

REACTIVE LOAD BANK TESTING

Field Reference & Technical Guide

Generator Commissioning | AVR Validation | NFPA 110 Compliance

Brad Panike

NERC Certified Senior System Operator (Retired)

30+ Years Transmission Grid Operations and Power Plant Electrical Experience

Kilovar Substack — kilovar1959.substack.com

LinkedIn — linkedin.com/in/brad-panike-198b0834

Intended audience: Generator technicians familiar with resistive load bank testing, engineers specifying standby power systems, and facility managers responsible for emergency power reliability. Voltage-agnostic — the math works at any system voltage.

Document preparation assisted by Claude (Anthropic). Technical content, operational procedures, and engineering judgment are solely the work of the author.

Scope, Code Authority, and AHJ Notice

This document describes recommended engineering practices intended to supplement, not replace, the minimum requirements of NFPA 110. Nothing herein creates a code obligation unless explicitly required by the Authority Having Jurisdiction (AHJ) or adopted by project specification. Final acceptance criteria, test scope, and documentation requirements remain subject to AHJ approval, manufacturer requirements, and site-specific conditions.

Professional Reliance Disclaimer

This document is a technical reference and training aid. It does not replace professional engineering judgment, manufacturer commissioning procedures, or site-specific analysis. Application of the procedures described herein is the responsibility of qualified personnel acting within their scope of training, authority, and licensure where required.

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Foreword

This document is organized into logical sections. Section 1 is intended for training and field assistance for technicians performing reactive load bank testing and explains why it should be done. Part 1 of Section 1 is written to stand alone for those who want a working explanation of the underlying calculations for quick availability. Section 2 is written for facility owners and specifying engineers who want to deepen their knowledge and improve the specifications they write. Appendix A contains reference cards that can be printed and laminated for quick reference in the field. Technicians who prefer to skip the training material may go directly to Appendix A. Appendix B contains sample test documents that can be used as-is or adapted as the basis for your own in-house documentation. Appendix C contains sample specification language that can be used to enhance bid documents. This document is designed to be useful in whole or in part — take what you find valuable.

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SECTION 1 – FOR GENERATOR TECHNICIANS

Training and Technical Information useful to Technicians in the Field

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Part 1 — Quick guide for performing a Reactive Test

This section is intended for the experienced Generator Technician familiar with performing resistive load bank testing. It is meant to provide a quick reference to run through the calculations for performing a reactive load test in step form. It's at the front to make it easy to find and print if needed.

1. Review Generator nameplate data in advance if possible.
 - a. Obtain rated Kilowatt (kW)
 - b. Rated nameplate full-load current in amperes
 - c. Rated Power Factor (PF), **do not assume 0.8 rating.**
2. Calculate reactive needs, because kW and kilovolt amperes reactive (kVAr) are out of phase it is not a straightforward amperes-to-kilowatts calculation and requires trigonometry to determine the required kVAr. Use the nameplate amperes and rated phase to phase rated voltage to calculate kilovolt ampere (kVA) rating if not listed on nameplate. Amps X Volts L-L X $\sqrt{3}$ X .001 = kVA. (example, 500 X 480 X 1.732 X .001 = 415.7 kVA). Alternative formula Amps X Volts L-N X 3 X .001 = kVA (example, 500 X 277 X 3 X .001 = 415.5 kVA) You will need to keep a good full function scientific calculator app on your phone for these formulas.
 - a. $\sqrt{(kVA^2 - kW^2)} = kVAr$
 - b. $\cos^{-1}(PF) = \text{Phase angle } (\emptyset)$
Calculator note: $\cos^{-1}$ is the same as arccos (arccosine). On your calculator or phone app, press SHIFT (or 2nd) then COS to get $\cos^{-1}$. Same pattern: SHIFT + SIN = $\sin^{-1}$, SHIFT + TAN = $\tan^{-1}$.
 - c. $kW \times \tan \emptyset = kVAr$
 - d. $kVA \times \sin \emptyset = kVAr$
 - e. $\sqrt{3} \times \text{Voltage L-L} \times \text{Amps} \times \sin \emptyset \times .001 = kVAr$
3. Verify test equipment before proceeding into field
 - a. Sufficient resistive kW capacity to meet the need.
 - b. Sufficient reactive capability to meet the need.
 - c. Verify there is no capacitive load testing required (rare) (different load bank)
 - d. Sufficient test cable to carry both resistive and reactive load, if a single cable run is used it should exceed the full nameplate amp rating of the generator.
 - e. Verify instrumentation and paperwork needed to measure and record test results are in your setup
 - i. A traceable calibrated true RMS multimeter with frequency function. Either clamp meter format or plug in current probe for multimeter. Consider having several if you want to take continuous readings. If equipment meters are used, you want to verify accuracy with a calibrated meter.
 - ii. Optional small hall effect DC clamp meter to measure exciter field current.
 - iii. Optional three phase power recorder to make an electronic recording of all the parameters of the test. Makes it possible to generate high quality reports that include trends. Some will accept a fourth channel to record exciter field current.
 - iv. Clipboard with a supply of recording documents, or a laptop/tablet with fillable forms loaded.
4. Onsite quick math calculations
 - a. Rated Nameplate Amps X Rated Power Factor = Full resistive load current or full kW load (note current to resistive load banks only)
 - b. Rated $\cos^{-1}(\text{Power Factor}) = \emptyset$ then $\emptyset \text{ sine} \times \text{Rated Nameplate Current} = \text{reactive current}$ (note current to reactive load banks only)
 - c. Use the above formulas on the cable feeding the individual load banks. If you measure the current on a common cable feeding both load banks, you will get the vector sum of the two currents (not 1+1).

Part 2 — Why Resistive-Only Testing Is Insufficient

A resistive load bank is an essential tool and the right choice for verifying that a generator's prime mover, governor, and fuel system can deliver rated kilowatts. For that specific purpose, it is accurate and adequate. The problem is that resistive-only testing has become the default — and often the only — load test performed, even on generators whose actual connected loads are predominantly inductive.

A large percentage of commercial and industrial electrical loads consists of motors, transformers, and ballasted lighting — all inductive, all lagging power factor. When those loads transfer to emergency power, the generator must supply not only the watts to do the work but also the reactive (magnetizing) current to maintain the electromagnetic fields in every motor and transformer on the bus. A resistive load bank tests none of this.

What resistive-only testing cannot validate:

- AVR response to lagging power factor load — the most common real-world condition
- Exciter capacity and thermal performance under reactive current demand
- Voltage regulation with combined real and reactive load — the generator's actual operating environment
- Voltage transient behavior on transfer of motor loads
- Hunting and stability margins of the voltage regulator loop
- Winding temperature rise under combined real and reactive current
- Whether the generator will sustain voltage when a large motor starts (high inrush, severe lagging PF)

NFPA 110 specifies a minimum load expressed in kilowatts. It does not mandate reactive loading. A generator can pass the NFPA 110 annual test with a purely resistive load bank and be issued a compliance certificate while its AVR is hunting, its exciter is borderline, and its voltage regulation under lagging load is unknown. This is the gap that reactive load bank testing closes.

NFPA 110 establishes minimum generator testing requirements expressed in kilowatts (kW). Reactive load bank testing is not required by NFPA 110 for compliance. The procedures described in this document represent recommended engineering practice intended to validate AVR performance, exciter capability, and voltage regulation beyond the minimum code compliance threshold.

Part 3 — Reactive Power Fundamentals

Reactive power (measured in VAR — volt-ampere reactive) is real current flowing in real conductors, producing real I^2R heating, while doing zero net work over a complete cycle. This distinction confuses technicians coming from a purely resistive background, so it is worth being precise.

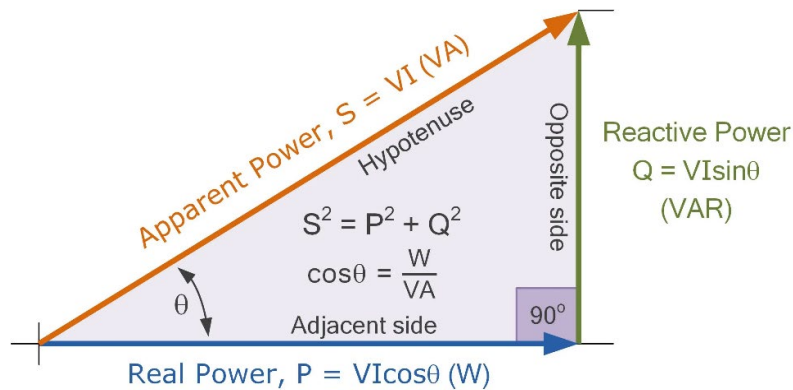
In a purely resistive circuit, voltage and current are in phase. The product of instantaneous voltage and instantaneous current is always positive — power flows from source to load every instant of every cycle. In an inductive circuit, current lags voltage by up to 90 degrees. During the portion of each cycle where voltage and current have opposite signs, power flows back toward the source. The net power over a full cycle is the real power — but the peak current, and therefore the I^2R loss in the winding and cables, is determined by the total (apparent) current including the reactive component.

This is why a generator rated and operating at 500 kVA at 0.8 PF can only deliver 400 kW of real power to load before its windings reach thermal limit. The remaining 300 kVAR of capacity is consumed supplying magnetizing current to inductive loads. The winding does not know or care whether the current through it is doing useful work — it heats up the same either way.

Part 4 — The Power Triangle

The relationship between apparent power (S, kVA), real power (P, kW), and reactive power (Q, kVAR) is a right triangle. This is not a simplification or an approximation — it is the exact mathematical relationship derived from the phase angle between voltage and current. (Pythagorean Theorem)

Component	What It Represents
S (kVA) — Hypotenuse	Generator nameplate rating. Total apparent power the machine is supplying. Determined by winding thermal limits. Sometimes only provided in the current rating.
P (kW) — Adjacent	Real power — does work, spins motors, produces heat and light. What the kWh meter measures. Limited by prime mover (engine) output. Shown as the kW rating on the generator nameplate.
Q (kVAR) — Opposite	Reactive power — supplies magnetizing current to inductive loads. Consumes kVA capacity without producing net work. Limited by exciter and winding capacity.
θ (theta)	Phase angle between voltage and current. $\cos(\theta)$ = Power Factor. A 0.8 PF load has $\theta = 36.87^\circ$



Power Triangle or Right Triangle is used to visually represent the three elements of the power equation

The practical implication: a generator loaded to full kW on a resistive load bank is at full prime mover output but partial winding loading. Adding reactive load to reach nameplate kVA at rated PF loads both the prime mover and the windings simultaneously — the only condition that actually validates the complete machine.

Part 5 — Leading vs. Lagging: What It Means for Your Generator

Power factor is described as lagging when current lags voltage (inductive loads) and leading when current leads voltage (capacitive loads). For emergency and standby generator applications, lagging power factor is the dominant operating condition.

