

# Power and Cooling for VoIP and IP Telephony Applications

## Executive Summary

The advent of IP telephony required the development of techniques that deliver power to IP phones from Ethernet LAN switches. Although IP phones were the first powered devices, other devices that use Power over Ethernet (PoE), such as wireless hubs and IP surveillance cameras, development of Power over Ethernet, pioneered by Cisco Systems, and the advent of the IEEE 802.3af standard for power deliver over data cabling, new and innovative applications for Power over Ethernet are now emerging, ranging from magnetic card readers to electric guitars.

The deployment of Power over Ethernet devices such as IP telephones can cause unexpected or unplanned power and cooling requirements in wiring closets and wiring rooms. Many Enterprises require IP telephony to be as available as existing legacy PABX systems. However, most wiring closets do not have uninterruptible power available, and do not provide the ventilation or cooling required to prevent equipment overheating that could impact availability. Understanding the unique cooling and power requirements of Power over Ethernet equipment allows planning for a successful and cost-effective deployment.

This paper explains how to plan for IP telephony power and cooling needs, and describes simple, fast, reliable, and cost-effective strategies for upgrading old facilities, as well as building new ones.

## Introduction

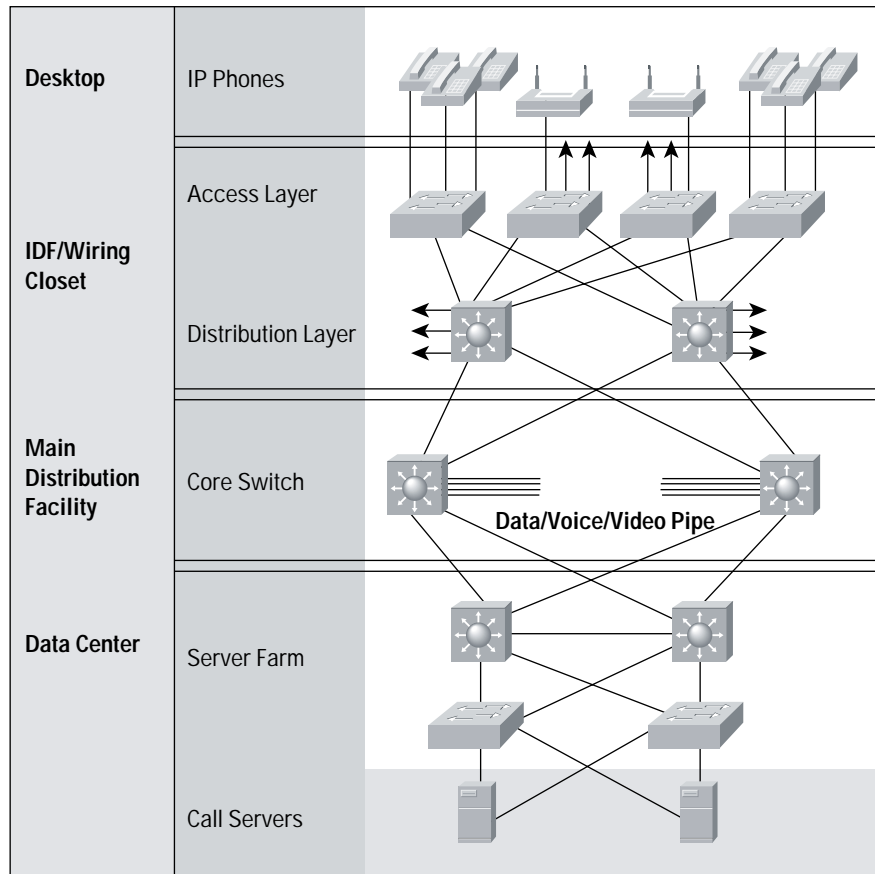
To replace traditional private automatic branch exchange (PABX) phone systems, IP telephony must deliver similar, or higher, availability. One of the major reasons why a traditional PABX system has high availability is the fact that it has been built around practices found within public telephone exchanges. A typical PABX exchange has built-in battery backup that ensures long run time in the event of a power outage, and also provides power to the phone. IP phones have been developed to exploit the field-proven, time-tested concept of providing power with signal, which eliminates local power supplies, by powering the IP phone from the Ethernet switch. To provide the same availability as legacy PABX systems, the Ethernet switches must be protected against power outages. As Ethernet power to the IP phones, the wiring closet, which used to house low power LAN switches and hubs, is now required to accommodate power delivery capable Ethernet switches and long run time UPS to ensure network availability. Due to the increased power delivery requirements, cooling and airflow in these wiring closets become a critical consideration to ensure continuous operation.





A typical Campus LAN network is built in layers, and each layer is made of components that reside in one of the four physical locations (Figure 1). Power and cooling requirements for these four locations vary as described in the following sections.

Figure 1  
Typical IP Telephony Network Layers and Locations



### Communications Devices

Typically, the Powered Devices that are found within Campus LAN Networks are IP phones (Figure 2), wireless hubs (Figure 3), and laptops running “soft phones” providing IP phone functions. Although IP phones, such as the Cisco® IP Phone 7960G, typically draw 6-7 Watts, although watts, devices such as wireless Access Points may draw more power. The IEEE 802.3af standard limits the maximum current drawn by a Powered Device (PD) from CAT5 cables to 350mA that delivers approximately 13W<sup>1</sup> of power at the powered device up to a distance of 100M (328 ft). For devices that require higher power consumption, the powered device cannot be powered by an IEEE 802.3af compliant power source and is required to use local power sources (power bricks).

1. IEEE 802.3af actually provides a maximum of 15.4W at the PSE device and a maximum of 12.95W at the powered device.



Figure 2  
IP Telephone



Figure 3  
Wireless Access Point



## Environment

Powered devices may be located on desktops, sometimes wall or plenum mounted and typically used in an office environment. For newly deployed powered devices and upgraded networks, the powered devices will most likely be powered over the data lines, although in some cases they may be powered from the local AC power outlets.

## Problems

Powered devices such as IP phones typically need to be as available as the traditional PABX phones they replace. The biggest problem to be solved here is to ensure their continuous operation even during an extended power outage.

## Best Practices

Sending power over the data line to the phone (Power over Ethernet) is the best way to solve this problem because it can eliminate some of the problems of economically delivering uninterrupted power delivery at the desktop location. By deploying Power over Ethernet (PoE), power is now fed to the phone by an Ethernet switch located in the wiring closet, which may be supported by a long run time UPS system. This cost effectively provides highly available IP phone and network infrastructure. For those powered devices that do not support Power over Ethernet, or those that require greater than 15.4W can be powered from a local AC power outlet with a small UPS system with battery back-up.

## Intermediate Distribution Frame (IDF)

An intermediate distribution frame (IDF) or wiring closet typically comprises Ethernet access and distribution LAN switches, such as Cisco<sup>®</sup> Catalyst Multiservice switches, patch panels, UPS system with a battery back-up as well as any other miscellaneous telecommunications equipment mounted in a two post rack (Figure 4 and 5). To support IP phones and other powered devices, power source equipment (PSE) capable LAN switches, such as Cisco Catalyst



Multiservice LAN switches, that support the ability to supply power over the data lines (“end-span” power supplies), must be supported in the IDFs. For switches without this capability, IEEE 802.3af describes an external “mid-span” PSE that may be used to inject in-line power.

