Types of Electrical Meters in Data Centers

White Paper 172

Revision 1

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> Executive summary

There are several different types of meters that can be designed into a data center, ranging from high precision power quality meters to embedded meters (i.e. in a UPS or PDU). Each has different core functions and applications. This white paper provides guidance on the types of meters that might be incorporated into a data center design, explains why they should be used, and discusses the advantages and disadvantages of each. Example data centers are presented to illustrate where the various meters are likely to be deployed.

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Introduction

Meters provide data that offers insight into the operation of the data center infrastructure (i.e. power and cooling systems) within a data center. Specific types of meters exist for various reasons, from tracking the use of electricity to analyzing the power quality in a facility and reporting problems such as transients and harmonics to measuring the power usage effectiveness (PUE) of the data center.

As energy initiatives and legislation continue to increase, the necessity for more in-depth metering to better understand and optimize energy use is also increasing. Meters enable you to benchmark the data center's energy use, identify improvement opportunities, and measure results from energy improvement projects.

Within a data center, you'll likely find meters in place that measure power (kW), energy (kWh), voltage & amperage, harmonics, power factor, flow rates, temperature & humidity, and more. This paper focuses only on *electrical* meters that exist in a data center; and discusses their applications and purpose, their typical placement in the electrical and mechanical infrastructure, their relative costs, and their advantages and disadvantages. The scope of this paper is on the physical meters, and does not discuss the management software used in conjunction with the meters for visualization, reporting, etc.

Table 1 lists the key attributes that differentiates the various types of electrical meters in a data center. This paper discusses these attributes to help data center designers select the right meters for their needs.

Table 1

Key attributes that differentiate meters

Attribute	Explanation
Core function	Core functions range from ensuring uptime and identifying root-cause of problems to measuring energy (i.e. for PUE reporting).
Type of data	Some meters collect power quality data such as harmonics, voltage sags/swells, and voltage transients in addition to power metering data such as energy, power, voltage, current, power factor, and frequency; Others collect a subset of this data.
Data access	How the data is used and analyzed varies from meter to meter. Data from meters may be accessed directly on the meter, through a building management system (BMS), through an energy management system, and/or DCIM system. Some meters require software with special drivers to access real-time and historical elements.
Accuracy of data	The accuracy (how close the measured value is to the actual value) varies by meter. Accuracy may be validated by a third party – i.e. ANSI C12.1 & IEC 62053-21 (compliance within 1% accuracy) purposes with meters.
Frequency of data	The time interval(s) for data collection can vary significantly from one meter to the next. It is important to understand the required frequency of data collection (i.e. is data needed every millisecond, second, minute, hour?).
Cost	Both first cost (meter cost & installation) and ongoing cost (maintenance/calibration) factor into the overall cost of the metering system.
Form factor	Some meters are stand-alone devices, while others are embedded in other devices such as UPSs, PDUs.

Value & classification of metering

Metering systems provide critical data and analytics that help ensure safe, reliable, high quality, and efficient data center power distribution. Specifically, metering systems (together with building, energy, and data center infrastructure management systems) can provide the following value:

- Enable PUE reporting
- Decrease unplanned downtime events
- Recover quickly from downtime events
- Improve the effectiveness of maintenance activities
- Maximize asset utilization
- Decrease energy operating expense
- Enable charge-backs of energy use to internal and/or external clients

Enable PUE reporting – Due to regulations across the globe and/or internal company initiatives, more and more data centers are trending and reporting their power usage effectiveness (PUE). Reporting PUE starts with measuring power consumption, of both the IT loads and the physical infrastructure components that make up the total data center power consumption. Meters at various points throughout the architecture enable this. Sometimes temporary meters are put in place to address this need. See the *side-bar* for an overview of temporary meters and their role (and limitations) in an energy efficiency plan.

> Temporary meters for efficiency measurements?

This paper focuses on **permanent electrical meters** that are designed into data center infrastructure systems to collect and report data on an ongoing, continuous, basis.