Lagging PF — Inductive Load

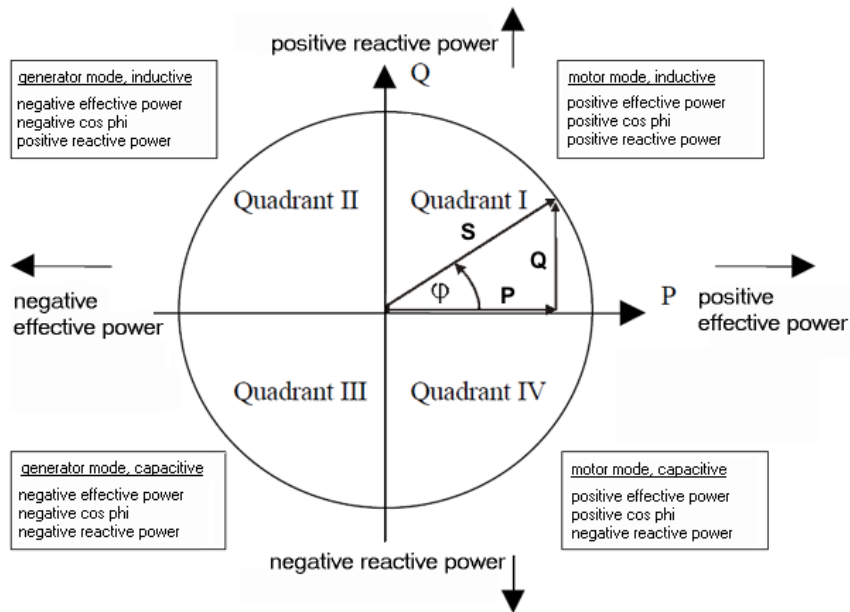
Motors, transformers, HID lighting. Current lags voltage. Generators must supply magnetizing current in addition to real current. AVR responds by increasing excitation. Exciter field current increases. This is the condition that stresses the AVR and exciter, and the one your load bank test must replicate.

Leading PF — Capacitive Load

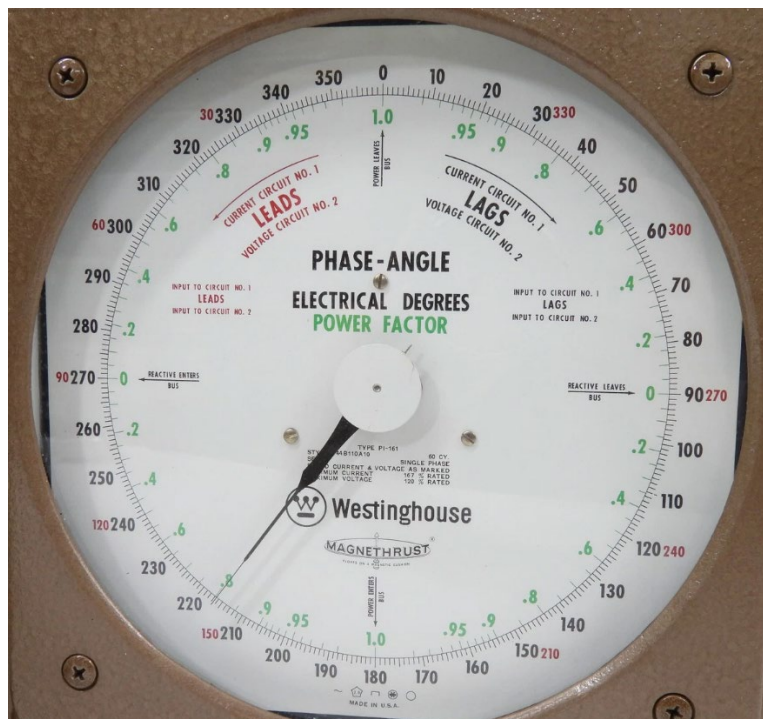
Lightly loaded cables, capacitor banks, some electronic loads with PFC. Current leads voltage. AVR responds by reducing excitation. Risk of under-excitation and loss of stability in large machines. Less common in typical emergency generator applications but relevant in data center environments with significant UPS capacitive correction.

Unity PF — Resistive Load

Heating elements, incandescent loads, resistive load banks. No reactive component. AVR holds steady with minimal correction. Does not challenge AVR response or exciter capacity. An accurate test of governor and prime mover only.



Quadrant plot of power flow with an example power triangle superimposed. The diameter of the circle represents the kVA. Radian line S from the center (origin) to the circle represents the phase angle (theta). The vertical line (axis) is the division in direction of power flow, right of the vertical axis is power out of the bus, left of the vertical axis is power into the bus. The horizontal line (axis) is the division between positive and negative reactive power flow. Above the horizontal axis is VAr's out of the bus, below the horizontal axis is VAr's into the bus. The power triangle shows how this four quadrant plot ties in with the power calculations, this would solve for a positive kVA, positive kW, and a positive kVAr load.



This image is of the faceplate of a vintage Westinghouse PI-161 phase angle meter. This is an actual piece of field equipment used for decades, now considered obsolete. Notice the faceplate divided into quadrants similar to the four quadrant plot. Also note the PF markings alongside the phase angle markings. This is a great historical piece that ties all of this conversation together into a real-world instrument. An analog phase angle meter is basically a synchroscope with a different faceplate and some additional circuitry for current.

Part 6 — Reactive Load Bank Types and Characteristics

Type	Power Factor	Characteristics	Typical Application
Inductive	Lagging (0.1–0.8 PF typical)	Iron core reactors. Simulates motor and transformer load. Fixed steps. Generates harmonics if iron saturates. Heavy and requires cooling.	AVR validation, motor load simulation, NFPA 110 reactive testing
Capacitive	Leading (0.1–0.9 PF typical)	Switched capacitor banks. Simulates lightly loaded cable systems. Less common in field commissioning.	UPS and data center reactive testing, leading PF validation
Combined (R+L or R+C)	Adjustable, lagging or leading	Most flexible. Can produce any combination of kW and kVAR independently. Best choice for commissioning.	Commissioning, full-system validation, complex PF testing

Part 7 — Portable Connection via Temporary Cable

Portable reactive load bank connection via temporary cable is the standard field method for generators that do not have a permanent load bank connection installed. The connection point is typically the generator output terminals, main breaker load side, or an available feeder breaker in the switchgear. The choice of connection point affects the test's validity and must be documented.

Cable Sizing — The Critical Step

Temporary cable must be sized for the full apparent current (kVA-based), not for the real power (kW-based) draw of the load bank. At 0.8 PF, sizing on kW alone will undersize the cable by 25%. The reactive current flows through the cable regardless of power factor. *At unity power factor, kW-based and kVA-based current calculations converge. At any power factor below unity, kVA-based current is higher and governs conductor ampacity.*

Size temporary cable for this current — derate for length, ambient, and bundling per NEC 310

$$I(\text{full load}) = (\text{kVA} \times 1000) \div (V(\text{LL}) \times 1.732) \quad \text{[3-phase]}$$

Connection Sequence

1	De-energize and lock out the connection point per facility Lock Out Tag Out (LOTO) procedure. Verify absence of voltage with properly rated test equipment.
2	Install temporary cable from load bank to connection point. Verify cable lug sizing, torque specs, and phasing. Label all connections clearly.
3	Verify load bank is set to zero output and all switches are open before removing LOTO.
4	Remove LOTO. Energize connection point if separate from generator output. Verify voltage at load bank input terminals before proceeding.
5	Verify generator is ready to start and that ATS is in test mode or bypassed as appropriate for the test plan.
6	Proceed with test sequence per applicable field card (Card 4, 5, 6, or 7).
7	On test completion: reduce load to zero, open load bank breaker, de-energize. Remove temporary cable in reverse order. Restore all equipment to normal. Verify ATS is out of test mode.

⚠ WARNING

Never connect or disconnect temporary cables under load. Never bypass safety interlocks. Verify that the temporary connection point has adequate short-circuit withstand rating for available fault current. Document the connection point and cable routing in the test record.

Part 8 — AVR and Exciter Behavior Under Reactive Load

The Automatic Voltage Regulator is a closed-loop control system. Its input is sensed terminal voltage; its output is exciter field current. Its job is to maintain terminal voltage at setpoint regardless of what load is connected. Under resistive load, this is straightforward. Under reactive load, it becomes a dynamic control problem.

What Happens When You Apply Lagging Load

When inductive load is applied, the generator's terminal voltage tends to drop due to the voltage drop across the stator reactance caused by reactive current. The AVR senses this drop, and commands increased exciter field current. The exciter responds by increasing the main field current, which restores terminal voltage. The speed and accuracy of this response determine the generator's voltage regulation performance.

Exciter Thermal Loading

The exciter supplies field-current to the main generator rotor. Under sustained lagging load, the exciter runs at higher output than under resistive load alone. Exciter winding temperature rises accordingly. A generator that operates within limits on a purely resistive load bank test may approach or exceed exciter thermal limits under the combined real and reactive load of an actual emergency condition. This is the operational risk that resistive-only testing does not reveal.

How dramatic is this difference? When a generator moves from full kilowatt loading at unity power factor (a resistive load bank test) to full kVA loading at its rated power factor of, for example, 0.8 lagging (what the machine actually sees in service), the exciter field current is commonly observed to increase on the order of 40 to 60 percent, depending on machine design and magnetic saturation. That is a 40–60% increase in the current flowing through the rotor field winding that a resistive-only test never sees, never measures, and never validates. Every amp of that increase produces I^2R heating in the rotor and exciter windings. If the exciter cannot sustain that current, or if the rotor winding insulation cannot handle the resulting temperature rise, you will not discover the problem until real inductive load transfers during an actual emergency. That additional heat is also ejected into the room via the generator cooling air. For unit mounted radiator cooled units, the heat ultimately flows through the engine cooling radiator, also affecting its ability to cool the engine.

AVR Stability and Hunting

An AVR with gain set too high will overcompensate — increasing excitation past what is needed, causing terminal voltage to overshoot, which then triggers a reduction in excitation, causing a new undershoot. This hunting or oscillation may be subtle under resistive load but become pronounced under reactive load where the control loop is working harder. Reactive load bank testing is the only way to observe and diagnose AVR stability under real operating conditions.

Part 9 — Interpreting Test Results

Observation: Voltage sags and does not recover when reactive load is applied

Likely cause / action: AVR gain too low, or exciter capacity insufficient. Check AVR sensitivity setting first. If increasing gain causes hunting, exciter may be the limiting factor. Consult OEM.

Observation: Voltage oscillates (hunts) under reactive load

Likely cause / action: AVR gain too high or damping too low. Reduce gain in small increments (typically 5–10% at a time). Allow stabilization between adjustments. Document all changes.

Observation: Voltage regulation good at low reactive load but degrades at high reactive load

Likely cause / action: Exciter approaching saturation or thermal limit. Could also indicate exciter winding degradation on an older machine. Record the kVAr level at which degradation begins — this is the effective reactive capacity of the machine.

Observation: Large voltage dip on step-load application but fast recovery

Likely cause / action: AVR response is good but gain may be slightly low. Check if dip exceeds connected equipment voltage tolerance. May be acceptable depending on application.

Observation: Voltage overshoot on load removal exceeds 15%

Likely cause / action: AVR is over-exciting during load removal. Check droop setting and AVR de-excitation response. Particularly important in hospitals where sensitive equipment cannot tolerate overvoltage.

