DATA CENTER Frontier Special Report

Understanding Importance of Power Quality in the Data Center

Finding the Ghost in the Machine

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Introduction

There are several fundamental infrastructure elements that create the basis of a functional data center environment; power, cooling and a secure facility. Of these prerequisites, clean uninterruptible conditioned power is one of a data center's most critical elements which can have the most immediate impact if any issues occur.

Most availability discussions are focused on redundancy levels in the power chain, and mitigating any failures; starting with the utility and continuing through switchgear and back-up generators, UPS, power distribution and down to the branch circuits to the IT racks.

While extensive time, money and effort go into the design, installation, operation, and maintenance of the data center, there exists a critical but invisible risk in many data centers' power chain—the lack of monitoring of power quality.

Clean uninterruptible conditioned power is one of a data center's most critical elements which can have the most immediate impact if any issues occur.

This white paper will examine the equipment, operational characteristics and conditions that can influence various points in the data center power chain, which ultimately can the impact the power quality and operation of the IT equipment.

Understanding Key Elements of Data Center Availability

Generally speaking, the term data center "availability" is focused on maintaining the security of a physical facility and the power and cooling infrastructure systems that support the IT equipment (ITE). The data center industry has several different organizations which have developed guidelines and terminologies which are commonly used as an availability classification reference.

Organization	Rating System Name	Rating System Nomenclature
The Uptime Institute	Tier System of Availability	Tiers I-IV®
*TIA TIA-942-B:	Rated	Rated Levels 1-4
Industry Generic	"N" Single Component, System or Path	N, N+1, 2N, 2(N+1)

**Telecommunications Industry Association*

Availability Rating**	Redundancy Level	Relative Level of Fault Tolerance	Notes
1	N	None	Not recommended for enterprises
2	N+1	<u>Moderate</u> Some equipment can fail or be taken off-line for maintenance without impacting Critical Load	Can be cost effective for lower priority applications
3	2N	<u>Good</u> - Allows for "Concurrent Maintenance" - Fully redundant dual paths and equipment - Individual equipment be taken off-line for service while other system supports Critical Load	- Most commonly used for enterprise applications. - Balances cost effectiveness vs risk
4	2(N+1)	<u>Highest</u> - Provides "Concurrent Maintenance and Fault Tolerance" - Fully redundant dual paths (N+1 equipment each path) - Equipment or either path can be taken off-line for service without impacting Critical Load Remaining N+1 system will still be fault tolerant	- Used for the most critical, highest value applications - Most expensive to build

Table 1 - Availability Levels

***Note: The chart is a non-specific general correlation of generic availability and redundancy levels.*
The Uptime Institute created the Tier System of Availability (Tier I, II, III and IV®), which is a registered trademark.

It should be noted that in addition to the Uptime Institute, the Telecommunications Industry Association "TIA" also has a similar rating structure (1-4) contained in their TIA-942-B document. It is a design specification referenced by many in the industry

Also to be noted that the redundancy requirements apply to power and cooling systems, as well as other critical infrastructure elements of the data center.

Counting the 9s

In addition to the four redundancy levels noted above, data center owners, operators and customers are concerned about remaining operational 7x24. From the facility perspective, this is primarily focused on ensuring there is no loss of power and cooling, and is referenced annually in the form of a percent (i.e. 99.999%), and informally, expressed as the number of 9s: the proverbial "Five 9s".

This whitepaper will focus on the power path and related electrical components that provide clean uninterruptible power to the Information Technology Equipment (ITE).

Power Path

However, while all this is the industry norm, it does not necessarily address the issue of quality of the power delivered to the ITE. In fact, it is possible to have some undetected power quality issues (such as random transients), which may impact the ITE or network resulting is data errors or loss, yet not be considered as "downtime" since power was never lost.

The power path can range from a very basic single path design or contain as many redundant components as required to deliver desired level of fault tolerance which is considered by many as the primary measure of evaluating electrical availability to the IT equipment and cooling systems, as well as other miscellaneous loads, such as lighting, and other security and support functions.

