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Study of Data Center Design

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Abstract—*Data centres are the "nerve centres" of the new economy or special environments that house the latest advances in computer processing and business innovation. Data centres centralize and consolidate information technology (IT) resources, enabling organizations to conduct business around-the-clock and around the world. In this paper, we present the different tier topology according to uptime institute. We start discussion with the basic data centre design and standards and, thereafter we will discuss about the various data centre design considerations for the electrical system and ventilation system with comparison and finally we will discuss about the data centre design considerations.*

Keywords*: data center, design, electrical system*

1. INTRODUCTION

Data centres are comprised of a high speed, high demand networking communication Systems capable of handing the traffic for SAN (Storage Area Networks), NAS (Network Attached Storage), file/application/web server farms, and other components located in the controlled environment. The control of the environment relates to humidity, flood, electrical, temperature, fire controls and of course physical access. Communication in and out of the data centre is provided by WAN, CAN/MAN and LAN links in a variety of configurations depending upon the needs of the particular centre.

A properly designed data centre will provide availability, accessibility, scalability, and reliability 24 hours a day, 7 days a week, 365 days per year minus any scheduled downtime for maintenance. Telephone companies work for 99.999% uptime and the data centre is no different. There are two basic types of data centres: corporate and institutional data centres (CDCs) and Internet Data Centres (IDCs). CDCs are maintained and operated from within the corporation, while IDCs are operated by Internet Service Providers (ISPs). The ISPs provide third party web sites, connection facilities and other data services for companies such as outsourced email. Corporate data centres and Internet data centres share many common attributes and vary mostly in terms of scale and user base served. Most corporate data centres provide connectivity, application services and support to hundreds (or thousands) of workers within a building, campus or remote company facility. Internet data centres are like 21st century commercial versions of a telco-central office. Instead of merely providing dial tone, these IPCOs (IP Central Offices) provide IP services over which customers may opt to run voice and video along with their data.

There are many common functions in data centres today whether they are owned and operated by corporations or leased from an Internet data centre operator. For the most part, all data centres require:

- Internet access and wide area communications
- Application hosting
- Content distribution
- File storage and backup
- Database management
- Failsafe power
- Adequate heating, ventilation and air conditioning (HVAC) and fire suppression
- High-performance cabling infrastructure
- Security (access control, video surveillance)

2. DATA CENTRE TIER CONFIGURATION

Data centre facilities are classified as Tier 1 through Tier 4 as described by the Uptime Institute, Inc. (Level 1 through Level 4) and are based on the their respective facility infrastructure and redundancy (Tier 1 being the lowest and Tier 4 being the highest in terms of reliability requirements).higher the tier, higher the availability one by one description is given below.

a) Tier 1:

A tier 1 type is a basic data centre with non-redundant capacity components and a single non-redundant. Distribution path serves the sites computer equipment. Planned work requires most or all of the systems to be shut down, impacting the computer systems. Single line diagram for the Tier 1 data centre is given below:

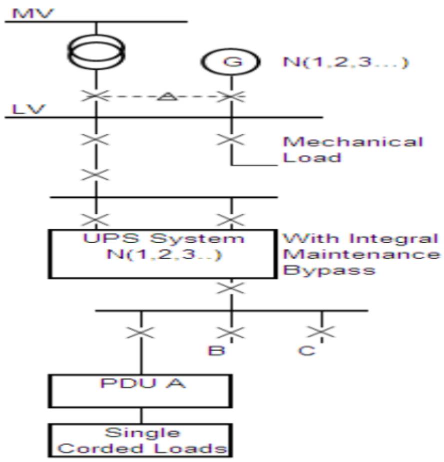

Figure 1. Single line diagram for the Tier 1.

