GE VERNOVA

GRIDOS WAMS & WAMPAC SOLUTIONS

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GridOS®

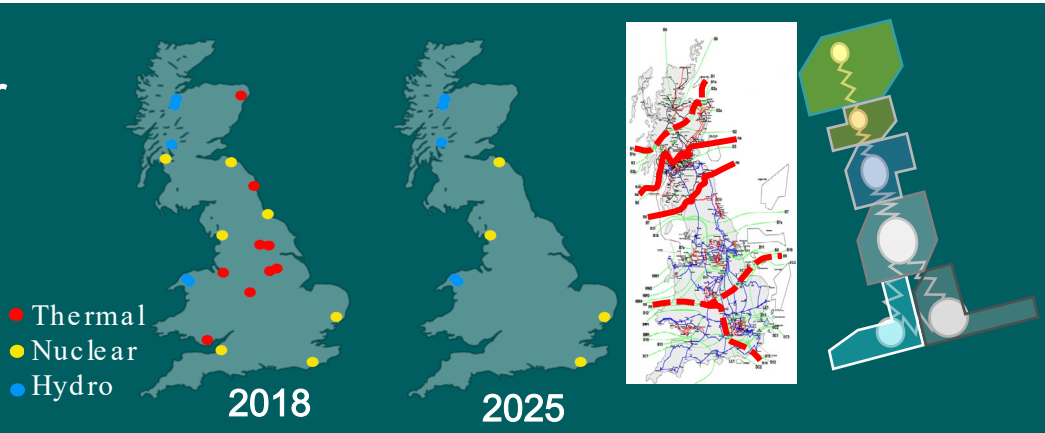
Key industry drivers

GE VERNOVA

Higher Renewables Penetration

- ✓ Need for higher resolution visibility and faster agility to monitor and manage the grid.
- ✓ Greater and regional variability in frequency (due to reduced/sparse inertia)
- ✓ Grid operating closer to its stability limits (frequency and voltage)

→ **Need for Better Visibility and Higher Agility**

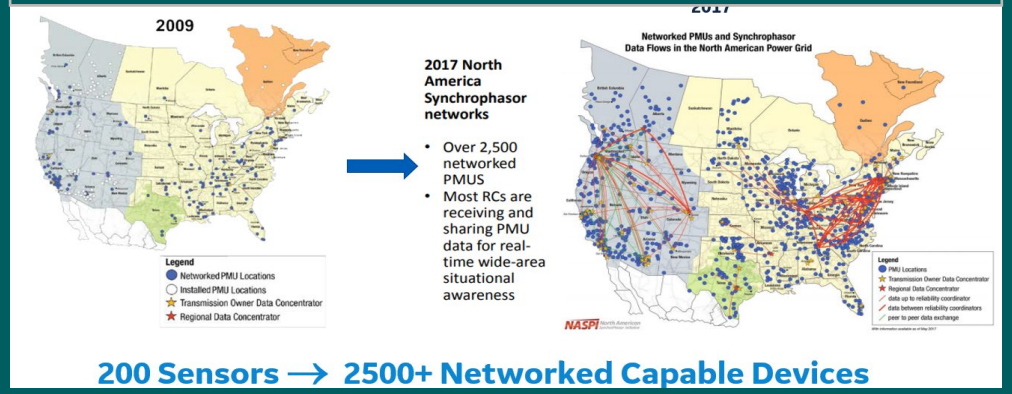


Accelerated Adoption of WAMS sensors

- ✓ Customer field installations growing from 100s → 1000s (e.g. ONS, Brazil 1000+ ; PowerGrid, India 2500+)
- ✓ Multifunctional IEDs (such as Relays &Fault Records) capable of providing WAMS data.

→ **Need for Scalable and High Performance WAMS platform**

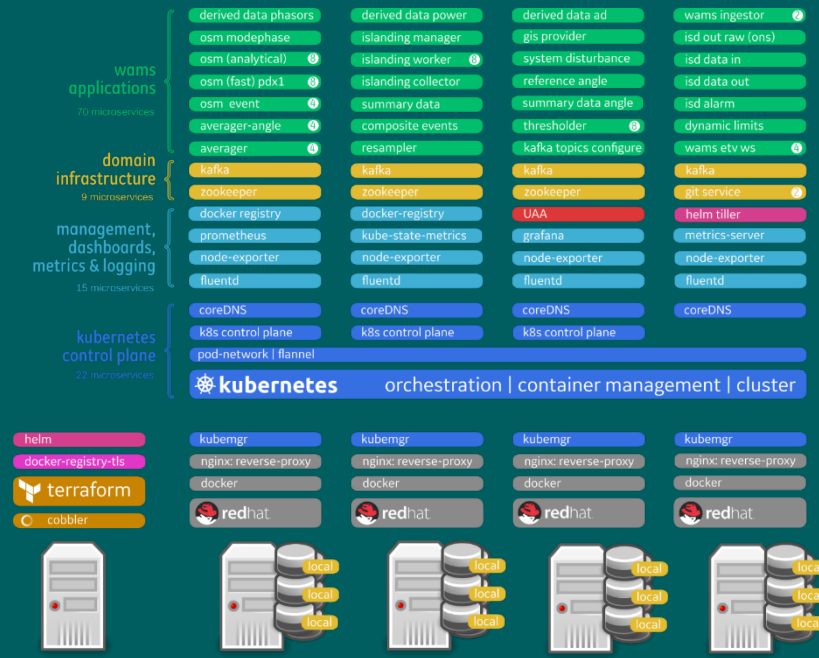
Changing Landscape of WAMS Sensors (e.g. North America)