Observation: Exciter field current continues to rise without terminal voltage recovery

Likely cause / action: Serious condition — potential loss of voltage control or field winding issue. Shut down immediately and consult OEM.

Observation: Voltage imbalance between phases that increases with reactive load (minimal or absent at no-load and light resistive load)

Likely cause / action: Possible open rotating rectifier diode in the brushless exciter. An open diode often goes undetected at light load because the remaining diodes can carry the reduced current. Under reactive load the exciter works harder, and the remaining diodes are overstressed — voltage imbalance becomes visible. Check phase-to-phase voltage balance (V-AB, V-BC, V-CA) at each load step. If imbalance exceeds 1% and increases with load, shut down and inspect the rotating rectifier assembly. Test all diodes — if one has failed, replace the entire set, as the remaining diodes have been carrying excess current and may be degraded.

Observation: Voltage runs high and AVR cannot regulate down to setpoint, or abnormal voltage waveform distortion is present

Likely cause / action: Possible shorted rotating rectifier diode. A shorted diode creates an uncontrolled excitation path, and the AVR may be unable to reduce field current sufficiently to maintain voltage setpoint. High voltage ripple may be reflected back through the exciter stator. If the AVR has an exciter diode monitor (EDM) function, check for alarm condition. Shut down and inspect the rotating rectifier assembly. A shorted diode can damage exciter rotor windings rapidly under load — do not continue testing if this condition is suspected.

Part 10 — Safety Considerations

WARNING

Reactive load bank testing involves high currents, high voltages, and rotating machinery. NFPA 70E arc flash analysis and PPE selection apply at every connection point. This section covers considerations specific to reactive testing — it does not replace your facility's electrical safety program or LOTO procedures.

Arc Flash

Perform or obtain arc flash analysis for the connection point. Select PPE per NFPA 70E for the available incident energy. Reactive load banks do not reduce arc flash hazard.

Cable Temperature

Temporary cables under sustained reactive load run hotter than their kW-only rating would suggest. Monitor cable temperature during extended tests. Keep cables off the ground if possible, to allow better heat dissipation.

Equipment Cooling

Inductive load banks generate heat in iron cores as well as resistive elements. Ensure adequate ventilation. Follow manufacturer's derate guidelines for ambient temperature.

Harmonic Content

Inductive load banks with iron cores can generate significant harmonics if operated near saturation. Operating equipment within voltage ratings reduces harmonic content. Harmonics can affect metering accuracy. Use true RMS instrumentation only.

Generator Cooling

A generator at full kVA loading at rated PF runs hotter than the same unit at full kW on resistive load. Monitor coolant and oil temperatures continuously. Allow full thermal stabilization before final data recording.

Transient Recovery

Voltage transients during step load tests can exceed connected equipment tolerance. Coordinate with the facility to protect sensitive loads before performing step-load tests.

Fuel

Extended reactive testing burns fuel at a slightly higher rate than a simple resistive test due to decreased generator efficiency — plan accordingly.

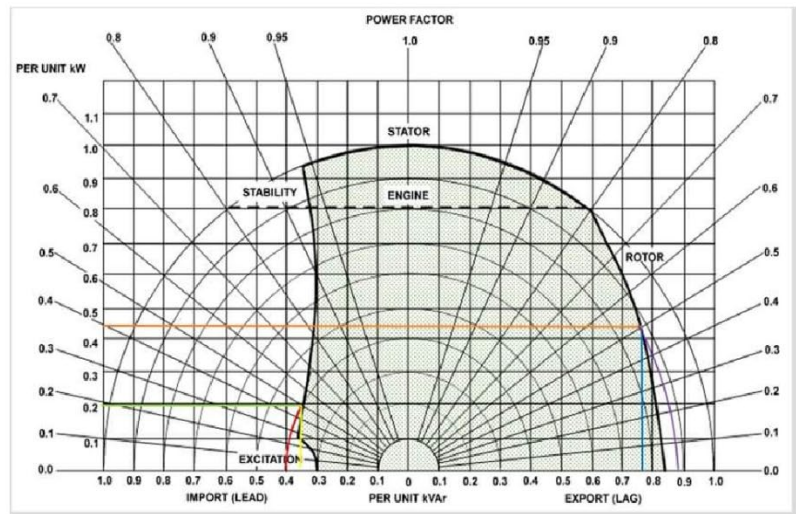
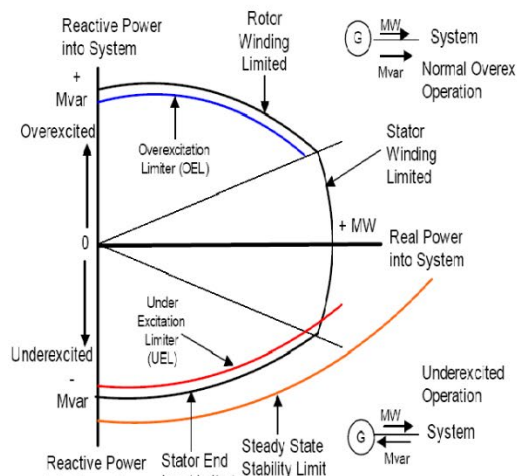
Part 11 — Understanding the Capability Curve

The capability curve (also called a reactive capability diagram or D-curve) is the single most important reference document for reactive load bank testing. It defines the safe operating envelope of a specific synchronous generator — the boundary between operating conditions the machine can sustain continuously and conditions that will cause thermal damage. Every technician performing reactive load bank testing should understand how to read one and how to plot their test point on it.

What the Capability Curve Shows

The capability curve is plotted on two axes. The horizontal axis is real power (kW or MW). The vertical axis is reactive power (kVAR or MVAR). The curve itself is a composite of three thermal limits drawn as arcs on this plot: the stator winding heating limit (the outermost arc, set by I^2R losses in the stator conductors), the rotor (field) winding heating limit (the arc on the lagging/upper side, set by the exciter and field winding thermal capacity), and the end-iron heating limit (the arc on the leading/lower side, relevant when the machine operates at leading power factor with reduced excitation). (Note that some manufacturers [Cummins] rotate the plot axis 90 degrees)

The intersection of these three arcs creates an irregular boundary. Any operating point inside this boundary is thermally safe for continuous operation. Any point outside it will result in overheating of the component whose limit is being exceeded.



These are examples of generator capability curves, the curve on the right is rotated 90 degrees. Looking at the left plot the center line is kW loading, and the surrounding envelope is the limit of the kVAR output. To use the plot, find your kW point on the center line and move straight out to the edge of the envelope, that is your kVAR limit at that kW load.

How to Use It During Testing

Before beginning a reactive load test, obtain the generator end part-number specific capability curve from the manufacturer's customer documentation package. Generic family curves are not acceptable — individual machine designs vary based on winding configuration, cooling system, and altitude/temperature derating. During the test, plot your measured kW and kVAR values as a point on the capability curve. This point should fall well inside the

boundary at every test condition. If your test point approaches or touches the boundary, you are at the machine's thermal limit for that operating condition.

Pay particular attention to the rotor heating limit when testing at lagging power factor (the normal condition for reactive load bank testing). As you increase kVAR demand, your operating point moves upward on the capability curve toward the rotor limit arc. If exciter field current begins rising without corresponding voltage recovery, you may be approaching this limit.

What to Look For

A healthy machine operating within its ratings will produce test points that fall comfortably inside the capability curve boundary at nameplate kW and kVAR. If test points consistently fall near the rotor heating limit at loads below nameplate rating, the exciter or field winding may be degraded. If the machine cannot reach nameplate power factor without approaching a thermal limit, document the actual achievable power factor — this is the effective capability of the machine regardless of what the nameplate says.

If no part-number specific capability curve was provided with the generator documentation, flag this as a documentation deficiency. Request the curve from the manufacturer. See Section 2 for specification language requiring this deliverable on new installations.

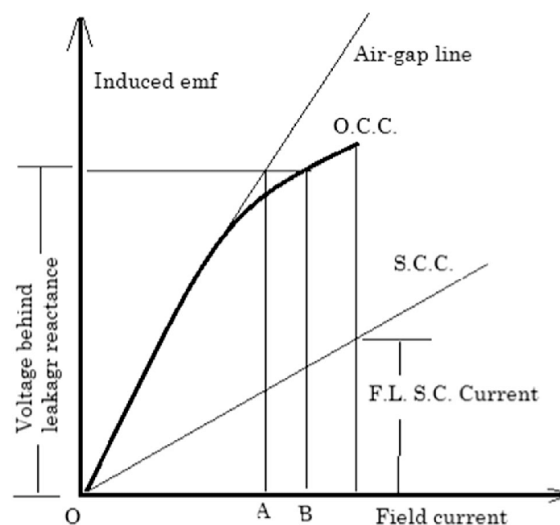
Part 12 — Understanding the Saturation Curve

The open-circuit saturation curve (OCC) (also called the no-load saturation curve or magnetization curve) plots the relationship between field current (horizontal axis) and terminal voltage (vertical axis) for a synchronous generator operating at rated speed with no load connected. It is the fundamental characterization of the machine's magnetic circuit and is essential for understanding excitation requirements and AVR behavior. The Short-Circuit Characteristic (SCC) plots the stator current against field current with a bolted short applied to the stator terminals. Full load short circuit (FLSC) is the sustained fault current the generator can produce.

The Air-Gap Line and the Knee

At low excitation levels, the relationship between field current and terminal voltage is nearly linear. This straight-line portion is called the air-gap line — it represents the voltage that would be produced if the iron in the machine had infinite permeability (no saturation). As field current increases, the iron in the stator and rotor begins to saturate magnetically. The actual voltage curve bends away from the air-gap line and flattens. The point where the curve begins to noticeably depart from the straight line is called the knee of the saturation curve.

Above the knee, each additional amp of field current produces progressively less additional terminal voltage. This has direct implications for AVR behavior: under heavy lagging load, the AVR must push the exciter harder and harder to maintain terminal voltage because the machine is operating in the saturated region of the curve. This is why exciter thermal limits become critical under reactive load — the exciter is working much harder per volt of regulation than it does in the linear region.



Saturation curve, horizontal axis is field current, vertical axis is voltage. The OCC is done with nothing connected to the load terminals, the SCC is done with a bolted three phase short applied to the terminals.

Comparing Field Data to Factory Curves

During commissioning (Card 6, Step 5), the open-circuit saturation curve check compares actual field performance to the manufacturer's factory test data. You are looking for the measured curve to closely match the factory curve. Significant deviations may indicate winding issues, air gap problems, or residual magnetism anomalies on a new machine. On an older machine being recommissioned, shifts in the saturation curve compared to the original data can indicate winding degradation or changes in the magnetic circuit.

⚠ CAUTION

The open-circuit saturation curve test requires driving the field current above the knee of the curve, which means operating the machine at above-rated terminal voltage. Do not exceed 110% of rated voltage unless the OEM procedure explicitly allows a higher value. Prolonged over-excitation risks overheating the rotor field winding and can damage stator core end laminations. On older or smaller machines, this risk is elevated. This test should be performed under OEM supervision during initial commissioning. It is not a routine field maintenance test. If the manufacturer did not provide a unit-specific saturation curve, request one — do not attempt to generate one in the field without OEM guidance.