Tier 1 characteristics are given below:

- 99.671% availability
- Susceptible to disruption from both planned and unplanned activity.
- Single path for power and cooling distribution,
- No redundant component (N).
- May or may not have a raised floor, UPS, or generator
- Take 3 months to implements
- Annual downtime is 28.8 hour
- Must be shut down completely for perform preventive maintenance

b) Tier 2:

A tier 2 type is a data centre with redundant capacity components and a single non-redundant distribution Path serves the sites computer equipment. Planned work requires most or all of the systems to be shut down. Failure to perform maintenance work increases the risk of unplanned disruption as well as the severity of major failures. Single line diagram for the Tier 2 data centre is given below:

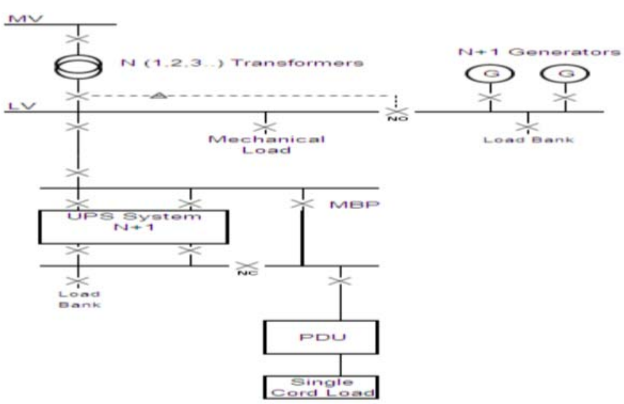

Figure 2. Single line diagram for the Tier 2

Tier 2 characteristics are given below:

- 99.741% Availability
- Redundant Components
- Less susceptible to disruption from both planned and unplanned activity
- Single path for power and cooling disruption, includes redundant components (N+1)
- Includes raised floor ,UPS and generator
- Takes 3 to 6 months to implement
- Annual downtime of 22.0 hours.
- Maintenance of power path and other parts of the infrastructure require a processing shutdown:

c) Tier 3:

A tier 3 type is a concurrently maintainable data centre with redundant capacity components and multiple distribution paths serve the sites networking equipment. Generally, only one distribution path serves the networking equipment. Each and every capacity component of the distribution path can be removed from service on a planned maintenance window without causing any computer equipment to be shut-down. In order to establish concurrent maintainability of the critical power distribution system, Tier 3 sites require all computer hardware to have dual power inputs. Single line diagram for the Tier 3 data centre is given below:

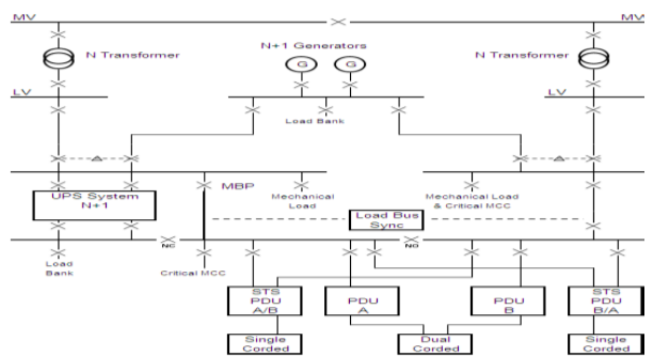

Figure 3. Single line diagram for the Tier 3

Tier 3 characteristics are given below:

- 99.982% Availability.
- Concurrently Maintainable.
- Enables planned activity without disrupting computer hardware operation, but unplanned events will still cause disruption.
- Multiple power and cooling distribution paths with only one path active, includes redundant components (N+1)
- Takes 15 to 20 months to implement.
- Annual downtime of 1.6 hour.

- Includes raised floors and sufficient capacity and distribution to carry load on one path while performing maintenance on the other.

d) Tier 4:

A tier 4 type is a fault tolerant data centre with redundant capacity systems and multiple distribution paths. Simultaneously serves the sites computer equipment. Each and every capacity component of the distribution path can be removed from service without causing any computer equipment to be shut-down. In order to establish fault tolerance and concurrent maintainability of the critical power distribution system, Tier 4 sites require all computer hardware to have dual power inputs. Distribution paths must be physically separated (compartmentalized) to prevent any single event from impacting either systems or paths simultaneously. Single line diagram for the Tier 4 data centre is given below:

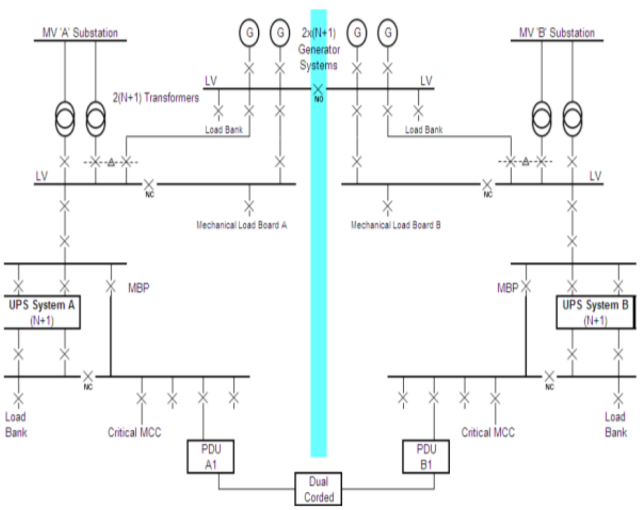

Figure 4. Single line diagram for the Tier 4

Tier 4 characteristics are given below:

- Fault Tolerant
- 99.995% Availability
- Planned activity does not disrupt critical load and data centre can sustain at least one worst case unplanned event with no critical load impact.
- Multiple active power and cooling distribution paths, includes redundant components (2 (N+1) that is 2 ups each with N+1 redundancy)
- Takes 15 to 20 months to implement
- Annual downtime of 0.4 hours

Table 1 is showing the comparison between different tier topology.

TIER TOPOLOGY				
	TIER 1	TIER 2	TIER 3	TIER 4
ACTIVE CAPACITY COMPONENTS TO SUPPORT THE IT LOAD	N	N+1	N+1	N After any failure
DISTRIBUTION PATH	1	1	1 Active and 1 Alternative	2 Simultaneously active
CONCURRENTLY MAINTANABLE	1	NO	YES	YES
FAULT TOLERANT	NO	NO	NO	YES
COMPARTMENATLIZATION	NO	NO	NO	YES
CONTINUES COOLING	NO	NO	NO	YES
AVAILABILITY IN %	99.671	99.741	99.982	99.995
ANNUAL DOWNTIME IN HOUR	28.8	22	1.6	0.4
MONTHS TO IMPLEMENT	2 TO	3 TO	[illegible]	[illegible]

Table 1 Comparison Between Different Tier Topology.

3. ELECTRICAL SYSTEMS

In electrical systems, it is important to always consider initial and future loads, in particular part and low-load conditions, when designing and selecting equipment for a data centre's electrical system.

a) Basic Electrical Requirement

Data centres typically have an electrical power distribution path consisting of the Utility service, switchboard, switchgear, alternate power sources (i.e. backup generator), paralleling equipment for redundancy (i.e. multiple UPS's and PDU's), and auxiliary conditioning equipment (i.e. line filters, capacitor bank). These components each have a heat output that is tied directly to the load in the data centre. Efficiencies can range widely between manufacturers and variations in how the equipment is designed.

b) Uninterruptible Power Supplies (UPS)

UPS systems provide backup power to data centres, and can be based on battery banks, rotary machines, fuel cells, or other technologies. A portion of all the power supplied to the UPS to operate the data centre equipment is lost to inefficiencies in the system. The first step to minimize these which equipment, if not the entire data centre, requires a UPS system. For instance the percent of IT power required by a scientific computing facility can be significantly lower than the percent required for a financial institution.

Increasing the UPS system efficiency offers direct, 24-hour-a-day energy savings, both within the UPS itself and indirectly through lower heat loads and even reduced building transformer losses. Among double conversion systems (the most commonly used data centre system) UPS efficiency ranges from 86% to 95%. When a full data centre equipment load is served through a UPS system, even a small improvement in the efficiency of the system can yield a large annual cost savings. For example, a 15,000 square foot data centre with IT equipment operating at 100 W/SF requires 13,140 MWH of energy annually for the IT equipment. If the UPS system supplying that power has its efficiency improved from 90% to 95%, the annual energy bill will be reduced by 768,421 kW/h, or about 4879473.35 INR at 6.35INR/kWh (Tamil Nadu), plus significant additional cooling system energy savings from the reduced cooling load. For battery-based UPS systems, use a design approach that keeps the UPS load factor as high as possible. This usually requires using multiple smaller units.

c) Power Distribution Units (PDU)

A PDU passes conditioned power that is sourced from a UPS or generator to provide reliable power distribution to multiple pieces of equipment. It provides many outlets to power servers, networking equipment and other electronic devices that require conditioned and/or continuous power. Since the beginning of data centre technology to till now there is a dramatic changes in power requirement and how power is utilized in data centres that have challenged this architecture, specifically driven by increasing power density, the increasing number of separate IT devices within the data centre, and the need to add and remove IT devices on a continuous basis. An ideal power distribution system would have the following attributes:

- New circuits can be added or changed on a live system safely
- No under-floor cables needed
- All circuits monitored for power
- All breaker status remotely monitored
- IT zones and associated power distribution can be deployed over time
- All power levels supported using only a single cable to the IT enclosure
- Receptacle types can be changed at the IT enclosure by IT personnel
- Capacity and redundancy are managed on every circuit
- No excess copper is installed that is not needed
- High efficiency

Power distribution systems have been evolving in response to the needs of the modern data centre, and various improvements have been introduced to the power distribution system over time, most notably:

- Branch circuit power metering
- Overhead cable tray with flexible power cords
- Overhead fixed bus way with removable power taps
- High power, pluggable rack power distribution units
- Transformer less Power Distribution Units
- Power capacity management software

There are two main way to distribute the power in the rack first one is through modular power distribution system another one is through bus way to the rack.

1) Modular Power Distributions

The modular distribution system has two steps. For larger data centres the main critical bus power from the uninterruptible power supply (UPS) is distributed to IT rows using one or more overhead bus ways as shown at the top of Figure 5. The bus ways are installed up front and traverse the entire planned IT rack layout. When a group of racks is to be installed, a low foot print modular PDU is installed at the same time and plugged into the overhead bus way. The connection to the bus way is also shown in Figure.

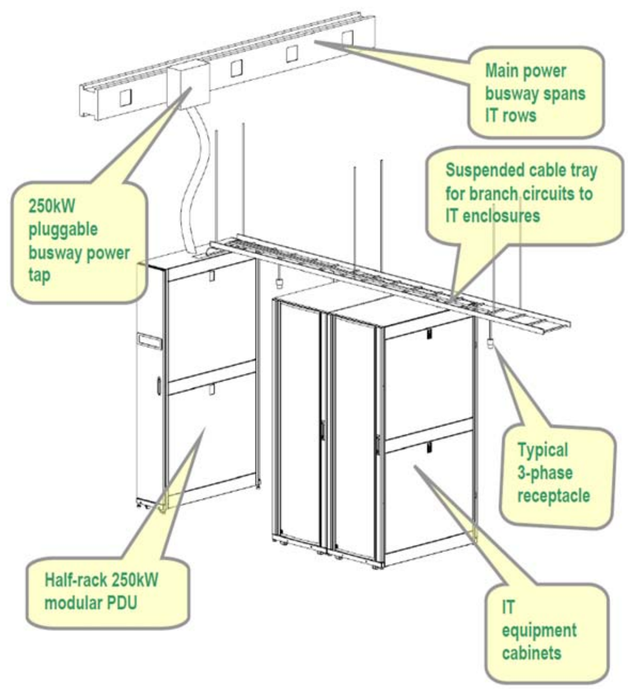

Figure 5. Modular Power Distributions

Instead of traditional circuit breaker panels with raw wire terminations, the modular PDU has a backplane into which pre-terminated shock-safe circuit breaker modules are installed. This arrangement allows the face of the PDU to be much narrower, and eliminates on-site termination of wires.

The modular PDU initially has no branch circuit modules installed. The power circuits from the modular PDU to the IT racks are flexible cable that are plugged into the front of the modular PDU on site to meet the requirements of each specific rack as needed. The branch circuit cables to the IT enclosures are pre-terminated with breaker modules that plug into the shock-safe backplane of the modular PDU.

In the modular power distribution system, there is built-in current and energy monitoring on every circuit at all levels of the hierarchy (outlet-level monitoring is optional in some configurations). In addition, the branch circuit breakers in the PDU are monitored for status. All of the monitoring communicates via simple network management protocol (SNMP) open standards protocol. Capacity management software is used to monitor every circuit in the system and enforce safety margins, verify redundancy, and identify available capacity.

2) **Bus-way to the rack**

In the bus way to the rack system, the IT enclosures directly connect into the overhead bus way via breaker boxes as shown in Figure 6.

Figure 6. Bus-way to the rack

The bus-way is pre-installed over all IT equipment rows. This solves a number of the problems with traditional distribution, making changes easier and removing under-floor cabling. Bus-way was the first alternative to traditional distribution that achieved a flexible, reconfigurable distribution system. Bus-way to the rack is compared to modular distribution in Table 3.

