-type: none"> • Low voltage (500 to 2400 V) DC test. 	<ul style="list-style-type: none"> • Detects if the insulation system is in good conditions. • There is no a specific target requested by any standard. • High megger readings are good, new units test around 1000 MΩ at 20°C.
Insulation power factor	<ul style="list-style-type: none"> • All windings shall be immersed in insulating liquid. • All windings short-circuited. • All bushings in place. • Average temperature of windings and oil between 10°C and 40°C, preferably as near to 20°C. • Top liquid temperature measured and recorded. 	<ul style="list-style-type: none"> • Measures the capacitance and the ratio of the real power dissipated on the insulation system (W) and the apparent power consumed (VA) • This is done between different components, L-G, H-G and H-L. • There is no a guaranteed value or requirement on any IEEE Std. • Prolec GE internal benchmark is not to test more than 1.00% for mineral oil and no more than 2.00% for natural ester.

Routine tests – Losses tests:

Test	Description of the test	Purpose
No-load loss (core loss) and excitation current	<ul style="list-style-type: none"> The test consist of applying rated voltage and frequency on one of the windings and the other winding in open circuit. No-load losses is the average of values tested at neutral (N) and the adjacent boost position (1R). Per IEEE Std C57.12.00 no-load loss shall not exceed the design value by more than 10%. 	<ul style="list-style-type: none"> Measure losses generated by the core and the excitation current required to generate the excitation.
Load loss and impedance	<p>Load loss:</p> <ul style="list-style-type: none"> The test consist of shorting one of the windings while the other is input with voltage and adjusted to cause rated line current to flow. It can be tested as an autotransformer or as a two winding transformer. Load loss is the average of values tested at 16R, 15R, 15L and 16L. Per IEEE Std C57.12.00 total losses (NLL+LL) shall not exceed the design value by more than 6%. 	<ul style="list-style-type: none"> Measure losses generated by the resistance on the windings due to load current and stray losses due to eddy currents induced by leakage flux in the windings, core clamps, magnetic shields, tank walls and other conducting parts.
	<p>Impedance (%Z):</p> <ul style="list-style-type: none"> The input voltage that causes rated current to flow is known as “impedance voltage”. The %Z is calculated based on the impedance voltage, then divide it by the rated voltage and multiply it by 100. Per IEEE C57.15 sec 9.6.4.3, a VR shall have a tolerance of $\pm 10\%$ of the design value. 	<ul style="list-style-type: none"> In contrast with a conventional transformer, the %Z of a VR is commonly not request by the customer and the measured value is not reported on the nameplate. The maximum %Z of a VR is generally less than 0.6%.

Routine tests – Dielectric tests:

Test	Description of the test	Purpose
Applied voltage	<ul style="list-style-type: none"> • Low frequency test • One winding is connected to a specified potential (all its parts joined together) • The other winding and tank are grounded • The duration of the test is 1 min. 	<ul style="list-style-type: none"> • Detect energized elements without proper distance against parts that are connected to ground • Detect weakness in coil to ground insulation.
Induced voltage	<ul style="list-style-type: none"> • Low frequency test. • The test is performed at 2X rated voltage. • The duration shall be 7,200 cycles or 60 s whichever is less. 	<ul style="list-style-type: none"> • Detect tear/break insulation within the windings (Layer-to-Layer) • Detect damaged and/or poor conductor insulation (Turn-to-Turn).
Lightning impulse	<ul style="list-style-type: none"> • High frequency test. • Exciting and series windings are considered as a single winding for the purpose of this test. • S&L terminals are tied together through a resistor of 450Ω to limit the induce voltage. • The test is applied at S terminal for type A while set at 16L. • Test is applied at L terminal for type B while set at 16R. 	<ul style="list-style-type: none"> • Simulates a lightning surge hitting the VR. • Proves the capability of the insulation system to withstand these events.

