Mission CRITICAL Whitepaper

Rack Power Distribution:

Just the end of the Power Chain, or Key Strategic Advantage?

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Data centers have become vital to virtually all aspects of our society, and in many cases are considered an essential part of our critical infrastructure. Ensuring continuous and reliable power to the IT equipment is one of the most fundamental aspects of a mission critical system. Professionally engineered data centers are designed to avoid any downtime by providing various levels of redundancies in the primary power system components.

This requires a significant capital investment for redundant primary switchgear, UPS units and generators, as well as the facility's overall downstream power distribution system, which ultimately supports the IT equipment in the cabinets. However, in some cases, the power distribution units (PDU) within the IT cabinets are sometimes overlooked or given little consideration as to their inherent importance as the last, but critical, link in the power chain.

This whitepaper examines the current technical and operational challenges faced in high-density power distribution, as well as how the various available power distribution and management solutions can provide economic and strategic advantages.

Rack Power Distribution

Rising Power Demands

The power demands and size of the data center have increased dramatically over the past several years. Moreover, the overall facility power density (per square foot) and more significantly, the power density at the rack level has risen quite considerably as well.

Historically when the typical server cabinets were fed by 120 volt 15-20 amp branch circuits supporting 1-2 kilowatts of load, the rack Power Distribution Unit (PDU) was referred to as just a "power strip." However, modern server cabinets require the rack PDU to support much greater power requirements. Typically the lower end ranges between 2-4 kW and many facilities have medium-density cabinets operating at 5-9 kW. And while not as widespread, 10-25 kW cabinets are no longer making headlines.

While several different data center organizations have various definitions of power density, AFCOM released a whitepaper in 2014 that categorized Rack Power Density into four levels.

ered and analyzed by monitoring software, which helps ensure accurate power availability and redundancy, as well as capacity planning. Moreover, the need for remote power monitoring and management has been driven by the change in strategy in enterprise computing and the widespread use of colocation by the enterprise and has now become an essential requirement for many organizations. Some PDUs offer the ability to control individual outlets, allowing remote rebooting of hung IT equipment if necessary. This can improve problem resolution response time and, in many cases, reduce the need and cost for on-site technical support.

The Green Grid - PUE Metric

No discussion about power can avoid the issue of energy metering and efficiency, and of course PUE. The Green Grid created the Power Usage Effectiveness "PUE" metric in 2007, which is now a commonly accepted international metric. Several whitepapers that provide detailed information on the PUE metric and methods of measurement can be found at www.thegreengrid.org.

Rack Power Density Level	Power Range (kW)
Low	0-4
Moderate	5-8
High	9-15
Extreme	16 and above

(Source: AFCOM Data Center Institute Standards Endorsed Whitepaper DCISE-001 September 2014)

These high and increasing-power densities and the related higher operating temperature ranges represent myriad engineering and operational challenges on multiple levels, for both the manufacturers of rack-level PDUs, as well as data center operators.

Rise of the Intelligent PDU as a Strategic Management Asset

While the locally metered PDU has been available for approximately 20 years, it was a fairly basic device initially and not widely deployed. The need for better energy management and efficiency has given rise to the demand for the new generation of remotely monitored and managed PDUs, also known as the "smart" or "intelligent" PDU. These later generation PDUs gained popularity especially in the last five years and have really come to the forefront by offering more-sophisticated features with each generation. These products offer additional granular rack-level information, which can be automatically gath-

A simplified view depicting PUE measurement is shown below in Figure 1—and while the metric name incorporates the word "power," it is important to note that as of 2011 Power Usage Effectiveness refers to annualized energy (measured or averaged over 12 months of operation).

In order to provide an assessment of facility energy usage and efficiency of a data center, energy metering at several key points of the power chain and distribution system as shown are the prescribed method to determine a facility PUE—both as a baseline of existing performance and to examine the results of any changes made. As seen in Figure 1, the highest level of accuracy is obtained by measurement at the rack (PUE Category 3, also known as Level 3 measurement). Regardless of your data center size and power density, tracking energy usage and being able to correlate it to IT asset utilization is an essential element to data center management and strategic planning.

Footnote: The use of the words "smart" or "intelligent" (as they pertain to a PDU) are meant as a generic reference and not meant to imply or refer to any manufacturers' product trademarks that incorporate those words.