If no part-number specific saturation curve was provided with the generator documentation, flag this as a documentation deficiency. See Section 2 for specification language requiring this deliverable.

NOTE — EXISTING EQUIPMENT

Capability curves and saturation curves may prove very difficult or impossible to obtain for existing equipment. If this documentation cannot be obtained, fall back to math calculations and do the best you can. Part load reactive loading limits will be impossible to accurately determine without the capability curve.

Part 13 — Capacitive Load Banks and Reverse VAr Protection Verification

Capacitive load bank testing is uncommon in routine generator maintenance but is critical in specific applications, particularly data centers with significant UPS capacitive power factor correction and facilities with large capacitor banks. The primary purpose of a capacitive load bank test is to verify the proper operation of the generator's reverse VAr (loss of excitation) protection relay under leading power factor conditions.

Why Capacitive Testing Matters

When a generator supplies leading power factor load (capacitive), the AVR must reduce excitation to maintain terminal voltage. If excitation is reduced too far, the machine risks losing synchronism — a potentially damaging condition for the generator and connected loads. The reverse VAr relay (device 32 or 40, depending on the protection scheme) is specifically designed to detect this condition and trip the generator before damage occurs.

The problem in practice is that reverse VAr relays are frequently set too conservatively by protection engineers who have never seen the relay tested under actual leading power factor conditions. An overprotective setting causes nuisance trips when the generator encounters a legitimate leading power factor transient — such as the load-side capacitor banks in a UPS system charging after a transfer. The result is a generator trip during the exact emergency condition it was installed to serve.

When to Specify Capacitive Testing

Capacitive load bank testing should be specified for any installation where the connected load includes significant capacitive correction (UPS systems, power factor correction capacitor banks, lightly loaded long cable runs), or where the generator protection scheme includes a reverse VAr or loss of excitation relay. The test verifies that the relay operates at the correct point on the capability curve — not so aggressively that it causes nuisance trips, and not so conservatively that it fails to protect the machine. See Card 8 for the test procedure and Appendix C for specification language.

Of the major load bank manufacturers, only a handful — Avtron, Simplex, Crestchic, and ULB — offer the full resistive-inductive-capacitive triad, reflecting the reality that capacitive load bank capability remains a specialized and relatively recent market segment driven largely by data center demand.

SECTION 2 – FOR ENGINEERS AND FACILITY MANAGERS

Training and Technical information on why reactive load bank testing should be included in specifications for new and existing standby generators.

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Why Reactive Load Bank Testing Belongs in Your Specification

If you are an engineer specifying a new generator installation, or a facility manager responsible for the reliability of an existing standby power system, this section explains why reactive load bank testing should be part of your commissioning and maintenance requirements — and what you risk by omitting it.

The Gap in Current Practice

NFPA 110 establishes minimum generator testing requirements expressed in kilowatts (kW). Reactive load bank testing is not required by NFPA 110 for compliance. The procedures described in this document represent recommended engineering practice intended to validate AVR performance, exciter capability, and voltage regulation beyond the minimum code compliance threshold.

NFPA 110 specifies a minimum load expressed in kilowatts. It does not mandate reactive loading. This means a generator can pass every code-required annual test with a purely resistive load bank and receive a compliance certificate while its Automatic Voltage Regulator (AVR) response is untested, its exciter thermal capacity is unknown, and its voltage regulation under the actual load conditions it will face in an emergency has never been verified.

The loads that transfer to emergency power in a commercial or industrial facility are overwhelmingly inductive: motors, transformers, UPS systems, and variable frequency drives. These loads demand reactive (magnetizing) current in addition to the real power that does useful work. A resistive load bank tests the engine and governor. It does not test the electrical machine — the generator, the exciter, and the AVR that must maintain voltage under reactive current demand.

To put a number on this gap: when a generator moves from full kilowatt loading at unity power factor (the resistive load bank test condition) to full kVA loading at its rated power factor of 0.8 lagging (the actual service condition), the exciter field current typically increases by 40 to 60 percent, and possibly more depending on the machine design. That increase translates directly to additional I^2R heating in the rotor field winding and exciter — heating that a resistive-only test never produces, never measures, and never validates. A generator can pass a resistive load bank test with comfortable thermal margins while its exciter is incapable of sustaining the field current required to maintain voltage under actual inductive load.

The Cost of Discovery During an Emergency

An AVR that hunts under lagging load, an exciter that cannot sustain field current under combined real and reactive demand, or a voltage regulator loop that becomes unstable when large motors start — these are conditions that only manifest under reactive loading. If the first time a generator experiences real-world reactive load is during an actual emergency, the consequences range from voltage excursions that damage sensitive equipment to complete loss of voltage and a generator trip while critical loads are on the bus.

The cost of discovering these problems during commissioning or scheduled maintenance testing is measured in load bank rental fees and technician hours. The cost of discovering them during an actual emergency is measured in damaged equipment, interrupted operations, and — in Level 1 (life safety) installations — potentially in lives.

Motor Starting and Generator Voltage Stability — Why Oversizing Is Not Always the Answer

Motor starting represents one of the most demanding transient events a standby generator will experience. Unlike resistive loads, which place a straightforward demand on the generator's real power output, motors draw a large inrush current at the moment of starting that is primarily reactive in nature. This inrush — typically four to six times the motor's full load current — places an immediate demand on the generator's excitation system to maintain terminal voltage while the motor accelerates to running speed.

The generator's ability to ride through this event without excessive voltage dip depends heavily on two factors: the subtransient reactance of the alternator, and the capability of the excitation system to force maximum field current into the alternator at the moment it is needed most.

The Shunt Excitation Problem

Many generator sets use shunt excitation, meaning the automatic voltage regulator and exciter draw their power directly from the main stator output terminals. This creates a fundamental vulnerability during motor starting: at the exact moment the excitation system needs to push maximum field current to recover terminal voltage, the

voltage dip caused by motor inrush reduces the power available to the exciter. The result is a system that chases voltage recovery rather than leading it.

This limitation has historically led specifying engineers to oversize the generating unit, reasoning that a larger alternator with lower subtransient reactance will experience a smaller voltage dip for the same motor starting event. While this approach can work, it addresses the symptom rather than the cause, and introduces its own complications including poor load factor operation, increased fuel consumption, and in diesel applications, elevated risk of wet stacking at light loads.

Excitation System Alternatives

Modern generator sets offer excitation system options that largely eliminate the shunt excitation vulnerability:

- **Permanent Magnet Generator (PMG):** A dedicated PMG provides exciter power independent of terminal voltage, allowing the AVR to maintain full field forcing throughout the voltage dip event.
- **Current Transformer (CT) Boost:** Uses load current rather than terminal voltage as the excitation power source, providing increased exciter output precisely when motor starting current is highest.
- **Auxiliary DC Supply:** Used on larger systems, provides a fully independent excitation power source immune to terminal voltage variations.
- **Field Forcing:** The percentage of field current over-boost the excitation system will deliver above rated field current during a transient voltage event. Higher field forcing capability allows the AVR to push harder into a motor starting dip, accelerating voltage recovery. Note that field forcing is typically time-limited by the AVR to prevent thermal damage to the exciter field windings.

When any of these options is specified, the generator supplier can often meet a demanding motor starting voltage dip requirement with a properly sized unit rather than an oversized one. The specification is the mechanism that opens that conversation.

Putting Accountability Where It Belongs

The most effective approach is to specify the required performance outcome — a maximum allowable voltage dip during starting of the largest identified motor — and require the supplier to demonstrate compliance in the submittal. This places the burden of proof on the party with the engineering tools and product knowledge to evaluate it correctly.

For this approach to work, the engineer of record must provide a complete load schedule as part of the procurement package, including identification of the largest motor, its starting method, and the assumed connected load condition at the time of start. A specification issued without this information cannot be evaluated by the supplier and will not produce a meaningful compliance demonstration.

Refer to Appendix C for recommended specification language implementing this approach.

What to Require in Your Specification

At minimum, the Owner or Engineer of Record should require the following for commissioning and acceptance testing: a reactive load bank test at nameplate power factor for a minimum of 2 hours, demonstrating stable voltage regulation within $\pm 2\%$ of rated under combined real and reactive load; AVR validation per Card 6 of this document, with documented step-load response and transient recovery; and for installations with automatic paralleling switchgear, a reactive load sharing verification per Card 9.

For ongoing maintenance, specify an annual reactive load bank test in addition to the NFPA 110 kW-based minimum. This annual test does not need to be as comprehensive as the commissioning test, but it must verify that the AVR, exciter, and voltage regulation system continue to perform as commissioned.

Require Generator End Part Number Specific Curves in Customer Documentation

Your specification must require the manufacturer to provide a generator end part-number specific capability curve and a part-number specific open-circuit saturation/short-circuit characteristic curve as part of the customer documentation package. These curves must be generated from factory test data on the specific generator end part-number of the machine being delivered — not from generic family curves for the product line. Generic curves represent a typical machine of that model family. Your machine may differ based on winding configuration, cooling

system options, and manufacturing variation. Without design-specific curves, field technicians have no baseline to validate their test data against, and the capability curve — the safe operating envelope — is unknown.

Expect pushbacks from manufacturers on this requirement. Some will claim that generic curves are adequate, or that design-specific testing adds cost and lead time. Hold firm. The capability curve and saturation curve are the two documents that define what your specific machine can and cannot do. Without them, reactive load bank testing is being performed without a map.

Optional: Reverse VAR Protection Verification

For installations where the connected load includes significant capacitive power factor correction (data centers with UPS systems, facilities with power factor correction capacitor banks), consider specifying a capacitive load bank test to verify the reverse VAR (loss of excitation) relay settings. This test, described in Card 8, verifies that the relay will not cause nuisance trips during legitimate leading power factor transients while still protecting the machine against actual loss of excitation. If you are unsure whether your installation warrants this test, consult with your protection engineer.

See [Appendix C](#) for sample specification language that can be copied directly into your bid documents.

NOTE — UNDEREXCITED OPERATION AND GENERATOR DESIGN

The ability of a generator end to operate in the underexcited region is a function of its design. Utility scale generators are often constructed with robust underexcited operating areas because the underexcited region is used to absorb reactive power and control power system voltage under light load conditions. These machines incorporate stator core end-region design features (stepped end laminations, flux shields, enhanced end-region cooling) and lower synchronous reactance to extend the stable underexcited operating boundary. Amortisseur (damper) windings provide additional dynamic stability margin when operating near the underexcited limit. These are not typically specifiable options on an industrial standby generator, but the information is included for reference.

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Appendix A - FIELD QUICK REFERENCE CARDS

Print the card(s) that apply to your job. Each card is self-contained.