Power Quality Issues – The Devil is in the Details

There are many terms generally used to describe power quality issues; glitches, spikes, disturbances, flicker, blinks, etc. However, while they all connote that "something" occurred, the IEEE has defined this in seven categories:

Type	Description	Potential Impact in Data Center
Transients	Spikes, other short term events that raise the voltage and/or current	Possible damage to electrical or mechanical systems, as well as IT equipment.
Interruptions	Complete loss of supply voltage - categorized as instantaneous, momentary, temporary, or sustained	- Loss or corruption of data if interruption occurs on the UPS output to ITE - Loss of cooling system while waiting for back-up generator to start and compressor restart lockout delay
Sag / Undervoltage	- Sag: Reduced AC voltage - duration of ½ cycles to 1 second - Undervoltage: period of several seconds or longer (i.e. "brown out" of utility power)	- Can impact motorized device such as compressors - Problem, for ITE if it exceeds CEBMA limits
Swell / Overvoltage	Inverse of a sag, increased AC voltage	Possible damage to electrical or mechanical systems, as well as IT equipment
Waveform distortion	- Any imperfections of a sine wave: Harmonic Distortion, voltage or current clipping or spiking. - Also includes DC offset	- Introduction of noise into network and IT equipment - Waveform distortion may also include a DC offset on the output of a UPS
Voltage fluctuations	Unstable random or repeated voltage changes: short or long term	- Relatively minor impact if small range: plus or minus 5% of nominal - Can cause UPS to reject input power and go to battery
Frequency variations	Any change from nominal frequency	- Can impact synchronous motors - Can cause UPS to reject input power and go to battery

Table 2 - Types of Power Quality Issues

Power Management vs Power Quality Monitoring

The impact of some of these type of issues, (interruptions and sag / undervoltage), are relatively apparent and can be detected by basic power metering and recorded by logging software. Others, such as Transients, which can be random and extremely short, as well as waveform distortions, are not normally detected by typical power meters.

Moreover, older and smaller data centers in particular, usually lack basic power measurement or monitoring systems. In those cases, the only way they become aware of a potential power problem is when IT support personnel report the issue. In some cases, even when redundant A-B power paths exist, if one side of redundant circuits fail, IT administrators may not be aware of the exposure since the IT equipment that have dual power supplies will continue to operate. Even many newer, larger data centers which may have more comprehensive power measurement at the branch circuit level, do not have a complete picture of some of the issues of assessing power quality to IT equipment.

While power loss is a detectable event at any level in the power chain (i.e. at any point in the path starting from the utility down to IT cabinet branch circuit), with standard power monitoring, most systems do not detect or record the disturbances listed in the above PQ Table 2.

PQM is now more affordable and cost effective

There is significant and increasing investment in redundant backup power systems to ensure availability. However, historically, the relatively high cost of purchasing and installing power quality monitoring with sufficient granularity and sensitivity to detect and identify power quality issues throughout the power chain has been an inhibitor in the data center industry. As a result, it was not typically specified unless there were obvious known or expected power problems. More recently, just as the cost of other digital devices have come down while becoming more powerful; PQM has also become more sophisticated and intelligent. The result, now PQM is far more cost effective and justifiable, even for smaller data centers.

If there is a UPS to provide "clean" power why would we need a PQ monitor for the ITE?

