APP NOTE

Data Center Power Monitoring

Table of Contents

Contents

Abstract

As technology becomes more integrated into our daily lives, the prevalence of data centers has also increased. Our need for remote computing has grown so much that even artificial intelligence (AI) has been incorporated into data centers to enhance our usage. Data centers consist of computers and accompanying infrastructure that enable us to store and compute data remotely, such as search queries, calculations, and AI chatbots.

To illustrate the importance of data centers, consider the limited functionality of AI chatbots without a network connection to their servers; sometimes these chatbots can't function at all without a connection. Powering these data centers requires a more complex infrastructure than that of a typical household. For example, see Figure 1.

This application note focuses on the need to monitor power in data centers, how AI is disrupting traditional monitoring, and how NI can assist.

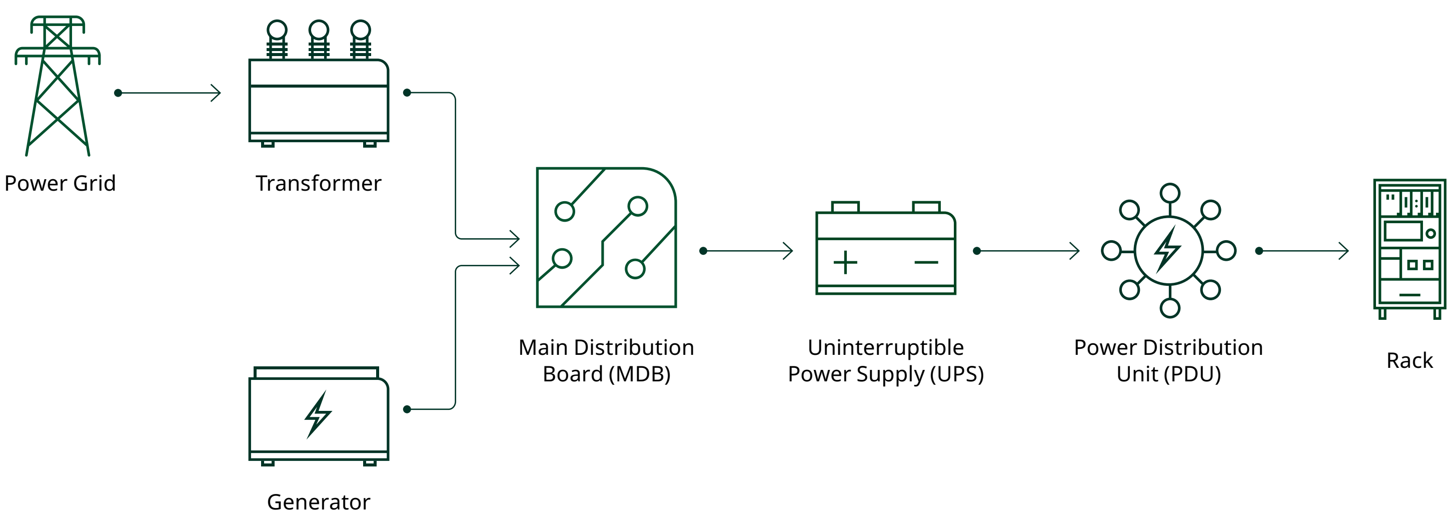

FIGURE 1
Data Center Power Distribution Components

Background

Why is it important to monitor power? It allows data center operators to maintain their infrastructure, increase uptime, and optimize energy usage. Maintaining infrastructure is crucial for operators to preserve their assets and investments. Uptime is critical because operators want to provide reliable service to their customers. Lowering energy usage is desirable for operators because it helps drive down operational costs and benefits the environment. According to Uptime Institute's Data Center and IT Spending Survey 2022, "power is driving the greatest unit cost increases for most operators" (Smolaks, 2023).

In addition to rising costs, power usage increases with AI workloads, which have recently become popular. According to Goldman Sachs, "on average, a ChatGPT query needs nearly 10 times as much electricity to process as a Google search" (Goldam Sachs, 2024).

Why is AI different than the applications we've seen before? Building these systems requires specialized hardware like GPUs to accelerate computation, enhanced storage requirements for large data sets, and time to train the AI models. All these factors contribute to the need for more energy.

Another challenge of AI is its rapid growth, making it hard to estimate energy usage. The issue is that workloads are "black boxes" and harder to characterize than traditional workloads. In Joule, Alex de Vries estimates that "annually, this quantity of servers (1.5 million) could consume 85.4–134.0 TWh of electricity" (Vries, 2023).