200 Sensors → 2500+ Networked Capable Devices

GridOS WAMS

- Performance and Scalability
- Flexibility and Agility
- Modularity and Extensibility
- Additive Solution



GridOS® Advanced EMS

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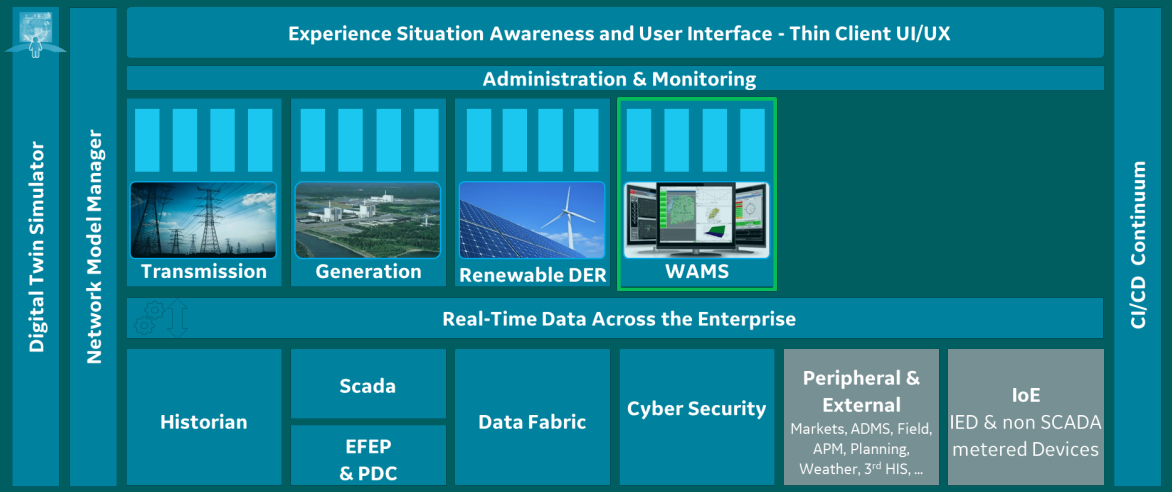

