THE GREEN GRID DATA CENTER POWER EFFICIENCY METRICS: PUE AND DCiE

the green grid™

Executive Summary

The Green Grid is an association of IT professionals seeking to dramatically raise the energy efficiency of data centers through a series of short-term and long-term proposals. This is an update to the very first white paper published by the Green Grid in February 2007 called “Green Grid Metrics: Describing Data Center Power Efficiency” to refine the nomenclature and intent of that paper. In that paper, The Green Grid proposed the use of Power Usage Effectiveness (PUE) and its reciprocal, Data Center Efficiency (DCE) metrics, which enable data center operators to quickly estimate the energy efficiency of their data centers, compare the results against other data centers, and determine if any energy efficiency improvements need to be made. Since then, PUE has received broad adoption in the industry but DCE has had limited success due to the misconception of what data center efficiency really means. As a result, this paper reaffirms the use of PUE but redefines its reciprocal as data center infrastructure efficiency (DCiE). This refinement will avoid much of the confusion around DCE and will now be called DCiE.

In the long term, The Green Grid is developing metrics to measure data center productivity as well as efficiency metrics for all major power-consuming subsystems in the data center. To promote these metrics and drive greater data center energy efficiency for businesses around the world, The Green Grid will publish future white papers that provide detailed guidance on using these metrics. We will also continue to

collaborate with organizations such as the EPA, ECMA and Climate Savers that promote a similar goal and vision.

Table of Contents

Introduction

The Green Grid believes that several metrics can help data centers better understand and improve the energy efficiency of their existing data centers, as well as help them make smarter decisions on new data center deployments. In addition, these metrics provide a dependable way to measure their results against comparable IT organizations.

Why the need for greater energy efficiency? Because data center power and cooling are two of the biggest issues facing IT organizations today, and growing companies need a way to control these costs while enabling future expansion. With more efficient data centers, IT organizations can better manage increased computing, network, and storage demands, lower energy costs, and reduce total cost of ownership (TCO)—all while remaining competitive and able to meet future business needs.[1]

The Green Grid is a non-profit trade organization of IT professionals that addresses power and cooling requirements for data centers and the entire information service delivery ecosystem. The Green Grid does not endorse any vendor-specific products or solutions, but instead provides recommendations on best practices, metrics, and technologies designed to improve overall data center efficiency.

Short Term (Tactical)

The Green Grid recognizes the importance of establishing metrics for data center efficiency, and offers guidance on technologies that claim to improve performance-per-watt. Ideally, these metrics and processes will help determine if the existing data center can be optimized before a new data center is needed. In the earlier white paper, the Green Grid supported two related metrics Power Usage Effectiveness (PUE)[2] and Data Center Efficiency (DCE)[2,3]. Since then PUE has received broad adoption in the industry but DCE has had limited success due to the misconception of what data center efficiency really means. As a result, this paper re-affirms the use of PUE but redefines its reciprocal as data center infrastructure efficiency (DCiE). This refinement will avoid much of the confusion around DCE and will now be called DCiE.

Power Usage Effectiveness (PUE) and Data center Infrastructure Efficiency (DCiE)

The PUE is defined as follows:

$$PUE = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}} \quad (1)$$

and its reciprocal, the DCiE is defined as:

$$DCiE = \frac{1}{PUE} = \frac{\text{IT Equipment Power}}{\text{Total Facility Power}} \times 100\% \quad (2)$$

For equations 1 and 2, the Total Facility Power is defined as the power measured at the utility meter — the power dedicated solely to the data center (this is important in mixed-use buildings that house data centers as one of a number of consumers of power). The IT Equipment Power is defined as the equipment that is used to manage, process, store, or route data within the data center. It is important to understand the components for the loads in the metrics, which can be described as follows:

1. IT Equipment Power. This includes the load associated with all of the IT equipment, such as compute, storage, and network equipment, along with supplemental equipment such as KVM switches, monitors, and workstations/laptops used to monitor or otherwise control the data center.

2. Total Facility Power. This includes everything that supports the IT equipment load such as:

- Power delivery components such as UPS, switch gear, generators, PDUs, batteries, and distribution losses external to the IT equipment.
- Cooling system components such as chillers, computer room air conditioning units (CRACs), direct expansion air handler (DX) units, pumps, and cooling towers.
- Compute, network, and storage nodes.
- Other miscellaneous component loads such as data center lighting.