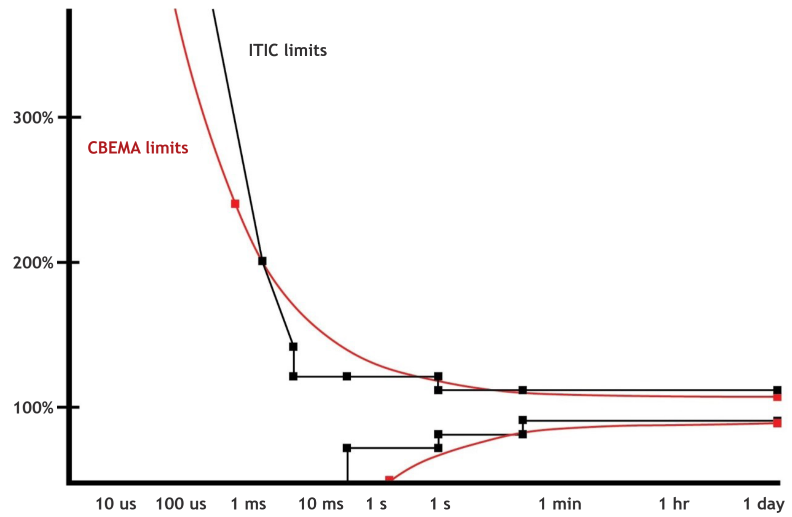
The backbone of ensuring clean uninterrupted power to ITE, is the "double conversion" on-line UPS. While this type of UPS does isolate and mitigate most utility side power problems, it cannot protect ITE from power issues such as noise from harmonics which are generated downstream of the UPS output.

By their very nature ITE Power Supply Units (PSU) are nonlinear loads which can introduce harmonic distortion. In addition to the issues generated by the ITE PS themselves, other equipment such as some supplemental high density cooling systems (typically fan motors with variable frequency/speed controllers) that are also powered by the UPS.

IT Power Supplies

Computer and Business Equipment Manufacturers Association (CBEMA) was reorganized and was renamed the Information Technology Industry Council (ITI).

The CBEMA chart originated in the 1970s and was widely referenced in the IT industry for several decades. While it was updated and superseded in 2000, by Information Technology Industry Council ITIC curve (New CBEMA Curve), they are still not immune to surges, spikes and other disturbances, such as harmonic distortion and related noise.



Courtesy of CBEMA/ITIC

Furthermore, the drive for energy efficiency has resulted in significant improvements in ITE PS electrical characteristics. Nonetheless, theses PSUs are based on switched-mode power conversion. They still have input power factors and harmonic distortion. While ITE power supplies have greatly improved in energy efficiency and power factor, they can still introduce harmonic into the power distribution system.

The US Energy Star program for data center equipment has detailed this in their specifications. However, while these specifications apply to latest Energy Star PS requirements, many non-ES servers PS many have greater THD and lower PF. This is especially true for non-major server vendors and for older servers.

Power Supply Ratings	Maximum Total Harmonic Distortion (THD*)	Notes
Less than or equal to 1500 Watts	2%	Small – Midsize Servers
Greater than 1500 Watts	5%	Bladeservers, large network and storage systems

Table 3 – Energy Star version 3.0 Computer Server Specifications: Maximum Total Harmonic Distortion

**THD up to and including the 13th harmonic*

Power Supply Type	Rated Output Power	10% Load	20% Load	50% Load	100% Load
Ac-Dc Multi-output	All Output Ratings	N/A	0.80	0.90	0.95
Ac-Dc Single-output	Output Rating ≤ 500 W	N/A	0.80	0.95	0.95
	Output Rating > 500 W & Output Rating ≤ 1000 W	0.65	0.80	0.95	0.95
	Output Rating > 1000 W	0.80	0.90	0.95	0.95

Table 4 - Energy Star version 3.0 Computer Server Specifications: Power Factor

Note that the power factor decreases at lower loads. For those data centers that use dual corded redundant PS, the normal load on each PS is usually much less than 50%, which results in a lower power factor.

Finding "The Ghost in the Machine"

The loss of conditioned power to ITE is easy to detect and has an obvious and immediate major impact. The influence of power quality issues are not necessary immediately visible or consistent and may not be even considered when there are computing or communications errors or other data integrity problems. This is especially true when they manifest themselves as random unexplained occurrences, which are frequently blamed on the IT or network equipment or data cabling.

