

White paper

Advanced tools for data center commissioning of critical systems

A measurement-driven approach to operational readiness, resilience, and lifecycle performance in hyperscale, AI, and Colocation data centers

Executive summary

Data center commissioning verifies that highly interconnected electrical, mechanical, cooling, controls, networking, and life-safety systems operate together as intended before live workloads are placed at risk. The goal is to demonstrate reliable facility performance under normal operations, maintenance conditions, utility disturbances, equipment failures, and emergency events, while meeting the owner's requirements for availability, resilience, safety, and sustainability.

Commissioning risk is increasing as data centers become denser, more modular, and more dependent on high-power AI and GPU workloads. Higher voltages, greater power density, liquid cooling, and accelerated hyperscale construction schedules create more opportunities for installation defects, configuration issues, unsafe conditions, and performance gaps. These conditions make precise, repeatable, well-documented testing essential throughout each commissioning phase.

With a foundation in precision measurement, calibration, and mission-critical applications, Fluke instruments help commissioning teams generate accurate, traceable data for acceptance — evidence that a facility is ready to transition to operations. That discipline is especially valuable in hyperscale environments, where commissioning records become the baseline for long-term operations, predictive maintenance, resiliency planning, and performance optimization.

This paper follows the commissioning lifecycle from factory verification through installation readiness, startup, functional testing, integrated systems testing, and long-term operational baselines — identifying the risks each phase addresses, the measurements that matter most, and where disciplined testing turns one-time acceptance data into a lasting operational asset.



In this paper

The commissioning sequence runs from Factory Acceptance Testing (FAT) through construction verification, pre-functional testing, Functional Performance Testing (FPT), and Integrated Systems Testing (IST) to the operational baseline:

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Commissioning scope and standards

A defined commissioning scope gives every stakeholder — owner, contractor, integrator, and operator — a shared understanding of what will be tested, to what standard, and who is accountable for the result. Establishing that scope early, before construction verification begins, reduces disputes over acceptance criteria, prevents gaps between design intent and installed reality, and gives the operations team a documented foundation to build on after turnover.

Commissioning scope

At a minimum, a commissioning scope document should:

- **Validate owner requirements:** Confirm that the facility meets capacity, redundancy, maintainability, safety, monitoring, and operational goals.
- **Reduce operational risk:** Discover defects, coordination gaps, sequence issues, and documentation errors before turnover.
- **Demonstrate integrated performance:** Prove that electrical, mechanical, controls, life-safety, security, and IT-supporting systems operate together under normal, maintenance, and failure scenarios.
- **Prepare the operations team:** Provide training, procedures, asset data, test records, and system manuals required for stable operation.
- **Create defensible evidence:** Establish a documented record of acceptance criteria, test results, deficiencies, corrective actions, and final readiness.

Critical systems in scope

No system operates in isolation: cooling must support the IT load, life-safety and security systems must function under both normal and emergency conditions, and the supporting IT infrastructure must be in place before any of it matters. Major systems typically in scope include:

- **Electrical:** Utility service, switchgear, UPS systems, batteries, generators, power distribution units, remote power panels, grounding, protection coordination, metering, and power monitoring.
- **Mechanical:** Chillers, cooling towers, pumps, computer room air handler (CRAH)/computer room air conditioner (CRAC) units, fan walls, economizers, containment, liquid-cooling support systems, humidification, leak detection, and thermal controls.
- **Controls and monitoring:** Building management systems (BMS), data center infrastructure management (DCIM) systems, electrical power monitoring systems, alarms, trend logging, dashboards, notification pathways, and sequence integration.
- **Life safety and security:** Fire alarm, suppression, emergency power-off interfaces, access control, CCTV, emergency lighting, and evacuation-related systems.
- **IT support infrastructure:** Network pathways, structured cabling, environmental sensors, rack power monitoring, and interfaces required for operational visibility.

Standards that guide commissioning

Commissioning standards give a structured methodology for ensuring facilities are designed, installed, tested, and operated in accordance with the owner's project requirements. Standards vary by organization and region, but they generally emphasize documented requirements, staged verification, integrated testing, and operational readiness. ASHRAE Guidelines 0 and 1.1, for example, provide commissioning process and HVAC/mechanical procedures respectively — they don't cover electrical or network systems, and related ASHRAE guidance such as TC9.9 and Standard 90.4 is design-focused rather than commissioning-specific.