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CARD 1 – REACTIVE LOAD BANK FIELD REFERENCE CARD

Quick-reference for test execution — see full document for theory and diagnostics

Before you start

- 1. Confirm generator is at normal operating temperature — run at least 30 min on resistive load first
- 2. Confirm fuel level is adequate for full test duration
- 3. Confirm coolant temp and oil pressure are in normal range before adding reactive load
- 4. Verify load bank is set to inductive (lagging) mode — not resistive only
- 5. Record starting voltage at generator terminals — all three phases

Test sequence

- 1. Apply resistive load to 100% kW rating — allow to stabilize (5 min minimum)
- 2. Begin adding reactive (inductive) load in steps — do not jump to full reactive load at once
- 3. At each step, pause and allow voltage and frequency to stabilize before adding more
- 4. Record voltage, current, and power factor reading at each step
- 5. Hold at full combined load (kW + kVAR) for duration specified — minimum 2 hours per NFPA 110
- 6. Remove reactive load first, then resistive load — never drop all load at once
- 7. Allow cool-down run at no load — minimum 5 min before shutdown

What to watch during the test

- Voltage — should remain steady, not hunting up and down
- Frequency — should hold steady at 60 Hz; minor variation is normal during step changes
- Coolant temperature — rising slowly is normal; rapid rise or approaching red zone is not
- Oil pressure — should remain stable throughout
- Exhaust — increasing smoke on reactive load addition may indicate AVR or exciter issue
- Power factor reading — confirm it is lagging (inductive), not leading

Pass / Fail

PASS • Voltage stays within $\pm 5\%$ of rated • Frequency holds at 60 Hz ± 0.5 Hz steady state • No alarms or shutdowns during test • Coolant temp stable within normal range • Power factor reads lagging throughout	FAIL • Voltage hunts continuously or dips below $\pm 5\%$ • Generator cannot accept full reactive load • Any protective shutdown occurs • Power factor drifts to leading (capacitive) • Coolant or oil alarm activates
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STOP THE TEST IMMEDIATELY IF — • Voltage collapses and does not recover within 10 seconds of a load step • Any engine alarm (high temp, low oil pressure) activates • Unusual noise, vibration, or smell from generator or load bank • Any protective relay trips
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Reactive Load Bank Field Reference v1.1 — Appendix A | Full theory, AVR diagnostics, and NFPA 110 compliance detail in main document

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CARD 2 – FORMULA QUICK REFERENCE

All formulas used in this document — voltage agnostic

POWER TRIANGLE

Formula	Description
$S = \sqrt{P^2 + Q^2}$	Apparent power from real and reactive
$P = S \times PF$	Real power from apparent power and PF
$Q = \sqrt{S^2 - P^2}$	Reactive power from apparent and real
$Q = P \times \tan(\theta)$	Reactive power from real power and phase angle
$PF = P \div S = \cos(\theta)$	Power factor
$\theta = \cos^{-1}(PF)$	Phase angle from power factor (see calculator note in Part 1)
$P = Q / \tan(\theta)$	Real power from reactive power and phase angle
$S = Q / \sin(\theta)$	Apparent power from reactive power and phase angle
$\sin(\theta) = Q / S$	Sine of phase angle from reactive and apparent power
$\tan(\theta) = Q / P$	Tangent of phase angle from reactive and real power

CURRENT

Formula	Description
$I = (kVA \times 1000) \div (V(LL) \times \sqrt{3})$	3-phase full-load current (amps)
$I = (kVA \times 1000) \div V(LN)$	Single-phase full-load current (amps)
$I = (kW \times 1000) \div (V(LL) \times \sqrt{3} \times PF)$	3-phase current from kW and PF
$Q = \sqrt{3} \times V(LL) \times I \times \sin(\theta)$	3-phase reactive power (VAR) from voltage, current, and phase angle

COMMON PF VALUES

Formula	Description
PF 0.8 lagging: $\theta = 36.87^\circ$	$\tan(\theta) = 0.75 \rightarrow Q = 0.75 \times P$
PF 0.85 lagging: $\theta = 31.79^\circ$	$\tan(\theta) = 0.62 \rightarrow Q = 0.62 \times P$
PF 0.9 lagging: $\theta = 25.84^\circ$	$\tan(\theta) = 0.484 \rightarrow Q = 0.484 \times P$
PF 1.0: $\theta = 0^\circ$	$Q = 0$ — purely resistive, no reactive component

GENERATOR DERATING

Formula	Description
Altitude > 1000 ft:	Derate ~3.5% per 1000 ft above 1000 ft (verify OEM spec)
Ambient > 104°F (40°C):	Derate per OEM — typically 1% per °C above 40°C

CARD 3 – REACTIVE FUNDAMENTALS POCKET REFERENCE

The math your resistive load bank training skipped

THE POWER TRIANGLE

Term	What It Means
Apparent Power (S)	kVA — what the generator is actually supplying. The hypotenuse of the triangle. Set by winding thermal limits.
Real Power (P)	kW — the resistive component. Does work. What your kWh meter reads. Limited by prime mover output.
Reactive Power (Q)	kVAr — inductive/capacitive component. Real current, real heating, zero net work. Supplies magnetizing current to motors and transformers.
Power Factor (PF)	$\cos(\theta)$ — ratio of kW to kVA. Unity (1.0) = purely resistive. 0.8 lagging = typical motor/transformer load.

KEY FORMULAS

Formula	Use
$S = \sqrt{P^2 + Q^2}$	Apparent power from real and reactive
$Q = \sqrt{S^2 - P^2}$	Reactive power from apparent and real
$PF = P \div S = kW \div kVA$	Power factor
$Q = P \times \tan(\theta)$	Reactive power from real power and angle
$kVA = kW \div PF$	Apparent power from real power and PF
$Q = \sqrt{3} \times V(LL) \times I \times \sin(\theta)$	Reactive power from measured voltage, current, and phase angle
$\tan(\theta) = Q / P$	Quick check: ratio of reactive to real power

WORKED EXAMPLE — 500 kVA GENERATOR AT 0.8 PF LAGGING

Nameplate Rating	500 kVA
Power Factor	0.8 lagging
Real Power (kW)	$500 \times 0.8 = 400 \text{ kW}$
Reactive Power (kVAr)	$\sqrt{500^2 - 400^2} = 300 \text{ kVAr}$
Resistive load bank covers:	400 kW — the kW portion ONLY
Reactive load bank needed:	300 kVAr at 0.8 PF to fully load the machine
What resistive-only testing misses:	AVR response, exciter response, voltage regulation under reactive current, winding heating under full-load

THE NUMBER THAT MATTERS:

In this example, moving from full kW at unity PF (the resistive load bank test) to full kVA at 0.8 PF lagging (actual service conditions), the exciter field current typically increases by 40 to 60% — possibly more depending on machine design and magnetic saturation. That is a 40–60% increase in rotor heating that a resistive-only test never sees. If the exciter or field winding cannot sustain it, you will find out during the emergency, not during the test.

LEADING vs. LAGGING — QUICK GUIDE

Condition	What It Means
Lagging PF	Inductive load — motors, transformers. Current lags voltage. Generator must supply magnetizing current. AVR increases excitation. Most common field condition.
Leading PF	Capacitive load — lightly loaded cables, capacitor banks. Current leads voltage. AVR reduces excitation. Risk of loss of excitation if not controlled.
Unity PF	Purely resistive — heating elements, resistive load banks. No reactive component. AVR holds steady. Accurate test of governor and prime mover only — does not challenge AVR or exciter.

CARD 4 – NFPA 110 LEVEL 1 REACTIVE LOAD TEST

Loss of power could result in loss of life or serious injury — hospitals, surgical suites, life safety systems

Reactive load bank testing is recommended as the best practice for Level 1 systems due to the consequences of failure. It is not a code-mandated requirement unless specified by the Authority Having Jurisdiction (AHJ) or the project specification.

⚠ WARNING

Level 1 testing typically allows little tolerance for undocumented deviations. AHJ sign-off is required. Ensure your documentation package is complete before starting. Notify facility management and affected departments before any test that transfers critical loads.

NFPA 110 LEVEL 1 — MINIMUM TEST REQUIREMENTS

Requirement	Detail
Monthly operational test	30 minutes minimum at $\geq 30\%$ nameplate kW rating
Annual load test	2 hours minimum at $\geq 30\%$ nameplate kW rating
Reactive test requirement	NFPA 110 specifies kW loading. Resistive-only testing does not validate AVR response, voltage regulation under reactive current, or exciter capability. Reactive testing is best practice for Level 1 systems.
Supplemental load bank	Required when monthly test cannot reach 30% from facility load alone. Document facility load and load bank contribution separately.
Transfer time	Must be documented. Normal: ≤ 10 seconds for Level 1. Verify ATS operation is included in test protocol.

PRE-TEST CHECKLIST — LEVEL 1

Obtain signed facility management authorization	☐
Notify AHJ and schedule inspection if required	☐
Confirm load bank kVAr rating matches test requirement	☐
Verify temporary cable sizing for full test current (kVA-based, not kW-based)	☐
Confirm portable load bank is calibrated and meters verified	☐
Review generator nameplate: kVA, kW, PF, voltage, frequency	☐
Verify AVR setpoints are documented and accessible	☐
Confirm ATS test mode and transfer sequence with facility engineer	☐
Verify fuel level — minimum 8 hours run time recommended for Level 1	☐
Brief all personnel — confirm communication plan	☐

Verify all critical loads accounted for in load sequencing	
Document ambient temperature and altitude (affects derating)	

TEST SEQUENCE — LEVEL 1 REACTIVE LOAD TEST

1	Start generator and allow to stabilize at no-load for a minimum of 5 minutes. Record no-load voltage and frequency. <i>Accept: Voltage $\pm 2\%$ of rated, Frequency ± 0.5 Hz of rated</i>
2	Apply 25% resistive load. Record V, Hz, kW, kVAR, PF, and coolant temp at 5-minute intervals. Allow to thermally stabilize.
3	Increase to 50% resistive load. Record same parameters. Allow to thermally stabilize.
4	4a. With the generator at 50% resistive load from Step 3, increase resistive load to 100% of nameplate kW rating. Allow to stabilize and record V, Hz, kW, kVAR, PF, and coolant temp at this resistive-only full-kW load point. 4b. With the generator at 100% nameplate kW resistive load, apply inductive (lagging) reactive load to bring the combined power factor to nameplate rating (typically 0.8 PF lagging). The machine is now at full kVA at rated PF — this is the condition that validates the AVR, exciter, and complete machine. Note: NFPA 110 requires a minimum of $\geq 30\%$ of nameplate kW. That is the code minimum, not the test target. A reactive test at only 30% kW will not adequately stress the exciter or reveal AVR stability problems. <i>The reactive component is in addition to the resistive load — total kVA draw must reflect nameplate PF</i>
5	Hold at test load for a minimum of 2 hours (annual) or 30 minutes (monthly). Record V, Hz, kW, kVAR, PF, kVA, coolant temp, oil pressure, and exhaust temp every 15 minutes.
6	Observe and document AVR behavior. Voltage should remain within $\pm 2\%$ of rated under steady state reactive load. Note any hunting, instability, or step response anomalies.
7	Remove reactive load first, then reduce resistive load in steps. Do NOT drop full load simultaneously — observe for voltage overshoot. <i>Record voltage immediately after each load step reduction</i>
8	Allow generator to run at no-load for a minimum of 5 minutes before shutdown.
9	Document all findings. Complete test record form. Note any deviations from expected performance.