Figure 4  
IDF (wiring closet)

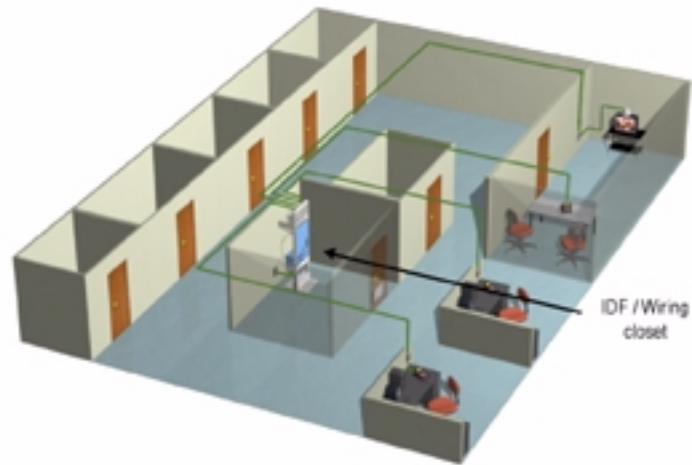
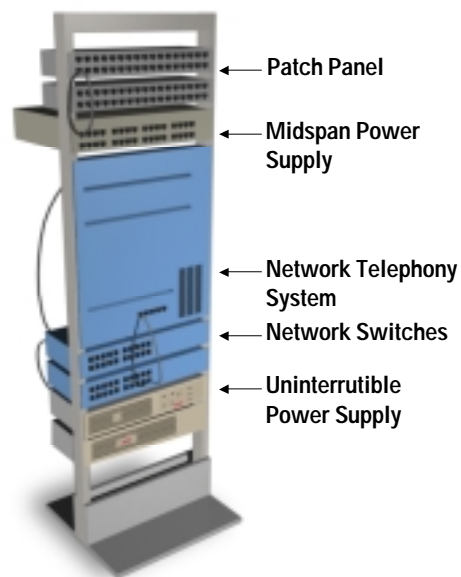


Figure 5  
Typical IDF Layout





## Environment

These IDF or wiring closets are typically hidden in remote locations within a building, with little or no ventilation and illumination. Unless the customer is moving into a new building, they will want to reuse these wiring closets because of cost considerations and the attendant disruption associated with re-cabling. Traditionally, wiring closets were used mainly for cable wiring closets mainly for cable termination, patch panels, and a small stackable hubs or modular switches. Although PSE capable Ethernet switches will fit within a standard 19" -inch enclosure, PSE capable Ethernet switches require and dissipate considerably more power than the non-power capable Ethernet switches. Additionally, PSE capable Ethernet switches have larger cooling and airflow requirements, and have varying air flow patterns depending on the PSE LAN switch manufacturer (for example side to side, front to back, etc.) In general a typical IDF houses between one and three racks of equipment, and may draw between 500W to 6000W of single phase AC power per PSE-capable device.

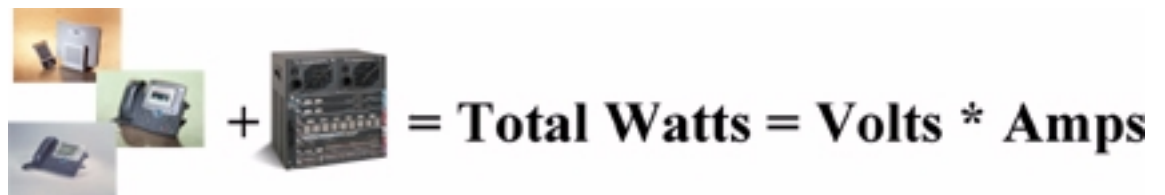
This may have a considerable impact if a user decides to upgrade the power supplies and line cards of an existing chassis to support Power over Ethernet, or increase the number of powered devices a chassis can support. Although extending Power over Ethernet support to existing chassis is easily achieved using modular switch systems such as Cisco Catalyst 6500 and Catalyst 4500 Ethernet switches, what must be remembered is that the wiring closet power and cooling requirements may also need to be upgraded.

## Problems

When deploying Power over Ethernet, the IDFs typically need the most attention in terms of power and cooling as the PSE draws power in the range from 500W to as high as 6000W single phase at either 120 or 208 VAC, depending on the type of switch used and the number of powered devices that need to be supported.

The amount of power required to support all powered devices, ie IP phones, wireless access points and the PSE hardware, that is the line cards, supervisors, fabric modules, etc (Figure 6), must be calculated to determine the size of power supply required. To calculate the total maximum power load required is relatively simple because it is the sum of the maximum power draw of each powered device plus that of the switch components. It should be remembered that although the power manager may use the powered devices maximum budgeted power draw, the powered device rarely uses the maximum.

Figure 6  
Power Consumption Components



Once the power requirements are understood, the wiring closet power infrastructure can be determined. Once the power requirements have been determined, the right type of receptacle (e.g. L5-20, L5-30, L6-20, L6-30) and right amount of power with the right circuit breaker protection to all the network equipment can be provisioned. Additionally, the uninterrupted power supply (UPS) and power distribution unit (PDU) requirements for the wiring closet can be determined. Cooling and airflow are often a bigger, but often ignored, problem to address in these wiring closets.



## Best Practices

To protect against power outages and potentially damaging power fluctuations, all equipment in the IDF should be protected by a UPS system. The selection of the UPS system is based on:

- The total power required in Watts
- The run time required in minutes
- The level of redundancy or fault tolerance desired
- The voltages and receptacles required

The UPS system should be sized to the sum of the Watt ratings of the loads. A common rack-mount UPS such as the American Power Conversion Corporation's APC Smart-UPS (Figure 7) will provide approximately four nines (99.99 percent) of power availability, whereas an N+1 redundant UPS with built-in bypass, such as the APC Symmetra RM (Figure 8), with 1-hour run time, provides approximately five nines (99.999 percent availability, a level that may be sufficient for most applications. See the Appendix for details on availability analysis.

Figure 7  
APC Smart-UPS



Figure 8  
APC Symmetra RM



UPS products are available with battery packs to provide different durations of run time. Products of the type shown in Figures 7 and 8 have optional battery packs that can be used to extend run time to up to 24 hours.

Higher levels of availability such as six or seven nines may be needed for some critical applications such the emergency 911 service. These requirements may be met by using network switches with dual PSUs and power cords, dual UPSs, and concurrently maintainable electrical architectures with generator backup. Many companies, such as American Power Conversion Corporation, have dedicated availability consulting services to evaluate and recommend high availability power infrastructures for these critical networks.



Finally, identify the plugs and receptacles required for all the equipment including the UPS in the wiring closet. Ideally all the equipment should be plugged directly into the back of the UPS or the transformer, and the use of additional outlet strips or rack PDUs should be avoided. However if there is a lot of equipment this may not be practical, and a rack PDU strip should be used. In that case a high-quality rack PDU specifically designed for the purpose should be used. The PDU should have enough receptacles to plug in all the current equipment with some spares for future needs. PDUs with a meter displaying the current power consumption are preferred because they reduce human errors such as accidental overloading and resultant load drops.