Despite the large amount of electricity used, our bigger concern is the variability of this usage. Even if it's apparent we're using more power, it's even more critical to characterize how much we really need.

Power monitoring is important as it drives costs and is increasingly needed to support new AI systems. In addition, monitoring data can help us maintain our assets and increase the uptime of our data centers. Now that we better understand the "why," let's look at a solution.

Requirements

What does our system need to be effective? A key challenge is that it's harder to characterize AI energy usage. So, our solution must handle both making measurements and being flexible to meet the evolving needs of AI. With new components like GPUs, our system must measure with greater fidelity and resolution to avoid missing any transients. Lastly, even if the data is accurate, it needs to be actionable. To debug these systems, we can't wait for post-processing; our monitoring must provide real-time results. Here's a more detailed list of our system requirements:

1. **Power Measurement:** The system must measure voltage and current sensor readings.
2. **High Channel Density:** As systems become more complex, we need to scale and expand to handle higher channel counts.
3. **Data Resolution:** We must capture data with enough resolution to detect transients.
4. **Flexibility:** The system must interface with different I/O.
5. **Real-Time Data Insight:** The system must produce real-time insights, avoiding the need for post-processing.
6. **Reliability:** The system must be reliable enough to perform the necessary monitoring and prevent downtime.
7. **Customizability:** The system must be customizable to keep up with the rapid development of AI systems and their analysis needs.

Figure 2 below shows a simplified diagram of where we'll place our measurement device in the data center.

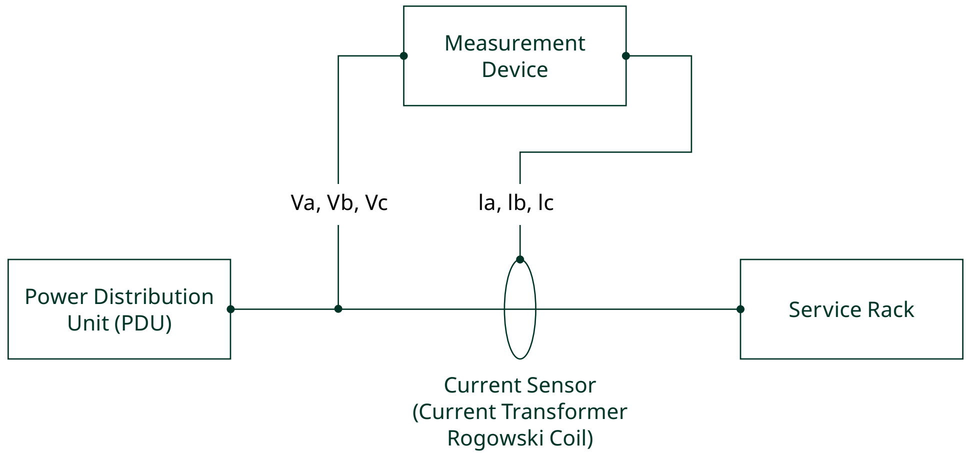

FIGURE 2
Example of Measurement Device in a Data Center Context

Traditional Approach

Measuring power is nothing new. Conventional approaches have included power quality meters (PQMs) and phasor measurement units (PMUs). PQMs are excellent tools for measuring harmonics, sags, swells, and transients. PMUs are industry-standard devices that measure the magnitude and phase angle of an electrical phasor using a common time source for synchronization.

Although these tools are highly effective, they're inflexible, as they're purpose-built for different applications. For example, PMUs are generally deployed in the field for measuring the electrical grid and synchronize with GPS. However, GPS is typically unavailable in data centers, as they're enclosed within buildings and lack line-of-sight to the sky.

Another example is industry standards like IEEE C37.118, which PMUs adhere to. The problem is that PMUs only provide periodic phasor information, which isn't enough to recreate the time-domain waveform (see Figure 3 in the below). PMUs will likely only cover the standard and may not have an open platform to expand to a higher data rate or may use proprietary means to meet that rate. Not being able to recreate the time domain restricts further analysis, such as harmonic measurements, and hinders our ability to fully meet the requirements.