Table 1. Summary of key commissioning standards

Standards and guidelines	Purpose	Relevance to data centers
ASHRAE Guideline 0	Overall commissioning process guidelines	Establishes the framework for planning, verification, testing, and turnover.
ASHRAE Guideline 1.1	HVAC and mechanical commissioning procedures	Widely used for cooling systems, controls, and instrumentation — not applicable to electrical or network systems.
NFPA 70 (NEC)	U.S. electrical installation requirements	Ensures safe installation of power systems in U.S. jurisdictions.
IEC 60364	International low-voltage electrical installation standard	Generalized international equivalent to NFPA 70; national codes such as BS 7671 (UK) implement it locally.
NFPA 70B	Electrical equipment maintenance	Supports baseline testing and reliability programs.
NFPA 110	Emergency and standby power systems	Applicable to generators, transfer switches, and backup power.
TIA-942	Telecommunications infrastructure standard for data centers	Addresses redundancy, cabling, and availability considerations.
ISO/IEC 11801-5	Generic cabling for customer premises — data centers	International equivalent providing cabling infrastructure requirements.
Uptime Institute Tier Standard	Tier certification methodology	Verifies topology, maintainability, and fault tolerance.
ISO/IEC 50600 series	International/European standard for data center design, construction, and operation	Four parts: (1) general concepts — availability and risk classification; (2) design and infrastructure — building, power, cooling, security; (3) operations and management — maintenance and disaster planning; (4) key performance indicators, including LinkIQ™ power usage effectiveness (PUE).
ISO 50001	Energy management systems	Supports energy performance and sustainability initiatives.
EU Energy Efficiency Directive (EED)	EU energy-efficiency requirements and reporting	Mandatory legal requirement for covered facilities operating in the EU.

Regional equivalents exist in most markets — for example BS 7671 in the UK, and comparable national electrical and data center codes in Japan, Australia, and Singapore. Global projects should confirm the applicable local code alongside these references.

Factory acceptance testing

Factory Acceptance Testing (FAT) is the earliest opportunity to catch deficiencies before equipment reaches the site. Validating performance in a controlled manufacturing environment — with equipment energized under load — lets project teams reduce commissioning risk, avoid costly field rework, and establish baseline measurements for later comparison against installed and operational performance.

Electrical equipment commonly subject to FAT includes transformers, medium-voltage switchgear, UPS systems, battery energy storage systems, diesel or gas turbine backup generators, and control panels. Once this equipment is energized under factory load-bank testing, key measurements include voltage stability, harmonic distortion, transfer sequences, synchronization events, thermal baselines, and battery conductance.

Thermal imaging, power quality analysis, and battery diagnostics performed while equipment is energized give integrators, commissioning teams, and owners a documented factory baseline — evidence that can later be compared against site and operational measurements to confirm nothing changed in transit or installation. Table 2 summarizes the equipment, measurements, and Fluke technologies most relevant to this phase.



Table 2. Fluke technologies supporting factory acceptance testing

Equipment	Typical measurements	Recommended Fluke technologies
Transformers	Winding insulation resistance, grounding and earth resistance, phase rotation, voltage validation, thermal baselines, infrared inspection, partial discharge inspection	1587 FC Insulation Multimeter, 1625-2 Ground Tester, 1777 Power Quality Analyzer, 1738 Power Logger, TiX580 Thermal Camera, ii915 Acoustic Camera
Medium-voltage switchgear	Infrared inspection, breaker verification, partial discharge inspection	TiX580 Thermal Camera, ii915 Acoustic Camera
UPS systems	Total harmonic distortion (THD), transients, voltage stability, infrared inspection for high-resistance connections, acoustic inspection for partial discharge or micro-arcing	1777 Power Quality Analyzer, 1738 Power Logger, ii915 Acoustic Camera
Battery energy storage systems (BESS)	Battery conductance, DC/AC current, internal resistance, voltage and ripple, thermal anomalies	BT521 Battery Analyzer, Ti480 PRO Thermal Camera, TiX580 Thermal Camera — where appropriate for the battery chemistry and scale in use
Diesel or gas turbine backup generators	Load profiling, voltage stability, output quality, harmonic distortion, load-transfer transients, synchronization, transient response	1777 Power Quality Analyzer, 1738 Power Logger, TiX580 Thermal Camera, ii915 Acoustic Camera

Field example: IR windows as a factory-installed advantage

IR windows are not typically part of the factory acceptance test itself, but system integrators can add lasting value by installing them into switchgear before shipment. This reduces the need to modify energized equipment in the field, supports faster periodic inspections, and enables safer thermography surveys later in the equipment's life.

