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## **POWER QUALITY PROTECTION IN MODERN DATE CENTERS**

*WHY LINE VOLTAGE MONITORING AND SURGE PROTECTION  
ARE ESSENTIAL FOR MISSION-CRITICAL RELIABILITY*



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## EXECUTIVE SUMMARY

For consulting engineers, specifying engineers, mechanical contractors, and electrical contractors involved in the construction or modernization of data centers, success is measured through uptime, resiliency, efficiency, and long-term operational reliability.

Redundancy is engineered into compute architecture, cooling systems, networking infrastructure, backup power systems, and network connectivity. However, one critical variable continues to be underestimated in many facility designs: power quality.

Uptime Institute's Annual Outage Analysis 2025 reports that outage prevention remains a strategic priority for data center owners and operators. The report also notes that more than half of respondents, 54%, said their most recent significant, serious, or severe outage cost more than \$100,000, and one in five reported a cost greater than \$1 million (Uptime Institute, Annual Outage Analysis 2025). These findings reinforce the need for comprehensive resiliency strategies that extend beyond traditional backup power and redundancy planning.

Uptime Institute also identifies power issues as the most common cause of serious and severe data center outages, despite ongoing improvements in infrastructure equipment, design practices, and operational discipline (Uptime Institute, Annual Outage Analysis 2025). Modern facilities are increasingly vulnerable to voltage disturbances, transient surges, phase imbalance, utility instability, and grid-related events due to higher rack densities, intelligent cooling systems, expanding AI workloads, and increasingly sophisticated power electronics.

IEEE Std 1100, commonly known as the Emerald Book, presents consensus best practices for powering and grounding electronic equipment used in commercial and industrial applications. For mission-critical environments, this includes attention to grounding, surge suppression, power quality management, and the mitigation of electrical disturbances that can affect sensitive electronic equipment (Institute of Electrical and Electronics Engineers, IEEE Std 1100-2005).

The operational reality is clear: advanced infrastructure cannot maintain reliability if incoming electrical

power is unstable.

This paper examines the impact of real-world power disturbances on data center operations, outlines why surge protection and line voltage monitoring should be incorporated into modern specifications, explains the growing importance of protecting data center chillers and mechanical cooling systems, and demonstrates how ICM Controls solutions support resilient and field-proven protection strategies for mission-critical applications.

## WHERE DESIGN ASSUMPTIONS MEET UTILITY CONDITIONS

Engineering models and design documentation are developed around known operating parameters. Equipment selections are validated, protection schemes are reviewed, and commissioning procedures confirm baseline performance.

Once systems are energized and transferred into operation, facilities become subject to the realities of the electrical grid.

In its 2025 outage analysis, Uptime Institute states that “the complexity of modern architectures and evolving external threats present new risks that operators must actively manage” (Uptime Institute, “Uptime Announces Annual Outage Analysis Report 2025”). While redundancy remains fundamental to data center design, increasingly interconnected infrastructure means that small electrical disturbances can produce disproportionately large operational impacts.

Utility inconsistencies, switching transients, nearby industrial loading, weather-related disturbances, and voltage instability introduce conditions that are often not apparent during design or commissioning.

The U.S. electrical infrastructure is also experiencing increasing stress from demand growth, electrification, aging infrastructure, severe weather, and the rapid expansion of data center capacity. NERC's 2025 Long-Term Reliability Assessment reports that summer peak demand is forecast to grow by 224 GW over the next ten years, with new data centers for artificial intelligence and the digital economy accounting for most of the projected increase (North American Electric Reliability Corporation, 2025 Long-Term Reliability

Assessment).

Within a data center environment, even brief electrical disturbances can create cascading operational consequences.

Cooling systems may fall outside operating tolerances. Power supplies can experience stress conditions. Control systems may reboot or enter fault states. VFDs may trip. Chillers may lock out. Sensitive electronic equipment becomes increasingly vulnerable as power quality deteriorates.

IEEE guidance identifies power disturbances, grounding practices, and proper power-system design as important considerations for protecting electronic equipment in commercial and industrial environments (Institute of Electrical and Electronics Engineers, IEEE Std 1100-2005).

In many cases, the issue is not equipment failure. The issue is insufficient protection and insufficient visibility into the electrical conditions feeding the system.

## **WHY POWER QUALITY MATTERS MORE THAN EVER**

Modern data centers are operating under tighter electrical and thermal tolerances than ever before.