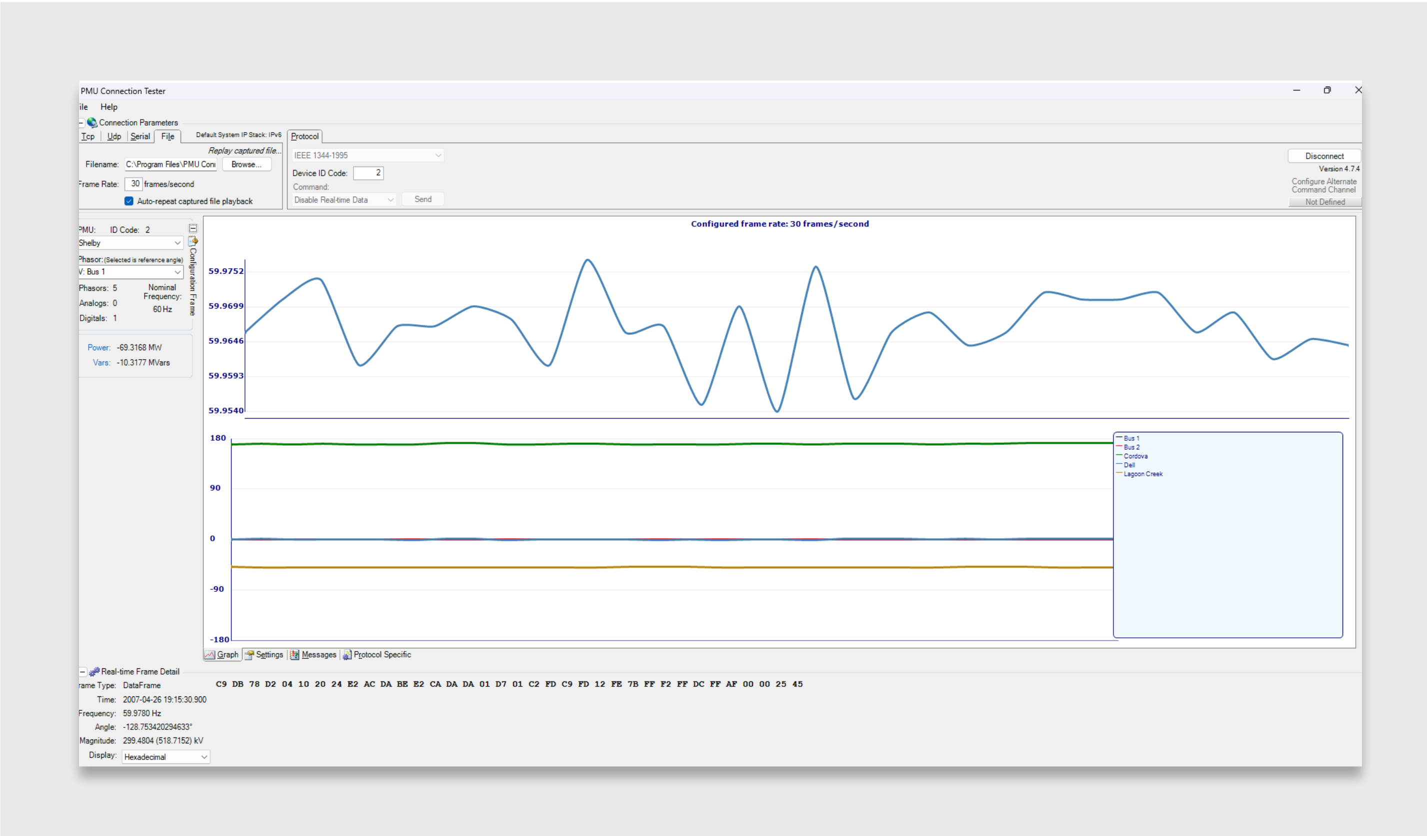

FIGURE 3
Example of PMU Output

Although traditional approaches have been sufficient in the past, they don't excel in meeting the requirements we need today, especially for AI data centers.