Temporary electrical meters can provide data center operators with a point-in-time snapshot of energy consumption or performance when no permanent meters are in place. It is important to remember, however, that efficiency varies over time because the IT load varies over time, the outdoor conditions vary over time, and the cooling mode of the data center can change over time. All of these factors affect the data center efficiency and the result is that data center efficiency is constantly changing.

White Paper 154, *Electrical Efficiency Measurement for Data Centers*, discusses how a mathematical model is the key to creating a process and system for efficiency management and the value of the point-in-time data center efficiency measurement is in establishing the parameters of the efficiency model.

Decrease unplanned downtime events – Information from meters provides data to reduce the likelihood of outages of the data center's power system. The data, for example, can alert the operator(s) to over-loaded UPSs, generators, & IT rack circuits before redundancy and availability are compromised.

The trending of data from meters also enables predictive maintenance programs, where maintenance activities are scheduled based on critical performance parameters. This type of maintenance reduces human interaction with the systems, which reduces the risk for human error.

Further, power quality meters enable detailed root-cause analysis on electrical distribution system downtime events to reduce the probability of the same event occurring in the future. Collected data on electrical parameters during a utility outage can also be shared with the utility company to help them improve service over time.

Recover quickly from downtime events – Metering data is crucial to reducing the length of a downtime event, should one occur. Operators receive critical alarms based on defined data triggers (such as breaker trips, ATS events, generator problems, UPS module failures, etc.) via SMS or email, for example (from their management systems). Having this real-time data allows for immediate action plans to be put in place. Time-stamped, detailed data enables root-cause problem solving to get the system up fast.

Improve the effectiveness of maintenance activities – Whenever a maintenance activity occurs, there is a risk of human error causing downtime. In fact, downtime from human error is commonly reported as ranging from 30-50% of all downtime. Ensuring that technicians have accurate information prior to, during, and after a maintenance activity is critical to minimizing technician error.

Maximize asset utilization – A significant amount of "oversizing" of assets has traditionally occurred within data centers due to the uncertainty of current and future loads, and the need to ensure redundancy and availability levels. Metering data, along with effective management systems, allow data centers to operate at small safety margins, minimizing the capex of the infrastructure assets (i.e. UPS, PDUs).

Decrease energy operating expense – Energy makes up a significant percentage of the annual operating expense of data centers. Quantifying and tracking the cost of inefficiencies in the power distribution infrastructure (i.e. UPS, transformer, harmonic losses), provides insight into improvement projects to reduce energy operating expenses.

Enable charge-backs of energy use to internal and/or external clients – Enterprise data centers often want the ability to "charge-back" or bill data center expenses to the departments that use their IT resources, including the energy consumed by those resources and the support infrastructure. Likewise, colocation companies may want to track and charge energy consumption by client. Having such a charge-back process is dependent on meters to report consumption, down to the usage level. The level of accuracy required for this allocation process will determine with number, type, and location of meters within the infrastructure. Billing generally requires validated 1% accurate meters. See White Paper 161, *Allocating Data Center Energy Costs and Carbon to IT Users*, for more information on the trade-offs between detailed metering schemes and basic metering schemes for this purpose.

Levels of meters

There are four general levels of metering within a data center as shown in **Figure 1**[1]. The hierarchy starts with the whole building level (most aggregate) and ends with very specific measurements of particular systems or equipment.

Not all levels are necessarily needed in a data center – it depends on the objective(s) of the metering system and the data center's infrastructure. For example, if the data center is a purpose-built dedicated facility, and the objective is PUE measurement, metering is necessary at the building level (total data center power consumption), and at the end-use level (UPS output or PDU output as a proxy for IT load). If, on the other hand, the data center is within a shared facility (other non-data center tenants are in the facility), PUE measurement may require meters at switchboards and circuits to capture the support infrastructure specific to the data center.

