THE EVOLUTION OF MODULAR DATA CENTERS: CURRENT PRACTICES AND FUTURE TRENDS IN ELECTRICAL DESIGN

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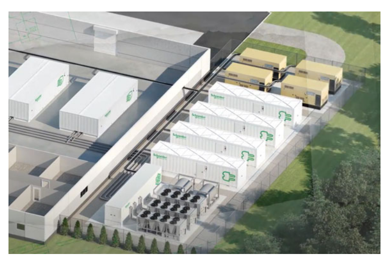
TOPICS

- ✓ What are Modular Data Centers and Their Benefits
- ✓ Current Design Methodologies
- ✓ Future Trends in Electrical Design



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INTRODUCTION

What Are Modular Data Centers?

A flexible and scalable approach to deploying data center capacity

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BENEFITS OF MODULAR DATA CENTERS

- **Rapid deployment and scalability**
  - ✓ 50% faster deployment vs. traditional builds.
- **Cost-effectiveness and efficiency**
  - ✓ 30% lower CAPEX with standardized components.
- **Enhanced energy efficiency and sustainability**
  - ✓ Energy savings up to 40% via optimized cooling/power

Power Modules

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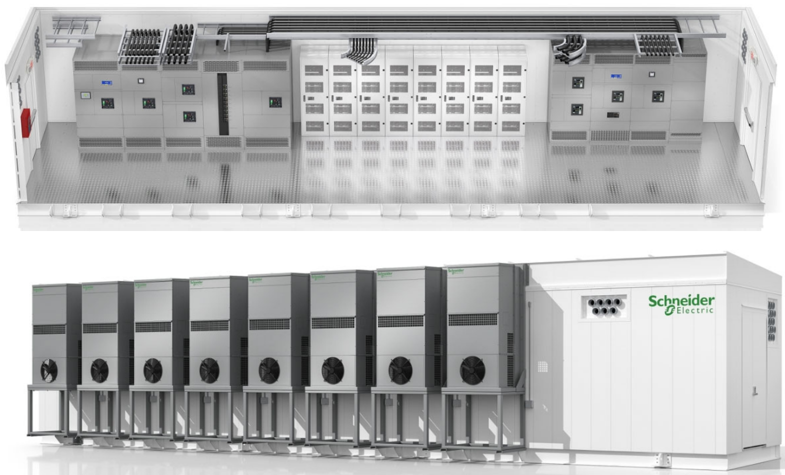
DIFFERENT TYPE OF MODULAR DATA CENETERS

- **POWER MODULES**



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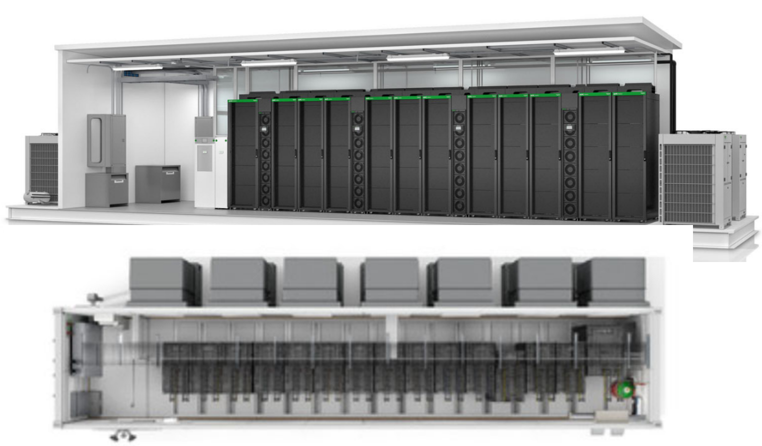
DIFFERENT TYPE OF MODULAR DATA CENETERS

- **ALL-IN-ONE IT MODULES**



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MODULAR DATA CENTER KEY ELECTRICAL COMPONENTS

- **Uninterruptible Power Supply (UPS)**
  Provides backup power to ensure continuous operation during outages
- **Battery Systems**
  Stores energy for use during power interruptions
- **Power Distribution Units (PDUs)**
  Distributes electrical power to various equipment within the data center
- **Panelboard, Switchboard, Switchgear**
  Manages and protects electrical circuits, ensuring safe operation
- **Transformers**
  Converts voltage levels to meet the requirements of different equipment
- **Automatic Transfer Switch (ATS)**
  Automatically switches to backup power sources during a primary power failure