The North American Electric Reliability Corporation has elevated concerns regarding large computational loads and data center power demand. In a recent Level 3 Essential Action Alert, NERC reported observing “significant oscillations that occur in seconds, leaving little or no room for real-time responses” and identified these conditions as a threat to bulk power system reliability (North American Electric Reliability Corporation, “NERC Issues Level 3 Alert”).

These developments highlight a growing challenge for facility designers: even as internal infrastructure becomes more sophisticated, external power quality risks may become more difficult to predict or control. Voltage monitoring and coordinated surge protection provide additional layers of resilience against these emerging grid-related uncertainties.

Higher-density computing, AI-driven workloads, edge computing deployments, electronically controlled

cooling systems, and intelligent building management platforms have significantly increased infrastructure sensitivity to electrical instability.

Industry organizations including ASHRAE and Uptime Institute continue highlighting the operational challenges associated with higher rack densities, advanced cooling architectures, AI infrastructure growth, and the need for resilient data center operations (ASHRAE, Data Center Resources; Uptime Institute, Annual Outage Analysis 2025).

Modern facilities increasingly depend upon:

- Precision cooling systems
- Data center chillers
- Variable frequency drives
- Intelligent control systems
- Building automation infrastructure
- High-efficiency power electronics
- Sensitive server and network hardware
- Communication networks and control platforms

While these technologies improve operational efficiency, they also increase sensitivity to:

- Voltage transients
- Brownouts
- Sustained under voltage
- Sustained over voltage
- Phase imbalance
- Phase loss
- Utility switching events
- Harmonic distortion
- Lightning-induced surges

For engineers and contractors, protecting against these conditions is no longer an enhancement. It is an essential component of operational resiliency.

## **THE CRITICAL ROLE OF DATA CENTER CHILLERS IN UPTIME AND RELIABILITY**

Historically, discussions surrounding data center reliability have focused primarily on servers, UPS systems, generators, switchgear, and electrical distribution equipment.

Today, that perspective is incomplete.

Cooling infrastructure has become one of the most critical systems within modern data centers. ASHRAE Technical Committee 9.9 is specifically concerned with “the design, operations, maintenance, and efficient energy usage of modern data centers and technology spaces” (ASHRAE Technical Committee 9.9). As rack densities increase and AI-driven workloads continue expanding, cooling infrastructure is becoming increasingly important to maintaining operational continuity.

ASHRAE’s Thermal Guidelines for Data Processing Environments addresses operating environment guidance for air-cooled equipment, liquid-cooled equipment, temperature and humidity measurement, airflow patterns, equipment placement, and heat-load reporting requirements (ASHRAE, Thermal Guidelines for Data Processing Environments). This guidance underscores the importance of cooling system performance, environmental control, and coordinated facility design.

Data center chiller plants often serve as the foundation of thermal management for enterprise, hyper scale, and colocation facilities.

These systems support:

- Chilled water distribution networks
- Computer room air handlers
- Computer room air handlers and computer room air conditioning systems
- In-row cooling systems
- Rear-door heat exchangers
- Coolant distribution units
- Liquid cooling infrastructure
- High-density AI and GPU deployments

The move toward high-density computing is placing new demands on thermal infrastructure. Recent market examples show liquid-cooling and hybrid cooling architectures designed to support rack densities from 50 kW to more than 100 kW per rack, illustrating the scale of cooling demand now being planned for AI and high-performance computing environments (Vertiv).

Modern chillers incorporate:

- Variable frequency drives
- Electronic compressor controls
- Networked monitoring systems

- Building automation interfaces
- Intelligent sensors and diagnostics
- Digital control boards
- Communication modules and control relays

Because these systems depend heavily on electronic controls, compressors, motors, and power electronics, they are particularly vulnerable to electrical disturbances.

Even brief voltage anomalies can result in:

- Chiller control faults
- VFD trips
- Compressor lockouts
- Communication failures
- Sensor disruptions
- Reduced cooling capacity
- Unplanned equipment shutdowns

Loss of cooling capacity can rapidly escalate into thermal events that threaten server reliability, equipment longevity, and facility uptime.

For this reason, protecting cooling infrastructure from electrical disturbances should be considered a fundamental component of data center resiliency planning.

