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SYNCHROPHASOR-BASED MONITORING, ANALYSIS & MITIGATION OF LARGE DATA CENTRE LOAD IMPACTS

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NEW RELIABILITY CHALLENGE: LARGE DATA CENTRE LOADS

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FROM

TO

Hyperscale data centres are transforming grid demand. Is our monitoring keeping up?

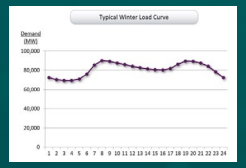
Traditional load models assume passive demand. Hyperscale data centres violate this assumption and can drive forced oscillations, voltage degradation, and ROCOF events under stressed conditions.

Data Centre Load

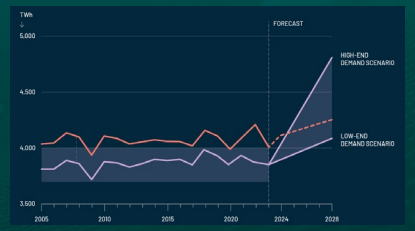
- Small, dispersed commercial & industrial.
- Passive did not interact with grid dynamics

- Hyperscale campuses: 100–1,000+ MW at a single point of interconnection

DEMAND

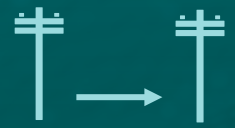


- Stable, passive, slowly varying load

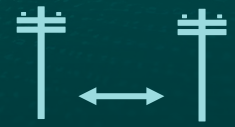


- Sustained high-MW demand with fast, correlated swings

POWER FLOW



- Predictable one-way flow
- Data centres had **minimal interaction with system-wide control**



- Unpredictable two-way flow
- System-level issue affecting voltage, congestion, and stability

Why PMUs? Closing the SCADA Visibility Gap

SCADA limitations for data centres:

- Scan rates of 2–4 s cannot resolve fast, correlated MW demand swings
- No sub-second visibility at the point of grid interconnection

What PMUs deliver:

- High-resolution, GPS-synchronized phasors at up to 60 fps, with higher rate in some PMUs (IEEE C37.118)
- Continuous frequency and RoCoF essential in low-inertia grids
- Wide-area time-coherent measurements across multiple substations

The capability this unlocks:

- Distinguish data centre driven events from generation or transmission faults
- Foundation for OSM, OSL, and post-event analysis

GE Vernova Monitor-Analyze-Act Stack

Phasor Data Concentrator
management & processing of WAMPAC data streams.

OSM & OSL — Monitor

OSM: Continuous full-spectrum oscillation monitoring across the wide-area network.

OSL: Identifies the source substation/asset driving oscillatory behaviour.

WAMS Server
receipt, analysis, monitoring, storage & visualisation of WAMS data.

PhasorPoint — Monitor

Full-featured, proven, market leading product - 20 years and 60+ customers.

GridOS WAMS — Monitor

20 years of WAMS experience re-architected in GridOS for scalability, extensibility, agility and enterprise-grade capability, availability & security.

PhasorControllers — Act

Virtual or Physical **platforms**

Programmable Logic Control (PLC) engine, expert-designed app block library, extensive communications protocols & ancillary functions.

Custom logic, signal processing & AIML for customer algorithms and innovation

Wide-Area Protection & Control: schemes to manage grid stability & security issues and provide fast coordinated grid control.

10+ years' experience in WAC design & delivery

Proven in operation

Analyze

AEMS Platform: Stability

Advanced AEMS Platform modules combining WAMS & EMS data to deliver extra insight to operators