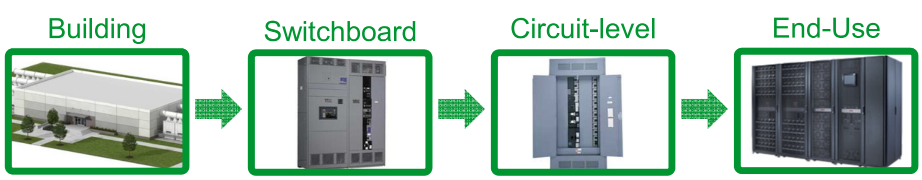

Figure 1

Levels of metering

Permanent vs. temporary meters

Meters can be either temporary or permanent, with the choice being driven primarily by the amount of time data must be gathered for.

Temporary meters – Low cost meters, such as clamp-on amp probes, are useful to capture a one-time spot measurement to determine a baseline, verify performance, or as a tool to diagnose a problem. Data loggers may also be used when measurements over a period of time are needed.

[1] Federal Energy Management Program, Metering Best Practices: A Guide to Achieving Utility Resource Efficiency, August 2011, Section 4.3

Permanent meters – When long term data measurements are desired for monitoring, trending, and control, permanent installation metering is more effective. In data center applications, where the energy consumption is influenced by weather, demand, and operating conditions, this is typical practice. Permanent meters are the focus of this paper.

Types of measurement devices

There are seven types of permanent electrical metering devices commonly used in data centers. This section explains and illustrates these devices.

- Power quality meters
- Power meters
- Digital relay embedded meters
- Electronic trip unit embedded meters
- UPS embedded meters
- PDU / busway embedded meters
- Rack PDU embedded meters

Current transformers (CTs) and potential transformers (PTs) are instrument transformers that play a key role in metering systems. A CT converts the current of an electrical circuit to a proportional, lower, secondary current appropriate as an input to an electrical metering or protection device. A PT converts the voltage of an electrical circuit to a proportional, lower, secondary voltage appropriate as an input to an electrical metering or protection device. In general, metering systems have CTs and PTs that are wired back to the location of the electric meter. Some of these devices can be more easily retrofit onto an existing live environment than others (i.e. split-type CTs that clamp around the wire). **Figure 2** illustrates what CTs look like installed around the wires they are measuring.

Figure 2

CTs role in metering

Source: http://en.wikipedia.org/wiki/Current_transformer

Power quality meters

Examples:
ION 7650 & PM870

A power quality meter is a meter that can monitor electrical parameters such as harmonics, voltage sags/swells, and voltage transients in addition to power metering parameters such as energy, power, voltage, current, power factor, and frequency. A power quality meter is a high accuracy (e.g. 0.2%), high precision device (e.g. 1024 data samples per cycle), that can provide detailed engineering data (e.g. waveforms) and compliance support (e.g. IEC 61000 4-30) tested to internationally recognized metering standards (e.g. IEC 62053-22 0.2S, 1A and 5A).

Locations: In a data center, power quality meters are typically installed to monitor the utility mains and onsite generators, and sometimes to measure the output of a UPS module or system bus.

Applications: With its detailed data, power quality meters can be used for power quality monitoring (i.e. voltage disturbances, harmonics), electric utility bill verification, power circuit loading and balancing, energy management, and maintenance activity support.

Advantages: Power quality meters provide detailed engineering data with high accuracy / precision, and a high frequency of data collection to improve power quality, reliability, and uptime.

Disadvantages: Because of the detailed data they provide, power quality meters are higher in cost, larger in device size, and requires a more skilled user (an engineer) to interpret the data.

Power meters

A power meter is a meter that can measure electrical parameters such as energy, power, voltage, current, power factor, and frequency. A power meter is generally an accurate (e.g. 0.5%) and precise (e.g. 32 samples per cycle) metering device tested to internationally recognized metering standard (e.g. IEC 62053-22 0.5S). Some power meters, such as branch circuit power monitors are accurate to 1-2%.

Examples:
Powerlogic BCPM & iEM3100

Locations: In a data center, power meters are typically installed to monitor mechanical loads (ex: pumps, chillers), power distribution units (PDUs) (mains and branch circuits), remote power panels (RPPs) (branch circuits), IT busway (feeders and plug-in units), and IT Panel boards (mains & branch circuits).

Applications: The common applications for power meters include power circuit loading and balancing, energy management to track use, cost allocation / billing, maintenance activity support (i.e. provides historical data for troubleshooting), and critical incident alarming.