## **WHY LINE VOLTAGE MONITORING IS ESSENTIAL FOR CRITICAL COOLING SYSTEMS**

Many protection strategies focus primarily on catastrophic electrical events. However, some of the most damaging conditions occur gradually and often remain undetected until equipment reliability begins deteriorating.

Data center chillers, pumps, cooling towers, compressors, fan systems, and VFD-driven mechanical systems depend upon stable incoming voltage. Conditions such as sustained under voltage, sustained over voltage, phase imbalance, phase loss, and improper phase sequencing can create significant operational stress long before a complete system failure occurs.

The U.S. Department of Energy notes that voltage unbalance at motor terminals can create current unbalance that is disproportionate to the voltage unbalance itself. These unbalanced currents can contribute

to torque pulsations, increased vibration, mechanical stress, reduced efficiency, overheating, and shorter winding insulation life (U.S. Department of Energy, Eliminate Voltage Unbalance).

For data center mechanical systems, these electrical conditions may result in:

- Increased motor heating
- Reduced compressor life
- Excessive current draw
- VFD nuisance trips
- Premature bearing wear
- Reduced cooling efficiency
- Unexpected shutdowns
- Loss of cooling redundancy
- Increased maintenance costs

Unlike catastrophic failures, voltage anomalies often develop gradually and may not immediately trigger traditional protective devices. Over time, however, these conditions can increase motor temperatures, reduce compressor life, contribute to VFD nuisance trips, and create operational instability within cooling systems that are essential to maintaining ASHRAE-recommended thermal environments (ASHRAE, Thermal Guidelines for Data Processing Environments).

Line voltage monitoring provides a proactive layer of protection by continuously evaluating incoming electrical conditions and disconnecting equipment when unsafe operating parameters are detected.

Rather than allowing a chiller or critical cooling asset to operate under damaging conditions, voltage monitoring helps ensure equipment only operates within acceptable electrical tolerances.

For consulting engineers and contractors, line voltage monitoring delivers three important benefits.

### **Equipment Protection**

Line voltage monitoring helps protect compressors, motors, drives, and controls from sustained electrical stress caused by over voltage, under voltage, phase loss, phase reversal, and phase imbalance.

### **Operational Visibility**

Monitoring devices provide diagnostic information

that helps identify utility-related issues, distribution problems, commissioning errors, and intermittent faults that may otherwise be difficult to trace.

### **Improved Resiliency**

Voltage monitoring can prevent nuisance failures that reduce cooling capacity or create cascading impacts throughout the facility.

As cooling systems become increasingly intelligent, electronically controlled, and integrated with building automation systems, line voltage monitoring should be viewed as a standard best practice rather than an optional enhancement.

## **DESIGNING FOR OPERATIONAL RESILIENCE**

For engineers and contractors, the objective extends beyond specification compliance.

The objective is to deliver systems capable of maintaining stability under real operating conditions.

IEEE 1100 guidance and IEEE C62 surge protection standards reinforce the importance of coordinated protection throughout mission-critical electrical infrastructure (Institute of Electrical and Electronics Engineers, IEEE Std 1100-2005; Institute of Electrical and Electronics Engineers, IEEE C62 Series).

Effective protection strategies should include multiple coordinated layers.

### **Service Entrance Protection**

High-capacity surge protective devices mitigate large transient events before disturbances propagate into facility distribution systems.

### **Distribution-Level Protection**

Localized suppression and voltage monitoring help identify abnormal electrical conditions before they affect downstream equipment.

### **Equipment-Level Protection**

Single-phase and three-phase monitoring devices protect critical systems against over voltage, under voltage, phase loss, phase reversal, imbalance, and unsafe restart conditions.

## Cooling System Protection

Critical cooling assets, including chillers, pumps, cooling towers, fan systems, compressors, and VFD-driven equipment, should incorporate dedicated surge protection and line voltage monitoring.

As AI and high-density computing continue increasing cooling requirements, electrical protection of cooling infrastructure becomes increasingly important to maintaining thermal stability and uptime (ASHRAE, Data Center Resources; ASHRAE, Thermal Guidelines for Data Processing Environments).

## WHY SURGE PROTECTION SHOULD BE INSTALLED AT EVERY CRITICAL SYSTEM

Surge protection is often viewed primarily as a service entrance requirement.

While service entrance protection remains essential, it represents only the first layer of a comprehensive protection strategy.