NI Approach

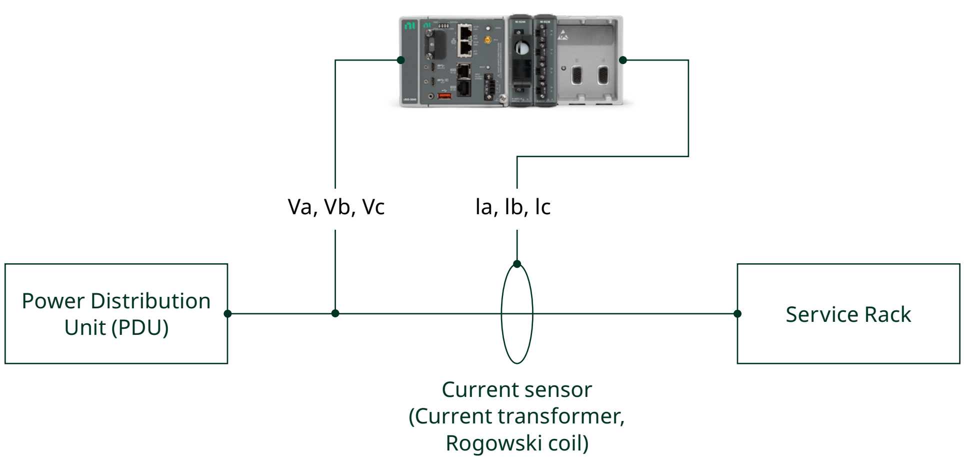

FIGURE 4
Example of NI System

NI has produced measurement hardware since the 1990s that scientists and engineers trust to collect essential data. We'll leverage this reliable hardware to build a solution that addresses challenges using readily available products. See Table 1 for examples of configurations based on the NI CompactRIO platform.

Configuration Option	Description	Quantity	Part Number
Single Three-Phase Bus Monitoring	**cRIO-9040:** 1.3 GHz dual-core, 2 GB DRAM, 4 GB storage, Kintex-7 70T FPGA, 4-slot controller	1	785624-01
	NI-9244: 400 Vrms L-N, 24-bit, 50 kS/s/ch, 3 ch, simultaneous, AI C Series Module	1	783106-01
	NI-9238: +/-500 mV, 24-bit, 50 kS/s/ch, 4 ch, ch-ch isolation, AI C Series Module	1	783311-01
	Current transducers with voltage output appropriate to the NI 9238 Voltage Input range (User selected and provided)	3	N/A
Software Required for All Configurations	NI LabVIEW	1	776678-35
	NI LabVIEW Real-Time Module	1	777844-35
	NI LabVIEW Electrical Power Toolkit	1	788443-35

TABLE 1
Example Configuration

Let's dive deeper into each component to understand how each piece in the table contributes to making measurements.

NI CompactRIO Platform

The CompactRIO platform provides high-performance processing capabilities, sensor-specific conditioned I/O, and a closely integrated software toolchain, making it ideal for Industrial Internet of Things, monitoring, and control applications. The platform's real-time processing offers reliable, predictable behavior, while its FPGA excels at smaller tasks that require high-speed logic and precise timing.

For our example configuration, let's use the NI cRIO-9040. The base specs of the device are 1.30 GHz dual-core CPU, 2 GB DRAM, 4 GB storage, -20 °C to 55 °C, Kintex-7 70T FPGA, and a 4-slot CompactRIO controller. We'll use the NI-9244 and NI-9238 modules with the cRIO-9040 to enhance our measurement capabilities.

NI-9244

The NI-9244 is a 400 Vrms L-N (690 Vrms L-L) CAT III, 50 kS/s/ch, 24-bit, 3-phase voltage input module. The wide measurement range makes it ideal for high-voltage measurement applications such as phasor measurements, power metering, and power quality monitoring. You can also perform transient and harmonic analysis with high-speed simultaneous sampling. The NI-9244 offers three channels, so you can connect single- or three-phase measurement configurations such as WYE and delta.

We'll use this module to directly measure the voltage of each phase.

NI-9238

The NI-9238 is a ±500 mV, 50 kS/s/ch, 24-bit, simultaneous input, 4-channel C Series voltage input module. The measurement range is compatible with many low-voltage sensors such as current shunts and current transducers in high-current applications. When used with higher-voltage C Series voltage input modules, the NI-9238 can measure power and energy consumption for applications such as power quality analysis, phasor measurements, and harmonic analysis.

We'll use this module to connect current sensors to measure the current in each phase.

NI LabVIEW Real-Time Module

The LabVIEW Real-Time Module helps us create deterministic, real-time applications with familiar LabVIEW graphical programming. In this system's context, it allows us to develop applications on the NI Linux Real-Time OS that runs on our CompactRIO platform.

NI LabVIEW Electrical Power Toolkit

The LabVIEW Electrical Power Toolkit is a software add-on for LabVIEW. It includes power measurement and power quality VIs to measure electrical power and quality parameters and perform harmonic analysis on the CompactRIO platform. This toolkit provides the IP for performing power analysis on our measurements.

Demo Code

Using the hardware and software, we put together demo code to illustrate what a system could be. This demo code is available upon request. The goal of this demo is to show that the system is capable of meeting the requirements laid out earlier in this application note.

Figure 5 below depicts the settings tab. Note that we have the ability to filter for a specific frequency range. In addition, we can change how many samples we use per cycle and adjust the maximum harmonic order we calculate for.