PASS / FAIL CRITERIA — LEVEL 1

Unless explicitly adopted by the Authority Having Jurisdiction, Owner, or Engineer of Record, the acceptance criteria in this document are provided for guidance only and do not constitute enforceable code requirements.

Parameter	Accept	Investigate	Fail
Voltage regulation (steady state)	$\pm 2\%$ rated	$\pm 3\%$	$> \pm 5\%$
Frequency regulation (steady state)	± 0.5 Hz	± 1 Hz	$> \pm 2$ Hz
Voltage transient on load application	$\leq 15\%$ dip, recovery ≤ 3 sec	15–25% dip	$> 25\%$ dip or no recovery
Voltage overshoot on load removal	$\leq 15\%$ above rated	15–20%	$> 20\%$
AVR hunting / instability	None observed	Minor, self-correcting	Sustained oscillation
Coolant temp (at full-load)	Within nameplate limits	Within 10°F of limit	Exceeds nameplate limit

CARD 5 – NFPA 110 LEVEL 2 REACTIVE LOAD TEST

Failure is less critical to life safety but impacts operations — offices, parking, non-critical facilities

Reactive load bank testing is recommended as the best practice for Level 2 systems due to the consequences of failure. It is not a code-mandated requirement unless specified by the Authority Having Jurisdiction (AHJ) or the project specification.

NOTE: Level 2 requirements are similar in structure to Level 1 but with more flexibility in pass/fail criteria and documentation. AHJ requirements vary by jurisdiction — verify locally. The reactive test protocol below represents best practice, not code minimum.

NFPA 110 LEVEL 2 — MINIMUM TEST REQUIREMENTS

Requirement	Detail
Monthly operational test	30 minutes minimum
Annual load test	2 hours at ≥30% nameplate kW rating
Key difference from Level 1	Consequences of failure are less severe. AHJ sign-off requirements and documentation depth vary by jurisdiction. Transfer time tolerance may be ≤60 seconds vs. ≤10 seconds for Level 1.
Reactive test	Same best-practice rationale as Level 1 — code minimum is kW-based, but reactive testing validates the whole machine, not just the prime mover.

PRE-TEST CHECKLIST — LEVEL 2

Obtain facility management authorization (written preferred)	
Verify load bank kVA rating matches test requirement	
Confirm temporary cable sizing for full test current	
Review generator nameplate: kVA, kW, PF, voltage, frequency	
Document AVR setpoints before test	
Verify ATS operation — confirm transfer sequence	
Verify fuel level — minimum 4 hours run time recommended	
Brief affected personnel and confirm communication plan	
Document ambient temperature and altitude	

TEST SEQUENCE — LEVEL 2 REACTIVE LOAD TEST

1	Start generator and stabilize at no-load for a minimum of 5 minutes. Record no-load voltage and frequency.
2	Apply 25% resistive load. Stabilize and record V, Hz, kW, kVA, PF.

3	Increase to 50% resistive load, or to a combined load that will allow reactive addition to reach $\geq 30\%$ of nameplate kW at target PF.
4	4a. With the generator at 50% resistive load from Step 3, increase resistive load to 100% of nameplate kW rating. Stabilize and record V, Hz, kW, and PF at this resistive-only full-kW load point. 4b. With the generator at 100% nameplate kW resistive load, apply inductive (lagging) reactive load to bring the combined power factor to nameplate rating (typically 0.8 PF lagging). The machine is now at full kVA at rated PF. NFPA 110 minimum is $\geq 30\%$ of nameplate kW — that is the code floor, not the test target.
5	Hold at test load for a minimum of 2 hours (annual) or 30 minutes (monthly). Record V, Hz, kW, kVAr, PF, kVA, and coolant temp every 15 minutes.
6	Observe AVR behavior under sustained reactive load. Document any voltage excursions or instability.
7	Remove reactive load first, then step down resistive load. Record voltage behavior at each step.
8	Run at no-load for 5 minutes then shut down. Complete test record.

PASS / FAIL CRITERIA — LEVEL 2

Unless explicitly adopted by the Authority Having Jurisdiction, Owner, or Engineer of Record, the acceptance criteria in this document are provided for guidance only and do not constitute enforceable code requirements.

Parameter	Accept	Investigate	Fail
Voltage regulation (steady state)	$\pm 3\%$ rated	$\pm 5\%$	$> \pm 7\%$
Frequency regulation (steady state)	± 1 Hz	± 1.5 Hz	$> \pm 2$ Hz
Voltage transient on load application	$\leq 20\%$ dip, recovery ≤ 5 sec	20–30% dip	$> 30\%$ dip or no recovery
AVR hunting / instability	None observed	Minor, self-correcting	Sustained oscillation
Coolant temp (at full-load)	Within nameplate limits	Within 15°F of limit	Exceeds nameplate limit

CARD 6 – AVR / VOLTAGE REGULATOR VALIDATION

Confirms the AVR can regulate voltage under reactive load — the test a resistive load bank cannot perform

NOTE: The AVR's job is to maintain terminal voltage regardless of load power factor. A resistive-only test never challenges the AVR's ability to supply magnetizing current to inductive loads. This card tests that capability directly.

WHAT YOU ARE TESTING

Concept	Explanation
AVR function	Senses terminal voltage and adjusts exciter field current to maintain setpoint. Under lagging load, terminal voltage tends to drop — AVR must increase excitation to compensate.
Droop setting	Intentional percentage of voltage drop with load, used for load sharing in parallel operation. Typically 2–5%. Verify this matches nameplate/spec before testing.
Reactive droop compensation	Allows generators in parallel to share reactive load proportionally. Testing a single unit: disable if present or document its effect.
Stability adjustment	AVR gain and damping settings affect response speed vs. hunting tendency. Critical to document before and after any adjustment.

INSTRUMENTATION RECOMMENDED

True RMS voltmeter/multimeter — with traceable calibration. Do not use average-responding meter.	
Power analyzer capable of reading kW, kVAr, kVA, PF, and Frequency simultaneously, optional fourth channel to measure exciter field current desirable.	
Oscilloscope or power quality analyzer recommended for transient capture	
Calibrated Clamp-on ammeter (true RMS) for current verification, a current probe for multimeter is acceptable.	
Generator exciter field current meter (if accessible) key indicator of AVR workload (hall effect DC clamp on ammeter)	
Thermographic camera if available — exciter and AVR heat signatures under load	

AVR VALIDATION TEST SEQUENCE

1	Document all AVR nameplate data and current setpoint settings before touching anything. Photograph the AVR panel.
2	Start generator. Record no-load voltage at all three phases. Confirm voltage balance within 1%. Adjust AVR setpoint if required and document final no-load voltage.
3	Apply 50% resistive load. Record V (all phases), Hz, kW, PF. Confirm AVR is holding voltage within ±2%.
4	Maintaining the 50% resistive load from Step 3, introduce reactive (inductive/lagging) load in 25% kVAr steps until the combined power factor reaches nameplate rating (typically 0.8 PF lagging) at this kW level. At each step, allow 2

	minutes to stabilize, then record V, Hz, kW, kVAr, kVA, PF, and exciter field current if measurable. This is the initial AVR stress test at partial load. <i>This is the primary AVR stress test — watch for voltage droop, hunting, or slow response</i>
5	Increase resistive load to 100% nameplate kW. Adjust reactive load to maintain nameplate PF (typically 0.8 PF lagging). The machine is now at full kVA at rated PF. Hold for 15 minutes. Confirm voltage remains stable and within $\pm 2\%$ of setpoint.
6	Perform a step-load application: from 25% to 75% of nameplate kVA at nameplate PF in a single step. Record voltage transient, recovery time, and frequency dip. <i>Use oscilloscope or power quality analyzer if available — transient response is a key AVR health indicator</i>
7	Perform a step-load removal: from 75% to 25% kVA in a single step. Record voltage overshoot and recovery time.
8	Remove all reactive load, then all resistive load. Record no-load voltage — compare to initial reading.
9	Document all findings, AVR settings, and any adjustments made. Note any instability, hunting, or abnormal behavior observed.

ADVANCED TECHNIQUE — EXCITATION SYSTEM STRESS TEST AT PARTIAL LOAD

With a generator end part number specific capability curve, it is possible to perform a dedicated excitation system stress test without reaching full nameplate kW. At 25 to 50% resistive load, locate the rotor field heating limit boundary on the capability curve at the corresponding point on the kW axis. Read the kVAr value at that boundary point. Reduce that kVAr value by 10 to 15 percent to establish a safety margin — this is your reactive load target.

At this operating point, the kVA calculation will show that total current is well below full nameplate amperes, but the excitation system is at or near its rated thermal limit. The calculated power factor will be very low (well below nameplate PF). This technique fully loads the exciter and field winding while the prime mover operates at partial load — useful when a full-kW resistive load bank is unavailable, or when the objective is specifically to validate exciter capability independent of prime mover capacity.

This technique requires the generator end part-number specific capability curve. Without it, the rotor field heating limit at partial load is unknown, and exceeding that limit risks damage to the exciter and field windings. Do not attempt this test using generic product-line curves.

AVR RED FLAGS — STOP AND INVESTIGATE

⚠ WARNING

Sustained voltage oscillation (hunting) under reactive load — indicates AVR stability/gain problem. Do not continue test. Voltage that does not recover within 5 seconds after step load application — indicates AVR or exciter capacity issue. Exciter field current that increases without limit under lagging load — indicates loss of voltage control. Shut down immediately.

CARD 7 – GENERATOR / EXCITER COMMISSIONING

New installation or major overhaul — first reactive load test

⚠ CAUTION

Commissioning testing is not routine maintenance. Involve the OEM or authorized service representative. This card provides field guidance for the reactive portion of commissioning — it does not replace the manufacturer's commissioning procedure.