Transient voltage events can originate from:

- Utility switching operations
- Lightning activity
- Generator transfers
- UPS switching events
- Capacitor bank switching
- Large motor starts
- Internal load changes
- VFD operation
- Fault clearing events
- Switching within mechanical systems

Many of these events originate within the facility itself and may never be fully addressed by service entrance protective devices.

As a result, sensitive equipment located deeper within the electrical distribution system can remain vulnerable.

IEEE C62 surge protection guidance supports the application and coordination of surge protective devices for low-voltage electrical systems and connected equipment (Institute of Electrical and Electronics Engineers, IEEE C62 Series). NFPA 70, National Electrical Code Article 242, also addresses over voltage

protection and surge protective devices for premises wiring systems (National Fire Protection Association).

For data center cooling systems, surge protection should be considered at multiple levels.

## Service Entrances

Service entrance surge protection helps protect against large utility-side transients before they move deeper into the facility.

## Distribution Panels

Panel-level surge protection provides localized suppression for branch circuits serving mechanical, electrical, and control infrastructure.

## Chillers and Mechanical Equipment

Equipment-level surge protection helps protect compressors, VFDs, electronic controllers, sensors, and communication systems.

## Building Automation Systems

Surge protection for controls and automation systems helps protect low-voltage electronics essential to system coordination and monitoring.

Installing surge protection at each critical system creates a coordinated defense strategy that can improve long-term equipment reliability and reduce the likelihood of unplanned outages.

## ICM CONTROLS: ENGINEERED AND MANUFACTURED FOR MISSION CRITICAL APPLICATIONS

ICM Controls designs and manufactures electronic controls, monitoring systems, and power protection solutions for commercial, industrial, OEM, aftermarket, HVAC/R, electrical, and mission-critical applications.

Headquartered in North Syracuse, New York, ICM Controls is an American electronics manufacturer with more than 40 years of experience designing, developing, and manufacturing electronic controls and power protection solutions (ICM Controls, About). ICM

Controls also identifies its facility as one of the most vertically integrated electronics manufacturing facilities in the United States, supporting concept development, prototyping, production, and shorter lead times (ICM Controls, FAQ).

This vertically integrated structure allows ICM Controls to move rapidly from concept development to design validation, prototype production, testing, and manufacturing deployment.

For customers operating within data center environments, this provides:

- Accelerated engineering support
- Faster response to application changes
- Rapid prototype development
- Improved communication between engineering and manufacturing
- Reduced lead times for design modifications
- Direct collaboration with in-house technical resources
- Support for application-specific protection strategies

ICM Controls solutions are engineered to help protect infrastructure against:

- Transient voltage surges
- Sustained over voltage and under voltage conditions
- Phase loss and imbalance
- Phase reversal
- Utility-side disturbances
- Compressor and motor stress
- Power instability affecting cooling systems
- Premature equipment failure

These solutions are developed to address operational challenges encountered by contractors, engineers, and facility operators responsible for maintaining uptime and equipment reliability within mission-critical facilities.

## **SPECIFICATION GUIDANCE FOR ENGINEERS**

Engineers specifying protection solutions for mission-critical facilities should consider requirements aligned with:

- IEEE Std 1100 Recommended Practice for Powering and Grounding Electronic Equipment
- IEEE C62 surge protection guidance
- NEC Article 242 over voltage protection requirements
- NFPA 70 electrical protection requirements
- ASHRAE TC 9.9 thermal guidance for data processing environments
- Uptime Institute resiliency and outage analysis findings

Recommended specification language may include:

- Surge protective devices installed at service entrance, distribution, and equipment levels
- Dedicated line voltage monitoring for chillers, pumps, cooling towers, and VFD-driven cooling equipment
- Voltage monitoring for all critical single-phase and three-phase mechanical systems
- Adjustable over voltage and under voltage protection thresholds
- Phase loss, phase reversal, and phase imbalance protection
- Automatic disconnect functionality during unsafe electrical conditions
- Automatic restart capability following voltage normalization
- Visible diagnostics and fault indication for commissioning and troubleshooting
- Fault history or event memory for maintenance review
- Integration capability with building management systems where applicable

These requirements can be addressed using ICM Controls solutions including:

- ICM493 single-phase line voltage monitor with surge protection
- ICM531 three-phase Type 1 and Type 2 surge protective device
- ICM450A and ICM450A PLUS+ programmable three-phase line voltage monitors
- 3VMS-60-208 and 3VMS-60-480 three-phase voltage monitor and surge protector solutions
- Sentry3N1 integrated single-phase voltage monitoring and surge protection disconnect

## CONCLUSION

Data center outages rarely originate from a single catastrophic event. In many cases, disruption begins with smaller electrical disturbances that remain undetected until they escalate into operational failures.