Advantages: Power meters are lower in cost than power quality meters, yet still provide high precision and accuracy. They are also simpler devices since they have a more targeted data set.

Disadvantages: Power meters are less accurate than power quality meters, collect fewer samples per cycle, and offer more limited power quality monitoring.

Digital relay embedded meters

Example:
SEPAM
Series 40

A digital relay is a stand-alone protective device that anlayzes the electrical distribution network and looks for electrical anomalies that require operator notification and, if required, automated circuit interruption. Many advanced digital relays also have metering functionality available. Common electrical monitoring parameters include energy, power, voltage, current, power factor, and frequency.

Locations: In a data center, digital relays are typically installed to protect medium voltage (MV) feeders, transformers, generators, & busbars.

Applications: The primary function of a digital relay is as a protective device, but secondary applications include power circuit loading and balancing, maintenance activity support, and critical incident alarming.

Advantages: Using an embedded meter on a digital relay offers a cost advantage vs. the cost to install and maintain a separate stand-alone meter.

Disadvantages: Digital relays are meant for large amperage inflows, so the current transformers or CTs (the component that measures electrical current) are not as accurate (typically 1% accuracy); In addition, digital relays don't always have power quality metering, and they don't usually have onboard data logs making it more complex to access the data and increases the potential for data loss.

Electronic trip unit embedded meters

Example: MicroLogic for Masterpact NT/NW

An electronic trip unit is a programmable protective device which measures and times current flowing through a circuit breaker and initiates a trip signal when appropriate. It is typically integrated into low voltage (LV) circuit breakers. This type of protective device analyzes the electrical distribution network and looks for circuit overloads and short circuits. Electronic trip units typically have metering functionality available, including power quality metering in some higher end units.

Locations: In a data center, electronic trip units are typically installed to protect low voltage power distribution equipment (e.g. LV switchboards, transformers), generators, and mechanical loads (e.g. pumps, chillers).

Applications: Embedded meters within electronic trip units can be used to replace both power quality and power meters in certain places in the electrical infrastructure; The primary function, however, is as a protective device; and secondary applications include power quality monitoring (e.g. voltage disturbances, harmonics), power circuit loading and balancing, energy management, maintenance activity support, and critical incident alarming.

Advantages: Embedded meters offer a cost advantage over stand-alone meters. In addition, because it is an integrated design, it is easier to manage.

Disadvantages: Electronic trip unit embedded meters are not as accurate, they generally do not provide the full power quality meter functions, and they don't usually have onboard data logs making it more complex to access the data and increases the potential for data loss.

UPS embedded meters

Example: Symmetra PX

Most UPSs have embedded power meters to measure a variety of electrical parameters such as: energy, power, voltage, current, and frequency on the input and output.

Locations: In a data center, UPSs exist to protect the load from utility power anomalies.

Applications: An embedded meter in a UPS can serve as a proxy for reporting IT load in a data center for PUE monitoring (per The Green Grid PUE Category 1). The embedded meter provides engineering data, input voltage, current, and power to enable loss calculations, voltage / frequency trending, power factor, etc. They are also used for critical incident alarming.

Advantages: Relying on the meters embedded in a UPS system saves cost by eliminating additional meters on the input and output of the UPS. In addition, using the embedded meters as a proxy for IT load saves cost by eliminating the need for additional meters closer to load.

Disadvantages: With an embedded UPS meter, the accuracy is generally not verified to national standards. In addition, the detailed data of a power quality meter is not in scope of UPS embedded meters. From a PUE calculation perspective, non-IT loads fed from UPS power (i.e. CRAHs, PDUs) would incorrectly be counted as IT load, resulting in less accurate PUE values.

PDU embedded meters

Example: Modular remote power panel (RPP)

Power distribution units (PDUs), remote power panels (RPPs), and busway distribute power within the IT space to the IT racks. They often have varying degrees of embedded meters. Some PDUs and RPPs, such as the modular RPP shown, have output metering and branch current / circuit monitoring. Busway often has embedded metering on the feeders and some also have it on the individual plug-in-units.