There are a number of practical disadvantages of bus-way to the rack that are overcome by the new modular PDU architecture. Table 3 shows that the modular power distribution system has some advantages over bus-way for the final distribution to the IT enclosure. Bus-way for the final distribution has the advantage of zero footprint, but the modular distribution system is more scalable and adaptable to changing density, is standardized globally, and requires less up front planning and engineering. In general, for distribution to the rack, bus-way is best suited for very large facilities with an open floor plan with a very well defined IT equipment layout. The modular distribution system has the greatest advantage when locations are not precisely defined in advance, the room is constrained in shape or has obstructions, or the power density is expected to vary significantly through the room. Either of these approaches is vastly superior to the traditional under floor conduit system, and a summary of key factors to consider in the selection between the approaches is provided in Table.

Table 2. Factors to consider when choosing between busway and modular distribution to the IT enclosure

Factors suggesting busway to the rack	**Factors suggesting modular distribution**
No floor space, even 5% of the space or less, can be used by the power distribution system	The IT enclosure layout is not well defined in advance. The layout is not a simple rectangle with defined rows.
Busway to the rack may not be the preferred choice when:	**Modular distribution may not be the best choice when:**
The locations of future IT enclosures are poorly defined. The power densities of future zones are not well known in advance. Overhead mounting is impractical due to ceiling construction or other constraints A global standard solution is required	No IT floor space, even 5% of the space or less, can be devoted to the power distribution system

d) DC Power Distributions

In a conventional data centre power is supplied from the grid as AC power and distributed throughout the data centre infrastructure as AC power. However, most of the electrical components within the data centre, as well as the batteries storing the backup power in the UPS system, require DC power. As a result, the power must go through multiple conversions resulting in power loss and wasted energy.

Table 3 Comparison of busway to the rack with modular power distribution to IT enclosures (best performance highlighted in dark)

Issue	Busway to the rack	Modular Distribution
Ability to handle mixed and changing power density	Busway must be sized in advance to the maximum density and capacity otherwise adding an additional busway in the future is disruptive and impractical	Power density is adjustable to suit the current configuration by adding or swapping branch circuits. Easier to install additional PDUs for extra capacity Power density is adjustable to suit the current configuration by adding or swapping branch circuits. Easier to install additional PDUs for extra capacity
Ability to handle specialized room layouts	Busway must be installed in advance over all expected enclosure locations	Flexible cable easily adapts to room obstructions, specialized IT cabinets, and constrained IT equipment floor plans
Safe & secure access to circuit breakers	Breakers are mounted on the overhead busway, requiring ladder access. This is not permitted due to local codes in many cases. Chain or other actuators may be required	All branch protectors behind a lockable door in one easily accessible location
Minimal floor footprint	Zero floor footprint	Consumes approximately 0.7 sq. M for every 100 kW of IT load, or approximately 2% of computer room space
Standardized global solution	Regulations for busway vary geographically, requiring different physical configurations or current ratings or data communications in different locations	Standard architecture meets all international regulations and has a global standard for monitoring
Energy monitoring of each rack branch circuit	Busway systems typically only monitor the total power in the bus using optional equipment, and rely on Rack PDUs to report individual rack power	PDU supports auto-discovery for new branch circuits installed and has a single communication port for all branch circuits Monitors power for each IT enclosure, even if the enclosure does not use a rack PDU, such as blade servers
Simplified engineering	Complex trade-offs between row length, density, busway ampacity, and cost must be made in each installation, even in different rows within the data center, in order to optimize the result and ensure the busway is not overloaded	Select from standard reference designs to meet requirements. Many decisions can be deferred to later phases
Minimal copper use	Busway copper must be oversized to maximum power density	Branch circuit copper is only deployed when needed and at the capacity needed
Standard length final distribution cable	The busway is always the same distance from the IT enclosure so all cable drops are the same length, simplifying spares inventory	The distance from the PDU and the IT enclosure vary, requiring different length cables. Long cables can be cut and re-terminated by the user, but this is less convenient
Can be used in situations where overhead mounting is impractical	Busway cannot be installed under-floor in many locations due to regulations	Power distribution cable trays can be suspended from overhead, mounted to the tops of the IT racks, or installed under-floor
Minimal up-front cost	Most of the busway cost is incurred in the initial build	Most of the power distribution cost is incurred only when and if needed
Efficiency	Busway sized in advance for maximum capacity (i.e. the greatest amount of copper) resulting in slightly lower losses. Efficiency payback over 50 years given high cost of copper	Copper sized more closely to actual load resulting in slightly more losses