To assist in the selection of an appropriately sized UPS model to meet the required power level, redundancy, voltage, and run time, American Power Conversion Corporation have developed a web based UPS selector that is available at <http://www.apcc.com/template/size/apc/>. This system has power data for all popular switches, servers, and storage devices, thereby avoiding the need to collect this data. In systems like this, the choice of configuring a UPS provides various receptacle options.

To ensure continuous operation of the equipment in the wiring closet, cooling and airflow issues must be identified and addressed. Power dissipation in the wiring closet should be calculated to decide on a cost effective way to solve the problem (please refer Table 1). The most important thing to note here is that many network switches draw a lot of power, but that does not mean they dissipate all the power consumed in the wiring closet. For example, an Ethernet switch may draw 1800W of power, but it may be dissipating only 200-500W in the closet. The rest of the power is supplied over the network to the various IP phones and dissipated over the office area.

Table 1 Wiring closet heat output calculation worksheet

Item	Data Required	Heat Output Calculation	Heat Output Subtotal
<b>Cisco Catalyst Multiservice Switches without in-line power, other IT equipment (except mid-span power units)</b>	Sum of input rated power in Watts	Same as total IT load power in watts	_____ Watts
<b>Cisco Catalyst Multiservice Switches with in-line power capability</b>	Input rated power in Watts	0.6 x Input power rating	_____ Watts
<b>Mid-span power units</b>	Input rated power in Watts	0.4 x Input power rating	_____ Watts
<b>Lighting</b>	Power rating of any lighting devices permanently on in Watts	Power rating	_____ Watts
<b>UPS system</b>	Power rating of the UPS system (not the load) in Watts	0.09 x UPS power rating	_____ Watts
<b>Total</b>	Subtotals of all other variables	Sum of all the heat output subtotals	_____ Watts

After calculating the power dissipated in the wiring closet, guidelines outlined in Table 2 can be followed.



Table 2 VoIP Wiring Closet Cooling Solutions Worksheet

Total Heat Load in Closet	Condition	Analysis	Action
< 100 W	Balance of building is conditioned space	Wall conduction and infiltration will be sufficient	None
< 100 W	Balance of building is hostile space: no heating, ventilation and air conditioning (HVAC) system.	Any fresh air from outside the room cannot be considered safe to use because of temperature or contaminants.	Install a self-contained computer air conditioner in the closet adjacent to the equipment.
100–500W	Dropped ceiling (overhead) HVAC system exists: balance of building is conditioned space.	Fresh air from outside the closet will be sufficient if drawn through, but the door may block air. Bring air in through the door and exhaust to the HVAC return.	Place a return grille in the overhead ventilation system in the top of closet, and place a vent in the bottom half of the closet door.
100–500W	No access from closet to any HVAC system; balance of building is conditioned space.	Fresh air from outside the closet will be sufficient if drawn through, but the door may block air. Bring air in the bottom of door and exhaust out the top of the door	Place an exhaust grille in the top of the closet door, and place an intake vent in the bottom half of the closet door.
500–1000W	Dropped ceiling (overhead) HVAC system exists: balance of building is conditioned space.	Fresh air from outside the closet will be sufficient if drawn through continuously, but the door may block air and continuous fan operation is required and not assured.	Place a return grille with ventilation fan assist in the top of closet, and place a vent in the bottom half of the closet door.
500–1000W	No access from closet to any HVAC system; balance of building is conditioned space.	Fresh air from outside the closet will be sufficient if drawn through continuously, but there is no way to get the air.	Place an exhaust grille with ventilation fan assist in the top of door, and place a vent grille in the bottom half of the closet door.
> 1000W	Dropped ceiling (overhead) HVAC system exists and is accessible: balance of building is conditioned space.	Fresh air from outside the closet will be sufficient if drawn directly through the equipment and no hot exhaust air from the equipment recirculates to the equipment intake.	Put equipment in an enclosed rack with a hot exhaust air scavenging system and place a vent grille in the bottom half of the closet door.
> 1000W	HVAC system is not accessible: balance of building is conditioned space	Moving air through the door is insufficient; local cooling of the equipment exhaust air is required.	Install a self-contained computer air conditioner in the closet adjacent to the equipment.

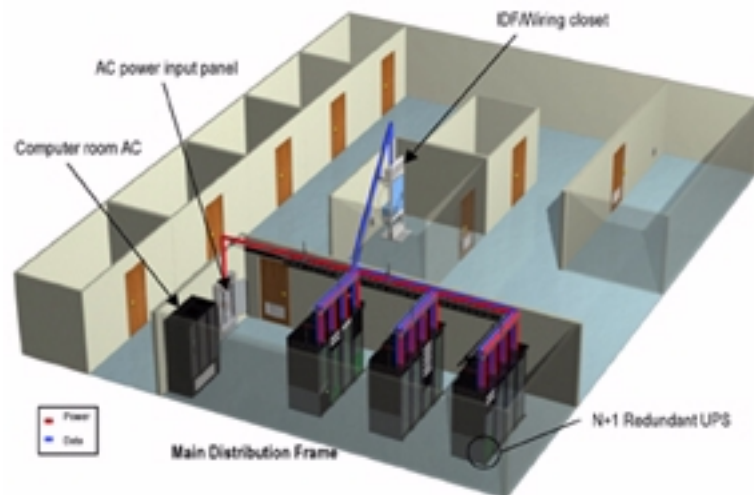


Finally, environmental monitoring (for example, temperature and humidity) for these wiring closets is highly recommended because it will flag any abnormal conditions, which allows enough time to take pro-active measures, and avoid downtime.

### Main Distribution Frame (MDF)

Main distribution frames (MDFs), also referred to as MERs (main equipment rooms) or POP (point of ping or presence) rooms, house the most critical IP telephony components such as Call Managers, Cisco routers, Cisco Catalyst Multiservice switches (for example the Cisco Catalyst 6500 series) and a variety of other networking, IT and telecommunications equipment such as mission critical application servers as shown in Figure 9.

Figure 9  
Main Distribution Frame



### Environment

MDFs are generally located in the basement or first floor. A typical MDF may have 4-12 racks of equipment and draw between 4 to 40 kW single or three-phase 208 VAC power, and may also require -48VDC power. Most of the racks in MDFs are two post open racks used to mount a variety of IP telephony and IT equipment. This equipment may have different airflow patterns, for example side to side, front to back, etc., and can be 19 or 23" rack mount type. However, most of the new IT equipment is 19" rack-mountable.

### Problems

Some MDF rooms do not have a UPS, many do not have adequate battery back-up time, and often they do not have a dedicated precision air-cooling system.



