



# Understanding the Impact of Electricity Metering

## White Paper

by Joe Polastre, PhD

### Executive Summary

Effective measurement of electricity use is central to establishing sustainable operations. With numerous types of meters, fidelity, accuracy, and granularity of readings, it is often difficult to identify the best solution. This paper discusses metering standards, meter types, and trade-offs associated with each option. Selection of the right metering system establishes energy consumption baseline and impacts achievable energy reduction.

### Electricity Measurements

The most basic units of electricity are voltage and current. Voltage is the difference of potential on the electrical line, while current is the rate of flow of electrons. Power, whose SI unit is the Watt (W), is voltage times current.

Electricity meters measure Root Mean Square (RMS) Voltage ( $V_{RMS}$ ) and RMS Current ( $I_{RMS}$ ).  $V_{RMS}$  is equal to the peak voltage in an AC sinusoidal curve centered at zero divided by the square root of 2. The same is true for  $I_{RMS}$ . Since alternating current is sinusoidal, the average power consumption ( $P_{avg}$ ) over one alternating current cycle is the product of  $V_{RMS}$  and  $I_{RMS}$ , if current and voltage waves take their peak at the same time. Thus,  $V_{RMS}$  and  $I_{RMS}$  are most commonly used and are the standard for electrical outlets (for example, a 120V AC outlet in North America has a  $V_{RMS}$  of 120V and a peak voltage of  $\sqrt{2} \cdot 120V$ ).

Figure 1: Important Electrical Metrics

Notation	SI	Definition	Meaning
$I_{peak}$ $V_{peak}$	A V	Peak Current Peak Voltage	Maximum value taken by the current / voltage.
$I_{RMS}$ $V_{RMS}$	A V	Root Mean Square Current Root Mean Square Voltage	The RMS measure of an AC signal is equal to the value of a continuous (DC) signal that would transfer the same energy as the alternating signal.
P	W	Active Power = $I_{RMS} \cdot V_{RMS} \cdot \cos(\phi)$ (also known as Real Power)	The power actually transferred to the load. When I and V waves do not coincide (separated in phase), then less power is transferred.
S	VA	Apparent Power $S = I_{RMS} \cdot V_{RMS}$	Measures the power drain, whether current and voltage waves coincide or not.
E	J	Energy = Power · T (for constant power drain)	Energy is the sum of the instantaneous power drain.
PF		Power Factor $PF = P_{avg} / S$	The closer to 1, the more power gets transferred to the load.
CF		Crest Factor $CF = I_{peak} / I_{RMS}$	Typically $\sqrt{2}$ , however some equipment pulls current in spikes causing a higher peak value, which distorts the source and increases power consumption.

Once  $P_{avg}$  is known, the sum of all  $P_{avg}$  readings over time is the amount of energy (E) used. Typically presented in kilowatt-hours, energy takes into account the time varying nature of electrical loads to get an accurate understanding of how much electricity is used in a specific time period. Thus, kilowatt-hours have become an electrical billing standard.

AC powered equipment, such as servers and storage, are composed of a combination of resistive, inductive, and capacitive components. If the server was purely resistive, all electricity would flow in one direction into the server. Instead, with capacitive components, incoming energy is stored during the rising part of the sinusoidal waveform and is discharged backwards into the line during the falling part of the sinusoidal waveform. The inductive components have the opposite behavior. The power that flows backwards is referred to as reactive power, whereas the power that flows forward is active power.

Due to the inflows and outflows, the apparent power (S, expressed in VA) of voltage times amperage is often larger than the active power used by the server. A common metric for understanding reactive power is power factor (PF), computed as the active power divided by the apparent power (which is the sum of active and reactive power). Reactive power causes a lag between voltage and current sinusoidal waveforms known as a phase angle. Instead of power factor, some meters provide phase angle or reactive power; power factor can be computed from these measurements. Most modern servers are “power factor corrected” as regulated by IEC 1000-3-2, where the server’s power supply actively stores and regulates energy to keep the power factor as close to 1.0 as possible.

