

## Integrated Electrical Design in Data Centers: A Collaborative Approach with Multidisciplinary Impact – A Case Study of a Confidential Data Center Project

### I. INTRODUCTION

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**Abstract**—This paper presents a comprehensive study of electrical design integration in data centers, emphasizing collaborative approaches with various engineering disciplines. Focused on a confidential data center project in Phoenix, the study explores the intricacies of designing and implementing efficient, reliable, and sustainable electrical systems in modern data centers. Electrical design, a critical component in ensuring uninterrupted operation and optimizing energy consumption, is analyzed in the context of multidisciplinary collaboration, highlighting the synergy between electrical, mechanical, architectural, and information technology disciplines.

The methodology encompasses a detailed examination of the Phoenix project's planning, design, and execution phases, with a specific focus on power distribution, backup systems, and energy efficiency measures. This case study provides valuable insights into the challenges and innovative solutions involved in the electrical design of data centers. Key aspects such as power redundancy, energy efficiency, and integration with cooling and architectural design are scrutinized to reveal the impact of collaborative approaches on project outcomes.

Results from the case study demonstrate significant advancements in energy efficiency, operational reliability, and scalability, achieved through the holistic integration of electrical design principles with other engineering domains. The findings underscore the importance of interdisciplinary collaboration in addressing the complex demands of modern data centers. The paper concludes with strategic recommendations for future data center projects, advocating for a unified approach to design and implementation. This study contributes to the field by offering a unique perspective on the role of electrical design within the broader context of data center development, serving as a valuable resource for engineers, designers, and project managers involved in similar endeavors.

**Keywords**—Data Center Design, Electrical Distribution, Energy Efficiency, Interdisciplinary Collaboration, Power Redundancy, Scalability, Sustainable Systems, Backup Systems, Operational Reliability, Cooling Integration.

The evolution of data centers from mere storage facilities to critical hubs for data processing and cloud services necessitates an advanced approach to their design and management, particularly in the realm of electrical distribution. As the backbone of these centers, electrical design plays a pivotal role in ensuring high availability, efficiency, and scalability. This is essential in addressing the exponential growth in data traffic and storage requirements. This paper focuses on the integration of electrical design in data centers, a subject that has garnered increasing attention in recent years due to the rising demands for energy efficiency and reliability in these facilities.

The significance of electrical design in data centers lies not only in its function of power distribution but also in its influence on the overall operational efficiency and sustainability of the facility. According to Giuseppe Parise and Luigi Parise in their 2019 work, the design of electrical distribution systems in data centers must ensure reliability and manageability while accommodating future growth and technological advancements [1]. This challenge becomes more complex when considering the integration of electrical design with other engineering disciplines, such as mechanical, architectural, and information technology. Interdisciplinary collaboration is key in developing a cohesive and efficient design that meets the multifaceted demands of modern data centers.

Moreover, the design of electrical systems in data centers is heavily impacted by the choice of power, architecture, and backup systems. As discussed by Shahzad et al. in their 2018 study, the selection of an appropriate UPS (Uninterruptible Power Supply) system and the design of power distribution networks are critical for ensuring uninterrupted operation and minimizing downtime [2]. The incorporation of renewable energy sources and sustainable practices, as suggested by Brown et al. in their 2020 paper, also plays a crucial role in the contemporary electrical design of data centers, aiming to reduce the carbon footprint and operational costs [3].

This study delves into a case study of a confidential data center project in Seattle, which exemplifies the intricate process of designing and implementing an efficient, reliable, and sustainable electrical system. The project is analyzed in its entirety, from planning and design to execution, with a focus on power distribution, backup systems, and energy efficiency measures. This case study is instrumental in illustrating the practical applications and benefits of an integrated approach to electrical design in data centers.