## Best Practices

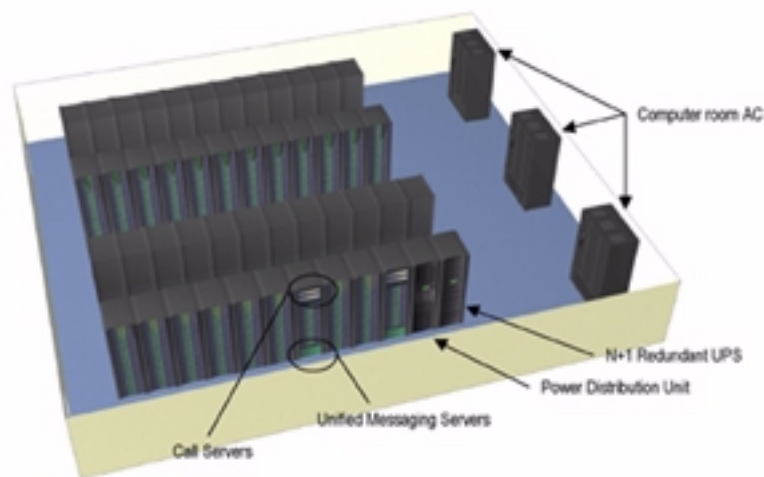
Because these MDFs house a variety of critical network, IT, and telephony equipment, they should be treated like a small data center or a computer room. To get approximately five nines of power availability, the MDF room should be protected by a modular, redundant UPS with internal bypass that provides at least 30 minutes of backup time. Higher run times, with higher levels of availability, for example six or seven nines, can be provided by using Ethernet switches equipped with dual PSUs with separate power cords, dual cords, dual UPSs, and concurrently maintainable electrical architectures with generator back up. Companies such as American Power Conversion Corporation have dedicated power availability consulting services to evaluate and recommend high-availability power and cooling architectures to support critical network infrastructure.

MDFs should also have their own precision air conditioning units with environmental monitoring and consideration should be given to providing redundant air conditioning units for mission-critical applications that require higher availability. For high power density racks (> 3kW per rack) additional air distribution and air removal units should be used to avoid hot spots. Unlike servers and storage devices, many switches use side-to-side airflow. This creates special issues when installed in an environment that uses enclosed racks. These issues are discussed in detail in the APC White Paper No. 50, "Cooling Solutions for Rack Equipment with Side-to-Side Airflow."

## Data Center or Server Farm

The data center or server farm (Figure 10), houses all mission-critical application servers including the IP telephony application servers (for example, Cisco Call Managers, unified messaging systems, etc.) In addition, based on the network architecture and the size of the organization, the data center or server farm may also house high performance Ethernet switches such as the Cisco Catalyst 6500 series multiservice switches and service modules, such as the content services module and firewall service module. Depending on their size (small, medium, or large) a typical data center or server farm may house from tens to hundreds of racks, loaded with tens or hundreds of servers and a variety of IT, networking, and computing systems that support business-critical applications such as enterprise resource planning (ERP), customer relationship management (CRM), and other Web-based services.

Figure 10  
Typical Data Center or Server Farm





## Environment

Data centers typically draw between 10-kW single- or three-phase 208 VAC power on the lower side, to hundreds of kilowatts of three-phase 480VAC power on the higher side. There can be some small –48V DC power requirement for some traditional telecommunications equipment, but predominantly the requirement is AC power loads. Most data centers have a UPS with battery back-up, generator, and precision air conditioning units.

## Problems

IP telephony servers and switches basically constitute an incidental incremental load to the data center that may require higher run time, redundancy and availability than other IT and networking equipment.

## Best Practices

Even though the data center may have its own UPS and generator, it may be appropriate to provide for a separate, redundant UPS with longer battery back-up time for the IP telephony equipment. To maximize the cost efficiency of providing this level of redundancy as well as minimize the effect of a failure, the IP telephony equipment requiring longer run time and higher availability should be identified and grouped in separate racks within the data center. These racks may then be provided with a dedicated UPS with longer run time and N+1, N+2, availability as required. This concept of “targeted availability” helps increase availability of business-critical IP telephony equipment without having to incur a large capital expense for the entire data center. Higher levels of redundancy such as dual feeds with dual generators and dual N+1 UPSs with dual power paths all the way to the server and other critical equipment in the rack may be considered for highly available data centers and networks.

It is always good planning to verify and ensure that the precision air conditioning equipment in the data center has enough cooling capacity for the additional Power over Ethernet requirements if large numbers of PSE capable Ethernet switches feeding powered devices are to be housed within the data center. In some circumstances redundant air conditioning units may be considered to provide higher availability. For high power density racks (> 3kW per rack), additional air distribution and air removal units should be used to avoid hot spots. Avoidable mistakes that are routinely made when installing cooling systems and racks in data centers or network rooms compromise availability and increase costs. For more information about this topic, please refer to APC White Paper No. 49, “Avoidable Mistakes that Compromise Cooling Performance in Data Centers and Network Rooms.”

## Conclusion

The requirement to provide Power over Ethernet to IP phones is not a new concept. Cisco Systems® has shipped over 8 million IP telephones since 1999 and the adoption of IP telephony is gaining increased acceptance. Additionally, the standardization of Power over Ethernet by the IEEE 802.3af, and the acceptance of Power over Ethernet is leading to new and innovative applications such as Power over Ethernet capable Intelligent Building management Systems and IP video surveillance.

Considerations with respect for power delivery, cooling and power availability, however, are often overlooked. This document briefly outlines the issues and considerations that need to be taken when considering Power over Ethernet implementation, and these are summarized briefly as follows.

- No problems exist with the powered devices as they are used in office environments.
- No major problems exist in the data center or server farms because the Power over Ethernet capable equipment is an incidental incremental load.



- ‘Targeted availability’ may be provided to critical PSE capable Ethernet switches.
- Limited problems with available run time within MDFs may occur, that can be solved by providing a generator or a larger battery back-up with UPS.
- The biggest problems in terms of power and cooling lie within the wiring closets. A small, dedicated UPS with extended run time is a cost-effective solution compared to one, large, centralized UPS powering all wiring closets. Cooling is a special problem for wiring closets, although, in many cases ventilation alone is sufficient. In some cases targeted spot air conditioning is required.

The American Power Conversion Corporation provides power availability consulting services to evaluate and recommend high-availability power and cooling architectures to support critical network infrastructure such as high-availability power designs for data center, data network and IP telephony implementations that compliment Cisco high-availability design principles.

#### Bibliography

1. APC White Paper No. 37: “Avoiding Costs From Oversizing Data Center and Network Room Infrastructure”
2. APC White Paper No. 5: “Cooling Imperatives for Data Centers and Network Rooms “
3. APC White Paper No. 24: “Effect of UPS on System Availability”
4. APC White Paper No. 43: “Dynamic Power Variations in Data Centers and Network Rooms”
5. APC White Paper No. 1: “The Different Types of UPS Systems”
6. APC White Paper No. 50: “Cooling Solutions for Rack Equipment with Side-to-Side Airflow”
7. APC White Paper No. 49: “Avoidable Mistakes that Compromise Cooling Performance in Data Centers and Network Rooms”

#### References

1. American Power Conversion Corporation
2. Cisco Systems
3. IEEE 802.3af-2003 *Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specification. Amendment: Data Terminal Equipment (DTE) Power via Media Dependent Interface*

#### Appendix

##### Availability Analysis Approach

APC’s Availability Science Center uses an integrated availability analysis approach to calculate availability levels. This approach uses a combination of reliability block diagram (RBD) and state space modeling to represent the environment to be modeled. RBDs are used to represent subsystems of the architecture, and state space diagrams, also referred to as Markov diagrams, are used to represent the various states the electrical architecture may enter. For example, when the utility fails, the UPS transfers to battery. All data sources for the analysis are based on industry-accepted third parties such as IEEE and RAC (Table A1). These statistical availability levels are based on independently validated assumptions.