This analysis assumes that we have a perfect sinusoidal alternating current electrical signal, but few electrical sources are so perfect. Additional statistical analysis on the waveform can provide insight into the electrical quality and type of equipment connected. The ratio between  $I_{peak}$  and  $I_{RMS}$  is typically  $\sqrt{2}$  as discussed above, but sometimes it can be much higher. This ratio is called the crest factor (CF),

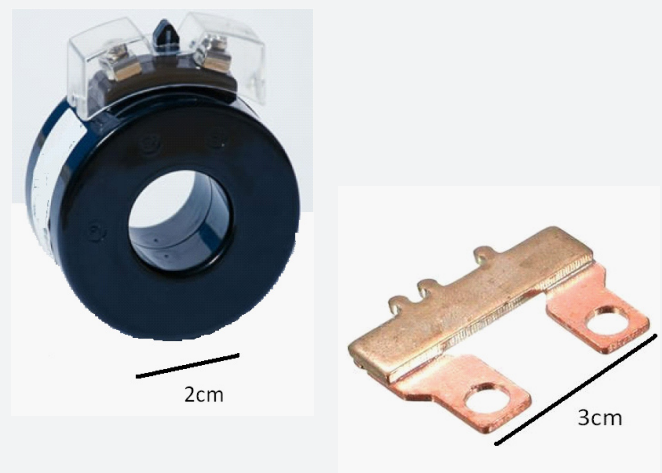
and computers that are not “power factor corrected” can have a crest factor of 3 or 4. Higher crest factors lead to more power consumed and more heat generated by power supplies. Similarly, the phase offset due to reactive power can generate harmonics in the electrical line.

In summary, electrical meters can measure  $I_{peak}$ ,  $V_{peak}$ ,  $I_{RMS}$ ,  $V_{RMS}$ ,  $P_{avg}$ , S, E, PF, CF. Figure 1 summarizes these metric properties. Each of these metrics provide insight into how efficiently electrical equipment is operating. The implications of each metric is described later.

### Meter Sensors

Measuring power consumption is generally achieved in one of two ways: with an inductively coupled element that surrounds the electrical cable or with a small resistive element (shunt) that goes in-line between the power outlet and electrical device, such as a server (see Figure 2).

**Figure 2: Picture of CT-based and Shunt Meters**



Typical CT for measuring currents (left). CT rings can range in size from a few millimeters in diameter to tens of centimeters depending on the intended measured load. Shunts (right) have a typical resistance of  $1m\Omega$  or less and vary in size from 1 mm to 3 cm. Like the shown CT, this shunt is appropriate for currents of up to 100A.

Figure 3: Measurement Equipment Summary

Type	I <sub>peak</sub>	V <sub>peak</sub>	I <sub>RMS</sub>	V <sub>RMS</sub>	P <sub>avg</sub>	S	E	CF	PF	Disconnection needed?	Accuracy	Current Range	Resolution
CT	✓	✗	✓	✗	✗	✗	✗	✗	✗	YES (solid-core) NO (split-core)	Up to ±0.5%	100mA to 50,000A (RMS)	10mA
CT w/Direct Connect	✓	✓	✓	✓	✓	✓	✓	✓	✓	YES (solid-core) NO (split-core)	Up to ±0.5%	100mA to 50,000A (RMS)	10mA
Shunt	✓	✓	✓	✓	✓	✓	✓	✓	✓	YES	Up to ±1%	10mA to 100A	10mA

Inductive coupling is commonly manifested in the form of a current transducer (CT) or hall effect sensor. Both require the separation of the neutral line from the hot line, otherwise the neutral and hot cancel each other due to the reverse flow of electrons on the neutral line. Solid-core CTs require the power cable to be disconnected from the source and reconnected, while split-core CTs can “clamp-on” to a running system. For single-phase electricity used by servers, CTs are not common because it is difficult to separate the neutral and hot lines, although they are frequently used in metering power distribution units (PDUs). For 3-phase equipment, such as fans and chillers, each phase is separated already and CTs are frequently used.