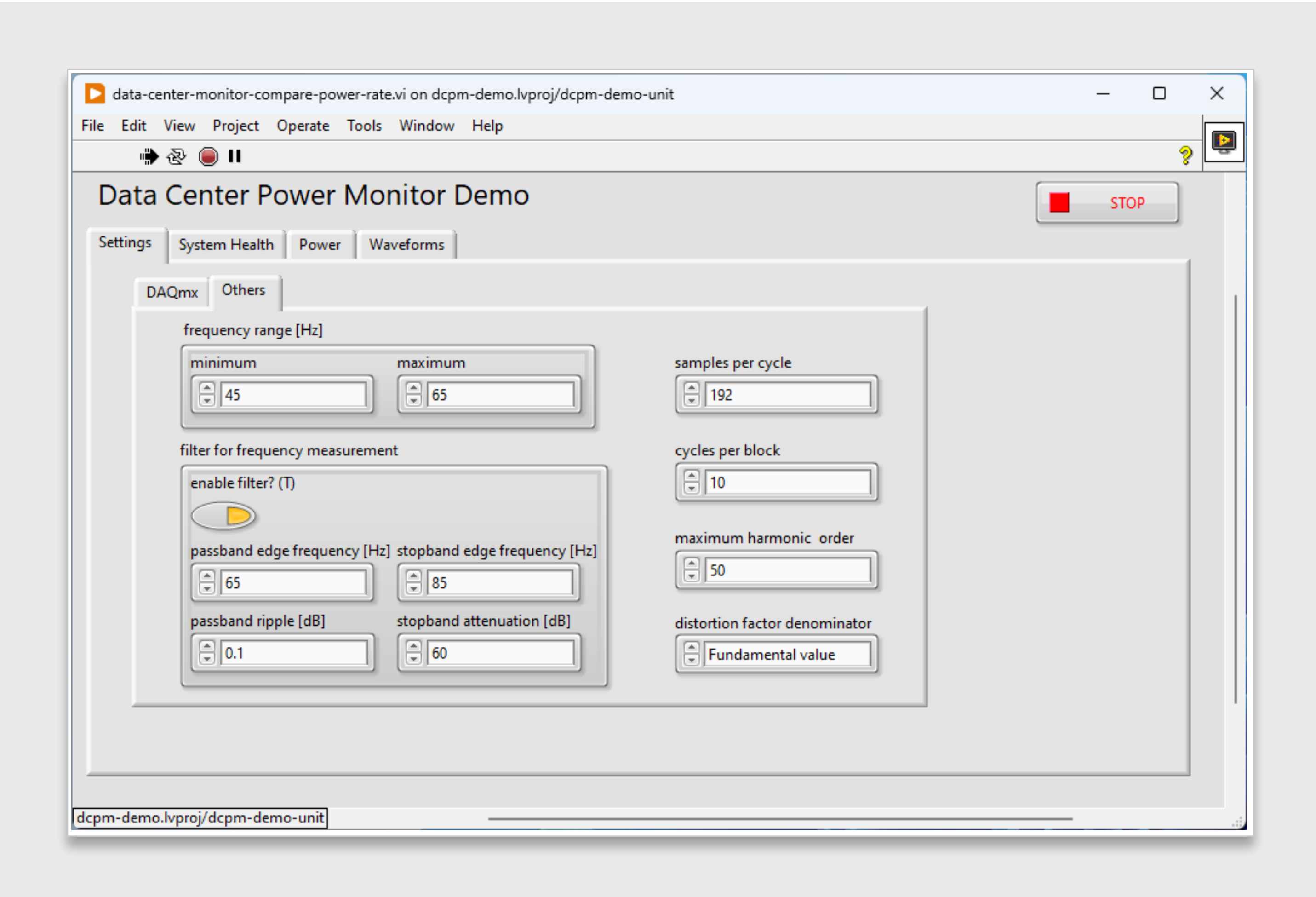

FIGURE 5

Demo Software Settings

Figure 6 depicts an overview of calculations on the system. On the left, we have a chart showing the overall power usage, including the active, apparent, and reactive power. The power factor is calculated on a scale from 0 to 1, as indicated on the left of the chart.

On the right, we have similar calculations for our current and voltage. THD stands for the total harmonic distortion across the three phases. In addition, we have phasor diagrams. Notice the slight lag in current from the voltage, which aligns with a power factor close to 1 noted on the chart.