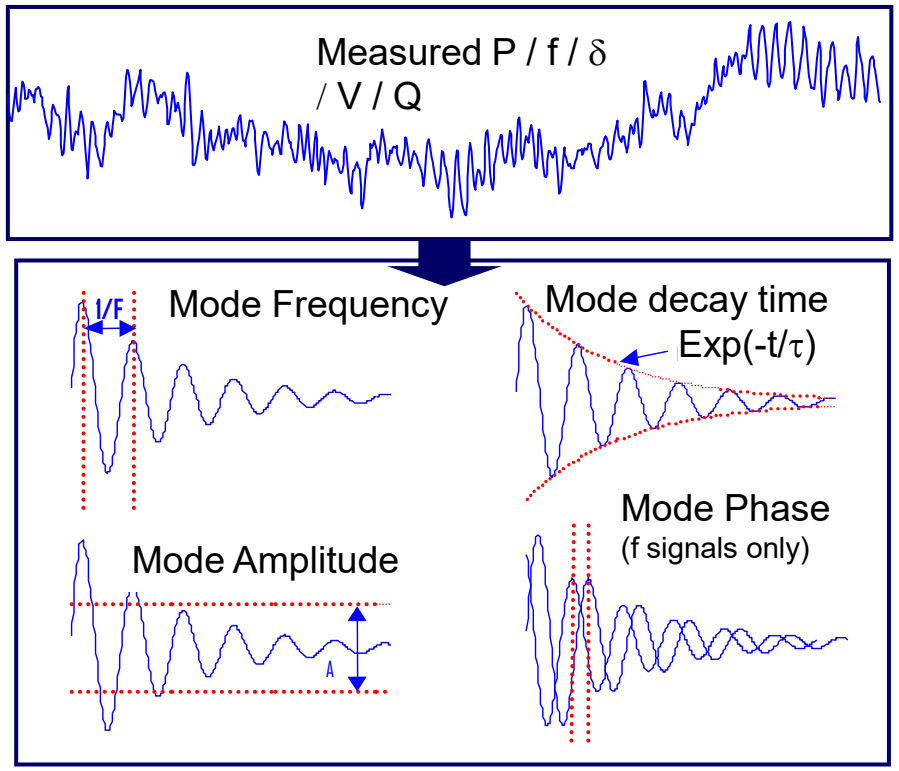
PhasorAnalytics Client

Historical advanced analysis client for WAMS & other data – use standalone offline or interface with WAMS Server.

This work builds from off-the-shelf GE Vernova applications and extends them to large data centre load monitoring, analysis, and mitigation.

OSM & OSL: Extended for Load-Driven Oscillation Detection at Data Centre Interconnections

Simultaneous multi-oscillation detection and characterisation measured at data centre POI and adjacent substations



PDX1 Fast Modal Analysis: **Alarms**

PDX2 Trend Modal Analysis: **Analysis**

OSL source attribution fed to operator dashboard

Operations

Provides early warning and source visibility for operator action

Unlimited oscillation frequency sub-bands

Independently configured alarms for each sub-band on **mode damping** and **mode amplitude**

Data Centre Load Monitoring : detecting demand-side forced oscillations at grid interconnection points

Planning & Analysis

Post-event reconstruction of data centre disturbances

Enables root-cause analysis using archived PMU data

Dynamic model validation

Damping controller performance assessment

Mode phase analysis operates on frequency signals – correlation analysis is used to identify & group occurrences of the same underlying oscillation across multiple signals.

Synchrophasor-based End-to-End Architecture

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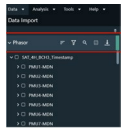

PhasorAnalytics-*Archived PMU data → Post-Event Analysis*

Central Control, Data Concentration, OSM (Oscillation Monitoring) | OSL (Oscillation Source Location) Applications

Energy Management System & WAMS

Virtual PHC

Phasor Control Logic platform

Zone A Control

Zone B Control etc.