Locations: In a data center, PDUs, RPPs, or busway exist to distribute power throughout the IT space to the racks housing the IT loads.

Applications: An embedded meter in a PDU, RPP, or busway can serve as a proxy for reporting IT load in a data center for PUE monitoring (per The Green Grid PUE Category 2). Manage power capacity to avoid overloads, do cost allocation, improve PUE calculation, and critical incident alarming

Advantages: Using metering that is embedded in a PDU, RPP, or busway is more cost effective than stand-alone meters, as no additional IT load metering is necessary for PUE reporting. It is also a simpler metering scheme in terms of number of devices.

Disadvantages: From a PUE reporting perspective, non-IT loads fed from the PDUs, RPPs, or busway would incorrectly be counted as IT load in PUE calculations. In addition, without branch circuit metering there is less visibility at the individual load level for capacity and change management.

Rack PDU embedded meters

Example: Metered Rack PDU

Embedded meters in rack PDUs (rack-level power strips) allow for active metering of individual outlets feeding IT loads within racks, which enables energy optimization and detailed capacity planning. Alarm thresholds can be set to mitigate the risk of overloading circuits. Information from the meters also aids in load balancing.

Locations: In a data center, rack PDUs exist to distribute power within the racks to the IT load devices.

Applications: The ideal PUE reporting methodology is to use metered-by-outlet rack PDUs to calculate each IT load and then aggregate across the data center, capacity and change management, and critical incident alarming

Advantages: This is the most accurate approach for PUE reporting, as documented by the Green Grid. Since it is close to the load, using rack level metering provides information to aid with capacity planning and change management, and helps reduce downtime from overloaded circuits. With branch circuit monitoring (as described in the "Power meters" section) require a lot of mapping to figure out which breaker positions feed which racks. With rack PDUs, it is more intuitive, with a one to one relationship. A further option of some rack PDUs is the ability to switch or control the individual receptacles on the power strip, which offers additional management advantages.

Disadvantages: Metered rack PDUs are more expensive than basic ones (approximately 50% more) which can limit their deployment. Also, when they are not used in all racks within an IT space, the meters give an incomplete picture of the total IT load. Lastly, these meters generally fall in a lower accuracy class of 2-5%, compared to the other upstream meters with typical accuracies of +/-0.5% or +/-0.2%.

Comparison of devices

The cost to fully meter the upstream electrical distribution of a dedicated data center will vary depending on the architecture. However, a range of US$50 to $230 per kW of IT load can be expected depending on how thoroughly the medium voltage and low voltage distribution systems are metered. This range assumes the following:

- The number of dedicated meters is minimized by taking advantage of embedded metering, digital relay metering, and electronic trip unit metering.
- The metering does not include the IT room: PDUs, RPPs, IT busway, or IT panel boards. The "adder" for this type of metering is below.

Metering into the IT floor typically adds the following costs:

- PDU/RPP circuit metering: US$20 to US$40 per kW of IT load
- LV busway plug-in unit metering: US$40 to US$90 per kW of IT load
- LV panel board branch circuit metering: US$20 to $40 per kW of IT load
- Rack PDU metering: US$60 to US$300 per kW of IT load (wide range due to cost implication at different densities)

Table 2 provides a summary of the seven types of meters, including their application and cost range.

Table 2

Application and cost comparison of meter devices

Type of meter	Applications	Installed cost per meter*
Power quality meters	• power quality monitoring • electric utility bill verification • power circuit loading & balancing • energy management • maintenance activity support	$5,000 - $11,000***
Power meters	• power circuit loading & balancing • energy management • cost allocation / billing • maintenance activity support • critical incident alarming	$600 - $3,000
Digital relay embedded meters**	• protective device for medium voltage equipment • power circuit loading & balancing • maintenance activity support • critical incident alarming	$1,200
Electronic trip unit embedded meters**	• protective device in low voltage circuit breakers • power quality monitoring • power circuit loading & balancing • energy management • maintenance activity support • critical incident alarming	$600 – 13,000***
UPS embedded meters	• engineering data support • PUE monitoring • critical incident alarming	Included in UPS price
PDU embedded meters	• PUE monitoring • management of power capacity • cost allocation • critical incident alarming	Included in PDU price
Rack PDU embedded meters	• most accurate "IT load" measurement per Green Grid • load balancing • rack level power capacity management	$0.04-0.06/watt premium over basic rack PDUs