PQ Influence on Data Network Performance and Integrity

Moreover, it is the harmonics which can generate electromagnetic interference (EMI) which poses a separate potential threat to the IT network, either by being induced in the unshielded copper Ethernet distribution cable system and copper jumper cables which reside in close proximity to the power cables in each ITE cabinet. This is especially true as power demands and equipment density have increased substantially, resulting in greater EMI emission within the cabinet.

While fiber optics cables are essentially immune from electromagnetic interference, however network cabling systems built with un-shielded copper conductors are vulnerable to interference from several sources: stray magnetic fields, harmonics or noise induced from nearby power cables and ground currents. These sources are typically related to the power-distribution system and its associated cabling. This potential exposure can also increase when network cable trays are closely run in parallel with non-metallic power distribution cables to IT cabinets.

The susceptibility of unshielded cables to noise increased as Ethernet speeds grew from 100 megabits second to 1, 10, 40 gigabits second. In some cases, a small amount of noise may cause some data packet transmission errors, which modern network equipment can detect and can accommodate by resending the packet. However, this does reduce the throughput of the network.

Effect of Increased Power Density

Power density per rack has gone from 3-5 kW, and now ranges from 5-15 kW or even higher in some cases. While there are many challenges for cooling these racks, electrically delivering higher power is relatively straightforward. It became common to see multiple 20-30 amp single phase circuits and PDUs (which take up significant space, blocking airflow), in each rack in order to meet the rising power demands. As a result, many organizations have been moving toward 3-phase power distribution to the rack to reduce the number of PDUs. (Discussion on phase imbalance)

The majority of ITE used in data centers use single phase power. In the US, single phase circuits to the rack are either 120 or 208 volts. This is derived from 3 phase 208V power panels on the wall or from PDUs on the floor. As noted previously, ITE use switched-mode power supplies, which, while power factor corrected, produce harmonic distortion, as well as varying the power factor and crest factor in relation to load conditions.

Impact on Power Distribution

- Phase imbalance
- Impact of non-linear (i.e. ITE-PS) single-phase loads power distribution panels, RPPs or PDU
- Related impact harmonics on PDU Step-down Transformers (k-factor)
- Grounding and Bonding Issues
- Phase to ground currents (ITE PS leakage currents)

IT Equipment Ground Leakage Currents

While most ITE PS meet safety approvals, they do generate a small amount of leakage currents into the chassis ground. The current are relatively small (ranging from less than a milliamp up to xx milliamps, from each ITE PS, depending on the PS. However, in a data center with hundreds or thousands of ITE PS the combined ground current can add up to several amps for a typical 200-300 KVA floor level PDU. This is safe as long as the power distribution system is properly grounded. Most large data center floor level PDUs measure ground conductor current, but unless it reaches an alarm set point, it goes unnoticed. Moreover, these ground currents often contain harmonics, which when combined may become significant in the output side neutral leg of a 208/120 volt 3-phase Wye system, where the neutral may be bonded to ground at the PDU.

PUE and the Quest for Energy Efficiency

The Green Grid introduced Power Usage Effectiveness (PUE) in 2007 and since then the quest for data center energy efficiency has influenced many areas of the data center infrastructure. This includes the increase use of variable frequency drives for cooling systems (see discussion about harmonics and noise).

Energy Efficient UPS

This has also driven UPS manufacturers to improve the mainstay of the conditioned power; the classic double-conversion online UPS. While there have been many clear improvements in the last decade in the efficiency of the double-conversion electronics (moving the average from the mid-80% range to the low-90% under low loads), another efficiency scheme was developed; the so-called “energy saver” or “eco-mode”. To reduce double-conversion losses, this “eco-mode” of operation monitors the quality of the power input to the UPS and if it is deemed satisfactory, automatically puts the UPS into static bypass of the inverter condition, via the internal static bypass switch (solid state), which routes utility power directly to the ITE Load. If the UPS software detects a problem with the input power, it transfers the load back to the inverter. UPS vendors claim this is safe, since the transfer occurs within 4-8 milliseconds (which is within the CEBMA curve). While this may be true, only a PQ meter with an event recorder could monitor, verify and document if there are any issues.