COMMISSIONING SEQUENCE — REACTIVE PHASE

1	Confirm all mechanical commissioning is complete: alignment, coupling, cooling system fill, lubrication, protection relay settings verified.
2	Confirm AVR initial settings per manufacturer spec. Document all potentiometer positions / digital settings before energizing.
3	Megger test stator windings before first start — document insulation resistance values. Polarization Index (PI) should be ≥ 2.0 for most machines. Consult OEM for minimum acceptable values.
4	Perform no-load run and voltage buildup test. Verify voltage builds smoothly to setpoint. Record build-up time, no-load voltage, and frequency at no load.
5	Perform open-circuit saturation curve check if test equipment allows, and OEM supervision is available — plot terminal voltage vs. field current. Compare to factory test data if available. CAUTION: Do not exceed 110% of rated voltage. Over-excitation risks rotor winding damage and stator end-iron heating. This test should be performed under OEM supervision on initial commissioning only — it is not a routine maintenance test. See Part 12 for detailed guidance.
6	Apply resistive load in 25% steps to full kW rating. Record V, Hz, kW, PF at each step. Confirm voltage regulation.
7	After completing the full resistive load test in Step 6, reduce resistive load to 50% of nameplate kW. From this 50% kW base, begin applying reactive (inductive/lagging) load in 10% kVAr steps until the combined power factor reaches nameplate rating (typically 0.8 PF lagging) at this kW level. Monitor exciter temperature closely during initial reactive loading. <i>First reactive loading of a new exciter requires careful monitoring — thermal behavior may differ from steady-state ratings</i>
8	With reactive load established at nameplate PF at the 50% kW level, increase resistive load to 100% of nameplate kW. Adjust reactive load as needed to maintain nameplate PF. The machine should now be at full kVA at rated PF. Hold for 30 minutes minimum. Monitor all temperatures, voltage stability, and exciter performance.
9	Perform step-load test: apply a single step from 25% to 75% of nameplate kVA at nameplate PF. Record voltage transient, recovery time, and frequency dip. Then remove from 75% to 25% kVA in a single step. Record voltage overshoot and recovery time.
10	If machine will operate in parallel, perform reactive load sharing test with parallel unit to validate reactive droop compensation settings.
11	Complete commissioning record. Document all settings in final as-built form. Photograph AVR panel settings. File with permanent equipment records.

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CARD 8 – CAPACITIVE LOAD BANK / REVERSE VAR PROTECTION VERIFICATION

Verifies reverse VAr relay settings under actual leading power factor conditions — the test that prevents nuisance trips during real emergencies

⚠ CAUTION

Capacitive load bank testing intentionally drives the generator toward under-excitation. This test must be coordinated with the protection engineer and the OEM. Do not disable the reverse VAr relay during testing — the purpose of the test is to verify its operation. Ensure all personnel understand the trip sequence before beginning. Have an emergency shutdown procedure in place.

WHAT YOU ARE TESTING

The reverse VAr (loss of excitation) relay protects the generator from operating in a dangerously under-excited condition. Under leading power factor load, the AVR reduces excitation. If the relay setting is too aggressive, it will trip the generator on legitimate leading PF transients (nuisance trip). If too conservative, it fails to protect against actual loss of excitation. This test verifies the relay operates at the correct threshold.

PRE-TEST REQUIREMENTS

Obtain relay manufacturer settings sheet and current setpoints. Document the relay type, model, pickup setting (VAr or impedance), and time delay. Obtain the unit-specific capability curve — the relay operating point should correspond to the end-iron (leading PF) heating limit on the capability curve. Confirm the capacitive load bank has sufficient kVAr rating. Coordinate with protection engineer and OEM before testing.

TEST SEQUENCE — REVERSE VAR VERIFICATION

1. Start generator and stabilize at no-load. Record baseline voltage, frequency, and exciter field current.
2. Apply 25–50% resistive load to establish a stable operating point. Record V, Hz, kW, PF, and exciter field current.
3. Maintaining the resistive load from Step 2, begin applying capacitive (leading) load in small steps (10–15% of rated kVAr per step). At each step, allow 2 minutes to stabilize. Record V, Hz, kW, kVAr, kVA, PF, and exciter field current.
4. Observe the AVR reducing excitation as leading kVAr increases. The exciter field current should decrease progressively. This is the normal response to capacitive load.
5. Continue increasing capacitive load until either (a) the reverse VAr relay operates (trips the generator), or (b) you reach the planned test limit agreed upon with the protection engineer and OEM. Do NOT push beyond the agreed limit.
6. If the relay trips, record the exact kW, kVAr, kVA, and PF at the moment of trip. Plot this point on the capability curve. Verify it falls at or near the end-iron heating limit.
7. If the relay trips at a power factor well above (less leading than) the expected threshold, the relay is overprotective and should be coordinated with the protection engineer for adjustment. Document the actual trip point and the recommended setting.
8. After relay operation or test completion, allow the generator to reset. Restore to no-load operation for 5 minutes before shutdown. Complete all documentation.

ACCEPTANCE CRITERIA

The reverse VAr relay should operate at a point that corresponds to the end-iron heating limit on the unit-specific capability curve, plus an appropriate margin (typically 10–15% inside the limit). A relay that trips at kVAr values significantly less than this threshold is overprotective and will cause nuisance trips during real emergency transfers with capacitive load. A relay that does not trip at or near the expected threshold may fail to protect the machine. Both conditions require coordination with the protection engineer.

Nothing in this document is intended to reinterpret or supersede NFPA 110. Final acceptance criteria and test requirements remain subject to AHJ approval.

CARD 9 – PARALLEL REACTIVE LOAD SHARING VERIFICATION

Verifies that paralleled generators share reactive load proportionally — critical for automatic paralleling switchgear installations

WHAT YOU ARE TESTING

When generators operate in parallel, they must share both real power (kW) and reactive power (kVAr) proportionally. Real power sharing is controlled by governor droop. Reactive power sharing is controlled by reactive droop compensation (also called quadrature droop or cross-current compensation). If reactive droop is mismatched between paralleled units, one generator will hog reactive load while the other runs under-excited. This can cause the over-excited unit to overheat its exciter while the under-excited unit risks loss of excitation. On automatic paralleling gear, this can happen without operator awareness.

REACTIVE DROOP — WHAT IT IS

Reactive droop is an intentional voltage reduction proportional to reactive current output. It ensures that when two paralleled generators see a reactive load increase, both respond proportionally rather than one machine trying to supply all the reactive current. Typical settings are 2–5% voltage droop from no-load to full reactive load. The setting must match between paralleled units (within 0.5% or per OEM specification) for proper sharing.

Cross-Current Compensation (CCC)

Cross-current compensation is an alternative (and in many modern paralleling systems, the preferred) method for achieving reactive load sharing. Instead of using voltage droop — which inherently reduces terminal voltage as reactive load increases — CCC uses current transformers on each generator to measure the reactive component of each machine's output. The CCC circuit compares the reactive current of each unit and feeds a correction signal into the AVR to equalize reactive sharing without the voltage droop penalty.

The advantage of CCC is tighter voltage regulation — the bus voltage remains at setpoint regardless of reactive loading because there is no intentional droop. The disadvantage is that traditional analog CCC requires physical wiring between the paralleled AVRs (the cross-current CT loop), which means it only works for generators that are permanently wired for parallel operation. It does not work for ad-hoc paralleling of portable units.

Network-Based Digital Load Sharing

Modern microprocessor-based digital AVRs (such as the Basler DECS-250 and similar products from other manufacturers) can perform reactive load sharing over Ethernet or RS-485 communication networks, eliminating the need for both physical CT loops and burden resistors. Each AVR measures the reactive current of its own generator, broadcasts that measurement to all other AVRs on a dedicated peer-to-peer network and compares its reactive output to the group total. The sharing algorithm adjusts excitation automatically to equalize the proportional reactive contribution of each machine. This approach provides the tight voltage regulation of CCC with the wiring simplicity of droop — no inter-unit CT wiring is required, only an Ethernet or RS-485 communication cable between AVRs. Network-based sharing is increasingly common on containerized data center generator installations where multiple packaged gensets operate in parallel. It is not yet typical on standard standby installations, but as digital AVRs become standard, this technology will become more prevalent.

Before Testing: Identify the Installed Method

Determine which reactive load sharing method is installed before beginning the test. The test procedure (Steps 1–8 below) is the same regardless of method — what changes is the adjustment approach when sharing is out of balance. For reactive droop systems: adjust droop percentage per Steps 5–6. For traditional CCC systems: verify CT loop wiring, CT polarity, and CCC gain calibration on the AVR. An incorrectly wired CCC CT will cause reactive load to diverge rather than converge — one machine will drive to full excitation while the other drops to minimum. This is a dangerous condition requiring immediate correction. For network-based digital sharing: verify Ethernet/RS-485 communication between AVRs, confirm load share ID settings, and check sharing algorithm

parameters in the AVR configuration software. Some modern digital AVRs support multiple sharing modes configurable in software — verify the active mode before testing.

TEST SEQUENCE — PARALLEL REACTIVE SHARING

1. Start both (or all) generators and synchronize onto the common bus per the paralleling switchgear procedure. Confirm stable parallel operation at no-load.
2. Apply 50% resistive load. Verify kW sharing is proportional (within 5% of each unit's rating). Record V, Hz, kW per unit.
3. Maintaining the 50% resistive load from Step 2, apply reactive (inductive/lagging) load in 25% kVAr steps. At each step, record kW, kVAr, kVA, PF, and exciter field current for each unit individually.
4. At each step, calculate the kVAr share percentage for each unit. Both units should carry kVAr proportional to their nameplate kVAr rating (within 10% tolerance or per OEM specification).
5. If one unit is hogging reactive load (carrying significantly more kVAr than its proportional share), its reactive droop setting is likely too low relative to the other unit. Increase its droop setting in small increments (0.5% at a time) and retest.
6. If one unit is shedding reactive load (carrying significantly less than its share), its droop setting is too high. Decrease in small increments and retest.
7. Repeat the adjustment and verification cycle (Steps 3–6) until kVAr sharing is within tolerance. Once balanced, reduce load to 25%, then increase back to 75% in a single step to verify the sharing remains stable under a load transient. Then hold at full load at nameplate PF for a minimum of 15 minutes to confirm thermal stability and sustained sharing accuracy.
8. Document final settings for each unit — droop percentage if using reactive droop, or CCC gain and CT wiring configuration if using cross-current compensation. Record the kVAr share percentage for each unit at the final test load point. These become the as-commissioned baseline. Photograph all AVR panels, droop potentiometers, and/or CCC configuration screens for each unit. File with permanent equipment records.

SYMPTOMS OF MISMATCHED REACTIVE DROOP

One unit running at high exciter field current while the other runs low. Diverging kVAr readings between units under the same load. One unit showing signs of overheating (high winding temperature) while the other runs cool. VAR circulating between generators (one generating kVAr while the other absorbs it) with low net kVAr delivery to the load. These conditions may not be apparent under resistive-only testing because resistive load sharing does not depend on reactive droop settings.

ACCEPTANCE CRITERIA

kVAr sharing between paralleled units should be proportional to nameplate kVAr rating within 10% at all tested load levels. No unit should show exciter field current more than 15% above its expected value at any test point. Reactive droop settings should match within 0.5% between units (or per OEM specification). No circulating VAR current between generators.

TEMPORARY CABLE SIZING — PORTABLE LOAD BANK

The portable load bank draws real current at a power factor below unity. Cable must be sized for full apparent power (kVA) current, not just kW.

Use this for cable sizing — NOT the kW-based calculation

$$I = \text{kVA} \times 1000 \div (V(\text{LL}) \times \sqrt{3}) \quad \text{[3-phase full-load current]}$$

$$I = \text{kVA} \times 1000 \div V(\text{LN}) \quad \text{[single-phase full-load current]}$$

NOTE: Example: 500 kVA load bank at 480V 3-phase: $I = (500 \times 1000) \div (480 \times 1.732) = 601 \text{ A}$. Size temporary cable for 601 A continuous, derate for length and ambient. Do not size based on kW alone — reactive current flows in the cable regardless of whether useful work is being done.