The PUE and DCiE provides a way to determine:

- Opportunities to improve a data center's operational efficiency.

- How a data center compares with competitive data centers.
- If the data center operators are improving the designs and processes over time.
- Opportunities to repurpose energy for additional IT equipment.

While both of these metrics are essentially the same, they can be used to illustrate the energy allocation in the data center differently. For example, if a PUE is determined to be 3.0, this indicates that the data center demand is three times greater than the energy necessary to power the IT equipment. In addition, the ratio can be used as a multiplier for calculating the real impact of the system's power demands. For example, if a server demands 500 watts and the PUE for the data center is 3.0, then the power from the utility grid needed to deliver 500 watts to the server is 1500 watts. DCiE is quite useful as well. A DCiE value of 33% (equivalent to a PUE of 3.0) suggests that the IT equipment consumes 33% of the power in the data center.

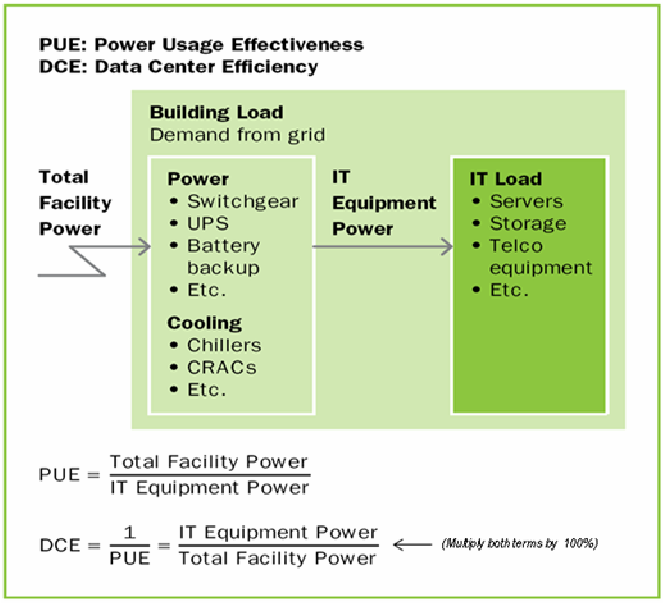

Figure 1: Illustration of How PUE and DCE Would Be Calculated In A Data center

In Figure 1, Total Facility Power is measured at or near the facility utility's meter(s) to accurately reflect the power entering the data center. This should represent the total power consumed in the data center. The data center-only portion of a building utility meter should be measured since power not intended to be consumed in the data center would result in faulty PUE and DCiE metrics. For example, if a data center resides in an office building, total power drawn from the utility will be the sum of the Total Facility Power for the data center, and the total power consumed by the non-data center offices. In this case the data center administrator would have to measure or estimate the amount of power being consumed by the non-data center offices (an estimate will obviously introduce some error into the calculations).

IT Equipment Power would be measured after all power conversion, switching, and conditioning is completed and before the IT equipment itself.

The most likely measurement point would be at the output of the computer room power distribution units (PDUs). This measurement should represent the total power delivered to the compute equipment racks in the data center.

The PUE can range from 1.0 to infinity. Ideally, a PUE value approaching 1.0 would indicate 100% efficiency (i.e. all power used by IT equipment only). Currently, there are no comprehensive data sets which show the true spread of the PUE for data centers. Some preliminary work indicates that many data centers may have a PUE of 3.0 or greater, but with proper design a PUE value of 1.6 should be achievable4. This theory is

supported by measurements completed by Lawrence Berkley National Labs5 which shows that the 22 data centers measured had PUE values in the 1.3 to 3.0 range. Other research indicates that PUE values of 2.0 are achievable with proper design6. However, there is currently no comprehensive industry data set that shows accurate PUE statistics for data centers.

Furthermore, there is no general agreement on what constitutes an efficient or inefficient data center. In the future the Green Grid will offer values that profile target PUE and DCiE metrics for a variety of typical data center configurations.