A number of studies have claimed substantial expected efficiency advantages for a DC power system, from 10% to 40%. However, these studies assume very low efficiency for AC power systems. Since these studies first came out, newer high efficiency AC power distribution architectures have become widely available with demonstrated efficiencies comparable with the hypothetical efficiency of DC systems. A quantitative analysis comparing AC vs. DC power efficiency can be found in the Green Grid White Paper 16, Quantitative Efficiency Analysis of Power Distribution Configurations for Data Centres and White Paper 127, A Quantitative Comparison of High-Efficiency AC vs. DC Power Distribution for Data Centres. These papers show that the best AC power distribution systems are nearly as efficient as DC, removing a key incentive to change the industry. The most important problem with DC power distribution is the lack of availability of compatible IT devices. While some IT devices are available with a 48 V DC input option, this is the least efficient DC distribution voltage and consumes large amounts of copper wiring.

The cost of transitioning the industry to DC would be very large and the lack of any significant cost or efficiency gains has removed the incentive to make this change. Therefore the industry is expected to remain AC based, although DC will be used as a distribution system within proprietary IT equipment including blade server chassis or racks, and within containerized servers

e) Lighting

Data centre spaces are not uniformly occupied and, therefore, do not require full illumination during all hours of the year. UPS, battery and switch gear rooms are examples of spaces that are infrequently occupied. There-fore, zone based occupancy sensors throughout a data centre can have a significant impact on reducing the lighting electrical use. Careful selection of an efficient lighting layout (e.g. above aisles and not above the server racks), lamps and ballasts will also reduce not only the lighting electrical usage but also the load on the cooling system. The latter leads to secondary energy saving.

4) COOLING

As recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the ANSI/TIA/EIA-942 data centre standard, the first step to gaining control of excess heat is to reconfigure the cabinet layout into a hot aisle/cold aisle arrangement. In the cold aisle, equipment rack are arrange face to face and in the hot aisle equipment placed back to back. The minimum aisle width should be at least three feet. Typically, cold aisles are four feet wide to allow for two fully perforated floor tiles in front of cabinets with active components. Hot aisles should be wide enough to allow for unrestricted access to data and power cabling. Additionally, the standard states that the data centre power distribution cabling should be located under the cold aisle and the cable trays for telecommunications cabling should be located under the hot aisle.

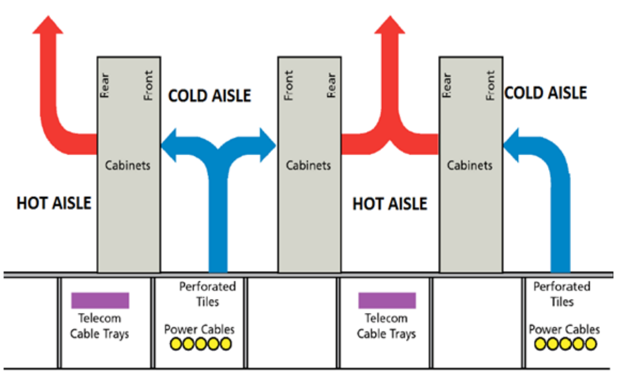

Figure 6. Hot aisle/Cold aisle arrangement.

It is also recommended that solid tops and solid side panels be installed between all cabinets in a row so hot air and cold air will not mix. Additionally, the installation of air dams in the front of the cabinet is recommended to block hot air from slipping around the sides of the mounted components and mixing with the cool intake of air. Finally, ASHRAE recommends that precision sized Computer Room Air Conditioners (CRAC) be placed at either end of the hot aisles.

4. CONCLUSION

This paper describes the basic data center and data center topology described by the Uptime Institute, Inc. (Level 1 through Level 4) and are based on the their respective facility infrastructure and redundancy, then after electrical system design for the data center has been discussed. Two alternative power distribution systems have been described, busway to the rack and modular distribution, both of which are major improvements over the traditional approach in terms of scalability, efficiency, re configurability, manageability, and power density. The modular power distribution system is shown to be particularly advantageous in practical data centers where layout is not precisely defined in advance, in retrofit applications, and in cases where the room layout includes unusual shaped floor plan or obstruction. Finally hot aisle and cold aisle system has been studied

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