

PMU Adequacy for Monitoring Data Center Oscillations

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Questions that were not fully addressed during the webinar

Chandan Chaudhary

Are these load demand profiles actually periodic in nature?

Response from another attendee:

Data centers reporting cyclic loads:

<https://techcommunity.microsoft.com/blog/azurecompute/power-stabilization-for-ai-training-datacenters/4460937>

AI data center loads have periodic demand profile. Each AI training iteration alternates between a high-power phase and a lower-power phase. The slower oscillations associated with the periodicity of the iteration cycles typically fall in the 0.1–1 Hz range, while faster fluctuations originating within the high-power computational phases may extend into the sub-synchronous (5–59 Hz) frequency range.

Evan Mickelson

Are there a strong body of real AI training waveform to help our understanding

Responses from other attendees:

Data center waveforms and load profiles are very hard to come by. There are very few that are public and from actual facilities, not test rigs.

Paper that talks about possible hardware, software and grid-side solutions for data centers' duty cycles : <https://arxiv.org/pdf/2508.14318>

This is in response to the question about real AI power profiles - The MIT Supercloud dataset has some labeled data on GPU power draw for different AI training/inference algorithms

Michael Brown

I thought the TVE requirement is 1%?

The IEC/IEEE PMU Standard requires $TVE < 1\%$ for steady state compliance assessment (without oscillations), and $TVE < 3\%$ for dynamic compliance assessment (oscillation scenarios under amplitude and/or phase modulation).

Ralph Brown

Can you provide a pointer to these reports on phasor measurement algorithms?

[The IEC/IEEE reference algorithm for phasor estimation can be found in Appendix D of the IEC/IEEE 60255-118-1 Std. A comprehensive review of other algorithms may be found in this paper \(<https://ieeexplore.ieee.org/document/11395444>\) and references therein.](#)

MICHAEL RIDENHOUR

how does the limitation of 15hz correspond to the TVE 3% of a P class PMU of 2 Hz?

For a PMU with a 30-fps reporting rate, the Nyquist criterion sets 15 Hz as the maximum frequency that can be observed without aliasing. The 2 Hz limit, however, arises from the phasor estimation filters, which attenuate higher-frequency oscillations. Accordingly, the IEC/IEEE standard requires P-class PMUs to maintain $TVE \leq 3\%$ up to ± 2 Hz, beyond which measurement accuracy degrades.

Denis Osipov

In real-world applications 1/4 of the reporting rate is more proper threshold.

I agree that in practice you should ensure that the frequencies of interest are well below the Nyquist frequency. The Nyquist frequency is referenced in this work because it provides a clear theoretical limit.

James Reilly

When phase angles are monitored, is there any advance notice that there is instability on the circuit serving the Data Center?

Michael Basler

Can synchronous generators with excitation systems equipped with PSS effectively damp these oscillations?

Power system stabilizers are usually designed for poorly-damped natural modes. They have very little impact on forced oscillations with a persistent energy source.

Mahendra Patel

Excellent presentation. One more aspect to analyze is to see what varying window of data used for phasor estimation. (even for standard compliant PMUs)

Thank you. Window length has a direct impact on the low-pass filtering.

Ralph Brown

https://resourcecenter.ieee-pes.org/publications/technical-reports/pes_tr_127_amps_1218724

Thank you for highlighting this task force report. It provides a comprehensive overview of synchronized waveform measurements and their applications in power systems, including oscillation monitoring.

James Reilly

If the data center is in a microgrid, where would the performance monitoring be taken? at the POI? grid side of substation?

What is the smallest large load worth measuring?

At POI. Different reliability coordinators and utilities have different definitions for large loads (e.g., ERCOT defines 75 MW or higher as large load). Please refer to NERC white paper: www.nerc.com/globalassets/who-we-are/standing-committees/rstc/whitepaper-characteristics-and-risks-of-emerging-large-loads.pdf

Walter Sattinger

we shall ask for standards - data center Connection requirement - have POW measurements available, same for PV parks and wind parks too!!

Thank you. That would certainly enhance performance monitoring.

James Reilly

Is there a value in taking measuring at critical nodes within an ISO?

Yes, monitoring critical nodes would help us to see how oscillations may spread in the network and impact grid assets at other locations.

Freddy Wilkins

Even if you had no attenuation for the higher frequencies often the oscillation component is a small component of the total signal (<1%). Would the current standards specify enough accuracy for such small differences being possibly order of magnitude of 0.1%?

The performance requirements on oscillation limits are meant for high amplitude oscillations. Very low amplitude oscillations may not be of concern for data center operations.

James Reilly

What does a distributed architecture look like?

In a distributed architecture, POW measurements are used locally for oscillation detection and performance monitoring. The results from these analyses are communicated globally to a control center over existing wide-area communication networks.