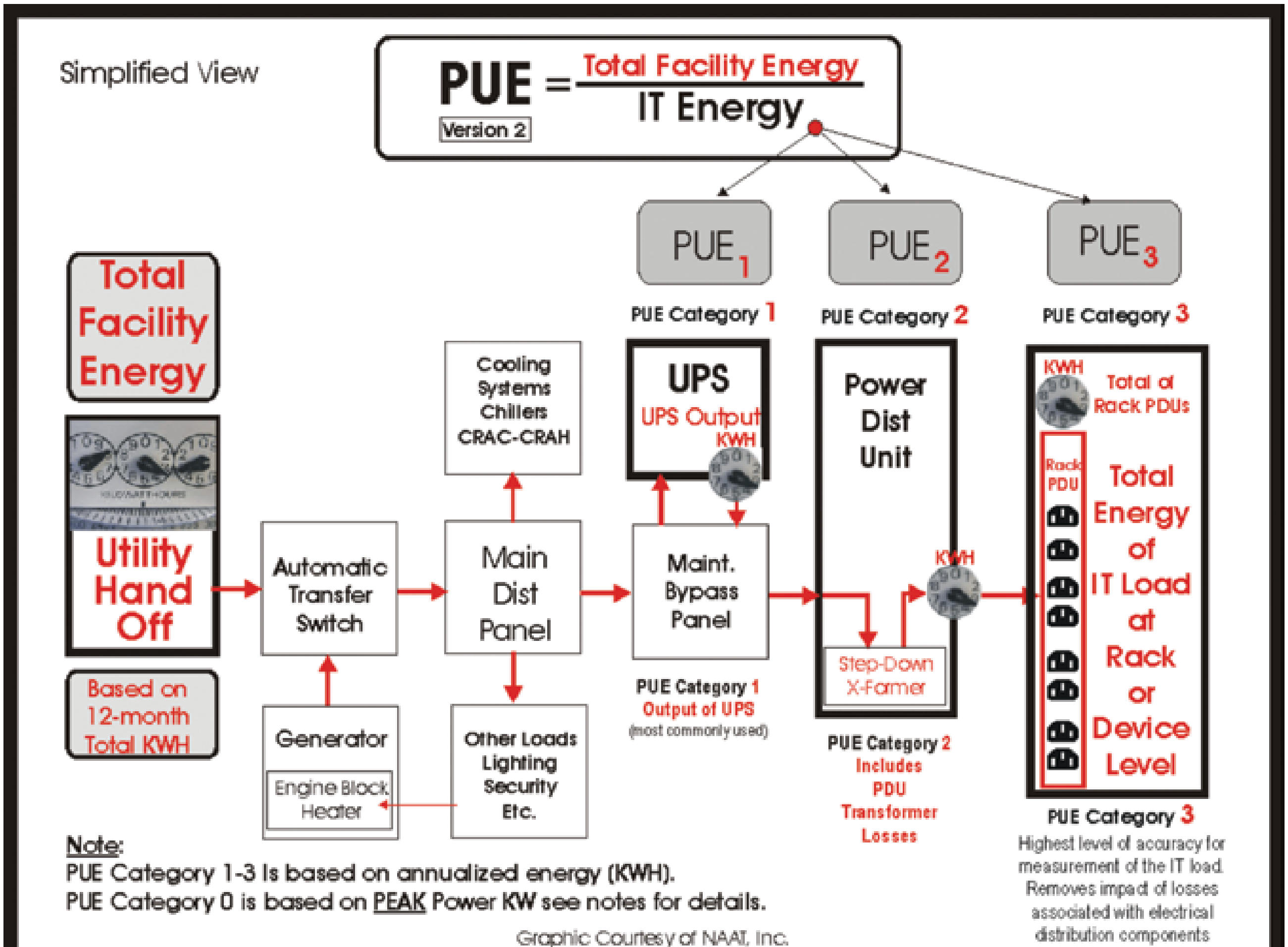

FIGURE 1. PUE Points of Measurement

Energy Cost Strategies: Enterprise vs Colocation

In a data center owned and operated by the enterprise, energy costs are a significant part of the Total Cost of Ownership (TCO). As such, it is always important to track how energy is used in order to optimize efficiency—both for the facility (PUE) as well as for the IT equipment. Nonetheless, the utility invoice to the facility owner is directly based on the actual energy used (kWh). This is not necessarily the case for a colocation customer. In a colocation data center the costs are based on two primary factors: the space (either per rack or caged area) and the power. However, colocation providers typically offer three general types of pricing models for power in their facility, as seen in Table 1 below.

The type of power pricing schemes can be either costly or advantageous to the customer, depending on their maximum power load as well as the actual average energy used on a monthly basis. For example, if the IT equipment specified for your rack requires a maximum of 20 amps at 208 Volts, a 30 amp circuit is required. (Based on the 80% limitation, the maximum total current that can be drawn safely is 24 amperes.) This means that the maximum power that can be delivered to that rack is approximately 5 kVA. You will still need to provision the circuit for the highest current demand expected. However, in many cases, the IT equipment may not continuously draw this amount of power during normal operation and may average only 50% of the energy of the circuit capacity.
As can be seen from Table 1 below, it becomes important to monitor and track IT equipment power (peak vs average) and actual energy usage trends. This is one of the reasons that many colocation customers are installing higher level intelligent PDUs in their racks that can measure and record peak power and energy usage, not just those PDUs that can measure only input amperes.

Colocation Provider Power/Energy Cost Model	Description	Impact on Customer
A: Per Circuit - Fixed Cost (based on Power capacity kVA—not energy usage)	Customer is charged a fixed price—regardless of the actual energy consumed.	Can be costly if circuits are underutilized.
B: Energy Metering (actual energy used kWh)	Customer is charged for the actual energy used (in kWh). Circuit charges included in facility overhead.	The energy charge should be based on underlying utility rates, plus the facility overhead (which is generally related to the PUE). Caveat: Each case is unique and subject to contractual language.
C: Combination (fixed per circuit power capacity—kVA, plus actual energy used - kWh)	Customer is charged a fixed cost for the circuit capacity (which would be lower than option A), plus the charge for the actual energy used.	

TABLE 1.

Limitations of Typical Building Management Systems

Facility based power management is generally handled by Building Management Systems (BMS), which typically monitor the main Switch Gear, UPS, and the Power Distribution Units (PDU) on the data center floor. However, in most cases, the ability to monitor power demand or track overall energy usage of the IT equipment most commonly occurs at the UPS output. Alternately, it can occur at the floor-level PDU, if it is equipped with power or energy monitoring (some units only have input monitoring, while others have branch circuit monitoring).