As modern facilities become increasingly dependent on electronically controlled infrastructure, advanced cooling systems, intelligent controls, and high-density computing environments, power quality protection becomes essential to maintaining uptime and long-term reliability.

As cooling infrastructure assumes a larger role in supporting AI workloads, liquid cooling deployments, and high-density computing environments, protecting data center chillers and associated mechanical systems becomes increasingly important. Voltage monitoring and coordinated surge protection help safeguard these critical assets from electrical disturbances that can compromise cooling performance, reduce equipment life, and increase the risk of downtime.

Industry analysis continues demonstrating that power-related events remain among the leading causes of impactful data center outages, even as infrastructure becomes more sophisticated (Uptime Institute, Annual Outage Analysis 2025).

For engineers and contractors, integrating surge protection and line voltage monitoring during the design phase reduces operational risk, improves system resilience, minimizes post-installation issues, and supports long-term facility performance.

Uptime Institute continues to report that outage prevention remains a strategic priority for operators despite improvements in infrastructure reliability. At the same time, NERC has issued its highest level reliability alert regarding risks associated with large computational loads and rapidly fluctuating data center demand. Together, these developments demonstrate that maintaining uptime increasingly requires attention not only to redundancy and backup power systems, but also to the quality and stability of the electrical supply feeding critical infrastructure (Uptime Institute, “Uptime Announces Annual Outage Analysis Report 2025”; North American Electric Reliability Corporation, “NERC Issues Level 3 Alert”).

ICM Controls provides engineered solutions, domestic manufacturing capability, technical support, and rapid development resources to help customers build infrastructure designed for real-world operating conditions.

## WORK CITED

- ASHRAE. Data Center Resources. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Accessed 3 June 2026.
- ASHRAE. Thermal Guidelines for Data Processing Environments. 5th ed., ASHRAE Datacom Series, Book 1, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2021.
- ASHRAE Technical Committee 9.9. Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Accessed 3 June 2026.
- ICM Controls. About. ICM Controls. Accessed 3 June 2026.
- ICM Controls. "3VMS-60-208." ICM Controls. Accessed 3 June 2026.
- ICM Controls. "3VMS-60-480." ICM Controls. Accessed 3 June 2026.
- ICM Controls. FAQ. ICM Controls. Accessed 3 June 2026.
- ICM Controls. "ICM450A and ICM450A PLUS+." ICM Controls. Accessed 3 June 2026.
- ICM Controls. "ICM493." ICM Controls. Accessed 3 June 2026.
- ICM Controls. "ICM531." ICM Controls. Accessed 3 June 2026.
- ICM Controls. "Sentry3N1." ICM Controls. Accessed 3 June 2026.
- Institute of Electrical and Electronics Engineers. IEEE C62 Series: Surge Protective Device Standards. IEEE Standards Association.
- Institute of Electrical and Electronics Engineers. IEEE Std 1100-2005: IEEE Recommended Practice for Powering and Grounding Electronic Equipment. IEEE, 2005.
- National Fire Protection Association. NFPA 70: National Electrical Code. NFPA, 2023.
- North American Electric Reliability Corporation. 2025 Long-Term Reliability Assessment. NERC, 2026.
- North American Electric Reliability Corporation. "NERC Issues Level 3 Alert, Reliability Guideline Focused on Large Load Challenges." NERC, 2026. Accessed 3 June 2026.
- Uptime Institute. Annual Outage Analysis 2025. Uptime Institute Intelligence, 2025.
- Uptime Institute. "Uptime Announces Annual Outage Analysis Report 2025." Uptime Institute, 6 May 2025. Accessed 3 June 2026.
- U.S. Department of Energy. Eliminate Voltage Unbalance: Motor Systems Tip Sheet #7. Office of Energy Efficiency and Renewable Energy.
- Vertiv. "Vertiv Introduces New Modular Liquid Cooling Infrastructure Solution to Support High-Density Compute Requirements." Vertiv, 2026. Accessed 3 June 2026.