If the UPS software detects a problem with the input power, it transfers the load back to the inverter.

There are many basic electrical code life-safety specifications and requirements for bonding and grounding the electrical system for any building. Data centers have numerous special requirements since data networks and ITE can be impacted by noise.

PDU Transformers

In the US, for most midsize and larger data centers the UPS is typically a 480V system and the voltage to the ITE is stepped down to 208/120 volts at a floor level PDU with an internal transformer. The type and rating (k-factor) of transformer will determine how well it can handle harmonics generated by load, which are primarily ITE switched-mode power supplies (which as noted earlier, have a harmonic currents and a power factor which can vary with load). The higher the k-factor rating specified in the PDU (typically K1, K4, k13, andK20) the better in can tolerate the harmonic content of the load.

However, the cost of the transformer increases with the k-factor and in some cases a lowest k-factor transformer (K-1) was used because the k-factor was not specified in a price based bid, or for other financial reasons. As a result, the transformer will heat-up (or overheat) as well as saturate, introducing waveform distortion, and therefore is a good candidate for PQ metering.

Grounding Issues

Grounding practices in data centers are a complex and often misunderstood issue. There are many basic electrical code life-safety specifications and requirements for bonding and grounding the electrical system for any building. Data centers have numerous special requirements since data networks and ITE can be impacted by noise. There are many technical whitepapers as well as IEEE and TIA specifications that addresses and differentiates data center and telecommunications system signal grounding from basic life-safety electrical grounding requirements. Standard practice is to have a separate single point telecomm grounding system which only connects with the main electrical ground at a single point.

Sometimes issues occur during initial construction when power distribution equipment in the data center is incorrectly grounded to building steel or if the neutral conductor is incorrectly bonded to ground in multiple places. This can also occur when new equipment is added to the power distribution system. These conditions can go undetected unless an extensive electrical survey is done which examines and measures the ground and neutral currents and voltage differentials. PQMs which can measure and record these ground and neutral data, as well as capture any harmonics can help identify and diagnose problems caused by these issues.

Data Center Infrastructure Monitoring (DCIM)

It is impossible to discuss monitoring power quality without mentioning Data Center Infrastructure Monitoring (DCIM), as well as power monitoring and management systems. Traditionally, the facility power and cooling systems are monitored by a Building Management System (BMS). Various DCIM systems have been introduced over the past decade, which offer a more granular insight to the data center whitespace and in some cases interfacing with existing BMS systems. In other cases, they are IT centric. In most cases, the power monitoring of various points in the power chain consists of the basic voltage and current sensors, as well as the derived kVa and kW metered data. PQ monitoring is not normally included. Data from PQ metering can be monitored in some DCIM systems. Large scale data center may install full scale power quality sensors as part of a high-level dedicated power management system. However, these PM/PQ systems are relatively expensive.

In most cases, the power monitoring of various points in the power chain consists of the basic voltage and current sensors, as well as the derived kVa and kW metered data.

PQ Surveys vs Installing PQ Monitoring

When PQ issues are suspected or blamed and there is no PQ metering, many times a professional engineer firm is engaged to do a PQ survey, so why would a data center operator spend the money and effort to install PQ metering?

While this is the normal "solution" to determine a suspected PQ problem, this has some inherent drawbacks. In order to do PQ survey, the engineer must install temporary PQ logging monitors which involves opening and connecting to one or more electrical panels in the power chain and then leaving them in place for a period of time (days or weeks), especially if the problems are intermittent. If multiple points in the power chain are suspected, several PQ loggers must be installed, further increasing the scope of the survey. This is not an inexpensive process and there is no guarantee that the issues will occur during the survey.

Alternately, by making a one-time investment and installing one or more low cost PQMs it will provide continuous detection and traceable data records of any power anomalies even if they occur randomly.

Where, Why and What to Monitor

The more points that are monitored the greater the granularity of the data, resulting in better correlation of the cause and faster pinpointing of the source or the type of problem. However, while ideal, it is also the most costly.