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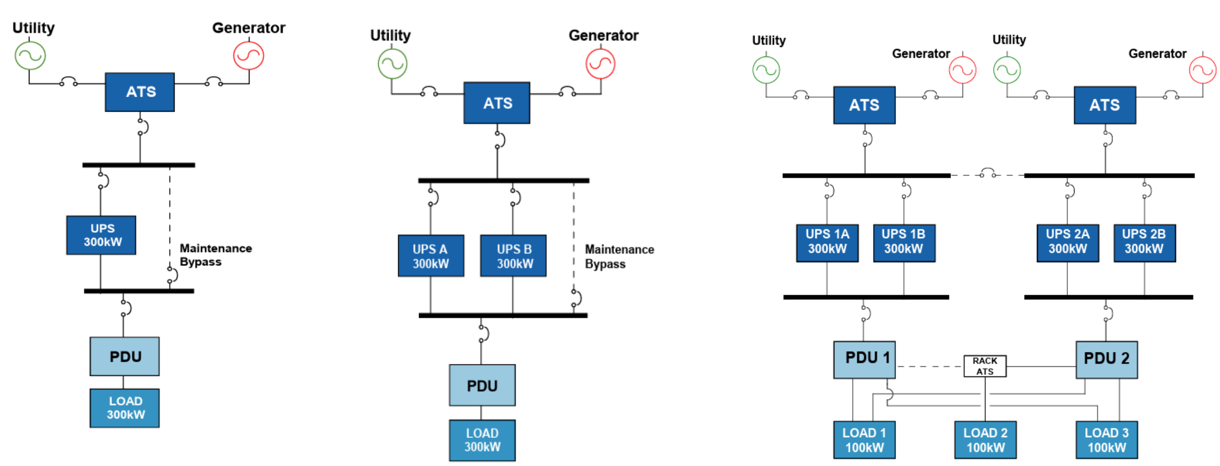
MODULAR DATA SINGLE LINE DIAGRAM



"N" SYSTEM "N+1" SYSTEM "2N" SYSTEM

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ELECTRICAL DESIGN PRINCIPLES OVERVIEW

Importance of electrical design in modular data centers

➢ **REDUNDANCY**

1. **Ensure Reliability**: Prevents downtime by having backup systems (N, N+1, 2N power systems).
2. **Fault Tolerance**: Allows continuous operation even if one component fails.
3. **High Availability**: Guarantees uninterrupted service.

Table 10: Tiering reference guide (electrical)

	TIER 1	TIER 2	TIER 3	TIER 4
ELECTRICAL				
General				
Number of Delivery Paths	1	1	1 active and 1 passive	2 active
Utility Entrance	Single Feed	Single Feed	Dual Feed (600 volts or higher)	Dual Feed (600 volts or higher) from different utility substations
System allows concurrent maintenance	No	No	Yes	Yes
Computer & Telecommunications Equipment Power Cords	Single Cord Feed with 100% capacity	Dual Cord Feed with 100% capacity on each cord	Dual Cord Feed with 100% capacity on each cord	Dual Cord Feed with 100% capacity on each cord
All electrical system equipment labeled with certification from 3rd party test laboratory	Yes	Yes	Yes	Yes
Single Points of Failure	One or more single points of failure for distribution systems serving electrical equipment or mechanical systems	One or more single points of failure for distribution systems serving electrical equipment or mechanical systems	No single points of failure for distribution systems serving electrical equipment or mechanical systems	No single points of failure for distribution systems serving electrical equipment or mechanical systems
Critical Load System Transfer	Automatic Transfer Switch (ATS) with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.	Automatic Transfer Switch (ATS) with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.	Automatic Transfer Switch (ATS) with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.	Automatic Transfer Switch (ATS) with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.
Site Switchgear	None	None	Fixed air circuit breakers or fixed molded case breakers. Mechanical interlocking of breakers. Any switchgear in distribution system can be shutdown for maintenance with by-passes without dropping the critical load	Drawout air circuit breakers or drawout molded case breakers. Mechanical interlocking of breakers. Any switchgear in distribution system can be shutdown for maintenance with by-passes without dropping the critical load
Generators correctly sized according to installed capacity of UPS	Yes	Yes	Yes	Yes
Generator Fuel Capacity (at full load)	8 hrs (no generator required if UPS has 8 minutes of backup time)	24 hrs	72 hrs	96 hrs