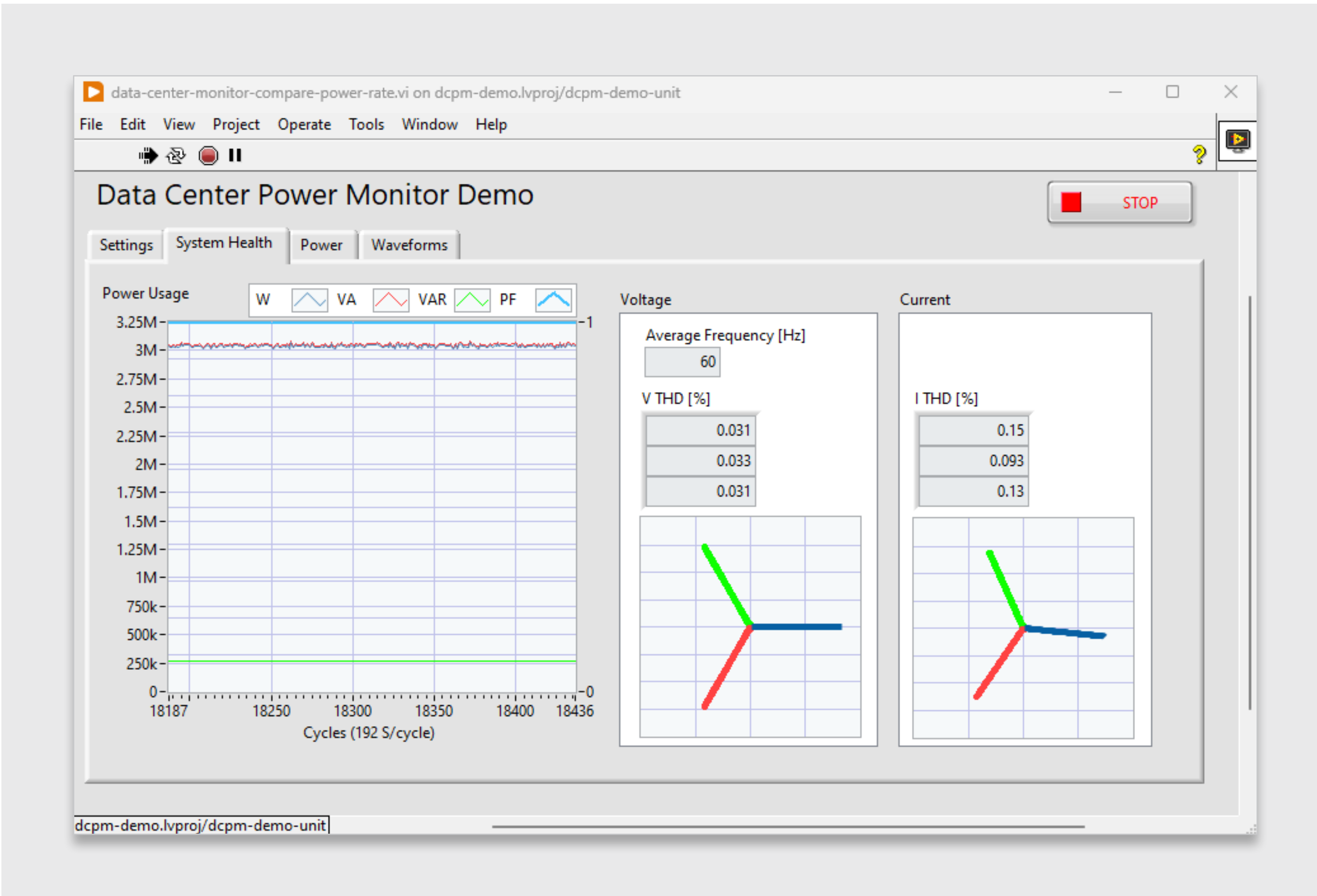

FIGURE 6

Demo Software System Health

Figure 7 depicts the raw waveforms for voltage and current before the electrical power toolkit IP runs analysis on our signals. One highlight is the 50 kS/s sample rate, which should capture most transients we expect in power monitoring. Having the raw samples available means there's potential to extend this code to any power measurement. In other words, since the time domain samples are available, they can be stored raw for future analysis, or we can modify this demo to add specific custom measurements as needed.