Without IR windows, technicians performing infrared inspections must open each energized switchgear cabinet — a task that typically requires two qualified personnel for safety, followed by closing the cabinet before moving to the next one.

That process is slow, labor-intensive, and increases exposure to energized equipment. Installing the windows at the factory removes that burden from every future maintenance inspection, improving safety, shortening inspection time, and lowering long-term maintenance cost.

Construction verification and installation readiness

Once FAT confirms equipment performs as designed, commissioning moves to the installed environment. Construction verification confirms that equipment, cabling, grounding, piping, and controls have been assembled correctly — in accordance with approved drawings, manufacturer recommendations, and project specifications — before energization or the introduction of fluids.

Electrical verification reduces risk from incorrect wiring, grounding deficiencies, loose terminations, protection-setting errors, and communication failures. Typical activities include phase rotation confirmation, grounding assessment, breaker coordination review, cable verification, and Supervisory Control and Data Acquisition (SCADA) communication checks — confirming that equipment conditions are measured, alarmed, displayed, and recorded correctly.

Where energized checks are appropriate, thermal and acoustic imaging can expose abnormal heating or leaks that visual inspection would miss.

Mechanical and cooling verification includes calibrating pressure and temperature transmitters, checking flow instrumentation and control loops, testing control valves, flushing cooling loops, and detecting leaks before fluid is introduced. Vibration analysis on newly installed pumps can detect early signs of imbalance, misalignment, looseness, or bearing wear — establishing a baseline before sustained operation.

Table 3 summarizes the systems, activities, and Fluke technologies supporting construction verification. Deficiencies found and corrected at this stage — before energization or fluid introduction — are the least expensive and least disruptive to fix anywhere in the commissioning lifecycle.



Table 3. Fluke technologies supporting construction verification

System	Commissioning activities	Recommended Fluke technologies
Utility substations	Phase rotation, grounding, breaker verification, thermal imaging (energized checks only)	1777 Power Quality Analyzer, TiX580 Thermal Camera, 1630-2 FC Clamp Ground Tester, ii915 Acoustic Camera
Transformers	Winding insulation resistance, grounding and earth resistance, phase rotation, voltage validation (line to line, line to ground, line to neutral), thermal baselines, infrared inspection, partial discharge inspection	1587 FC Insulation Multimeter, 1625-2 Ground Tester, 1777 Power Quality Analyzer, 1734 and 1738 Power Logger, TiX580 Thermal Camera, ii915 Acoustic Camera
Switchgear	Infrared inspection, bus connections, acoustic imaging for partial discharge (energized checks only)	TiX580 Thermal Camera, ii915 Acoustic Camera
Grounding systems	Ground resistance measurement	1625-2 Ground Tester, 1630-2 FC Clamp Ground Tester
Cooling systems	Pressure and temperature verification of transducers, valve testing, 4 to 20 mA control loop testing, closed-loop liquid -cooling leak detection	729/729Pro Pressure Calibrators, 754 Documenting Process Calibrator, 710 mA Loop Valve Tester, 773 mA Process Clamp Meter, ii915 Acoustic Camera
Fire suppression systems	Pressure testing validation with dry compressed air or nitrogen before halon, CO2, or other suppression gas is pressurized in the final system	Ii915 Acoustic Camera
Motors and pumps	Diagnosing imbalance, misalignment, looseness, and bearing wear	805 FC Vibration Meter, 832 Laser Shaft Alignment Tool
Network systems	Certification and continuity testing	DSX-8000 CableAnalyzer, CertiFiber Max™, LinkIQ™

Field example: Finding leaks before the system is wet

Every piping connection, valve, fitting, and manifold in a chilled-water or liquid-cooling system should be verified before that system is placed into service — a leak discovered after the system is filled can mean draining sections of piping, replacing fluid, and repeating pressure tests, all of which add cost, delay, and risk.