	TIER 1	TIER 2	TIER 3	TIER 4
UPS				
UPS Redundancy	N	N+1	N+1	2N
UPS Topology	Single Module or Parallel Non-Redundant Modules	Parallel Redundant Modules or Distributed Redundant Modules	Parallel Redundant Modules or Distributed Redundant Modules or Block Redundant System	Parallel Redundant Modules or Distributed Redundant Modules or Block Redundant System

TIA's ANSI/TIA-942 Standard
TIA: TELECOMMUNICATIONS INDUSTRY ASSOCIATION

ELECTRICAL DESIGN PRINCIPLES OVERVIEW

➢ **Scalability**

1. **Adaptable Growth**: Easily expand capacity as demand increases.
2. **Modular Expansion**: Add modules without major redesigns.
3. **Cost-Effective**: Scale resources efficiently without overspending.

Modular switchgear

ELECTRICAL DESIGN PRINCIPLES OVERVIEW

- **Energy efficiency** (Advanced Cooling Solutions, Enhancing energy efficiency Equipment , lithium-ion batteries).
  - Energy Optimization: Reduces power consumption (PUE) and operational costs.
  - Resource Management: Maximizes use of electrical infrastructure

All-in-one Liquid cooled modular data center

$$\text{PUE} = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}} = 1 + \frac{\text{Non IT Facility Energy}}{\text{IT Equipment Energy}}$$

CURENT ELECTRICAL DESIGN STEPS

- ✓ **Site Assessment**
  - Evaluate location and environmental conditions.
  - Determine space requirements.
- ✓ **Power Requirements**
  - Calculate total power needs based on IT load and infrastructure.
  - Create diagrams to represent electrical distribution. **SINGLE LINE DIAGRAM**
  - Design Uninterruptible Power Supply (UPS) systems for backup power.
  - Implement redundant power paths for continuous operation.
- ✓ **Cooling Systems Integration**
  - Crucial for maintaining optimal operating temperatures of IT equipment, preventing equipment failure and system crashes.
  - Planning the layout and airflow
- ✓ **Scalability and Flexibility**
  - Design scalable and flexible systems for future growth.
  - Utilize pre-assembled modules for quick deployment.
- ✓ **Safety and Compliance**
  - Ensure compliance with safety standards and regulations.

APPLICABLE STANDARDS AND CODES IN ELECTRICAL DESIGN

USA: NFPA Standards
- NFPA 70: National Electrical Code (NEC)
- NFPA 72: National Fire Alarm and Signaling Code
- NFPA 12: Carbon Dioxide Extinguishing Systems
- NFPA 2001: Clean Agent Fire Extinguishing System

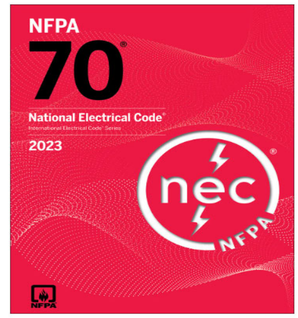
EUROPE: EN 50600 Series:
- EN 50600-1: General concepts and availability classes.
- EN 50600-2-2: Power distribution.
- EN 50600-2-4: Telecommunications cabling infrastructure.
- EN 50600-3-1: Management and operational information.

IEC 60364: low-voltage electrical installations.

CANADA: CANADIAN ELECTRIC CODE, CSA

UL Standards:

- UL2755: Modular Data Center Testing and Certification
- UL508A: construction of Industrial Control Panels



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ELECTRICAL DESIGNS CHALLENGES

Designing electrical systems for prefabricated modular data centers presents several unique challenges due to their modular, pre-assembled nature and the need for scalability, efficiency, and reliability.

- **High-density IT Loads Within A Compact Footprint And Space Constraints**

Unlike traditional data centers where worst-case scenarios are built in from the start, modular designs aim for "right-sizing."

Engineers must optimize layouts to fit high-capacity electrical systems into confined enclosures (e.g., shipping containers or skids) while ensuring accessibility for maintenance and compliance with safety codes.

ELECTRICAL DESIGNS CHALLENGES

- **Cooling And Power Integration**

CHALLENGE: Electrical systems must work in tandem with cooling solutions, which are often closely coupled in modular designs (e.g., in-row cooling).

Power delivery must account for cooling equipment demands alongside IT loads. -

Balancing power allocation between IT and cooling systems, while maintaining energy efficiency (low PUE), requires sophisticated design and real-time monitoring, especially in high-density setups.