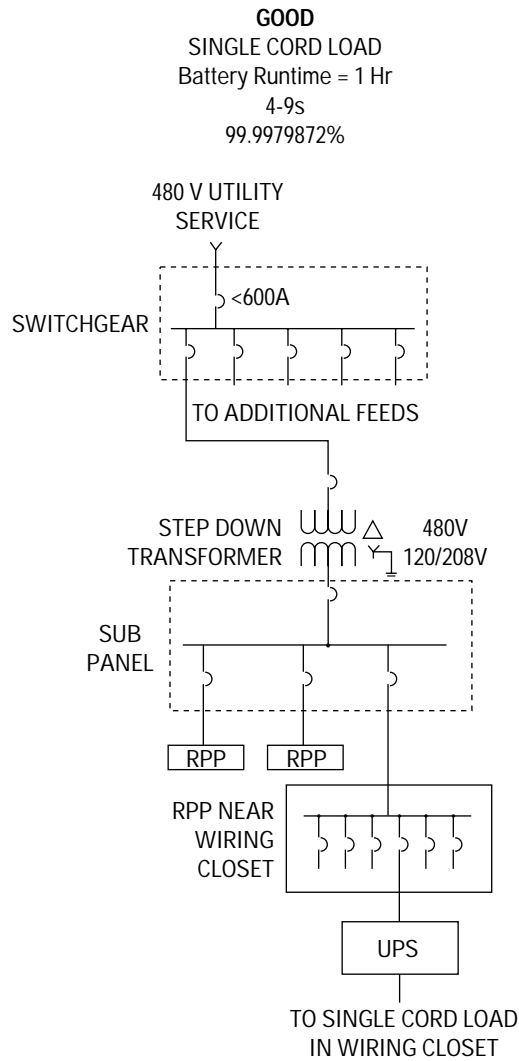


Professor Joanne Bechta Dugan, Ph.D., at the University of Virginia says,

*“[I have] found the analysis credible and the methodology sound. The combination of reliability block diagrams (RBD) and Markov reward models (MRM) is an excellent choice that allows the flexibility and accuracy of the MRM to be combined with the simplicity of the RBD.”*

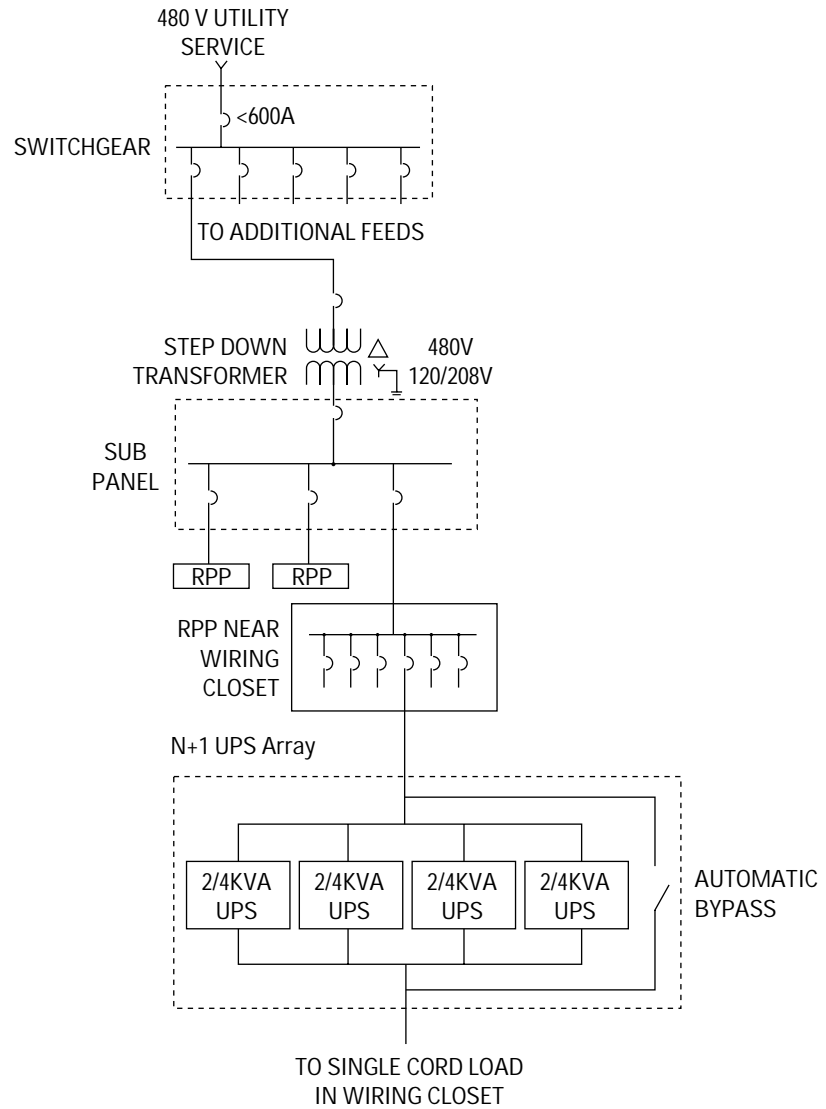
An availability analysis is performed to quantify the effects of various electrical architectures. The availabilities of 26 different architectures were calculated and compared against each other. Six architectures were then chosen to represent the good, better and best architecture for both a wiring closet and a data center. The choices were based on cost and availability trade-offs. The six architectures chosen are shown in the following sections, along with their availability results.