Inductive sensors, such as CTs, leverage the magnetic field created when current flows through a power cable. This magnetic field induces a current on the sensor, which can then be measured. Because the sensor is isolated from the source, it is preferred for high current electrical measurement.

Inductive sensors, do have a few downsides. If only the output of the CT is used, only I<sub>RMS</sub> and CF can be metered, severely limiting the electricity information available. Since V<sub>RMS</sub> is not measured, P<sub>avg</sub> must be inferred and thus is unsuitable for billing and precision measurement purposes. Most inexpensive PDUs have only I<sub>RMS</sub> measurement capability. If a meter is connected to both the CT and taps

onto the power lines, it can measure I<sub>RMS</sub> and V<sub>RMS</sub>, compare their phases, and compute PF. Since V<sub>RMS</sub> is measured, P<sub>avg</sub> and E can be accurately calculated and used for billing. (The downside is that sometimes the power source must be turned off for safety while the electrical lines are connected to the meter, but not always). Finally, CTs are much more expensive (\$10s to \$100s depending on the sensing current range) and more affordable CTs are less accurate than resistive in-line solutions.

In-line solutions employ a shunt with a very small resistance that goes in-between the power outlet and device. By measuring the voltage differential across the shunt, I<sub>RMS</sub> can be calculated. Since there is direct access to the electrical lines, V<sub>RMS</sub> and phase offset can be directly measured and P<sub>avg</sub>, E, CF, and PF directly and accurately computed.

Figure 4: Common classes and associated standards

Class	Standard	Accuracy
Class 2.0	IEC 1268	2.0%
Class 1.0	IEC 1036	1.0%
Class 0.5 S	IEC 687 ANSI C12.20 IEC 620053-22	0.5%
Class 0.2 S	IEC 687 ANSI C12.20 IEC 620053-22	0.2%

A shunt requires the equipment to be shut down while an in-line device is attached. The shunt also heats under high currents, so it is unsuitable for loads over 100A. Figure 3 recaps the pros and cons of CTs and shunts.