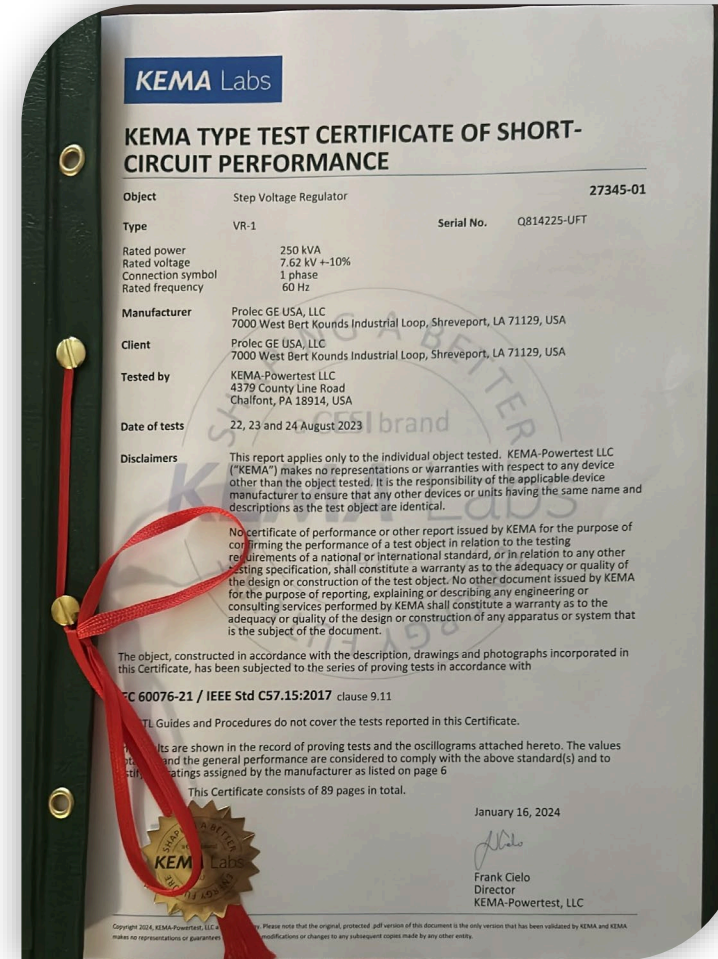
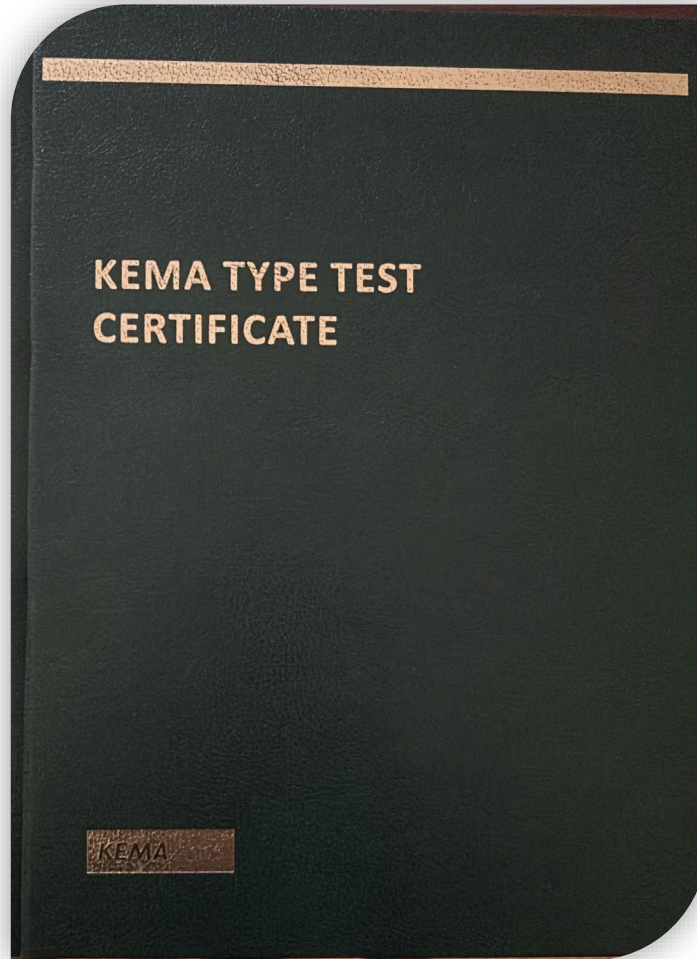
Routine tests – Additional tests:

Test	Description of the test	Purpose
Leak	<ul style="list-style-type: none"> An internal pressure of 10 psi is applied to the VR for 2 hours. 	<ul style="list-style-type: none"> The purpose of the test is to check the integrity of welds and gasket seals.
OLTC	<ul style="list-style-type: none"> OLTC fully assembled but without the contacts energized. Ten complete cycles (max boost to max buck and back) of operation shall be performed without failure. Auxiliary circuits shall withstand without failure an applied voltage test of 1.5kV from all live parts to ground for 1 min. 	<ul style="list-style-type: none"> Validate the integrity of all OLTC components and mechanisms. Detect abnormal contact pressure causing dragging or misalignment, causing bouncing or jamming.
Control system, applied voltage and operation	Applied voltage: <ul style="list-style-type: none"> Control system circuitry shall withstand without failure an applied voltage test of 1.5kV from all live terminals to ground for 1 min. The control front panel shall be totally disconnected during the test. 	<ul style="list-style-type: none"> Detect change in control performance
	Operation: <ul style="list-style-type: none"> All features of the control system shall be operated and checked for verification of proper function. 	

- **Temperature-rise test**
 - Proof that design meets the temperature-rise requirement for 55°C or 65°C winding rise rating.
- **Lightning impulse test**
 - Demonstrate the adequacy of the insulating materials breakdown and spacing under normal conditions.
- **Short-circuit test**
 - 25 times the rated current to a maximum of 16 kVA.
 - Duration of 250 ms.
 - **Prolec GE is capable of design and manufacture designs with 40 times short-circuit withstand.**
- **Sound level test**
 - Proof the design meets the sound level requirement for the specific power rating specified in table 13.

*per IEEE Std C57.15 sec

KEMA certificate for 40 times short-circuit withstand capability:



KEMA certificate for 40 times short-circuit withstand capability:



Video ▶

Production Testing – Other Testing

Prolec GE acquired in 2023 a certification against seismic zones, per the latest version of the standard:

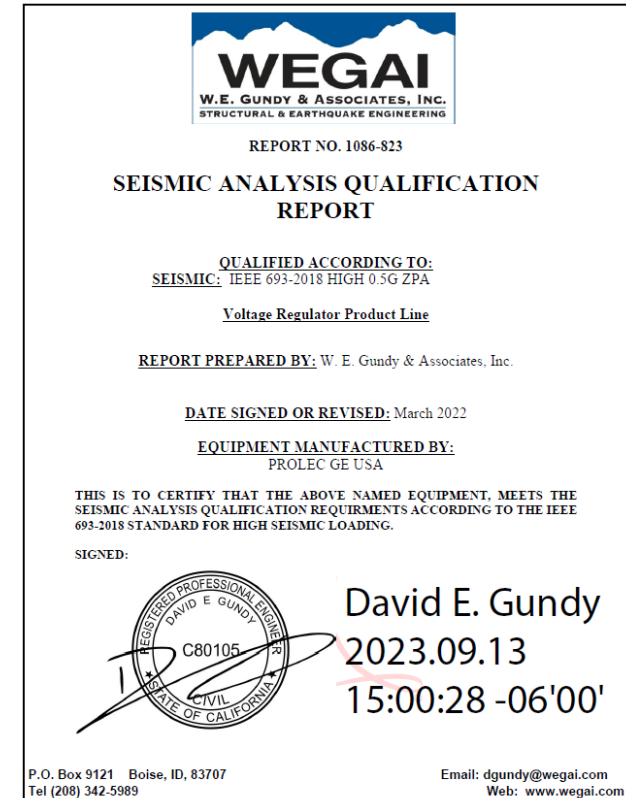
Standard	Focus on	Applicable to
IEEE Std 693-2018	Recommended Practice for Seismic Designs	for Substations

Previously, we held certification under the 2005 version of the standard.

However, in 2018, the requirements related to seismic zones were significantly revised.

In response, we developed new tank bases and subbase stands that comply with the 2018 version of the standard.