* Based on typical pricing in US market and assumes that the metering is ordered with, and installed into, the power distribution equipment
** Cost to add metering functionality to protective devices
*** Large price range due to functionality differences in embedded meters; low end trip unit meters are basic power meters whereas high end trip unit meters are power quality meters with breaker diagnostics

Example data center measurement points

In this section, three example applications are described to demonstrate where metering devices would typically be implemented in the infrastructure. **Figure 3** is the conceptual electrical architecture used to demonstrate the metering locations.

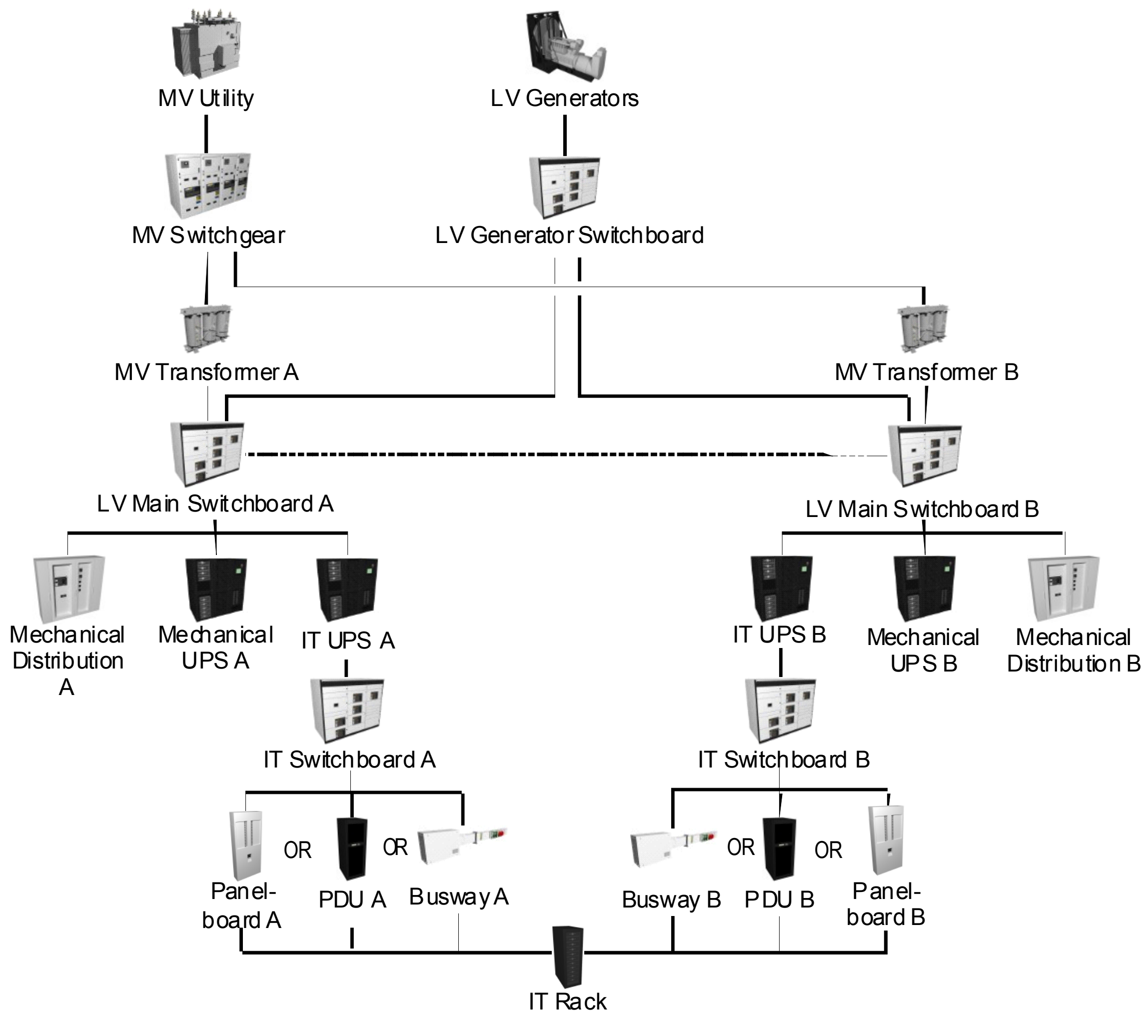

Figure 3

Sample data center infrastructure one-line

Example 1 – PUE reporting

In this example, the goal of the metering system is only to achieve Category 1 PUE reporting, as per The Green Grid definition, which requires kWh data from the utility input and the UPS output. Assuming that there is no utility input metering, just relays with protective functions, but the UPS modules have embedded metering, the strategy illustrated in **Table 3** could be used:

Table 3

PUE reporting example

Power equipment	Device type	Metering point	Comments
MV switchgear	Power meter	Utility main breaker	Meter is generally located in wall mount enclosure, CTs & PTs also required to monitor the circuits
IT UPS A	UPS embedded meter	UPS output	Use embedded metering
IT UPS B	UPS embedded meter	UPS output	Use embedded metering

Example 2 – Transformer loading & balancing

In this example, the goal of the metering system is to monitor, in real-time, the power loading and 3-phase balancing of the Medium Voltage (MV) transformers. This application requires current (amps) by phase (Ia, Ib, Ic) for the output of the MV transformers. A new construction metering strategy (**Table 4**) and a retrofit metering strategy (**Table 5**) are illustrated.

Table 4

Transformer loading & balancing for new construction example

Power equipment	Device type	Metering point	Comments
LV main switchboard A	Trip unit embedded meter	Utility main breaker	Utility main breaker located in LV main switchboard A is most cost effective metering point
LV main switchboard B	Trip unit embedded meter	Utility main breaker	Utility main breaker located in LV main switchboard B is most cost effective metering point