In conclusion, the electrical design of data centers is a dynamic and critical field that requires a comprehensive approach, combining technical expertise with a collaborative mindset. The insights gained from this study are intended to contribute to the broader discourse on creating efficient, reliable, and sustainable data centers, providing valuable guidance for engineers, designers, and project managers involved in such projects.

## II. BACKGROUND AND LITERATURE REVIEW

### Electrical Design and Interdisciplinary Collaboration:

The modern data center is a nexus of various engineering disciplines, making interdisciplinary collaboration not just beneficial, but essential. The integration of electrical design with mechanical, architectural, and IT infrastructure is crucial for the holistic development of data centers. This collaboration ensures that the electrical infrastructure supports the cooling systems, architectural integrity, and IT network demands. Particularly in electrical design, the synergy with mechanical engineering is vital in managing the heat produced by servers, as efficient cooling systems directly impact the overall energy consumption and reliability of the data center.

### Importance of Interdisciplinary Collaboration:

The significance of such collaboration cannot be overstated. The most successful data center projects are those where interdisciplinary teams work in tandem from the inception, ensuring that all systems are seamlessly integrated and optimized for performance and scalability. This approach not only enhances efficiency but also contributes to significant cost savings and increased operational reliability.

### The Phoenix Data Center Project:

Shifting the focus to the Phoenix data center project, it's important to consider the unique environmental factors impacting its design. Phoenix, known for its hot and arid climate, poses significant challenges for data center operation, primarily in cooling and energy efficiency. Data centers in such climates require innovative cooling solutions and robust electrical designs to maintain optimal temperatures and ensure uninterrupted service.

### Weather and Other Factors in Designing Data Centers:

The extreme temperatures in Phoenix necessitate a more robust and efficient cooling strategy, which in turn influences the electrical design. Cooling systems in such environments are not just about maintaining optimal server temperatures but also

about managing the immense energy expenditure involved in these systems. Therefore, the electrical design must be capable of supporting these high-demand cooling systems while maintaining energy efficiency. Incorporating renewable energy sources and advanced

cooling technologies like liquid cooling or evaporative cooling systems can significantly mitigate these challenges as discussed in the case study.

## III. CASE STUDY: ELECTRICAL DISTRIBUTION DESIGN FOR A HIGH-RELIABILITY DATA CENTER IN PHOENIX

In the heart of Phoenix, Arizona, a monumental task was undertaken to design and construct a state-of-the-art data center. Spanning an impressive 250,000 square feet with a substantial capacity of 30 MW, this project was not just about scale; it was about pioneering a new benchmark in reliability and efficiency in the world of data centers.

From the outset, the project team faced the dual challenges of Phoenix's blistering heat and the need to maintain an uninterrupted power supply in a highly demanding environment. The aim was crystal clear: create an electrical distribution system that was robust, efficient, and most importantly, reliable. Phoenix has a hot desert climate with extremely high temperatures, especially in the summer. Water cooled chillers tend to excel in dry conditions, offering optimal performance. On the other hand, air-cooled chillers demonstrate better capability in handling higher humidity levels. The decision between water-cooled and air-cooled chillers often entails a balance between energy efficiency and adaptability to diverse weather conditions. By carefully monitoring and optimizing these systems in response to seasonal changes, one can achieve improved overall outcomes.

This case study will illustrate how the Power Usage Effectiveness (PUE) graphs can effectively demonstrate the power energy consumption of different cooling techniques within the data center's cooling system. The objective is to determine which cooling technique exhibits lower energy consumption, ultimately contributing to an enhanced overall PUE for the data center.

The journey began with an intricate power distribution architecture, designed to ensure redundancy and reliability. Critical systems were given N+1 redundancy, ensuring that even in the event of a component failure, the data center would remain operational. Advanced UPS systems and emergency backup generators were installed, ready to kick in without missing a beat.