Figure 11  
Architectures for wiring closet or IDF





**BETTER**  
SINGLE CORD LOAD  
Battery Runtime = 1 Hr  
5-9s  
99.99938958%





**BEST**  
DUAL CORD LOAD  
Battery Runtime = 1 Hr  
6-9s  
99.99995489%

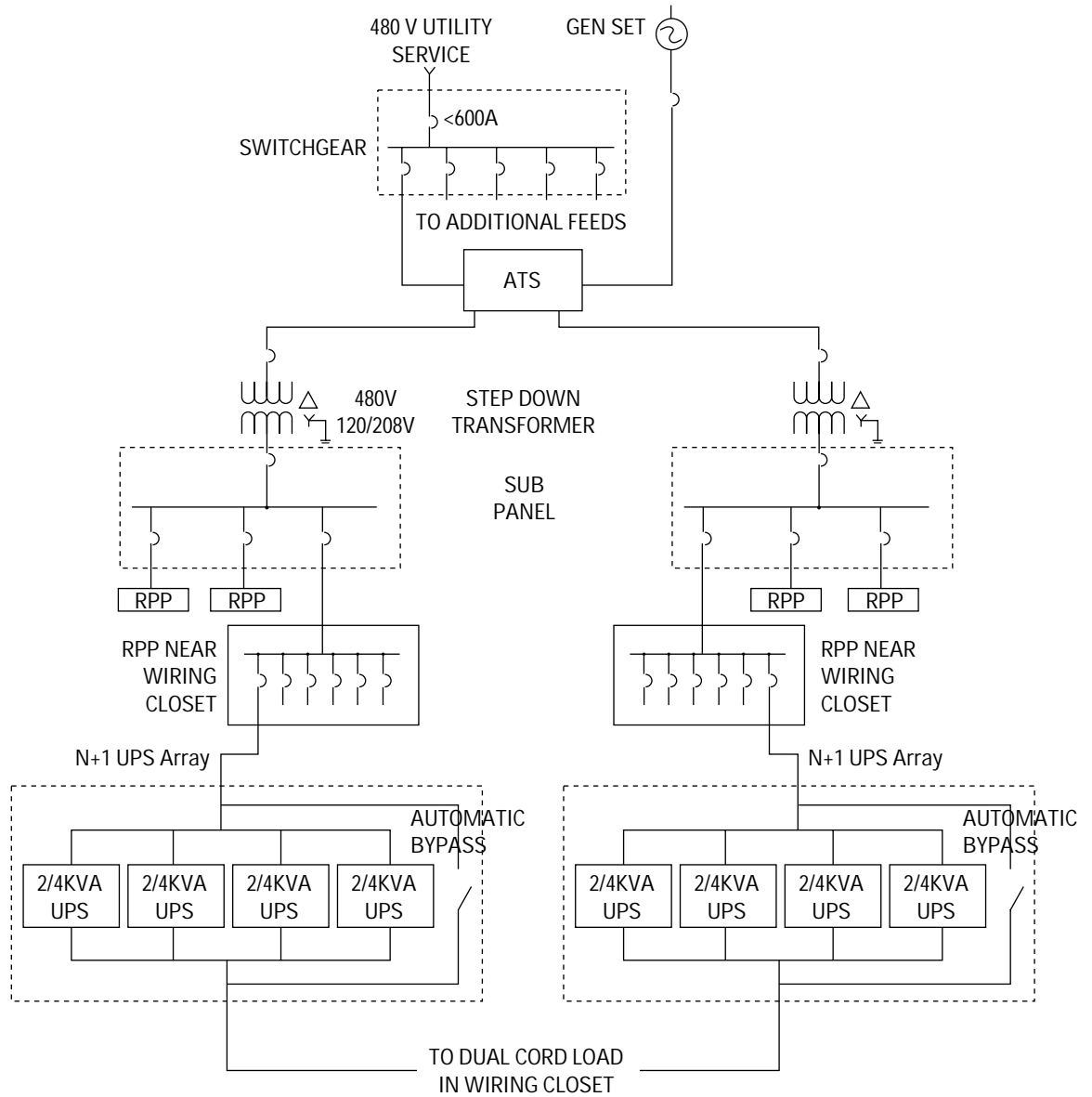
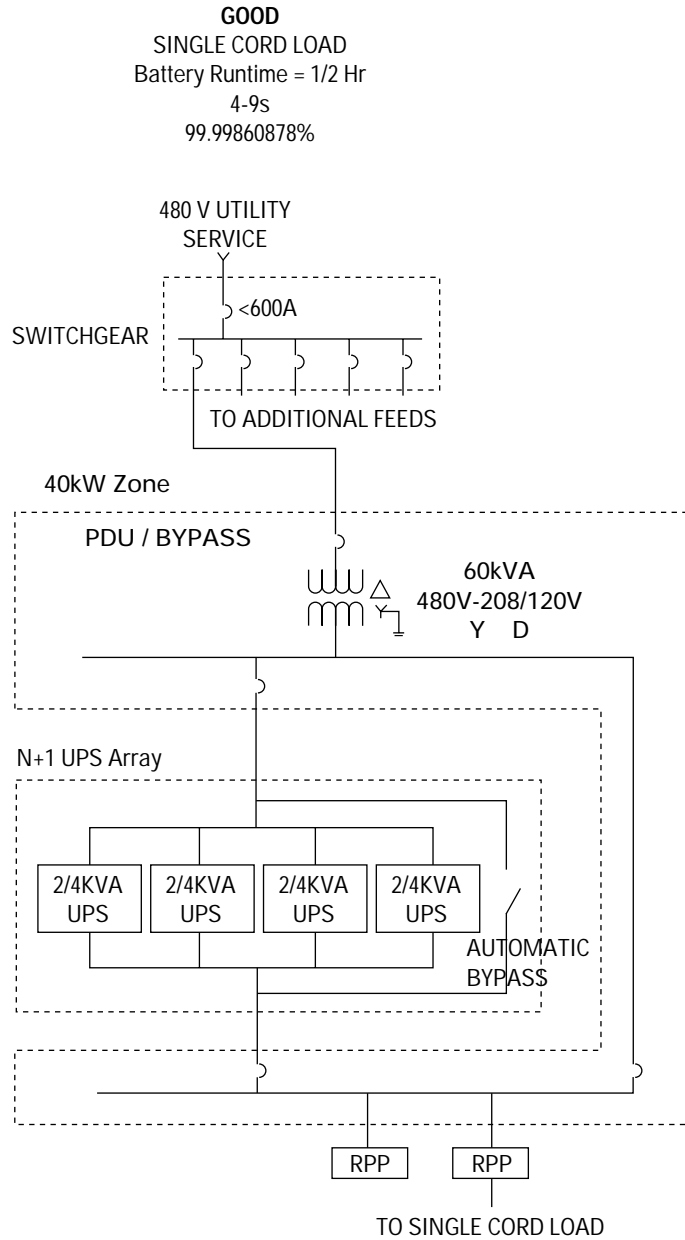