In addition, when redundant circuits are required (A-B feeds), pricing is usually based on the total maximum power required. Redundant circuits are also subject to the limitation of 80% of the individual maximum circuit value requirements, typically shared equally across both circuits. (However, regardless of the ratios, the A+B total cannot exceed 80% of the individual circuit value.) This puts the onus on the end-user customer to avoid exposure to "cascade failure." This fact is often misunderstood or overlooked by many IT administrators when provisioning new IT equipment in racks and when projecting estimated colocation power costs.

If the floor PDU (or electrical sub-panel) was not equipped with branch circuit monitoring, the only other way this could have been determined would be a request to facilities for a manual electrical survey of branch circuits in the PDU, or the sub-panel feeding the rack or group of racks. This is a labor intensive and intrusive process (opening of energized panels) that increases the risk of an accident and potential downtime due to human error. Moreover, the measurements taken are not 100% indicative of the maximum current drawn over an extended period of time under varying IT computing loads. These measurements are "snapshots"; they do not accurately represent the actual total energy used by the circuit (kVA/kW reading are instantaneous power, which varies—kWH represent the actual energy used over time—i.e. per hour, day, week, or month).As each generation of IT equipment increased rack power demands, using a basic unmetered "power strip" in the rack soon became inadequate. Beside needing to increase the capacity of the branch circuits feeding each rack, IT administrators found that without visibility into the amount of power that a rack was using, they had no way to know if or how many servers could be installed, or if a server refresh or upgrade would require an increase in the capacity or number of branch circuits supporting the rack. Moreover, without knowing how much current was being drawn, just adding a single server would be like playing "Russian Roulette," since it could result in in a tripped circuit breaker. The metered rack PDU can mitigate this type of exposure to an outage.

The lack of real-time power and energy monitoring at the rack can delay or disrupt a technical refresh or, worse yet, expose the rack to failure if the branch circuit protection trips when more or new IT equipment is installed. Moreover, the problem is exacerbated when redundant (A-B) branch circuits are used to feed racks full of servers with dual power supplies (dual corded devices normally share the load equally; however, some vary in how they distribute the load across each cord or simply fail-over to the alternate circuit).

The chart in Figure 2 below depicts a potential scenario wherein the typical manual "clamp-on" ammeter is used to measure (A-B) redundant branch circuits to a rack at one point in time, while the plot lines show continuous current measurements over time for the A and B circuits, as well as the sum (A+B) of both.

In this case, at the time the manual readings were taken, it would seem as if the total current drawn across (A and B) circuits were only 14 amps (7A+7A). However as the

Example of Manual Survey vs. Continuous Current Monitoring

20 Amp (A-B) Redundant Branch Circuits

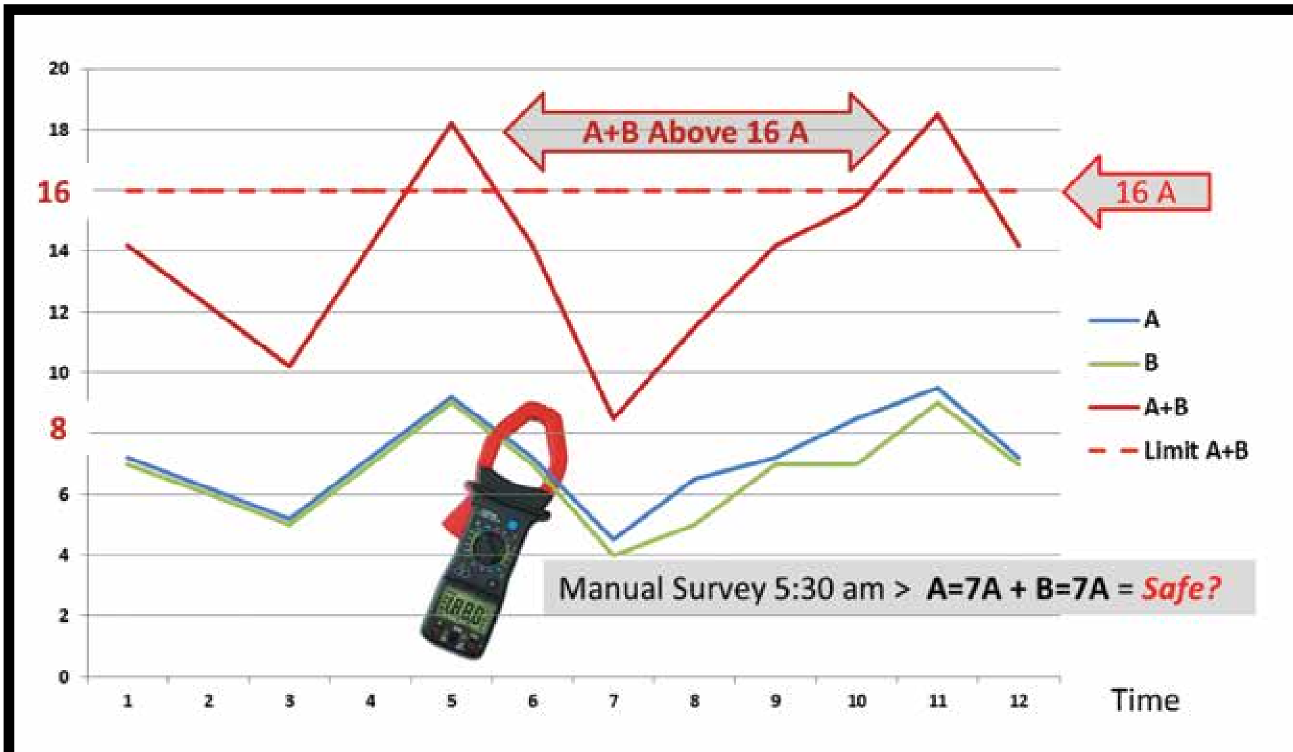

FIGURE 2. Example of Manual Survey vs. Continuous Current Monitoring

current plot over time shows, at multiple times during the day, the sum of the (A+B) circuits exceed the 16 amp (80%) threshold (which is the maximum current that should be safely drawn from a 20 amp branch circuit, per US National Electrical Code "NEC"). While under normal circumstances when both circuits are active, there would be no problem in the above example. Should a problem occur, such as the loss of either one of the branch circuits (either accidentally or during a maintenance procedure), the remaining active circuit could trip during the peak current excursions, since it would now be carrying the entire load (slightly above 18 amps). This represents a lurking exposure to cascade failure.