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ELECTRICAL DESIGNS CHALLENGES

- **Energy Efficiency**

Challenge: Achieving a low Power Usage Effectiveness (PUE) ratio is critical, especially as modular data centers are marketed as efficient alternatives to traditional builds.

WHY IT'S DIFFICULT: Electrical systems must integrate efficient UPS technologies (e.g., lithium-ion batteries instead of lead-acid), renewable energy options, and power management systems, all within a modular framework, which can limit design flexibility

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ELECTRICAL DESIGNS CHALLENGES

- **Regulatory and Safety Compliance**

Challenge: Electrical systems must comply with local codes (e.g., NEC in the U.S.) and safety standards, which can vary by region where the modular unit is deployed.

WHY IT'S DIFFICULT: Designing a universal electrical system that meets diverse global standards—or adapting it post-fabrication—adds complexity. Pre-certification (e.g., UL 2755) can help, but site-specific requirements may still arise.

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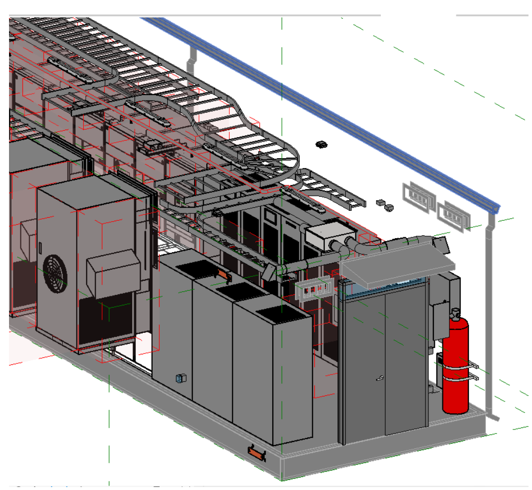
ELECTRICAL DESIGNS CHALLENGES

- **Cable Management and Connectivity**

Challenge: Efficient cable routing and termination are essential in a confined modular space, especially for power distribution and IT connectivity.

WHY IT'S DIFFICULT: Limited space can lead to cluttered or inaccessible cabling, increasing the risk of errors during assembly or maintenance. Designers must plan for pre-wired solutions or modular busways that simplify installation. requirements may still arise.



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THE AI DISRUPTION: CHALLENGES

Extraordinary acceleration in the growth of artificial intelligence (AI), transforming the way we live, work, and interact with technology.

Schneider Electric estimate	2023	2028
Total data center power consumption	57 GW	93 GW
AI power consumption	4.5 GW	14.0-18.7 GW
AI power consumption (% of total)	8%	15-20%
AI workload (Training vs Inference)	20% Training, 80% Inference	15% Training, 85% Inference
AI workload (Central vs Edge)	95% Central, 5% Edge	50% Central, 50% Edge

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THE AI DISRUPTION: ELECTRICAL DESIGN CONCERNS

AI workloads present key challenges that impact the power train, including switchgear, distribution, and rack power distribution units.

- Rack Management: AI workloads necessitate high-density clusters that traditional racks can't handle. 208/120V distribution is impractical to deploy.

- Increased risk of arc flash hazard complicates work practices
- Hybrid Cooling Approaches: Traditional air-cooling methods are insufficient for the heat generated by AI chip clusters. Data centers must adopt hybrid cooling solutions, such as air-assisted liquid cooling and rear door heat exchangers
- High rack temperatures increase risk of failures & hazards

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THE INVERTER-BASED LOADS EEFECT ON THE GRID

Inverter-based loads, such as those found in data centers, present several challenges to power system stability and network operations. Here are some key challenges:

Reduced System Inertia: Data centers often rely on inverter-based resources like UPS systems. These lack the rotational inertia of traditional generators, making the power system more susceptible to frequency fluctuations and less able to absorb disturbances.

Frequency Stability: Inverter-based loads can cause rapid changes in power output, leading to frequency instability.

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THE INVERTER-BASED LOADS EEFECT ON THE GRID

Voltage Stability: The integration of inverter-based loads can lead to voltage instability, especially in weak grids.

Harmonics and Power Quality: Inverters can introduce harmonics into the power system, affecting power quality and potentially damaging sensitive equipment. Effective filtering and harmonic mitigation strategies are necessary.

Protection Coordination: Traditional protection schemes may not work effectively with inverter-based resources. This necessitates the development of new protection strategies to ensure reliable fault detection and isolation.