Figure 12  
Architectures for Data Center or MDF





**BETTER**  
DUAL CORD LOAD  
Battery Runtime = 1/2 Hr  
6-9s  
99.99994652%

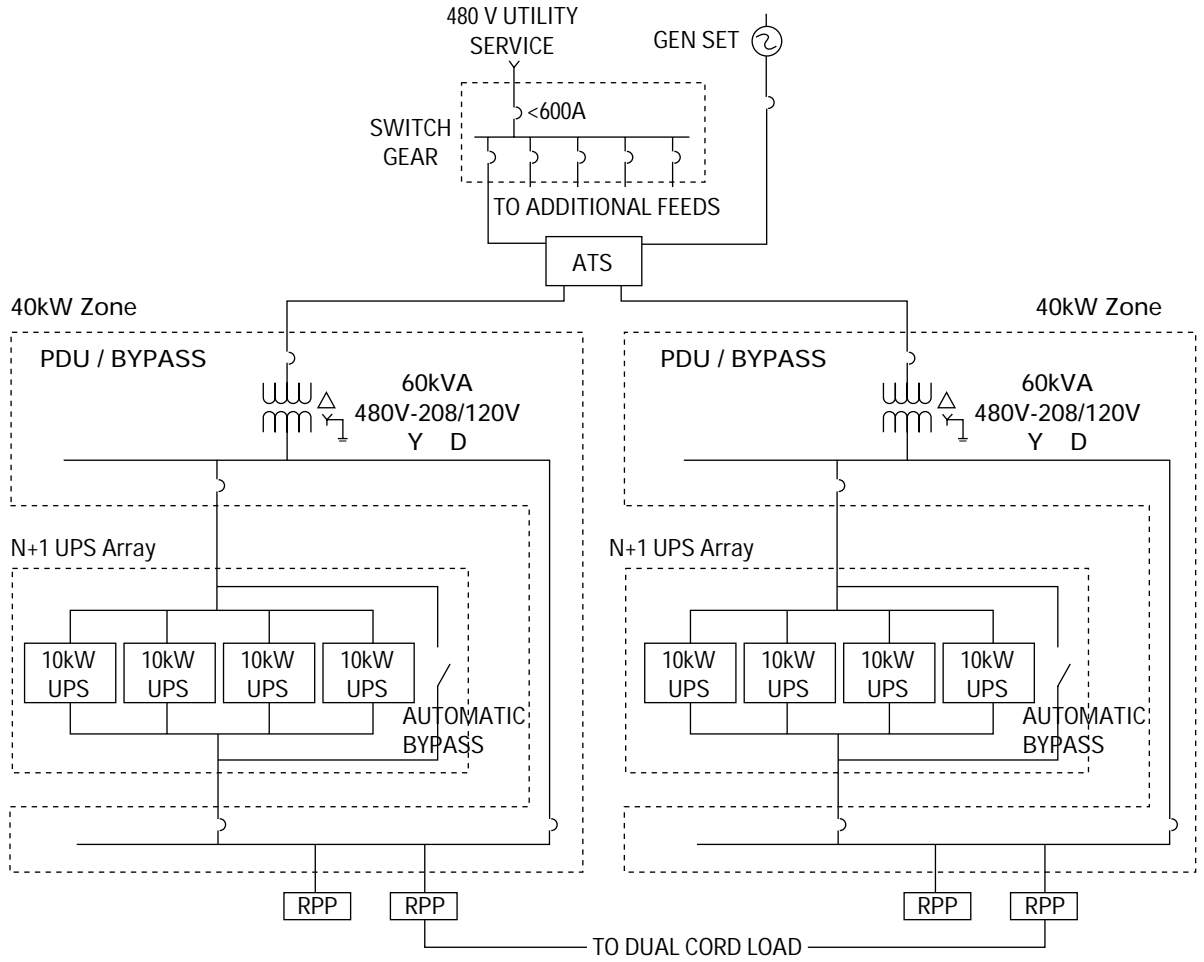
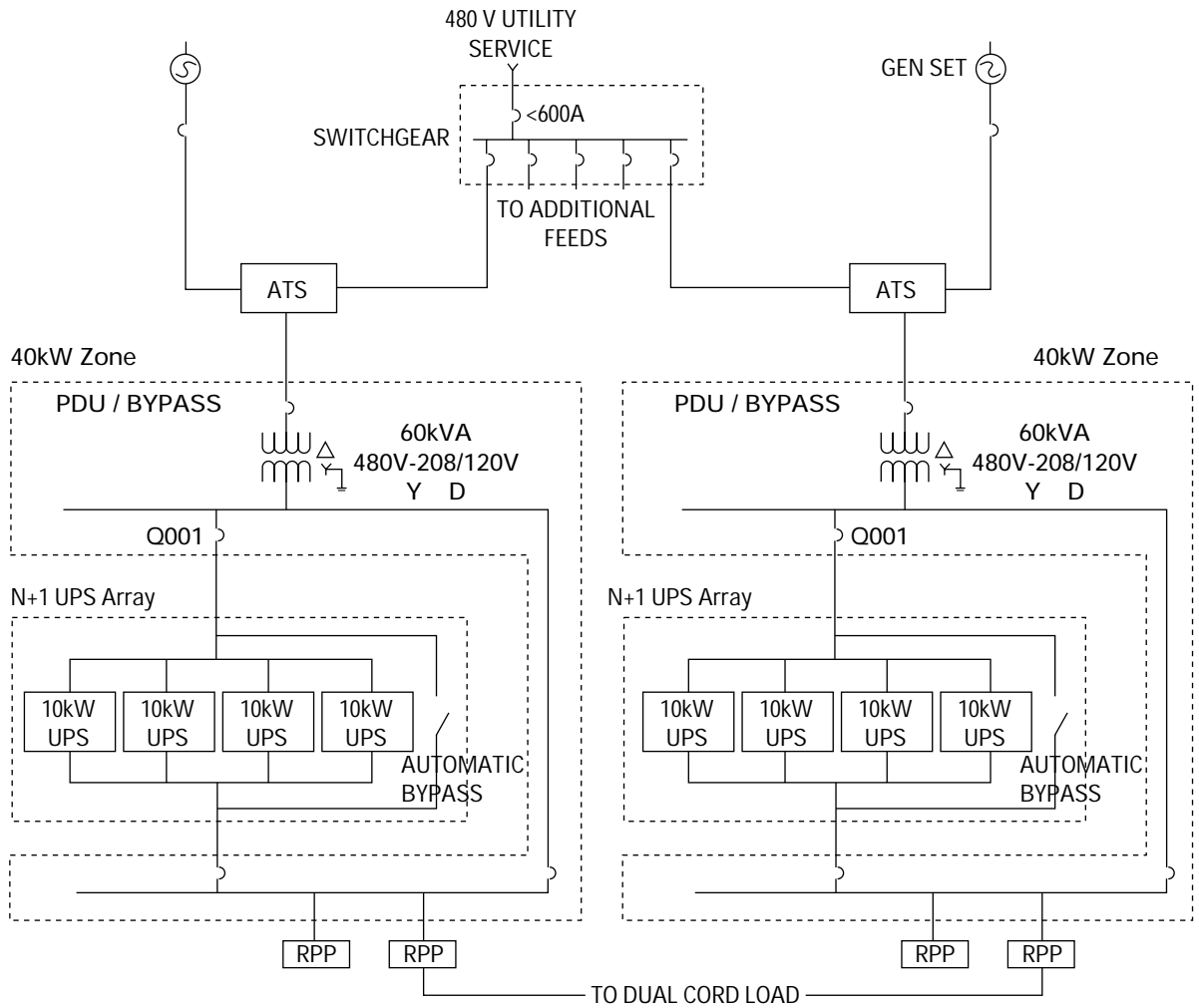




Figure 13  
Architectures for Data Center or MDF

**BEST**  
DUAL CORD LOAD  
Battery Runtime = 1/2 Hr  
7-9s  
99.9999517%





## Data Used in Analysis

Most of the data used to model the architectures is from third party sources. Data for the Rack ATS is based on field data for APC's Rack ATS product, which has been on the market for approximately 5 years and has a significant installed base. In this analysis the following key components are included:

1. Terminations
2. Circuit breakers
3. UPS systems
4. PDU
5. Static transfer switch (STS)
6. Rack ATS
7. Generator
8. ATS

The PDU is broken down into three basic subcomponents: circuit breakers, a step-down transformer and terminations. The subpanel is evaluated based on one main breaker, one branch circuit breaker, and terminations all in series. Table 4 includes the values and sources of failure rate (1/MTTF) and recovery rate (1/MTTR) data for each subcomponent, where MTTF is the mean time to failure and MTTR is mean time to recover.