As can be seen by the above example, these peaks would be very difficult to discover, even with regular manual survey snapshot readings. This exposure to cascade failure of redundant power paths can only be revealed by continuous monitoring and recording of current on each branch circuit (A-B) and then setting threshold alarms when the sum exceeds the prescribed limits.

If the wide swings in IT load current seems like an extreme example to those who are more accustomed to a relatively flat current draw for servers and other IT hardware, this is no longer an unlikely or extreme scenario. The quest for energy efficiency in IT equipment has significantly changed the load profile and the idle to maximum power range for modern servers. Whereas only a few years ago a typical server would idle at 50-60% of maximum power when idle, the newer servers have a much wider ratio and may idle at only 20-25% of maximum power (the peak current could be 4-5 times the idle current). As a result, a manual survey "snapshot" current reading is nearly meaningless, without a valid correlation to the servers' computing load status.

Computing Performance Energy Benchmarking

The PUE metric is fairly straight forward; however it only measures the efficiency of the facility infrastructure. The energy efficiency of computing systems has many aspects that make it far more difficult to quantify into a singular metric for many reasons, one of which is a universally accepted definition of "useful work." While there are rating systems for IT hardware such as SPEC power and the US Energy Star program, which helps purchasing decisions, they cannot account for how much actual energy will be used once software has been installed, as well as the actual operational utilization profile. Nonetheless, the relative efficiency of any given operational computing system functioning as a whole (IT hardware and software) can be benchmarked against itself. One of the advantages of individually metered (or metered/controlled) outlets in the rack PDU is the ability to measure the energy consumed by the individual IT equipment. This data can then be used to correlate the performance of IT equipment assigned to a computing task against its energy usage during that task. This level of analysis can provide a better assessment of how well the hardware and software perform collectively, as well as delivering an improved basis for capacity planning.

Determining the Energy Impact of Software Changes

As noted above by using energy monitoring, either at the rack level or, ideally, the IT device level, baselines can be established and correlated to relative computing loads. The impact of any software changes can then be compared to actual energy used by comparing known baseline trends over time. For example, with per-device monitoring, you may be able to observe that a software change resulted in slightly lower energy used by a group of web servers. However, the energy usage of the database servers and storage arrays may have increased significantly. This type of change would not have been readily detectable at the UPS output.

Identifying IT Energy Waste - Finding Zombies

Moreover, even the process of identifying and correlating the IT equipment, such as its owner and function, along with its rack location and which outlet of the PDU it is plugged into, can result in better organization of the IT assets. This is especially true in older enterprise data centers that have a history of having "zombies"—those servers and other devices that are no longer being used, yet are still drawing power (as well as adding to the cooling load).

The Uptime Institute conservatively estimated that up to 10% of enterprise servers are running obsolete or unused software having no function at all, yet remain in operation. Decommissioning a single 1U rack server can result in $500 per year in energy savings, an additional $500 in operating system license savings, and $1,500 in hardware maintenance costs.

Improving Availability and Uptime

Optimizing New Equipment Deployment Process

By utilizing rack PDUs with individual outlet switching, any unassigned outlets can be turned off, preventing the unauthorized activation of any new (or replacement) equipment in the rack without prior workflow approval processes. This could prevent an inadvertent overload of a heavily loaded branch circuit from tripping the breaker when unapproved IT equipment is plugged into any open outlet at random—resulting in the entire rack going down.

Color Coding to Help Reduce Human Error

The most common color for rack PDUs and their receptacles has been black. While this relieves the manufacturers from having to worry about colors, it makes it a bit more difficult for technical staff members who work in back of the densely packed, dark cabinets, particularly when they need to plug-in multiple cords of IT equipment to the correct PDU and outlet position.

One of the problems that sometimes occurs during the installation or replacement of servers (especially those with multiple power supplies) is when the technical staff may inadvertently put the plugs in the same PDU, negating redundancy of A-B feeds. Also, in the case of blade servers fed from 3-phase PDUs, it is difficult to consistently maintain equal and proper coordination of power cord distribution across the sets of phase pairs. In response to these issues, some manufacturers have recently begun offering PDUs in multiple colors (ideal for identifying A-B power) and also color-coded outlets on each phase pair to help balance the loads in 3-phase PDUs.

Better Phase Balancing

One common problem is trying to maintain phase balancing in the rack. Some manufacturers have recently developed PDUs that feature a 3-phase electrical distribution scheme related to the receptacle positioning pattern. It sequentially interleaves alternate phases in a continuous pattern (as well as color coding the outlets)—rather than grouping the outlets as a block of outlets per phase. This feature makes it more intuitive for IT personnel to evenly distribute the IT power cords across all the phases. This can also help reduce excessive power cord length and cabling congestion in the rack, which can impede IT equipment exhaust airflow, resulting in higher temperatures.