Table 5

Transformer loading & balancing for retrofit example

Power equipment	Device type	Metering point	Comments
LV main switchboard A	Power meter	Utility main breaker	When trip unit does not have metering functionality, add meter, CTs, install into switchboard metering cabinet
LV main switchboard B	Power meter	Utility main breaker	When trip unit does not have metering functionality, add meter, CTs, install into switchboard metering cabinet

Example 3 – IT customer cost allocation

In this example, the goal of the metering system is to enable the energy billing of IT customers based on the actual energy and peak power usage of the IT racks owned by each IT customer. Assuming that this is an existing colocation facility, the IT power distribution architecture uses perimeter PDUs with no existing meters, and 1% accurate revenue grade metering is required; the metering strategy illustrated in **Table 6** could be used.

Table 6

IT customer cost allocation example

Power equipment	Device type	Metering point	Comments
PDU side A	Power meters (branch circuit monitors)	Distribution panel	more than one branch circuit monitor may be necessary depending on the number of panels per PDU
PDU side B	Power meters (branch circuit monitors)	Distribution panel	more than one branch circuit monitor may be necessary depending on the number of panels per PDU

Conclusion

Metering systems help diagnose and mitigate power problems, improve power system reliability, reduce utility costs, and increases equipment utilization. For energy management, meters are used to establish a baseline, and track performance over time to show return on investment (ROI) on data center efficiency projects.

The level of metering should be determined by identifying the metering system's objective(s) and evaluating the physical infrastructure. Embedded meters in devices such as protective devices, UPSs, and PDUs are cost effective and should be implemented whenever possible, while still meeting the goals of the metering system.

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Resources

Allocating Data Center Energy Costs and Carbon to IT Users
White Paper 154

Electrical Efficiency Modeling for Data Centers
White Paper 113

Recommendations For Measuring and Reporting Overall Data Center Efficiency Version 2 - Measuring PUE for Data Centers (May 2011)
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