## Assumptions used in the analysis

As with any availability analysis, assumptions must be made to create a valid model. These assumptions are listed in Table 3.

Table 3 Assumptions of Analysis

Assumption	Description
<b>Reliability data</b>	Most of the data used to model the architectures is from third party sources. If data was unavailable, industry estimates are used. See Table A2 for reliability data summary.
<b>Failure rates of components</b>	All components in the analysis exhibit a constant failure rate. This is the best assumption, given that the equipment will be used only for its designed useful life period. If products were used beyond their useful life, then non-linearity would need to be built into the failure rate.
<b>Repair teams</b>	For "n" components in series, it is assumed that "n" repair persons are available.
<b>System components remain operating</b>	All components within the system are assumed to remain operating while failed components are repaired.
<b>Independence of failures</b>	These models assume construction of the described architectures in accordance with Industry best practices. These result in a very low likelihood of common cause failures and propagation because of physical and electrical isolation.
<b>Failure rate of wiring</b>	Wiring between the components within the architectures has not been included in the calculations because wiring has a failure rate too low to predict with certainty and statistical relevance. Also previous work has shown that such a low failure rate minimally affects the overall availability. Major terminations have still been accounted for.



Table 3 Assumptions of Analysis (Continued)

Assumption	Description
<b>Human error</b>	Downtime due to human error has not been accounted for in this analysis. Although this is a significant cause of data center downtime, the focus of these models is to compare power infrastructure architectures, and to identify physical weaknesses within those architectures. In addition, there exists a lack of data relating to how human error affects the availability.
<b>Power availability; the key measure</b>	This analysis provides information related to power availability. The availability of the business process will typically be lower because the return of power does not immediately result in the return of business availability. The IT systems typically have a restart time which adds unavailability that is not counted in this analysis
<b>No benefit of fault isolation</b>	The failure of any critical load is considered a failure, and equivalent to the failure of all loads at once. For some businesses, the failure of a single load is of less business consequence than the failure of all critical loads. In this analysis only one load was analyzed.

Table 4 Components and Values

Component	Failure Rate	Recovery Rate	Source of Data	Comments
<b>Raw utility</b>	3.887E-003	30.487	EPRI—Data for utility power was collected and a weighted average of all distributed power events was calculated.	This data is highly dependent on geographic location.
<b>Diesel engine generator</b>	1.0274E-04	0.25641	IEEE Gold Book Std 493-1997, page 406	Failure rate is based on operating hours. There were 0.01350 failures per start attempt per Table 3-4 page 44.
<b>Automatic transfer switch</b>	9.7949E-06	0.17422	Survey of Reliability/ Availability—ASHRAE paper No. 4489	
<b>Termination, 0-600V</b>	1.4498E-08	0.26316	IEEE Gold Book Std 493-1997, page 41	
<b>Six terminations</b>	8.6988E-08	0.26316	Computed from value by IEEE Gold Book Std 493-1997, page 41	Upstream of the transformer, one termination exists per conductor. Because there are 2 sets of terminations between components, a total of six terminations are used.



Table 4 Components and Values (Continued)

Component	Failure Rate	Recovery Rate	Source of Data	Comments
<b>Eight terminations</b>	1.1598E-07	0.26316	Computed from value by IEEE Gold Book Std 493-1997, page 41	Downstream of the transformer, one termination exists per conductor plus the neutral. Because there are 2 sets of terminations between components a total of eight terminations are used.
<b>Circuit breaker</b>	3.9954E-07	0.45455	IEEE Gold Book Std 493-1997, page 40	Fixed (including molded case), 0-600A
<b>PDU transformer, stepdown</b>	7.0776E-07	0.01667	MTBF is from IEEE Gold Book Std 493-1997, page 40, MTTR is average given by Marcus Transformer Data and Square D.	<100kVA
<b>Static Transfer Switch</b>	4.1600E-06	0.16667	Gordon Associates, Raleigh, NC	Failure rate includes controls; recovery. Rate was not given by ASHRAE for this size STS, so the value used is from the 600-1000A STS
<b>UPS backplane</b>	7.0000E-07	0.25000	Estimate based on Symmetra field data	
<b>UPS with bypass</b>	4.00E-06	3.00000	Failure rate is from Power Quality Magazine, Feb 2001 issue; recovery rate data is based on assumption of spare part kept on site.	This failure data assumes a modular UPS with bypass.
<b>UPS no bypass</b>	3.64E-05	3.00000	Failure rate is from Power Quality Magazine, Feb 2001 issue; recovery rate data is based on assumption of 4 hours for service person to arrive, and 4 hours to repair system	This represents a UPS without bypass. MTBF is 27,440 hrs without bypass per MGE "Power Systems Applications Guide"
<b>Rack ATS switch</b>	2.00E-06	3.00000	APC Redundant Switch field data	The APC Rack ATS MTTF was calculated to be 2 million hours. A conservative value of 500,000 hours was used.



## State Space Models

Six state space models were used to represent the various states in which the six architectures can exist. In addition to the reliability data, other variables were defined for use within the six state space models (Table 5).

Table 5 State Space Model Variables

Variable	Value	Source of Data	Comments
<b>PbypassFailSwitch</b>	0.001	Industry average	Probability that the bypass will fail to switch successfully to utility in the case of a UPS fault.
<b>Pbatfailed</b>	0.001	Gordon Associates— Raleigh, NC	Probability that the UPS load drops when switching to battery; includes controls
<b>Pbatfailed (Redundant UPS)</b>	0.000001	The square of the Pbatfailed value noted above	Assumes that both UPS battery systems are completely independent
<b>Tbat</b>	1 or _ hour		Battery run time dependent on scenario
<b>Pgenfail_start</b>	0.0135	IEEE Gold Book Std 493-1997, page 44	Probability of generator failing to start; failure rate is based on operating hours; 0.01350 failures per start attempt per Table 3-4 pg 44; this probability accounts for ATS as well.
<b>Pgenfail_start (redundant UPS)</b>	0.00911	50 x the square of the Pgenfail_start value noted above	Pgenfailed reduced by a factor of 50 to account for common cause failures between redundant generator sets
<b>Tgen_start</b>	0.05278	Industry average	Time delay for generator to start after a power outage. equates to 190 seconds



**Corporate Headquarters**

Cisco Systems, Inc.  
170 West Tasman Drive  
San Jose, CA 95134-1706  
USA  
www.cisco.com  
Tel: 408 526-4000  
800 553-NETS (6387)  
Fax: 408 526-4100

**European Headquarters**

Cisco Systems International BV  
Haarlerbergpark  
Haarlerbergweg 13-19  
1101 CH Amsterdam  
The Netherlands  
www-europe.cisco.com  
Tel: 31 0 20 357 1000  
Fax: 31 0 20 357 1100

**Americas Headquarters**

Cisco Systems, Inc.  
170 West Tasman Drive  
San Jose, CA 95134-1706  
USA  
www.cisco.com  
Tel: 408 526-7660  
Fax: 408 527-0883

**Asia Pacific Headquarters**

Cisco Systems, Inc.  
Capital Tower  
168 Robinson Road  
#22-01 to #29-01  
Singapore 068912  
www.cisco.com  
Tel: +65 6317 7777  
Fax: +65 6317 7799

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