Exposing Hidden Risks
In addition to measuring relative energy efficiency, a PDU with individually metered outlets can help detect hidden issues such as failed server power supplies (in equipment with redundant PS) by setting a threshold alarm if the power draw decreases to zero on any occupied outlet. This can help avoid a scenario that may have gone undetected by data center personnel, which has happened many times and leaves the device in a non-redundant, unprotected position.

Cord Retention
Regardless of how redundant the upstream power chain is, it will not matter if the IT equipment cord falls out of the PDU outlet. While this would seem like a simple issue not worth much discussion, it has been a long-standing quandary, particularly with the imperfect retention of IEC C13 receptacles and the C14 (in some cases also C19/C20) plug-on cord sets from some vendors. There have been many instances where power cords have just fallen out of the PDUs, either over time without any apparent reason or sometimes if a technician lightly brushes the dangling cord, or just from the minor vibration of plugging or unplugging an unrelated cord in the PDU. This has led to several solutions, the oldest typically using a cord clip or a comb-like piece of plastic or wireframe cage that prevents the plugs from falling out. This approach is somewhat inconvenient and sometimes cords have still fallen out. Some of these systems also limited the number of receptacles. More recently, as the demand for outlet density has increased, other solutions have developed.

Some users have purchased new IT cord sets that have a locking grip on the plug that must be released. These new locking cords can be used with existing PDUs, and are a good solution for older PDU models with a history of retention problems. However the need for a locking cord for each receptacle becomes a substantial added cost factor, if they must also be purchased for new PDUs. Some PDUs have new types of receptacles with a lever that can hold the plug in place, while other vendors offer high-retention force receptacles on the PDUs, eliminating the added cost of purchasing new locking cord sets.

Cooling System Energy Saving
Cooling systems are the largest user of energy other than the IT load itself. And many studies have shown that raising cooling supply air temperature can save a substantial amount of energy (ranging from 1-4 percent per degree Fahrenheit). However, one of the biggest issues that prevent many data center operators from raising supply temperatures is ensuring that the cabinets that are "running hot" stay within the ASHRAE envelope (or even going into thermal shutdown)—even if it means overcooling some or all of the other cabinets. This is especially true for those sites with insufficient airflow management and little or no rack-level temperature monitoring.

By using rack-level intake temperature monitoring (via PDU based sensors or other methods), airflow management issues can be identified, corrective changes can be made, and results can be immediately monitored and tracked. Once the airflow management issues have been resolved or substantially mitigated, then the cooling system temperatures can be slowly raised and the rack temperature ranges closely monitored to see the results. This allows energy savings while reducing the risk of IT equipment failure due to exposure to high temperatures. One of the known issues and concerns about higher IT intake temperatures is that at a certain point IT fans will speed up, resulting in higher power draw—in some cases negating the cooling system energy savings. While this improves the PUE, it may not lower the total facility energy, or could even increase it in extreme cases.

By using rack-level PDUs with temperature sensors, you will be able to determine the temperature correlation to

Reliability, Availability and Mean Time to Repair
Of course, the quality of the PDU is paramount to its reliability and therefore can affect its ability to deliver power to the IT equipment. It is therefore important to look for established manufacturers with proven track records. Nonetheless, it is a fact that no matter how well built they are, like any other device, PDUs can fail. While they can fail in several ways, some types of failures can affect the delivery of power to the IT equipment; others might only impact the management functionality. One of the more common modes of failure is the communications card. In this scenario, the power will most likely still be flowing to the IT load so there is no interruption. However, some manufacturers incorporate the network card as an internal component and to repair the PDU, it must be removed, impacting operational availability. Other manufacturers feature a plug-in network module with all the other connectors (temperature, cross linking, USB port, etc.), that can be hot swapped, so the PDU itself does not have to be removed from the rack and the IT equipment remains powered and fully operational.

any increased IT fan energy in real time (as well as trend it via software). You can also continuously analyze the data to find and optimize temperature settings based on your site conditions for maximum overall total energy efficiency (not just facility PUE)—even under changing operating conditions, as well as when IT equipment is refreshed over time.

Environmental Monitoring

The expected reliability of IT equipment is in part related to maintaining proper environmental conditions within the manufacturer's requirements—which in most cases fall within the ASHRAE "recommended" temperature and humidity envelope. However, as noted above, it is now well documented that it is no longer simply a matter of monitoring "room" temperature. Environmental monitoring at every rack has become extremely critical as power densities have risen significantly, especially in the last several years. According to ASHRAE's Thermal Guidelines for Data Processing 3rd edition (2012), for high-density racks, just taking average readings in the middle of the cold aisle is no longer sufficient. Each high-density rack should have up to three temperature sensors inside the front face of the rack (low, middle and high) to monitor the intake temperatures of the IT equipment and to ensure they remain within the recommended range.

Clearly, there are many independent systems available to monitor aisle and rack-level temperature. While the primary purpose of a rack PDU is power distribution, the advent of the intelligent/remotely monitored PDU has enabled adding environmental monitoring at the rack cost effectively, by adding small sensors as accessories that simply plug in to the PDU. The environmental information is then integrated into the rack PDU information, using the existing management console. This also saves the substantial cost of any installation and additional cabling for separate environmental sensors and systems. Even if wireless environmental sensors are installed, they require multiple receivers, located to ensure coverage, and which must be cabled and powered.