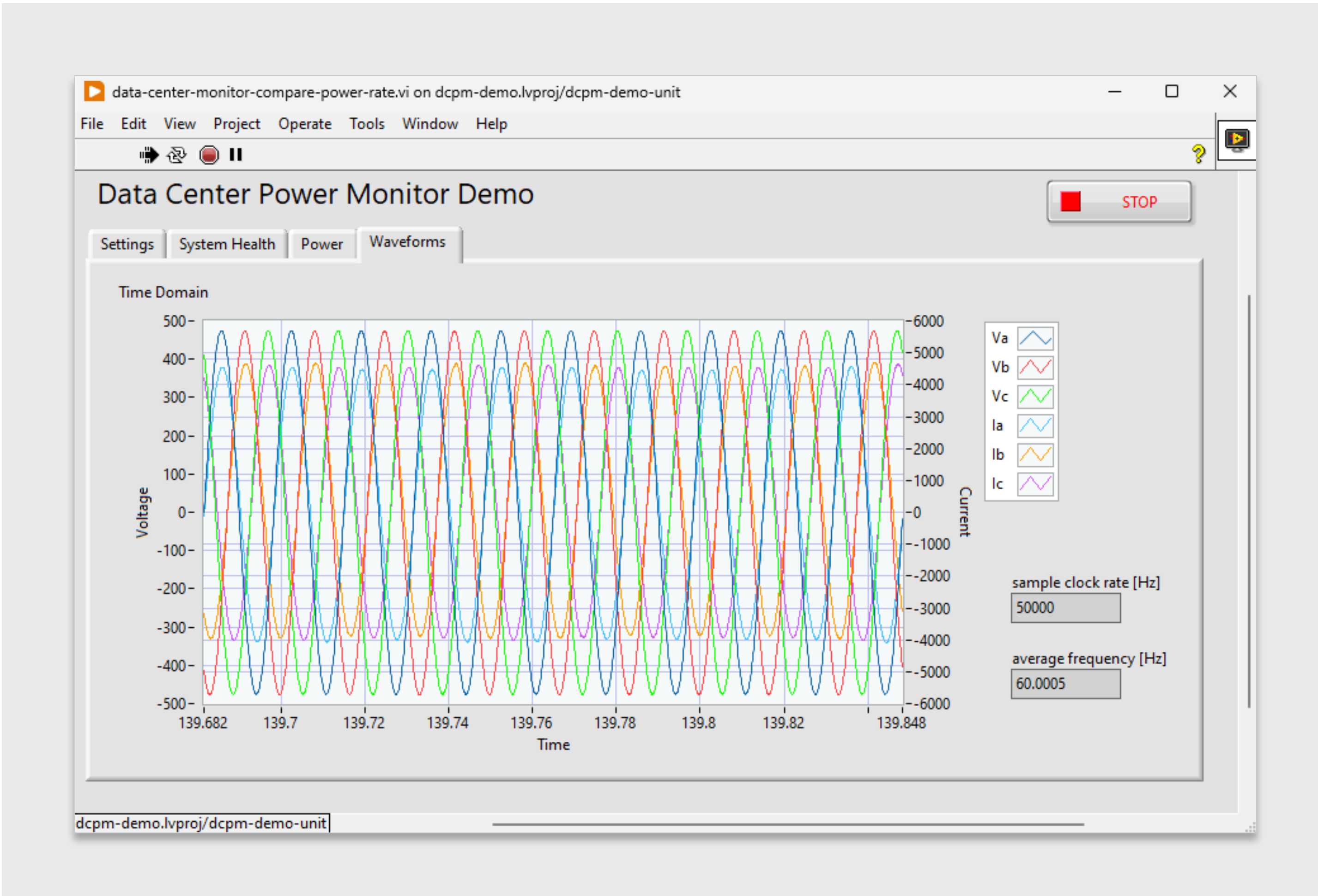

FIGURE 7

Demo Software Waveforms

Figure 8 demonstrates active power calculations at three different rates: 60, 10, and 1 sample(s) per second. Note that in the slower rates, we miss the true peak of the power fluctuations. For example, we see 3.08 MW as a peak at 60 S/s, but at the 1S/s rate, we might only see 3.04 MW. This demonstrates the need for data resolution in our solution.