One effective approach is to temporarily pressurize completed piping with clean, dry compressed air before filling the system. As air escapes through a defective fitting, weld, or joint, it produces ultrasonic sound that's inaudible to the human ear but detectable with an acoustic camera.

The Fluke ii915 Acoustic Camera converts that sound into a real-time visual image overlaid on the equipment being inspected, letting a technician scan large sections of piping from a safe distance and pinpoint a leak's exact location.

Compared to traditional soap-and-bubble testing — which requires physically accessing and inspecting every joint by hand — acoustic imaging lets one technician cover far more ground in far less time, while flagging only the joints that need repair. On a hyperscale project with thousands of mechanical joints, that difference compounds quickly.

The same technique applies to dry-pipe fire suppression systems, which use pressurized nitrogen and can develop slow leaks during both commissioning and ongoing operations. Finding those leaks early — during commissioning, and again during routine preventive maintenance — helps maintain proper system pressure, avoids unplanned nitrogen replenishment, and reduces the risk of inadvertent system activation.



Field example: Validate transformers and switchgear connections

For every transformer, electrical installers perform live-dead-live testing to validate the correctness of electrical connections, checking line-to-line, line-to-ground, line-to-neutral, phase rotation, and voltage for three-phase circuits on every transformer and switchgear unit installed. In hyperscale data centers, electrical installers must run hundreds of thousands of these tests.

With the 1734 Power Logger, users can reduce the workflow up to two-thirds, expediting the testing and entire project.



Pre-functional testing and system startup

With construction verification complete, pre-functional testing confirms that equipment is ready to be energized, started, controlled, and safely placed into service. This phase bridges installation verification and operational testing by proving that devices, sensors, valves, and controls are prepared for startup — before commissioning moves into the more complex Functional Performance Testing (FPT) and Integrated Systems Testing (IST) phases.

Liquid cooling for AI workloads has increased the risk here. Cooling distribution units (CDUs), rear-door heat exchangers, manifolds, and direct-to-chip cooling systems all depend on accurately calibrated pressure, temperature, humidity, and valve-position instrumentation to maintain thermal stability — and a miscalibrated sensor at this stage can look like a system failure later.

Pressure calibrators, process calibrators, and valve testers verify that instrumentation and control loops report accurate field conditions, while vibration and alignment checks on rotating equipment catch imbalance, misalignment, and bearing issues before sustained operation. Separating these basic device- and signal-level issues from higher-level system performance problems here makes startup troubleshooting faster and keeps simple field deficiencies from consuming time during FPT and IST.

Functional performance testing

With startup readiness established, Functional Performance Testing (FPT) evaluates whether individual electrical, mechanical, cooling, and controls systems operate as intended under expected operating conditions — demonstrating compliance with design intent and owner requirements.

Electrical commissioning teams analyze harmonic distortion, imbalance, waveforms, transients, frequency deviations, voltage sags and surges, UPS transfer events, generator synchronization, battery readiness, and transformer conditions. As AI workloads increase electrical loading dynamics, harmonic behavior during GPU startup events and variable-load conditions matter more than ever.

Mechanical testing validates chilled-water systems, containment strategies, cooling distribution units, CRAH units, rear-door heat exchangers, and fire suppression interfaces. Thermography verifies GPU inlet temperatures, rear-door heat exchanger operation, CDU performance, and pipe insulation integrity, while temperature instrumentation confirms delta T across cooling loops. Commissioning teams also validate flow rates, differential pressure, filter condition, pump vibration, and the calibration of the instrumentation behind those readings.