Higher PDU Temperature Requirements

In addition to requiring proper airflow, it should be noted that the operational temperatures of high density IT equipment have increased as well. The 2011 ASHRAE's Expanded Thermal Guidelines whitepaper (and the later formal release of the 3rd edition of the Thermal Guidelines) placed more emphasis on the wider A2 "allowable" range for most IT equipment, so that even commodity servers could operate at up to 95°F (35°C) intake temperatures. These higher temperature ratings were meant to help improve facility cooling system energy, as well as promote "free cooling" wherever possible.

However, these new operating ranges mean that some IT equipment can create a temperature rise (delta-t) of up to 40°F (22°C), or higher in some cases. This could generate exhaust temperatures in the back of the rack that can reach or exceed 122°F (50°C), which could be created by high-intake/Delta-T combination conditions. However, older PDUs and some current models on the market are only rated for 113°F (45°C). Furthermore, 113°F (45°C) conditions can be easily exceeded even with more moderate Delta-Ts, if higher "allowable" IT intake temperatures are encountered (see A3-A4 below).

The 2011 ASHRAE whitepaper also included the introduction of A3 and A4 extended "allowable" IT intake temperatures of 104°F (40°C) and 113°F (45°C) respectively. These new classes were added to encourage IT manufacturers to create future products with even greater energy saving opportunities by reducing or even eliminating mechanical cooling. Today they are no longer considered future products, since some major IT manufacturers are currently offering specific A3 and A4 rated servers. Furthermore, the increasing use of Solid State Disks (SSD), which can operate at up 140°F (60°C), have begun to be utilized in place of traditional spinning disks in storage arrays, allowing higher operating temperatures. In order to address these issues, some PDU manufacturers have introduced units that are rated up to 140°F (60°C). It is therefore important to consider PDUs with high temperature ratings for present and future purchasing criteria, even if you are not currently experiencing very high back-of-rack temperatures.

Total Cost of Ownership – PDU Budgeting and Relative Costs

There are several studies projecting the cost of building and operating a data center from different organizations. While they vary, a commonly cited whitepaper by the Uptime Institute estimated that costs range between $12,500 (Tier II) to $25,000 (Tier IV) per kW for the power and cooling infrastructure (plus $300 per square foot for the computer room space). In effect, the basic infrastructure cost to provide mission critical power and cooling for a 10 kW rack can range from $125,000 to $250,000. In sharp contrast, a 10 kW rack PDU which is the last link in the critical power chain, costs approximately one percent

Number of onboard PDU Breakers	Number of outlet groups (20 amp breakers per group)	Rated IT power (kVA)	Notes
3 Breakers (2 poles) 20 amps	3	12.5	Current draw limited to 35 amps due to only 3 breakers
6 Breakers (2 poles) 20 amps	6	14.4	Current draw 40 amps (80% of 50A branch circuit breaker)

TABLE 2A. Example of PDU capacity vs. PDU circuit breakers - for a 208/120 Volt - 50 amp 3-phase branch circuit.

Number of onboard PDU Breakers	Number of outlet groups (20 amp breakers per group)	Rated IT power (kVA)	Notes
3 Breakers (2 poles) 20 amps	3	25.0	Current draw limited to 35 amps due to only 3 breakers
6 Breakers (2 poles) 20 amps	6	28.8	Current draw 40 amps (80% of 50A branch circuit breaker)

TABLE 2B. Example of PDU capacity vs. PDU circuit breakers - for a 415/240 Volt - 50 amp 3-phase branch circuit.

or less of the invested facility cost (a PDU typically costs from $500 for an unmanaged basic unit to $1,500 for a fully managed unit). Yet, when it comes to selecting a PDU for a high-power rack, many times the lowest cost drives the budgeting and purchasing process, with little weight given to the importance of management or other critical performance features.

Clearly there are many different manufacturers that offer rack PDUs, each with different features and price points. Nonetheless, in addition to comparing the reputation of manufacturer and the product warranty, the person making the decision may not be completely aware of the strategic management advantages of a monitored or fully managed PDU. In some cases, the evaluator may not fully understand some of the basic differences between seemingly comparable, yet different models. They should consider various PDU specifications, such as the higher temperature rating and additional features such as integrated environmental monitoring capabilities required for high-density racks. They should also be aware of the significance of the number of on-board circuit breakers (3 vs. 6) in 3-phase units or other features, such as metering per sub-breaker group or individual outlet energy metering and control.

Outlet Density

The number of receptacles per PDU has increased to meet rising demands for more servers and other devices per cabinet. However, matching the power capacity of the PDU (and capacity of the branch circuit) to the projected power requirements is critical. Example: a common high-density rack configuration consists of (40) 1U servers @ 250 watts each (plus 1 kW for Top of Rack switches), total power 11 kW.

Phase Type (number of CB Poles)	Current Amps (US circuit / 80% de-rated)	Power each PDU (kVA)	Number of Outlets Per PDU	Number of PDUs (Single Feed)	*Total Power (kVA)	Total Number of Outlets	**Number of PDUs for A-B Redundant
Single-phase							
120V (1)	30/24	2.9	24	4	11.2	96	8
208V (2)	30/24	4.9	24-36	3	14.7	72-108	6
240V (1)	30/24	5.7	24-36	2	11.4	48-72	4
3-phase							
120/208V	30/24	8.6	24-42	2	17.3	48-84	4
120/208V	60/48	17.3	24-42	1	17.3	24-42	2
240/415V	30/24	17.3	24-42	1	17.3	24-42	2

TABLE 3. Examples of several common PDU configurations to support an 11 kVA rack.