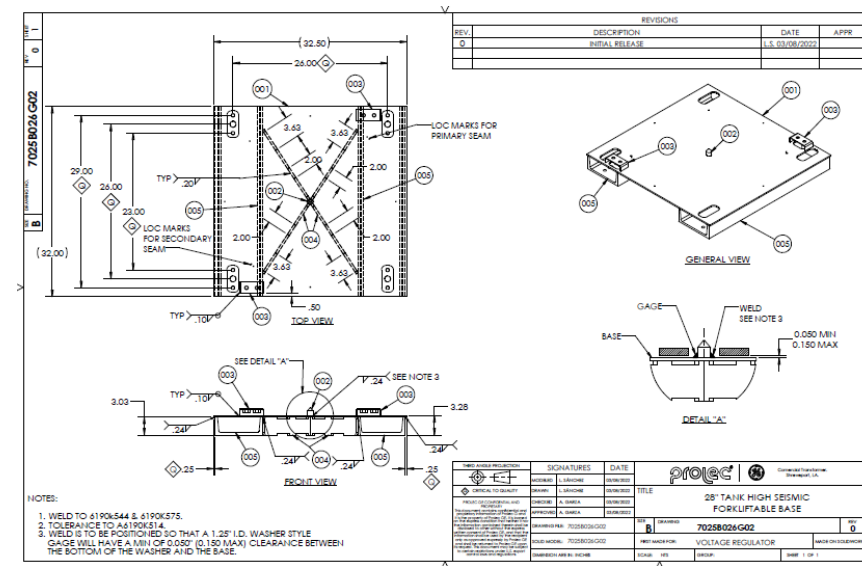
As result, we are now able to offer our customers products certified for “High” Seismic Zone levels.



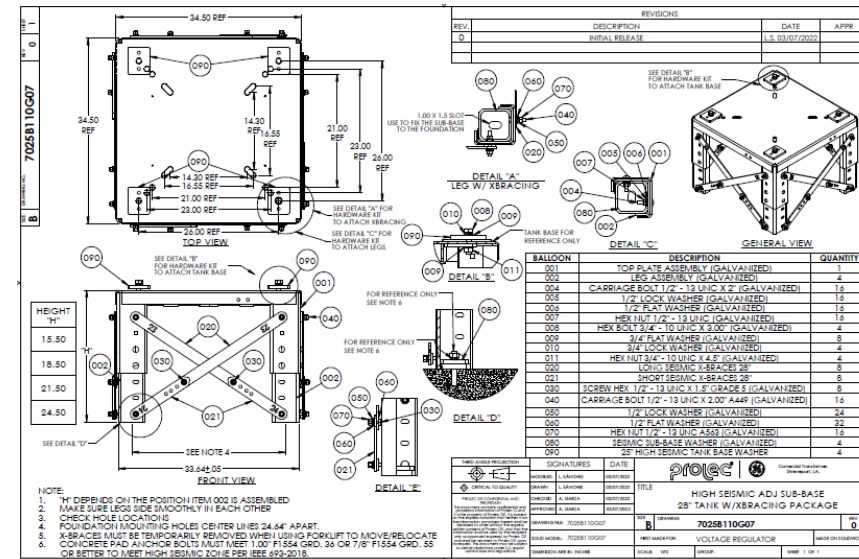
Production Testings – Other Testing

High quality materials are used on the seismic designs, to withstand the loads of the high seismic zone (Including some grade 50 carbon steel components and grade 5 120 ksi fasteners).

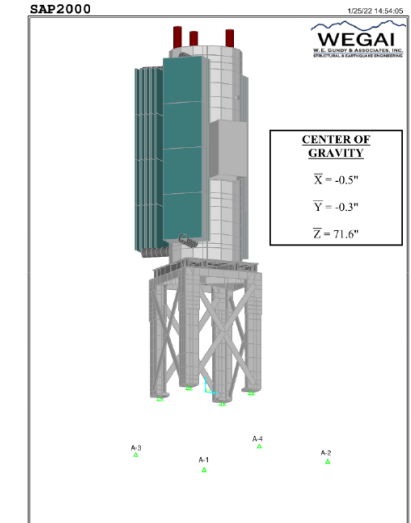
The certification covers the next components:



Three different tank bases, for 21", 25" and 28" diameters



Two different subbase stands, for all tank diameters, and different adjustable heights.



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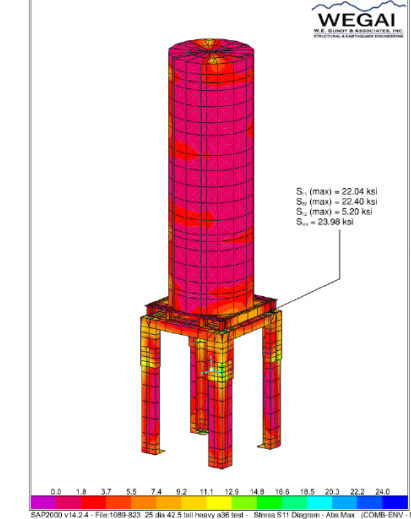


Figure C-4: S12/S12Max Shell Stress (Full Assembly -4)