From a practical matter and cost effectiveness perspective, even a single PQ meter placed in a critical location can provide a strategic view into the power chain.

Since the most critical and sensitive consideration the PQ to the ITE, the 480 volt input from the UPS and 208/120V output of a floor level PDU could be monitored by a single PQM with multichannel inputs. This could be relatively easy to install in the PDU. For sites with redundant UPS, PDUs and power paths obviously would be required.

The UPS will continue to supply the ITE load if there is utility power outage until the load can be transferred to back-up generator(s). However, there are large inrush currents upon transfer to the generator, which can impact power quality and may generate harmonic distortion. The same issue occurs when power is transferred back to utility when it becomes available.

If there are concerns that the utility power is questionable, again, a single unit could be installed at the output of the automatic transfer switch (ATS). This would allow monitoring the PQ of the incoming utility, as well at the PQ of output of the back-up generator.

> While the primary purpose of adding a PQM is the detection and logging of PQ issues, it also provides much more useful information and oversight for those sites which may lack a power management system.

When installed in the main distribution panel, a multichannel PQM can monitor the total power to the data center, as well as separately measuring the power consumed by cooling system and the UPS supporting the ITE. This, when combined with temperature and humidity monitoring, would help optimize the cooling system energy efficiency.

There are many more points that could be monitored; the above examples provide a great deal of insight, with a minimum investment.

Of course, while the primary purpose of adding a PQM is the detection and logging of PQ issues, it also provides much more useful information and oversight for those sites which may lack a power management system. This includes measuring: power demand, power factor, phase imbalance, ground currents, etc. This information can then be used to optimize the efficiency and maximize available capacity of the UPS and downstream power distribution.

Power Quality at the Edge

The computing architectures and communication system infrastructure has been undergoing a metamorphosis over the last several years. It began with so called “edge computing” in order to minimize latency and optimize responsiveness to end-user devices. It was accelerated in the anticipation of 5G communications and the expected demand of localized data processing.

While large data centers continue to be built, more and more computing systems are being deployed in remote areas. In many cases, they are collocated with cell sites and are not staffed. These remote sites are subject to multiple, varying and sometime frequent PQ problems and are candidate for a PQM which can send alerts and PQ data to a central monitoring location. It should be noted that in addition to PQ monitoring functions some multi-channel PQ meters can also accept data from temperature and humidity sensors, adding to their cost effectiveness. The need for these type PQMs at smaller server rooms, in satellite office locations, also should be considered.

Summary – The Bottom Line

The data center environment is highly dynamic. IT equipment is added or upgraded almost continuously. Even in well managed data centers, IT loads may not be well balanced across the phases, which can cause energy waste, as well as limiting power capacity throughout the power chain.

In addition, there are many elements that were discussed above that have the potential to create PQ issues which can impact IT operation.

This is not to say that every data center has been impacted by these issues. However, experience has driven a significant percentage of recently built data centers have specified PQ monitoring as a standard element of their power management systems.

Technology improvements have made standalone, smart PQMs cost-effective. Their small size makes them relatively easy to install into (or adjacent to), existing electrical distribution equipment.

This new generation of self-contained PQMs offers menu driven displays and can record PQ event data as well as send alerts and graphic plots of PQ event via email or over a network using industry standard protocols (such as IP, Bacnet, Modbus, SMNP, etc.).

The Self-Contained PQM

Power quality meters represent a small investment which could help detect power system based anomalies, and identify and mitigate the source of problem. Moreover, for colocation operators, which may have customers who experience ITE problems and erroneously assume it was a facility power issue, it could also help vindicate the facility operator, since PQ time stamped records could show that there were no PQ issues at the time of the IT problems.

If you suspect that you may have PQ issues, you should consider investing the cost one or more PQ meters. Early detection, investigation and response to a potential issue can help avoid or mitigate failure. If you are building a new data center or even a server room, it is very small initial investment relative to the long terms benefits.