Rack Power Distribution

Phase Type (number of CB Poles)	Current Amps (US circuit / 80% de-rated)	Power each PDU (kVA)	Number of 20/16 Amp receptacles (C19 or L6-20)	Number of PDUs (Single Feed)	*Total Power (kVA)	Total Number of Outlets	**Number of PDUs for A-B Redundant
Single-phase							
208V (2)	30/24	4.9	3-6	4	19.6	12-24	8
240V (1)	30/24	5.7	3-6	2	11.4	12-24	4
3-phase							
120/208V	30/24	8.6	6-12	3	17.3	18-36	6
120/208V	60/48	17.3	6-12	2	34.6	12-24	4
240/415V	30/24	17.3	6-12	2	34.6	12-24	4
240/415V	60/48	34.6	12-24	1	34.6	12-24	2

Footnotes: *Total power based on US voltage and de-rated current capacity. Actual capacity may change due to European and Asian localized system voltage standards (i.e. 380/220V - 400/230V - 415/240V), as well as codes that can impact branch circuit protection ratings.
** PDU count doubles for redundant A-B power.

TABLE 4. Example of PDUs to support 4 Blade Servers and other High Power IT equipment at approximately 20 kVA rack.

Blade Servers

The other common high-density configuration is for (4) Blade Servers (at approx. 4-5 kVA each). Typically each requires a minimum of 2 or 3 power supplies (each PS necessitating a 208-240V 20/16 Amp receptacle) and double the number of power supplies for A-B redundancy.
Note that the tables above represent a general summary of common types of PDUs (0U vertical) in each category range, from a variety of manufacturers. Many other models exist, as well as custom designed units from various vendors. In addition, some vendors also offer PDUs with higher ratings to support racks above 35 kVA.

As can be seen from the above tables, 3-phase power offers the greatest power capacity and therefore minimizes the number of PDUs for a given load or application. It also minimizes the total number of cables and circuit breaker (CB) poles in the upstream power distribution panel.   From a physical perspective, most racks can only accommodate four vertical PDUs, and it is preferable to only use two PDUs when possible to allow space for network cabling.

While a detailed discussion of cooling these high-density racks is beyond the scope of this whitepaper, it should be noted that it is important to ensure that the size and placement of the PDUs and the related server power cords, as well as the network cabling, does not block the exhaust airflow.

Clustering and Grouping

As can be seen in tables 3 and 4, multiple PDUs in higher-density racks are a common configuration. In addition, besides the need to provide power to each PDU, network communication is also required. This usually means a port on an Ethernet switch (either on the production network or a dedicated management network). This can become a costly aspect of managed PDUs, and some vendors have the ability to interconnect multiple PDUs (typically up to 4 units) so that only one network port is required. Moreover, they can be logically clustered together to be viewed as a managed group in each rack. Some manufacturers even provide cross powering to the communication cards (creating redundant power configurations), so that should either side lose input power, the communications card can still communicate and send out an alert.

New Builds vs Retrofit Upgrades

When designing a new facility, the type of power distribution system is critical to its ability to adapt to constantly changing IT equipment power requirements. Of course the basis of design requirements will need to be ascertained early on, in order to specify the critical power capacity, and therefore the capacity of the UPS systems. Thereafter, the downstream distribution voltage should be discussed. In Europe this is essentially predetermined at 400/230 volts generically (although it will vary by country from 380/220 V to 415/240V). In North America, the most common configuration for larger facilities uses a 480 volt UPS system, which feeds floor-level PDUs with stepdown transformers that then provide 208/120 volt power for distribution to the IT cabinets.

While a detailed discussion of cooling these high-density racks is beyond the scope of this whitepaper, it should

Retrofit Upgrade Challenges
One of the potential bottlenecks when trying to upgrade the power to a cabinet (especially to group of cabinets) can occur at the upstream power distribution panel. While an electrical survey of the input to the panel may show that there is current capacity still available, all or nearly all the branch circuit breaker positions may be full. This is very common in older facilities that used 120V branch circuits to feed the cabinets. As can be seen in tables 3 and 4, it would be wise to consider installing higher power 3-phase cabling and PDUs to maximize the capacity of existing distribution panels. Also, where possible, consider locating the new power cabling overhead, to improve cooling airflow, especially if the under-floor space is already filled with cabling.

be noted that it is important to ensure that the size and placement of the PDUs and the related server power cords, as well as the network cabling, does not block the exhaust airflow.

Some manufacturers have been offering 415/240V power distribution systems in the US marketplace. This has some advantages, especially for a new data center, since it can deliver double the power (415/240V vs. 208/120V volts) over the same-sized branch circuit cabling, saving initial costs and reducing the physical cabling and pathway size. This also means that the PDUs can deliver twice the power as well, thereby reducing the number of PDUs required for high-density cabinets, reducing costs substantially. This also saves space in the back of the cabinets (improving airflow). In addition, the IT equipment power supplies are more energy efficient at the higher input voltage, saving energy and reducing cooling requirements. In some data centers, 480/277 volt power distribution to the racks has been used; however, this is not yet a commonly deployed scenario.

Management Software
Of course all the sophisticated features and benefits of this latest generation of smart, remotely managed PDUs are minimized, without centralized software to track, record, analyze and display the information from hundreds or thousands of PDUs, as well as other information.