But the true technical prowess of the project lay in the meticulous calculations that formed the backbone of the design. Short circuit calculations were carried out with precision, ensuring that every piece of equipment could withstand the most extreme conditions. Voltage drop was a constant specter, especially given the sprawling size of the center, but through careful planning and design, voltage drops were maintained

within acceptable limits, even under the heaviest load conditions.

The specter of arc flash hazards loomed large, demanding a rigorous analysis to identify and mitigate these risks. The team calculated incident energy levels, ensuring that maintenance personnel could operate safely. This was complemented by a comprehensive Time Current Curve (TCC) coordination, ensuring that protective devices operated in perfect harmony, minimizing downtime and protecting equipment.

At the heart of the center's electrical prowess was an advanced Electrical Power Monitoring System (EPMS). This system didn't just monitor; it controlled, providing real-time data and insights, and integrating seamlessly with the Building Management System for comprehensive oversight.

Yet, the project wasn't just an electrical engineering feat. It was a symphony of interdisciplinary collaboration. Mechanical engineers worked hand in glove with the electrical team, ensuring that the cooling systems were in perfect sync with the electrical requirements. Architects and electrical engineers collaborated closely, ensuring that the electrical infrastructure was in harmony with the building design, addressing the myriad space and layout considerations.

The IT infrastructure was not left behind. The power distribution was designed to be in perfect harmony with the server racks and IT equipment, keeping an eye on Power Usage Effectiveness (PUE) strategies to ensure efficiency.

But Phoenix's climate posed its own unique challenges. The heat load was a constant battle, addressed with innovative cooling solutions and heat-resistant materials. Flexibility and scalability were key design principles, allowing for future expansion and adaptability. The design incorporated modular and scalable electrical components to accommodate growth, and energy efficiency was not just a goal but a guiding principle, with the integration of renewable energy sources and optimization of power usage.



Fig 1. Data center Site (PHX region)

#### IV. COMMERCIAL PROJECT INSIGHTS

##### Electrical Yard and Utility Feeds:

The Phoenix data center's electrical yard is a testament to advanced planning and scalability. Initially, it receives four 12kV feeders from the local utility, each capable of delivering up to 5MW of continuous power, thus providing a substantial 20MW to the facility. In anticipation of future needs, the client

has astutely negotiated with the utility company to supply an additional 20MW through four more 5MVA feeders.

##### Integration of Additional Power Feeds:

To incorporate these additional feeds seamlessly, a set of medium voltage switchgear is strategically installed. This switchgear plays a crucial role in integrating the new feeds into the existing electrical yard without disrupting ongoing services. This foresight in design highlights the emphasis on reliability and uninterrupted operation, key features for a high performance data center.

##### Distribution to Office Buildings:

The medium voltage switchgear feeds three similar sets of 480V switchgear via transformers. This 480V power is primarily directed to the office buildings within the data center complex. The design accommodates expansion at this distribution level by supporting each set of switchgear with a single transformer, ensuring scalability and flexibility in power distribution.

##### Configuration for Redundancy and Reliability:

Each 480V switchgear set is configured into two halves, connected through a tie breaker that is currently closed. This configuration provides a crucial redundancy, ensuring that if one half of the switchgear set encounters issues, the other half can seamlessly take over the load without impacting the overall power supply to the critical areas of the data center.

##### Critical Operations and UPS Deployment:

Understanding the importance of uninterrupted power for critical operations, the data center deploys Uninterruptible Power Supply (UPS) systems. These UPS systems are crucial in maintaining power stability and quality, safeguarding against potential power interruptions or fluctuations that could disrupt the data center's operations.

### Tier Classification and Reliability:

In terms of reliability and design complexity, data centers are often classified into four tiers, with Tier IV being the highest level, signifying a fault-tolerant site infrastructure. [4]. For this project in Phoenix, the design adheres to the Tier IV standards, which demand fully redundant subsystems and compartmentalized security zones controlled by biometric access methods. This stringent tier classification is chosen due to the critical nature of the operations housed within the data center. The Tier IV standard ensures that any individual component failure or maintenance activity does not disrupt the center's operations, thus offering the highest level of reliability and operational sustainability.