Table 4. Fluke technologies supporting functional performance testing

Test activity	Primary measurements	Recommended Fluke technologies
UPS testing	THD, ride-through, transients	1777 Power Quality Analyzer
Battery validation	Conductance, internal resistance, and voltage; power quality	BT521 Battery Analyzer (up to 1000 V DC), 1777 Power Quality Analyzer — where appropriate for the battery chemistry and scale in use
GPU rack health program	Rack inlet temperature and humidity, thermal behavior, power quality	Ti480 PRO Thermal Camera, 971 Temperature Humidity Meter, 1586A Super-DAQ, 1777 Power Quality Analyzer
Cooling performance	Pressure instrumentation verification; delta T via temperature instrumentation	729/729Pro Pressure Calibrators
Pump evaluation	Imbalance, misalignment, looseness, bearing wear, motor-pump alignment	805 FC Vibration Meter, 832 Laser Shaft Alignment Tool, RotAlign Elite™



Software and results-management platforms carry these measurements forward as traceable acceptance evidence, rather than isolated field readings:

- **LinkWare Live™ platform:** centralizes network and cabling certification results, project information, and reporting.
- **Fluke Connect™ and SmartView™ software:** support thermal inspection analysis, documentation, and reporting.
- **Fluke TruTest™ software:** organizes electrical installation test results and supports commissioning reports.
- **Alignment Reliability Center 4.0™ (ARC 4.0) platform:** documents and analyzes motor and pump alignment results.
- **eMaint™ CMMS:** carries asset, condition, and maintenance information from commissioning into ongoing operations.
- **CalStudio™ software:** supports calibration management, documentation, and traceability of instrument calibration results.

Together, this creates a record of what was tested, what was measured, and whether acceptance criteria were met — giving contractors clearer proof of completed work, and giving owners a defensible record of system performance at turnover and a known-good reference for future troubleshooting.

This combination of measurement and documentation also strengthens the transition to Integrated Systems Testing (IST), where individually validated systems are challenged together under abnormal, transfer, and failure scenarios.

Integrated systems testing

After individual systems demonstrate functional performance, Integrated Systems Testing (IST) verifies how those systems interact during abnormal events, maintenance configurations, and failure scenarios — evaluating facility-wide performance rather than individual components. The goal is to demonstrate that interconnected systems operate cohesively under upset conditions while maintaining continuous support for critical loads.

Typical IST scenarios include utility outages, UPS failures, generator startup sequences, cooling interruptions, battery events, communication losses, fire suppression releases, and maintenance bypass operations — each requiring simultaneous monitoring of electrical parameters, cooling-system performance, control responses, and network resiliency.

The measurements captured during FPT establish the known-good performance baseline that IST is tested against — and that same baseline carries forward into daily operations, letting teams recognize performance drift and troubleshoot faster long after commissioning ends. Table 5 summarizes typical IST scenarios, what to validate, and the Fluke technologies suited to each.

Table 5. Fluke technologies supporting integrated systems testing and infrastructure testing

Integrated scenario or activity	What to validate	Recommended Fluke technologies
Utility disturbance and UPS ride-through	Voltage sags, swells, transients, harmonics, THD, transfer behavior, critical-load continuity	1777 Power Quality Analyzer, 1738 Power Logger
Generator start, synchronization, and load transfer	Frequency stability, voltage response, step loading, synchronization events, transient recovery	1777 Power Quality Analyzer, 1738 Power Logger
Battery event or stored-energy support	Battery conductance, internal resistance, thermal anomalies, ride-through readiness	BT521 Battery Analyzer, TiX580 Thermal Camera
Cooling interruption or high-density thermal event	Rack inlet temperatures, delta T, CDU performance, pump response, thermal mapping	TiX580 Thermal Camera, 729/729Pro Pressure Calibrators, 805 FC Vibration Meter
Controls, instrumentation, valve response, and motor-pump alignment	Signal accuracy, loop checks, pressure and temperature calibration, valve stroke, control response	754 Documenting Process Calibrator, 729/729Pro Pressure Calibrators, 710 mA Loop Valve Tester, 773 mA Process Clamp Meter, 832 Laser Shaft Alignment Tool, RotAlign Elite™
Grounding and bonding verification	Ground resistance, bonding integrity, readiness during abnormal electrical events	1625-2 Ground Tester, 1630-2 FC Clamp Ground Tester
Fiber, copper, and network-path failover	Continuity, insertion loss, polarity, physical-layer certification, PoE, redundant-pathway performance	DSX-8000 CableAnalyzer, CertiFiber Pro™, CertiFiber Max, OptiFiber Pro™, LinkIQ™, LinkWare Live™
Leak detection and acoustic anomaly checks	Compressed-air and cooling-system leaks, partial-discharge indicators	ii915 Acoustic Camera

When a scenario does not perform as expected, these measurements help teams pinpoint where the sequence broke down, troubleshoot the responsible subsystem, and confirm the effect of corrective action. For the owner, the resulting evidence demonstrates facility-level resilience: whether critical operations remain supported through realistic failure and recovery scenarios.