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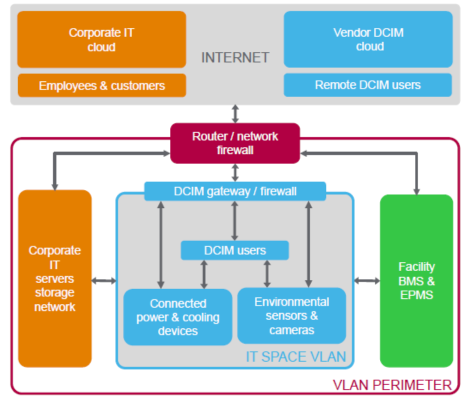
CYBER SECURITY CONCERNS

Network-connected, data center physical infrastructure equipment, the power, cooling, and environmental/security-monitoring devices found in the IT space - are necessary for ensuring availability and making operation of the data center efficient.

These network connections, particularly if poorly designed and implemented, could be used by cyber criminals as an attack surface.



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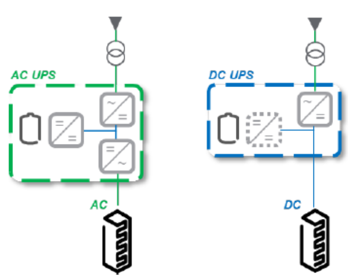
FUTURE TRENDS IN ELECTRICAL DESIGN

- ✓ **DC VS AC SYSTEM ARCHITECTURE FOR DATA CENETRS**

Higher Efficiency: DC systems reduce the number of power conversions required, minimizing energy losses and heat generation. This leads to improved overall efficiency
Simplified Power Distribution: DC power distribution is less complex, requiring fewer components and less space.
Improved Power Quality: DC systems provide consistent power quality with fewer interruptions and fluctuations, which is crucial for sensitive data center equipment
Space Savings: DC power equipment typically requires less physical space compared to AC systems, allowing for more efficient use of data center real estate Modular and Scalable
Integration with Renewable Energy: DC systems can more easily integrate with renewable energy sources like solar panels and batteries, supporting sustainability goals



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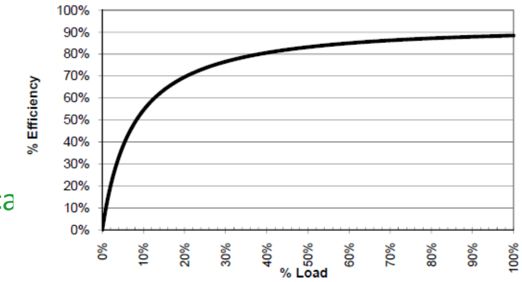
FUTURE TRENDS IN ELECTRICAL DESIGN

- **Efficient equipment**
  Making Large UPS Systems More Efficient

- **Modularity**
  Modularity is the third lever manufacturers ca use to decrease energy waste



A modular, scalable UPS system

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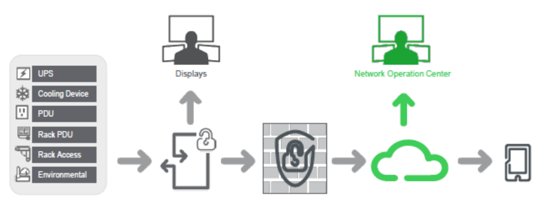
ADVANCED MONITORING

Remote and Digital Monitoring Impact on Edge Computing and Data Centers

Remote monitoring function	Traditional	Digital
Online[3]	No	Yes
Remote troubleshooting	Not typical	Common
Network operations center[4]	Yes	Yes
Incident tracking	Not typical	Yes
Analytics & AI	No	Yes
Mobile app with live data & notifications	No	Yes
Online service portal (history, etc.)	No	Yes
Online chat	No	Yes
Real-time monitoring	No	Yes
Onsite maintenance	More reactive & calendar-based	More proactive & asset health-based (eventually predictive)
Cloud-based storage	No	Yes
On duty status	No	Yes

Comparison between traditional and digital remote monitoring



Recommended digital monitoring architecture

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IMPORTANCE OF COMPLIANCE

Ensuring Security, Reliability, and Trust

- ✓ **Safety:** Compliance with standards like NEC, IEC, etc. ensures the safety of electrical installations, protecting both equipment and personnel.
- ✓ **Reliability:** Adhering to codes helps maintain consistent and reliable power supply, crucial for data center operations.
- ✓ **Legal Compliance:** Meeting regulatory requirements avoids fines and legal issues, ensuring smooth operations

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Any Question?

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