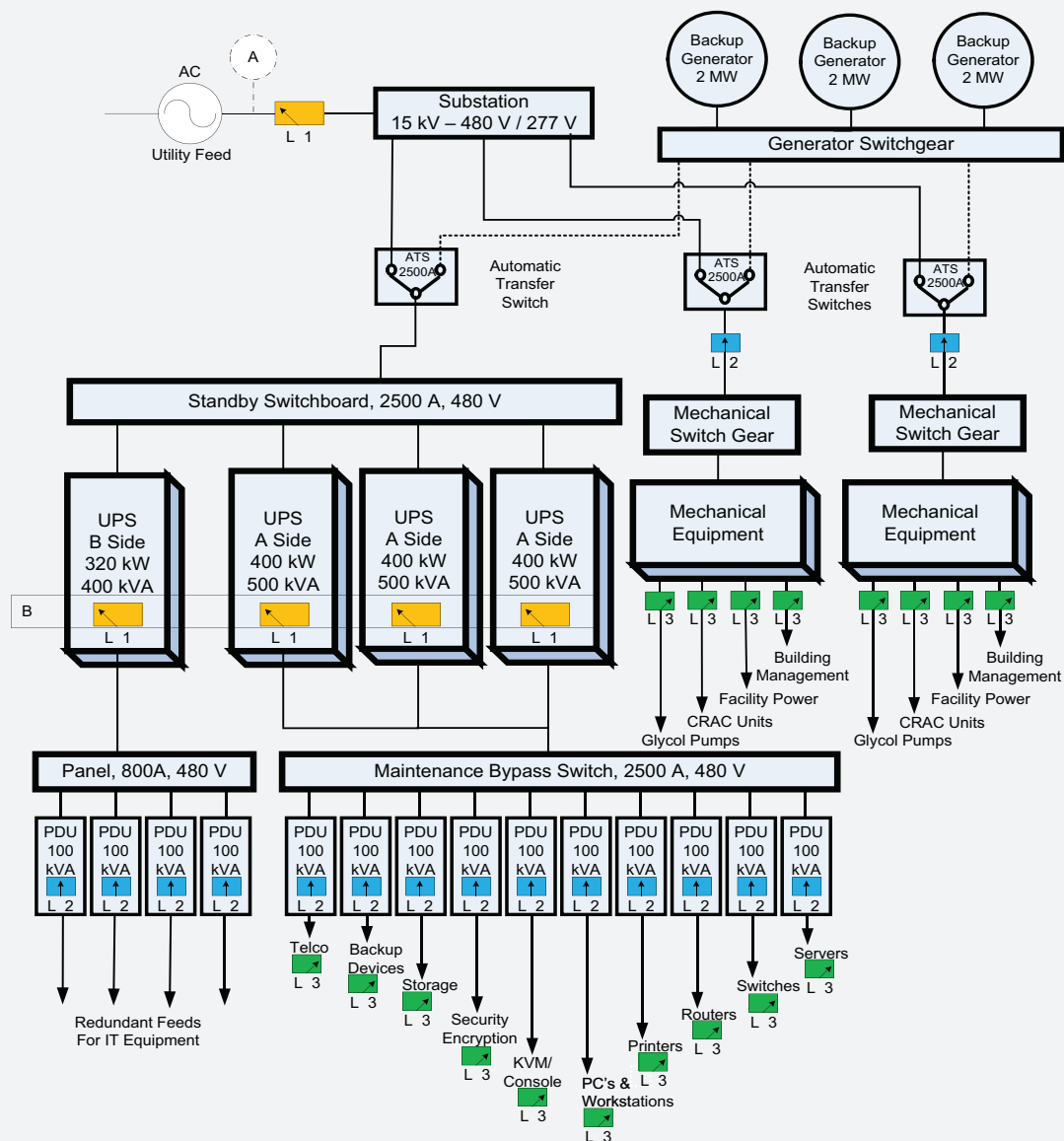
**Meter Accuracy**

The most common method of classifying meter accuracy is by Class. While a number of standards exist to test the accuracy of equipment, the rule of thumb is that Class X

has an accuracy of X%. The meter must be accurate to the specified class over its stated measurement range. Figure 4 shows common classes and associated standards. Class 2.0 is required of utilities for billing purposes.

The Green Grid requires that all meters are  $\pm 5\%$  accurate for calculating metrics like PUE and DCiE, although they recommend  $\pm 2\%$  accuracy. Meters with  $\pm 5\%$  accuracy are only recommended for the most coarse measurements, such as Level 1 measurements (as defined in Figure 6).

**Figure 5: Example of a data center physical organization**



EnergyStar’s Requirements for Computer Servers<sup>1</sup> specifies that managed servers must continuously report power consumption measurements with ±10% accuracy. This continuous measurement requirement only applies to EnergyStar-certified managed servers, but not to any other equipment (such as networking, storage, blade servers, or single power supply servers).

While the Green Grid and utilities intend that power meters be used continuously, taking a reading at only one point in time can be useful to establish baseline energy usage.

**Figure 6: Green Grid Guide to Meter Granularity**

	<b>Level 1</b>	<b>Level 2</b>	<b>Level 3</b>
<b>Level</b>	Basic	Intermediate	Advanced
<b>Typically Measured By</b>	UPS / Utility meter	PDU	PAU / Server
<b>Measures</b>	Total facility	Data center minus H/VAC	Direct IT load
<b>Minimum Measurement Frequency</b>	Weekly	Daily	Continuous (15 min)

**Meter Granularity**

To best manage a facility (an example of which is shown in Figure 5), energy consumption data is needed from multiple points. For example, measuring the total facility power and that of each PDUs provides enough information to calculate the ratio of facility energy use to IT energy use, often called PUE.

The Green Grid provides a guide to meter granularity, specifying three levels. Each level has both a granularity requirement and measurement frequency requirement.