**Generators for Backup Power:** In line with its commitment to reliability, the Phoenix data center is equipped with state-of-the-art generators designed to provide backup power in the event of a utility outage. These generators are sized to handle the full load of the data center, ensuring that all operations, including the critical IT infrastructure and cooling systems, continue to function seamlessly during power interruptions. Regular testing and maintenance schedules are established to ensure that these generators are always in a state of readiness.

**Power Distribution Unit (PDU) Design:** The data center's power distribution strategy includes advanced Power Distribution Units (PDUs) that are carefully designed to meet the specific needs of data center racks and IT equipment.[5] These PDUs offer not only effective power distribution but also include features such as remote monitoring, load balancing, and surge protection. The modular design of the PDUs allows for easy expansion and flexibility, aligning with the data center's future growth plans.

**Metering and Power Management Systems:** An integral part of the data center's electrical infrastructure is its sophisticated metering and power management systems. These systems provide real-time data on power usage, efficiency, and operational health of the electrical system. They are essential for optimizing energy consumption, identifying potential issues before they escalate, and ensuring that the facility operates within its designed power envelope. The power management system integrates with the data center's overall Building Management System (BMS) for cohesive control and monitoring.

**Interplay of UPS and Generators:** The Uninterruptible Power Supply (UPS) systems work in tandem with the backup generators. In the event of a power outage, the UPS systems provide immediate power, bridging the gap until the generators come online. This ensures that there is no interruption in power supply to the critical loads.

**Electrical Design Considerations for Phoenix's Climate:** Given Phoenix's hot and arid climate, special attention is given to the cooling requirements of both the IT equipment and the electrical components, including the

UPS systems and PDUs. The electrical design incorporates cooling solutions that are both efficient and resilient, ensuring that the systems operate optimally in challenging environmental conditions.

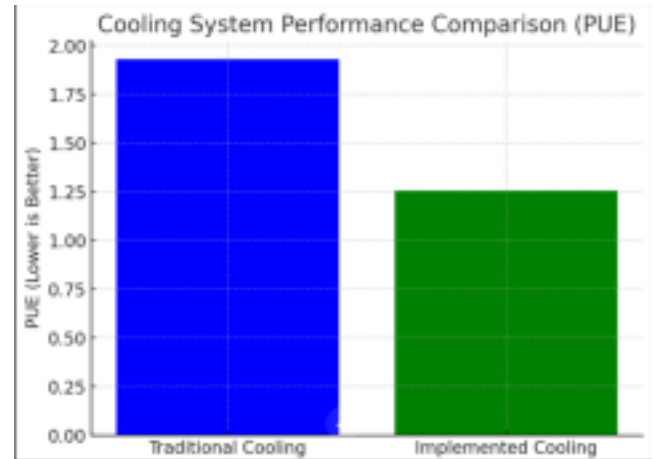


Fig 2. Cooling System Performance

The bar graph compares the Power Usage Effectiveness (PUE) of traditional cooling systems with the newly implemented system using Water Cooled Chiller technique than the traditional cooling using Air Cooled Chiller technique. The lower PUE value for the implemented system indicates higher efficiency.

**Electrical Distribution Design:** A well-evaluated electrical distribution design in data centers ensures optimal performance, scalability, flexibility, and cost efficiency. It also ensures compliance with industry standards. Integrating intelligent power management systems can enhance efficiency and incorporate efficient cooling systems. Modular and scalable components support easy expansion and adaptability. These measures lead to increased energy efficiency, reduced costs, and improved operations.

**Energy Consumption and Operational Costs:** Data centers consume approximately 1% of the world's electricity, and this number is expected to increase. Data center downtime can be costly, with an average cost of \$9,000 per minute. Therefore, an optimized electrical distribution design is crucial for reliability and scalability, as global internet traffic is expected to reach 8 zettabytes annually by 2025.