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APPENDIX B – TECHNICAL REFERENCE

Handy Printable Forms and Reference Cards for Field Technicians

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Recommended Test Instrumentation — Formal NFPA 110 Documentation

For routine load bank testing, a clamp meter and the test record forms in this appendix are sufficient. However, for facilities requiring formal NFPA 110 Level 1 documentation — hospitals, data centers, water treatment, and other critical infrastructure — a dedicated power quality recorder provides a significantly higher standard of defensible documentation.

The Fluke 1773/1775/1777 series represents the current standard for this application. The 1777 specifically offers continuous time-stamped logging of voltage, current, power factor, and frequency across all three phases simultaneously, with transient capture capability that records load step events automatically. A fourth current channel can be configured with a Hall effect DC clamp probe to simultaneously monitor field excitation current behavior correlated against AC output — providing direct visibility into AVR response during reactive load steps.

The practical value in a critical facility context is straightforward: if a facility ever experiences an incident and the generator's test history is called into question, a power quality recorder file is a court-admissible instrument record. A technician's handwritten log is not.

Note: The Fluke 1777 is a capital instrument investment appropriate for generator service companies performing formal NFPA 110 work at critical facilities. It is not required for routine commissioning or periodic testing where standard test documentation is acceptable.

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UNIT DATA SHEET

Fill in before starting any test — one sheet per unit

GENERATOR IDENTIFICATION	
Facility name:	
Location / building:	
Equipment ID / tag:	
Manufacturer:	
Model number:	
Serial number:	
Date of manufacture / installation:	
NAMEPLATE DATA	
Rated kVA:	
Rated kW:	
Rated power factor:	
Rated voltage (phase-phase):	
Rated current (full-load amps):	
Rated frequency (Hz):	
Temperature rise class:	
NFPA 110 classification (Level 1 / Level 2):	
AVR INFORMATION	
AVR manufacturer / model:	
Voltage setpoint (no-load):	
Droop setting (%):	
Stability / gain settings:	
TEST CONDITIONS	
Test date:	
Technician:	
Ambient temperature (°F):	
Altitude (ft):	
Load bank manufacturer / model:	
Load bank rating (kW / kVAr):	
Calibration certificate date:	

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NFPA 110 ACCEPTANCE CRITERIA SUMMARY

Quick reference — verify against current edition and local AHJ

NOTE: This summary reflects NFPA 110 general requirements. Local amendments and AHJ interpretation may impose stricter requirements. Always verify with the current adopted code edition for your jurisdiction.

Requirement	Level 1	Level 2
Consequence of failure	Loss of human life or serious injury	Less critical — operational impact
Monthly operational test	30 minutes minimum	30 minutes minimum
Annual load test duration	2 hours minimum	2 hours minimum
Minimum load level	≥30% of nameplate kW rating	≥30% of nameplate kW rating
Transfer time	≤10 seconds	≤60 seconds (verify AHJ)
Voltage regulation (steady state)	±2% rated (best practice)	±3% rated (best practice)
Frequency regulation	±0.5 Hz (best practice)	±1.0 Hz (best practice)
AHJ sign-off	Required	Varies by jurisdiction
Reactive loading required by code	No — kW-based minimum only	No — kW-based minimum only
Reactive loading recommended	Yes — validates AVR, exciter, full machine	Yes — best practice for any critical application

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TEST RECORD FORM

Record readings at each test point — attach to job file

NOTE: Record readings at every 15-minute interval during hold period. Add rows as needed.

Time	kW	kVAr	kVA	PF	V-AB	V-BC	V-CA	Hz	FC (DC A)	Coolant °F	Oil PSI	Notes

Observations / Anomalies / Actions Taken:

Test performed by:

Reviewed by:

AHJ / Witness (Level 1):

Date: _____

Date: _____

Date: _____

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APPENDIX C – SPECIFICATIONS FOR ENGINEERS AND FACILITY MANAGERS

Copy and paste into your bid documents to include reactive load testing in your specifications.

AUTHORITY HAVING JURISDICTION (AHJ) NOTICE — SCOPE AND INTENT

This appendix contains **sample specification language** describing recommended engineering practices for reactive load bank testing of standby and emergency generators. These specifications are intended to be **owner-driven contractual requirements** and are not intended to reinterpret, expand, or supersede the minimum requirements of **NFPA 110** or any other adopted code or standard.

NFPA 110 establishes minimum generator testing requirements expressed in **kilowatts (kW)**. Reactive load bank testing is **not required by NFPA 110** for compliance unless specifically adopted by the **Authority Having Jurisdiction (AHJ)** or incorporated into the project specifications by the Owner or Engineer of Record. The procedures and acceptance criteria described herein represent **recommended best practice** intended to validate generator electrical performance — including Automatic Voltage Regulator (AVR) response, exciter capability, voltage regulation, and reactive load sharing — beyond the minimum code compliance threshold.

Final determination of test scope, duration, loading profile, acceptance criteria, documentation requirements, and witness requirements remains solely with the **AHJ**, the Owner, and the Engineer of Record. Where conflicts exist between these specifications and adopted codes, standards, or AHJ directives, the **AHJ's interpretation shall govern**.

Sample Specification Language

The following specification paragraphs may be copied and adapted for inclusion in generator procurement and commissioning bid documents. Modify voltage, power factor, and duration values to match your specific installation requirements.

SPECIFICATION 1 — COMMISSIONING REACTIVE LOAD BANK TEST

The Contractor shall perform a reactive load bank test as part of generator commissioning and acceptance testing. The test shall demonstrate stable voltage regulation under combined resistive and inductive loading at the rated power factor shown on the generator nameplate. The combined load shall be maintained for a minimum of two (2) hours. Voltage regulation shall remain within $\pm 2\%$ of rated terminal voltage under steady-state conditions. Voltage transient on step-load application shall not exceed 15% dip with recovery to within 2% of rated within 3 seconds. The Contractor shall provide calibrated test instrumentation with current traceable calibration certificates. Test results shall be documented per the test record form included in this specification and submitted as part of the commissioning record.

SPECIFICATION 2 — ANNUAL REACTIVE LOAD BANK MAINTENANCE TEST

The Contractor shall perform an annual reactive load bank test to verify continued proper operation of the Automatic Voltage Regulator (AVR), exciter, and voltage regulation system. The test shall apply combined resistive and reactive load to achieve the rated nameplate power factor. The combined load shall be maintained for a minimum of thirty (30) minutes. Acceptance criteria shall match the commissioning test criteria. Any degradation from commissioning baseline performance shall be documented and reported to the facility manager with recommended corrective action.

SPECIFICATION 3 — MANUFACTURER DOCUMENTATION REQUIREMENTS

The generator manufacturer shall provide the following documentation as part of the customer documentation package. Generic product-line curves are not acceptable — all curves must be generated from factory test data for the specific generator end part-number being delivered:

- a) Generator end part-number specific capability curve (reactive capability diagram / D-curve) showing the stator heating limit, rotor heating limit, and end-iron heating limit plotted on kW vs. kVAr axes, with the rated operating point clearly marked.
- b) Generator end part-number specific open-circuit saturation curve showing terminal voltage vs. field current at rated speed and no load, with the air-gap line and rated voltage operating point clearly marked. It should also include short-circuit characteristic curve plotting stator current against field current with stator short applied.
- c) Factory test report documenting all electrical measurements taken during the manufacturer's production test, including no-load voltage, full-load voltage regulation at rated power factor, and (if performed) full-load short-circuit data.

SPECIFICATION 4 — REVERSE VAR PROTECTION VERIFICATION (OPTIONAL)

Where the connected load includes capacitive power factor correction equipment (UPS systems, power factor correction capacitor banks, or other sources of leading power factor), the Contractor shall perform a capacitive load bank test to verify proper operation of the reverse VAr (loss of excitation) protection relay. The test shall progressively increase leading reactive load until the relay operates or the pre-agreed test limit is reached. The relay operating point shall be documented and plotted on the unit-specific capability curve. The relay operating point shall fall within 10–15% inside the end-iron heating limit. If the relay operates at a point significantly inside this margin (overprotective), the protection engineer shall coordinate new relay settings and the test shall be repeated to confirm proper operation.

SPECIFICATION 5 — PARALLEL REACTIVE LOAD SHARING (WHERE APPLICABLE)

For installations with multiple generators configured for automatic parallel operation, the Contractor shall perform a reactive load sharing verification test during commissioning. The test shall demonstrate that all paralleled units share reactive load proportionally to their nameplate kVAr ratings within 10% tolerance at all tested load levels. Reactive droop settings shall be documented for each unit in the as-built commissioning record. The Contractor shall demonstrate stable reactive load sharing at nameplate power factor for a minimum of fifteen (15) minutes.

SPECIFICATION 6 — GENERATOR VOLTAGE STABILITY DURING MOTOR STARTING

The generator kW rating shall be determined by the engineer of record based on connected load calculations. The supplier shall demonstrate that the specified unit meets the voltage dip performance requirement through excitation system selection, alternator subtransient reactance, or a combination thereof. If compliance cannot be achieved with the specified kW rating, the supplier shall identify this in the bid submittal along with the minimum rating required to meet the performance specification.

For Owner/Engineer Responsibilities

The engineer of record shall provide the following information as part of the generator procurement package:

1. A complete load schedule identifying all connected loads, including motor loads with horsepower, voltage, starting method (across-the-line, reduced voltage soft start, or variable frequency drive), and full load amperes.
2. Identification of the single largest motor load and its starting method.
3. The assumed connected load condition at the time of largest motor start. The engineer shall specify whether this represents a worst-case fully loaded condition or a defined partial load scenario.

Note: The load schedule is a required attachment to the generator specification. Specifications issued without a load schedule do not provide sufficient information for the supplier to demonstrate voltage dip compliance and may result in bids that do not meet the intent of the specification.

Generator Supplier Responsibilities

The generator supplier shall demonstrate that the proposed generating set maintains terminal voltage above [XX]% of nominal voltage during starting of the largest identified motor with the specified connected load condition present. Compliance shall be demonstrated by one of the following methods:

1. Engineering calculation using the generator subtransient reactance and motor starting kVA, submitted with the bid package.
2. Factory test data from a comparable unit configuration.

The supplier submittal shall include:

- Excitation system type (shunt excited, permanent magnet generator, current transformer boosted, or auxiliary DC supply)
- Available field forcing percentage above rated field current, and the time limit applied by the AVR to prevent thermal damage to the exciter field windings
- Subtransient reactance (X''_d) of the proposed alternator
- Any conditions under which the voltage dip specification cannot be met without a unit upgrade or excitation system change

Note: Permanent magnet generator (PMG) excitation and current transformer (CT) boosted excitation systems significantly improve voltage recovery during motor starting by maintaining exciter power independent of terminal voltage collapse. Specifiers are encouraged to evaluate these options as an alternative to unit oversizing where motor starting loads are the governing design condition.

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REACTIVE LOAD BANK TESTING

Field Reference & Technical Guide

Brad Panike
NERC Certified Senior System Operator (Retired)
Kilovar Substack — kilovar1959.substack.com
LinkedIn — linkedin.com/in/brad-panike-198b0834

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