IT infrastructure commissioning

IT infrastructure commissioning typically begins during construction verification and continues through FPT and IST. The objective is to demonstrate that all communications pathways, cabling systems, environmental monitoring devices, and management interfaces perform reliably under both normal and abnormal operating conditions.

Structured cabling and network infrastructure

Commissioning teams first verify that installed copper and fiber cabling systems conform to design specifications, manufacturer requirements, and applicable standards such as TIA-942 and ANSI/TIA-568. Testing generally includes:

- End-to-end continuity verification
- Fiber polarity validation
- Optical insertion loss measurement
- Optical Time Domain Reflectometer (OTDR) testing
- MPO/MTP trunk certification
- Copper cable certification
- Verification of redundant network pathways
- Labeling and asset documentation

In AI data centers, where east-west traffic volumes are substantial, fiber infrastructure commissioning becomes especially critical because latency, attenuation, and connector cleanliness can significantly affect cluster performance.

Fluke Networks tools help commissioning teams prove that the physical network infrastructure meets required performance specifications — not simply that a cable is connected.

The Fluke Networks DSX-8000 CableAnalyzer certifies copper links against defined limits; CertiFiber Max and CertiFiber Pro Optical Loss Test Sets quantify fiber loss; the OptiFiber Pro OTDR locates and characterizes fiber faults; and LinkIQ™ tester validates connectivity, switch-port information, and PoE performance. Fiber inspection and cleaning are just as critical, since a contaminated end face can create loss and instability even when the cable itself is sound.

In hyperscale and AI environments, where thousands of high-speed fiber links support tightly coupled compute infrastructure, this prevents marginal cabling, excessive loss, polarity errors, and contamination from being misdiagnosed later as server, switch, or application problems. LinkWare Live™ adds centralized result management and traceability across large projects and multiple crews — supporting faster acceptance, less avoidable retesting, and a documented record of the network foundation delivered to the owner.

Field example: Reference-setting speed on hyperscale projects

Large fiber-optic projects can involve hundreds or thousands of multi-fiber links that must be tested, documented, and delivered under strict customer requirements. Contractors on these projects are often required to reset references after a defined number of tests or a set period of time — commonly a maximum of 250 tests per reference, or a mandatory new reference after one hour of use. When that process is slow, the delays compound across high cable counts and repeated reference cycles.

Fast, reliable reference-setting on CertiFiber Max — including automatic tracking of test counts and elapsed time between reference settings — helps crews stay compliant without losing productivity, contributing directly to shorter overall test times on the project.

Combined with reliable labeling, export accuracy, and centralized results in LinkWare Live™, this reduces avoidable retesting and improves confidence in final documentation.



Establishing baselines for long-term operations

Successful IST marks the transition from project acceptance to operational readiness. The same measurements captured throughout commissioning — electrical signatures, harmonic profiles, battery conductance, transformer temperatures, cooling-system pressures and temperatures, pump vibration signatures, grounding resistance, fiber attenuation, and thermal maps of GPU clusters — become the baseline against which future performance is measured.

For hyperscale and AI data center operators, where infrastructure density is increasing and power demand is more dynamic and volatile than ever, that baseline is worth more than its role in commissioning acceptance.

It defines what healthy operation looked like the day the facility was accepted — turning commissioning data into a reference point for the life of the asset.

By comparing current measurements against that known-good baseline, operations teams can distinguish normal behavior from meaningful change, troubleshoot faster, and catch developing problems before they affect availability.





Conclusion

Advanced test tools strengthen every phase of the commissioning lifecycle, replacing assumptions with objective, documented evidence. From factory verification through installation readiness, startup, functional testing, and integrated systems testing, they help teams catch installation defects, configuration issues, and performance gaps while those problems are still inexpensive to fix.

The value doesn't end at turnover. The measurements captured during commissioning become the operational baseline that helps owners and operators troubleshoot faster, support condition-based maintenance, detect performance drift, and operate mission-critical facilities with greater confidence throughout the life of the asset.

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