**Edge Computing Benefits:** Distributing "micro" data centers closer to utilization points reduces latency and costs compared to cloud or remote data centers. This approach can reduce capital expenses by 42% over a traditional build and offer benefits like shorter project timelines.



These pie charts illustrate the breakdown of operational costs before and after the optimization. The shift in cost distribution post-implementation shows a reduction in energy-related expenses, emphasizing the cost-effectiveness of the implemented strategies.

#### V. LOOKING AHEAD

The electrical design for data centers is evolving rapidly with new technologies aimed at enhancing efficiency, reducing costs, and meeting the increasing demands for data processing and storage. Some of the key technological advancements in this area for 2023 include:

**Edge Computing:** Edge computing involves shifting computing operations from the cloud or data centers to the edges of the network. This technology is particularly beneficial for IoT applications as it reduces latency and eliminates the need for a long-distance connection. AI-enabled networking, essential for Edge Computing, will enable dynamic routing and automation of tasks, thus reducing manual configuration and enhancing efficiency. The integration of 5G networking will further support faster data transmission and more reliable connections.

**Autonomous Data Centers:** These are self-managing and self-optimizing data centers that use artificial intelligence to automate various tasks, such as optimizing workloads, detecting anomalies, and automating security measures. The adoption of automation in data centers is expected to reduce operational costs and improve efficiency significantly.

**Increased Security:** With the growing importance of data security, data centers are focusing on implementing advanced security protocols and technologies like encryption, multi factor authentication, and advanced analytics to detect and respond to malicious activities in real-time. Disaster recovery solutions are also becoming crucial to protect against outages and data loss.

**Sustainability:** The push towards renewable energy sources and sustainable practices is leading to more efficient cooling systems, improved power supplies, and better server utilization in data centers. The adoption of virtualization, cloud computing, and energy-efficient

lighting, HVAC systems, and electrical systems are contributing to this trend.

#### VI. CONCLUSIONS AND INDUSTRY IMPACT

The comprehensive analysis of the confidential data center project in Phoenix has illuminated the paramount importance of integrated electrical design in modern data center infrastructure. This case study has not only highlighted the technical complexities involved in designing a highly reliable and efficient data center but also underscored the significance of a collaborative, multidisciplinary approach.

Key to the project's success was the seamless integration of various engineering disciplines. The synergy between electrical, mechanical, and architectural design teams, along with IT infrastructure specialists, created a cohesive and optimized environment for the data center's operations. Such collaboration proved to be indispensable in addressing the unique challenges posed by the Phoenix location, particularly

the extreme weather conditions and the need for efficient cooling solutions. The project's success in these areas serves as a testament to the efficacy of interdisciplinary collaboration in overcoming environmental and technical hurdles.

The electrical design's intricacy, featuring robust backup power systems, advanced PDUs, sophisticated metering, and power management systems, has set a new benchmark in the field. The strategic placement and integration of UPS systems, generators, and advanced cooling mechanisms, tailored to meet the demanding requirements of the data center, showcased a meticulous attention to detail and a deep understanding of the operational demands of such facilities.

Furthermore, the adherence to Tier IV standards in the data center's design and operation reflects a commitment to the highest levels of reliability and operational sustainability. This stringent approach ensures uninterrupted service and resilience against potential failures, embodying the pinnacle of data center design excellence.

In conclusion, the confidential data center project in Phoenix stands as a beacon of innovation and efficiency in the realm of data center development. It exemplifies the profound impact of integrated electrical design and the value of a multidisciplinary approach in creating state-of-the-art data centers. This project not only meets the current demands for data processing and storage but also sets a visionary template for future developments in this rapidly evolving field. The lessons learned and the methodologies applied here have broad implications for the design and operation of data centers worldwide, paving the way for more resilient, efficient, and sustainable data infrastructures.

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