Ricardo Lira

Despite the limitations in measuring oscillations beyond 5Hz, we can at least detect activity in higher frequency ranges. The MOSC (na ONS - openWAMS application) performs this consistently; for instance, modes are being detected at 11Hz, although their true amplitudes cannot be accurately estimated due to signal attenuation.

Thank you for this comment.

Sayeb Mohammad Tadvin

Is there any oscillation range for the AI data centers?

Usually, each AI training iteration alternates between a high-power phase and a lower-power phase. The slower oscillations associated with the periodicity of the iteration cycles typically fall in the 0.1–1 Hz range, while faster fluctuations originating within the high-power computational phases may extend into the sub-synchronous (5–59 Hz) frequency range.

Farrokh Aminifar

Great work and presentation. Just a comment. Even with POW, we still have instrumentation transformers impacts on the waveform signals. They are designed for fundamental frequency and impacting the other frequencies. Any insight on this?

Usually, instrument transformers have a broad frequency response covering a few hundreds of Hz. These have minor impact on sub-synchronous frequencies but major impact on switching frequencies. The impact of instrument transformers is common to both POW and PMU measurements.

Md Sen Bin Mustafiz

What are the problems associated with higher reporting rates of PMU?

There are no problems. However, increasing the reporting rate alone may not guarantee observability of high-frequency oscillations. Internal filters may pose additional constraints on the maximum observable frequency.

Deborah Ritzmann

To what extent are there differences in measurement adequacy between oscillations caused data centres and converter control interactions?

From a measurements standpoint, they are same. Monitoring higher-frequency oscillations from IBRs would also have same requirements as for a data center.

Chemseddine Allioua

The standard on PMU performance does not ask for compliance over 5 Hz, but there are a lot of PMUs who can cover oscillations to 30 Hz...

Not all of them have such narrow band due to low pass filter

Coverage is not same as accurate representation. Even if a 30 Hz oscillation is seen in the measurement reports, it may be an attenuated representation of the true oscillation.

Matt Backes

For the POW meters, is there a recommended sampling rate for taking data reliably on a data center?

Recommended methods and models would be useful too

There are no guidelines specific to data centers yet, but NERC has recommendations for IBRs. NERC PRC-028-1 recommends a minimum of 64 samples/cycle resolution for DFRs used in disturbance monitoring of IBRs.

Mahendra Patel

Even without a filter consideration, wouldn't 6 to 12 cycle window used for each report, which it self works as a filter, wouldn't that limit observable oscillations way below Nyquist limit?

This observation is correct. Long estimation windows can act as low-pass filters.

Matthew Rhodes

In the interim of setting up POW or other advanced oscillation monitoring, could we set up some type of oscillation triggering on DFRs to capture truer oscillation metrics?

Possible. But triggering DFRs for oscillations is usually difficult.

Chemseddine Allioua

And usually manufacturers give a datasheet defining the low pass filter

Yes, sometimes manufactures provide detailed information on internal filters, but not always.

James Reilly

Where can information on the event where a data center was asked to reduce power from the grid due to oscillations? Event analysis from NERC? PNNL?

Please refer to ERCOT's presentation, "Large Load Oscillation Event"

https://www.ercot.com/files/docs/2025/02/28/LL-Oscillation_LFLTF_Mar2025_Final.pptx

Please see the webinar recording for answers to the following questions

Evan Mickelson

Are there any limiting factors that stops the AI training waveform to stop going beyond a certain frequency?

Matthew Rhodes

Is it really important to see the side bands if the main frequency of the oscillation is say 10 Hz? Are those side bands of importance to see?

Matthew Rhodes

What does aliasing to imaging frequencies mean..just it will be filtered out?

Are the side bands magnitudes attenuated at their frequencies (50 and 70Hz in the example) but still seen or are those sidebands showing up as attenuated magnitudes in the in-band frequency?

James Reilly

When non compliance is known to system operator, how does it get communicated to the data center operator to correct? How long does the data center have to comply? Is there a control or energy management tool to make the correction, either at the data center facility - Is correction about the power flow to the UPS at the data center? DReducing power import from the frid?

Are there situations where the TSO would simply disconnect the data center?

Walter Sattinger

is the conclusion correct, that we need more and more POW measurement equipment on several interfaces?

Dame Jankuloski

What are the recommendations in terms of requiring PMU data from data centers? How to determine which loads should provide PMU data to ISOs?

Matthew Rhodes

Using PMUs as we do today for oscillation detection, are there areas for concerns if there is a detected 7.5Hz oscillation that we are really not seeing the true oscillation that is at a higher frequency and how should we be aware of this possible aliasing?

Rodrigo Barbosa

Thank you for the presentation. It was very clear and informative. I have one question. In your opinion, for utilities that already have a large installed base of PMUs operating at 60 fps, what would be the best practical path for oscillation monitoring: selective replacement, configuration improvements, or complementing synchrophasor data with waveform or DFR measurements at key locations?

Stephane Do

What is your view on the granularity required for the FFT done on POW. Is that what dictates the 1sec window ?