In the short term, The Green Grid suggests that data center owners begin using either the PUE or DCiE metrics. While the measurement points may not be clearly defined, The Green Grid feels it is important to begin measuring data center efficiency, even if the method currently requires data manipulation. In addition, The Green Grid also encourages data center owners to share and compare their respective PUE and/or DCiE results, which will help each data center owner better analyze their measurement methodology as well as understand how their results compare to the rest of the industry.

Long Term (Strategic)

A mixed-use building may house any number of functions, such as data center(s), labs, offices, etc. For these types of mixed-use environments, determining the power usage of just the data center environment is difficult. This is particularly true when the utility power grid enters the building through a single entrance point (e.g., through a utility room) and is then distributed to various building locations. These building configurations

also make it difficult to determine the power losses between the power entry into the building and its delivery to the data center.

To further complicate the calculation of PUE and DCiE, the latest cooling technologies integrate cooling elements such as pumps, refrigeration, blowers, and heat exchangers within the IT equipment itself. These technologies blur the lines between what has traditionally been a clear delineation between facility equipment and IT equipment. However, equipment used to provide power and cooling to the data center must be accounted for in the metrics described in this paper.

As part of the effort to promote dramatic efficiency improvements in the data center, The Green Grid will provide clearer distinctions between facility and IT equipment and recommend power consumption measuring techniques throughout the data center, as well as for the equipment itself.

Data Center Productivity (DCP)

For the long term, The Green Grid is working on metrics to define data center productivity. This is the natural evolution from PUE and DCiE and such a metric could be in a form that looks as follows[4]:

$$\text{Data center Productivity} = \frac{\text{Useful Work}}{\text{Total Facility Power}} \quad (4)$$

While data center productivity is much more difficult to determine, members of The Green Grid feel that this is a key strategic focus for the industry. In effect, this calculation defines the data center as a black box – power goes into the box, heat

comes out, data goes into and out of the black box, and a net amount of useful work is done by the black box. This in some ways parallels the work being done with the EPA and Standard Performance Evaluation Corporation (SPEC) at the server level in which the SPEC working group may produce a standard on the performance of a system, and the EPA provides a process by which to measure power consumed by the server. The Green Grid hopes to eventually increase the scope of that work to all IT equipment and will require broad participation from the IT community to help guide and define this work.

Further Power Usage Effectiveness (PUE) Developments

The Green Grid will also consider the development of metrics that provide more granularity for the PUE and DCiE metrics by breaking it down into the following components:[5]

$$PUE = \frac{1}{DCiE} = \text{Cooling Load Factor (CLF)} + \text{Power Load Factor (PLF)} + 1.0$$

Where all factors are ratios that are divided by the IT Load and:

- 1.0 represents the normalized IT Load. Effectively this is the IT Load Factor (ILF) but is always 1.0.
- Cooling Load Factor (CLF) is the total power consumed by chillers, cooling towers, computer room air conditioners (CRACs), pumps, etc. divided by the IT Load.
- Power Load Factor (PLF) is the total power dissipated by switch gear, uninterruptible power supplies (UPSs), power distribution units (PDUs), etc. divided by the IT Load.

These metrics will be designed to address the blurring of the lines between the IT equipment and facility infrastructure as discussed above. The Green Grid will look at these and other possible PUE and/or DCiE related metrics in the future.

Component Efficiency Standards

The Green Grid will also work with the industry to define energy efficiency guidelines for all of the components in the data center. Such components include the following:

- Uninterruptible power supplies (UPS)
- Switch gear
- Chillers
- Computer room air conditioners
- Direct expansion (DX) units
- Pumps
- Cooling tower
- Generators
- Distribution losses external to the racks
- Power distribution units (PDUs)
- Batteries
- Lighting
- Servers
- Storage

This effort will require close collaboration with other industry bodies such as the American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE).

Summary

In addition to developing best practices, metrics, guidelines, and standards to help improve data center efficiency, The Green Grid also proposes defining metrics at the rack level as rack-level cooling solutions become more prominent. The group will also offer guidance for measuring both power consumption and "useful work" at both the facility and rack levels, and will continue to provide technical updates as these metrics and measurement techniques evolve. In the meantime, The Green Grid recommends the use of either PUE or its reciprocal, DCiE.

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