PMU

Data Centre

BESS

PV

PROSUMER

Monitoring & Control points

Note:
Protection (P-)class PMU performance recommended

WAMPAC: Phasor-Informed Control Actions for Data Centre Load Events

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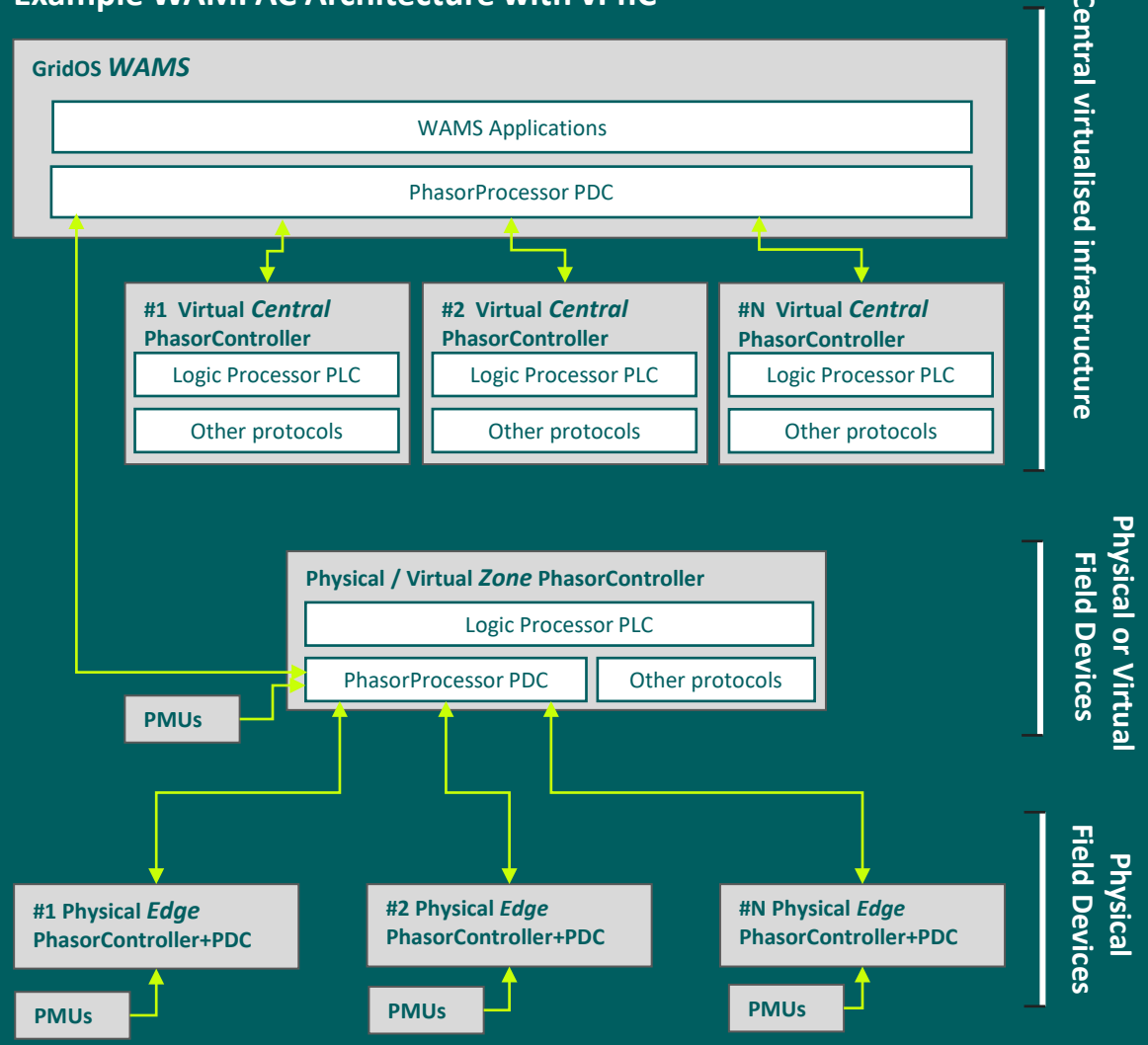
Delivered through the Physical or Virtual PhasorController
Enhanced Under-Frequency Load Shedding (UFLS)- Real-time RoCoF and frequency measurements from data centre POI PMUs enable faster, more precise load shedding thresholds reducing unnecessary disconnection during demand-driven frequency events vs. generation loss events.
Load Modulation Control- Phasor-informed modulation of data centre active power demand in response to detected oscillatory signatures or frequency deviations treating the load as a controllable resource rather than a disturbance source
Volt/VAR Control-Reactive power management at the data centre interconnection point, triggered by voltage phasor measurements mitigating voltage degradation associated with fast, large-step load transitions in low short-circuit capacity areas
Fast Instability Detection (FID)- Sub-cycle detection of unstable oscillation growth using the FID algorithm; triggers pre-emptive control actions before instability propagates wide-area closing the gap between PMU observation and protective response

Benchmark tests on virtualized Environment

- KVM on Ubuntu Linux
- PhC OS (64 bit) exclusive access to 4 CPUs of 8-core ARMv8
- Cycle time average: vPhC 10x faster than physical PhC-TPCOM

Example WAMPAC Architecture with vPhC



CONCLUSION

GE Vernova WAMS as the Platform
GridOS WAMS, OSM, and OSL provide the off-the-shelf monitoring foundation extended here to detect higher-frequency, demand-side oscillations at data centre interconnection points.

Closing the SCADA Visibility Gap
PMU-based monitoring resolves fast, correlated data centre load dynamics invisible to conventional SCADA enabling real-time detection of forced oscillations, frequency excursions, and voltage degradation.

From Monitoring to Action
PhasorAnalytics on archived PMU data enables post-event disturbance reconstruction and root cause identification; the PhasorController delivers UFLS, Load Modulation, Volt/VAR, and FID as coordinated mitigation actions.

Novelty
First end-to-end application of synchrophasor WAMS and WAMPAC to demand-side data centre load dynamics treating large loads as active participants in grid stability, not passive consumers

Path Forward
Beyond PMU-based visibility, point-on-wave measurements through WMU-type capability are being explored for higher-frequency data centre oscillation visibility.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