Beyond just managing PDUs, an entire new class of management software has come into the mission critical realm: Data Center Infrastructure Management (DCIM). The premise behind DCIM is the proverbial "single pane of glass," which promises to alleviate the challenges related to the traditionally cultural and management issues

Multi-Vendor Compatibility
Most vendors have their own management software that is optimized for their PDUs, some with proprietary features unique to their PDUs. Many vendors have also made their PDUs accessible via standards-based SNMP, and many software packages can communicate with most other brands of PDUs (although some proprietary features may not be fully addressable). This is done out of necessity in order to be competitive and functional in the multi-vendor environment common in most data centers. When reviewing the features of the PDUs and the vendor's own matching (or even competing) software, a review of compatibly is critically important.

of IT vs. Facilities. Originally, most DCIM products were fairly basic offshoots of Building Management Systems (BMS) and were primarily focused on the facility side, with a "PUE" dashboard added on. They have now gone through several generations, and in their current iteration have become far more sophisticated tool sets.

DCIM may have started primarily as a BMS/BIS facility-type platform, with data center-specific features (such as a PUE dashboard); however, the nature of entire data center-centric computing infrastructure and enterprise IT architecture itself has changed radically since DCIM's inception. While the topic of DCIM is a hotly debated industry subject, a detailed analysis is beyond the scope of this whitepaper. Nonetheless, there is a real need for a system that can collect and aggregate information from facilities and IT systems and deliver a cohesive picture in a manner that is meaningful and correlates to some actionable items for everyone.   However, not every organization is ready to fully commit to a major investment in DCIM. Alternately there are some management software offerings from the PDU manufacturers that can effectively meeting your basic management requirements, with a much lower initial investment.

The Bottom Line
The new generation of smart, remotely manageable PDUs has offered important management tools to many large enterprise organizations. However, the costs of owning and operating data centers have changed the landscape for both small and large organizations, giving rise to outsourcing in several forms. The days of the traditional enterprise data centers are diminishing as more organizations are moving toward outsourcing data center ownership and operations by moving to colocation providers

and cloud services. Colocation in particular has exploded, and has increased the need for better remote visibility and management at the rack level, since the colocation facilities may be situated far away from the IT team.

From a strategic management perspective, the days of the basic "power strip" are numbered. The need to lower TCO by C-level management requires real-time accurate data that can be distilled into actionable information. The added features of the latest generation of smart PDUs and management software can provide that insight. One of the ultimate goals of optimizing a data center's overall efficiency is to be able to measure various applications' utilization rates (and throughput) and correlate that to their energy consumption. That information can then be used by IT architects to make more intelligent, holistic decisions about IT performance and energy efficiency and related TCO. This data can then also be used to compare it with cloud-based services and to make capacity planning, as well as short- and long-term strategic and financial decisions that can more than justify the ROI question.

The PDU may be the last part of the power chain; however, like any link in a chain it is just as critical as any other component. From maintaining operational status and minimizing human error, the smart PDU is a key component in providing visibility within the rack. This granular information also allows more accurate management decisions to be made, such as capacity planning. It can also be a flexible and cost effective platform to add environmental monitoring at the rack level, which is essential in today's high-density data center. Moreover, the minor additional cost to include the remote monitoring or management function into a basic PDU is a fairly small incremental investment, especially compared to the total cost of the infrastructure of the entire facility, as well as the cost of the IT equipment it supports. The direct benefits it provides, such as mitigating the risk of needless overload-related outages and cascade failures (caused by circuit breaker trips), even in fully redundant power chains, clearly makes it a very worthwhile investment, if not a mandate.

About Julius Neudorfer

Julius Neudorfer is the CTO and founder of North American Access Technologies, Inc. (NAAT). Based in Westchester NY, NAAT's clients include Fortune 500 firms and government agencies. Julius has been designing and implementing Data Center Infrastructure and related technology projects for the last 25 years. He developed and holds a US patent for a high efficiency cooling system for rack mounted computer equipment.

Julius is a member of AFCOM, ASHRAE, BICSI, IEEE and The Green Grid. He is an instructor for the US Department of Energy "Data Center Energy Practitioner" "DCEP" program. He writes the "Hot Aisle Insight" column, and has also written numerous articles and whitepapers for various IT and Data Center publications and has presented seminars and webinars on data center power, cooling and energy efficiency.

About Server Technology

For over 30 years, Server Technology has been recognized as the global leader of innovative, intelligent power distribution products and solutions for data centers, telecommunications operations and branch offices. Over 60,000 customers around the world rely on Server Technology's cabinet power distribution units (cabinet-level PDUs) and power management solutions to help reduce downtime, facilitate capacity planning, improve energy utilization and drive efficiency.

With the best quality and longest mean time to failure (MTTF), Server Technology products provide uncompromising reliability and value for the datacenter. As a leader in product innovation, Server Technology holds many of the key patents for providing power in zero-U and horizontal PDU configurations compatible with today's racks and dense compute infrastructure requirements.

References:

ASHRAE: www.ashrae.com and http://tc99.ashraetcs.org/

AFCOM: www.afcom.com http://www.afcom.com/wp-content/uploads/2014/09/Strategic-Directions-DCISE-Size-Density-Standards-v1.0.pdf

The Green Grid: PUE Power Usage Effectiveness www.thegreengrid.org

http://www.thegreengrid.org/~/media/WhitePapers/WP49-PUE%20A%20Comprehensive%20Examination%20of%20the%20Metric_v6.pdf?lang=en

https://www1.eere.energy.gov/manufacturing/datacenters/pdfs/task_force_metrics_recommendations.pdf

SPEC Power: https://www.spec.org/sert/

US Energy Star Program: www.energystar.gov http://www.energystar.gov/products/spec/enterprise_servers_specification_version_2_0_pd

Uptime Institute: www. www.uptimeinstitute.com Whitepaper "Cost Model: Dollars per kW plus Dollars per Square Foot of Computer Floor" - By W. Pitt Turner IV, P.E. with Kenneth G. Brill – 2008