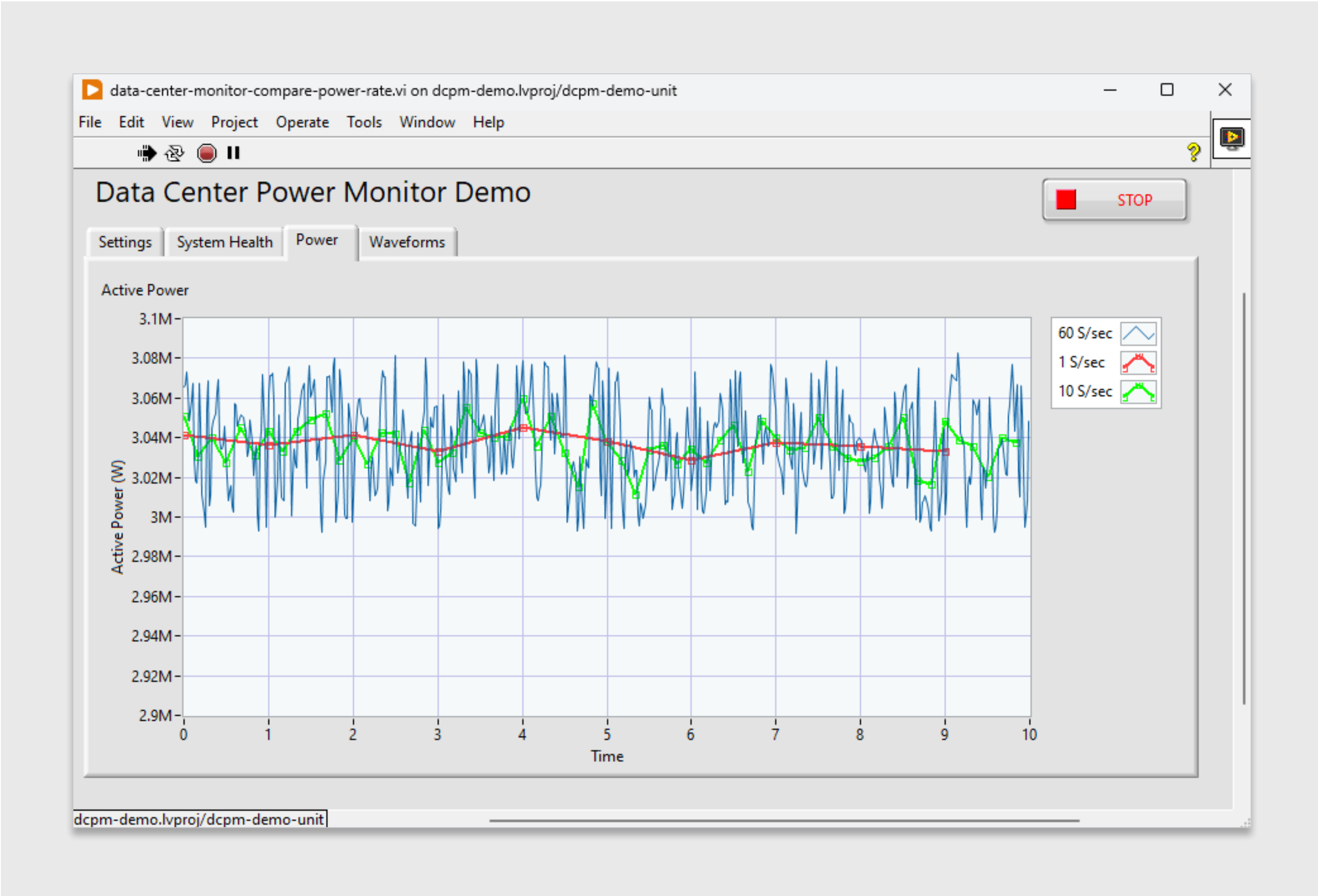

FIGURE 8
Demo Software Power

Conclusion

The increasing need for power monitoring in data centers, especially due to AI, demands flexibility. The NI approach offers the same measurements as traditional methods but is more adaptable for scalability and the specific needs of data centers.

In this application note, we've demonstrated how the NI approach can meet the following requirements, addressing the challenges of a data center power monitoring system:

1. **Power Measurement:** Direct voltage inputs at 400 Vrms L-N and current sensor inputs from ±500 mV.
2. **High Channel Density:** Using a 4-slot chassis to measure two three-phase systems (8-slot chassis are available for greater expansion).
3. **Data Resolution:** Simultaneous sampling at 50 kS/s/ch, capturing most transient events.
4. **Flexibility:** Configurable with different I/O modules for specific power monitoring needs.
5. **Real-Time Data Insight:** Monitoring system health without post-processing, providing immediate feedback to prevent downtime.
6. **Reliability:** Industrial-grade design ensures reliable performance in harsh environments, such as data centers or power plants.
7. **Customizability:** Seamless integration with LabVIEW for developing tailored monitoring solutions, from simple power quality analysis to advanced diagnostics.

By leveraging the NI approach, data centers can achieve more efficient and reliable power monitoring, ultimately enhancing their operational performance and resilience.

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