Level 1 meters are read weekly or monthly just like a utility meter. They provide the power use of the entire facility with coarse granularity. UPS meters are included in the Level 1 specification. Level 2 meters measure everything except for the H/VAC system, and are typically found in PDUs or branch circuit meters. Level 3 meters should be attached directly to the IT equipment – the equipment doing the work. While ideally these meters would be integrated into servers, today they are found in single power analysis units (PAUs) that are placed in line with each piece of IT equipment. These PAUs can also be integrated into “smart” PDUs, where every port of the PDU has energy measurement. Ports not connected to IT load must not be included in Level 3 measurements, typically filtered out with software.

Multiple levels of measurement are important to a sustainable data center. By comparing the energy consumption at every level, overhead and waste are easily identifiable. Continuous measurement at every level validates which overhead is a consistent, large problem.

**Implications**

Basic measurements are key to maintaining uninterrupted operation. Ensuring that the current ( $I_{RMS}$ ) stays below thresholds ensures that continuous power flows to IT equipment. When purchasing equipment, never consider equipment that can’t provide true power  $P_{avg}$  and accumulated energy E. Utility companies uses these same measurements to bill customers. With them, the true impact of each piece of infrastructure can be evaluated on a cost basis. Systems that only provide  $I_{RMS}$  or S are not useful for estimating operational costs.

<sup>1</sup>[http://www.energystar.gov/index.cfm?c=new\\_specs.enterprise\\_servers](http://www.energystar.gov/index.cfm?c=new_specs.enterprise_servers) : Draft 4

With more sophisticated measurement, oft-overlooked energy waste can be discovered. If the crest factor (CF) is high due to a single piece of old equipment, all equipment on that circuit will be subject to increased peak current. As a result, all equipment on that circuit will consume more energy and generate more heat. Continuous voltage measurement ( $V_{\text{peak}}$  and  $V_{\text{RMS}}$ ) can ensure that your facility's electrical signal is clean. Dirty voltage can lead to higher energy consumption since  $P_{\text{avg}}$  is directly related to  $V_{\text{RMS}}$ . Voltage harmonics reduce equipment lifetime and performance and can be corrected if detected.

Software that automates meter reading can ensure continuous readings. Continuous measurements uncover trends in energy consumption that can identify energy savings opportunities – candidates for consolidation, periods of inactivity, and misconfigured equipment. Continuous data can even show the interdependence of time of day, application, and system load on energy consumption, enabling better provisioning and prediction of future capacity requirements.

## Conclusion

The best measurement strategy is one that uncovers the most savings opportunities while minimizing the operational and financial impact on the data center. It is important to understand the different types of metering to fully evaluate the impact that can be made in your facility. Energy metering is becoming more prevalent in power distribution equipment (UPSs, PDUs, etc). With an understanding of energy measurements and their impact, energy data from all pieces of infrastructure can be leveraged to take action and operate an energy-efficient, sustainable data center.

## About the Author

Joe Polastre is co-founder and chief technology officer at Sentilla Corporation, Joe is responsible for defining and implementing the company's global technology strategy and for orchestrating Sentilla's product road map. Winner of the 2009 Silicon Valley/San Jose Business Journal 40 Under 40 award and finalist in BusinessWeek's Best Young Tech Entrepreneurs 2009, Joe sits on numerous technical boards and commissions and is regularly sought by industry forums to speak on physical computing and its role in energy management. Joe holds an M.S. and Ph.D. in Computer Science from University of California, Berkeley, and a B.S. in Computer Science from Cornell University.

## About Sentilla

Sentilla® provides enterprise software for managing power use in the data center. The platform, Sentilla Energy Manager for Data Centers™ measures and analyzes the entire data center's energy profile and makes recommendations to reduce energy use. By approaching power efficiency from an IT management perspective, Sentilla's software analytics provide IT managers visibility and control to intelligently reduce energy, while decreasing operational costs and increasing IT equipment utilization. For more information, please visit the Sentilla website at [www.sentilla.com](http://www.sentilla.com).

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