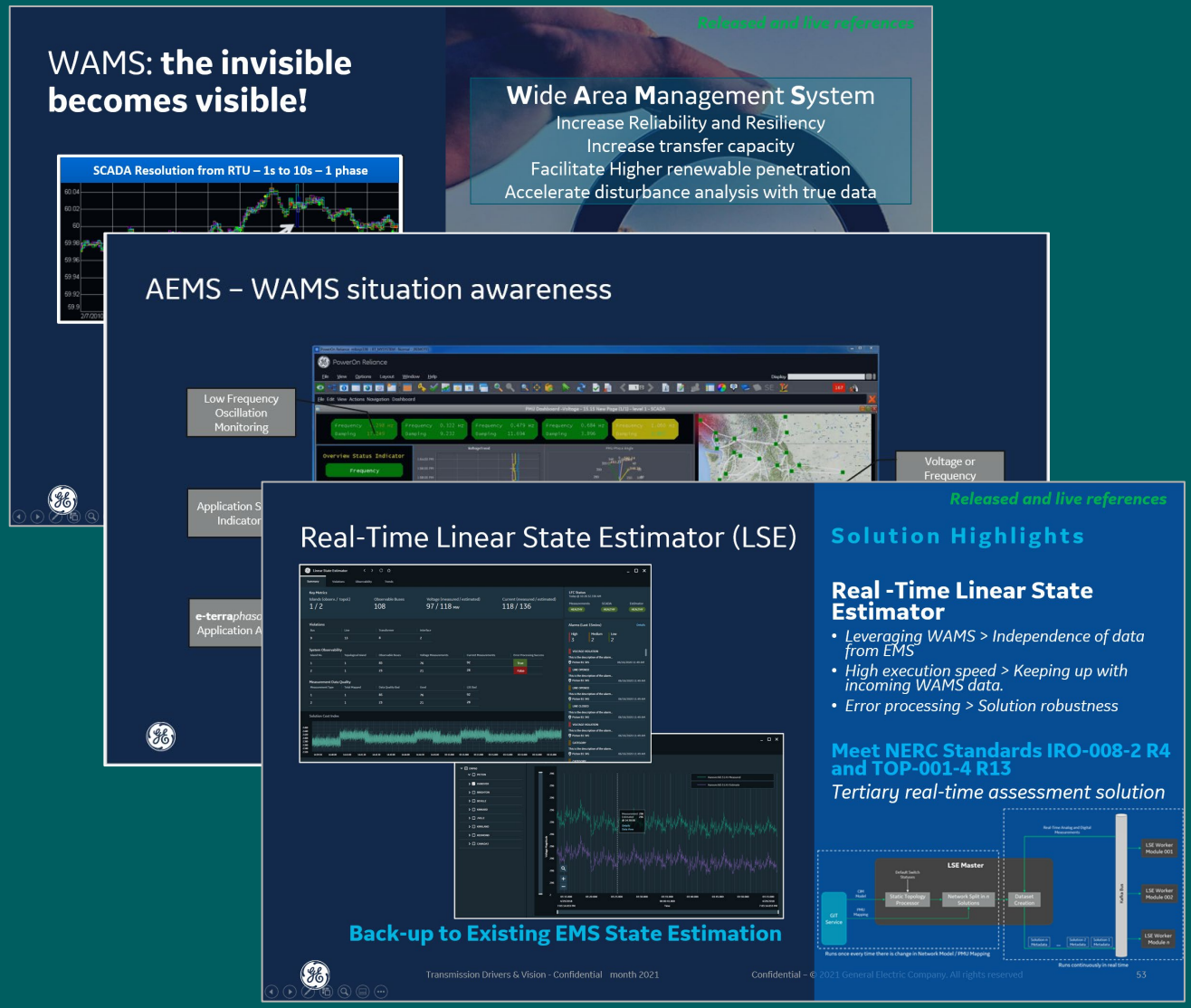

ARCHITECTURE

GridOS WAMS

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Smaller Total Cost of Ownership

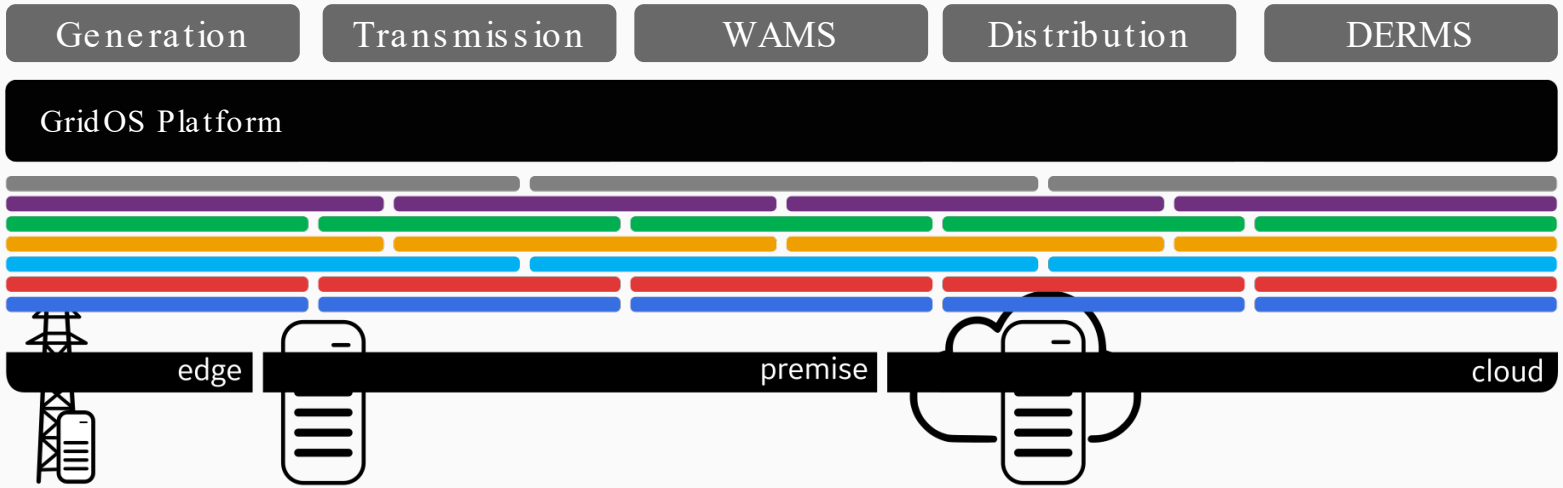
- Leverages Continuous Integration & Continuous Deployment
- Full Test Automation

Just the right bits

- Natively modular solution

Future proof

- Cluster based. Vertical and Horizontally scalable
- On-Prem; Hybrid or Cloud. Your choice



GridOS WAMS

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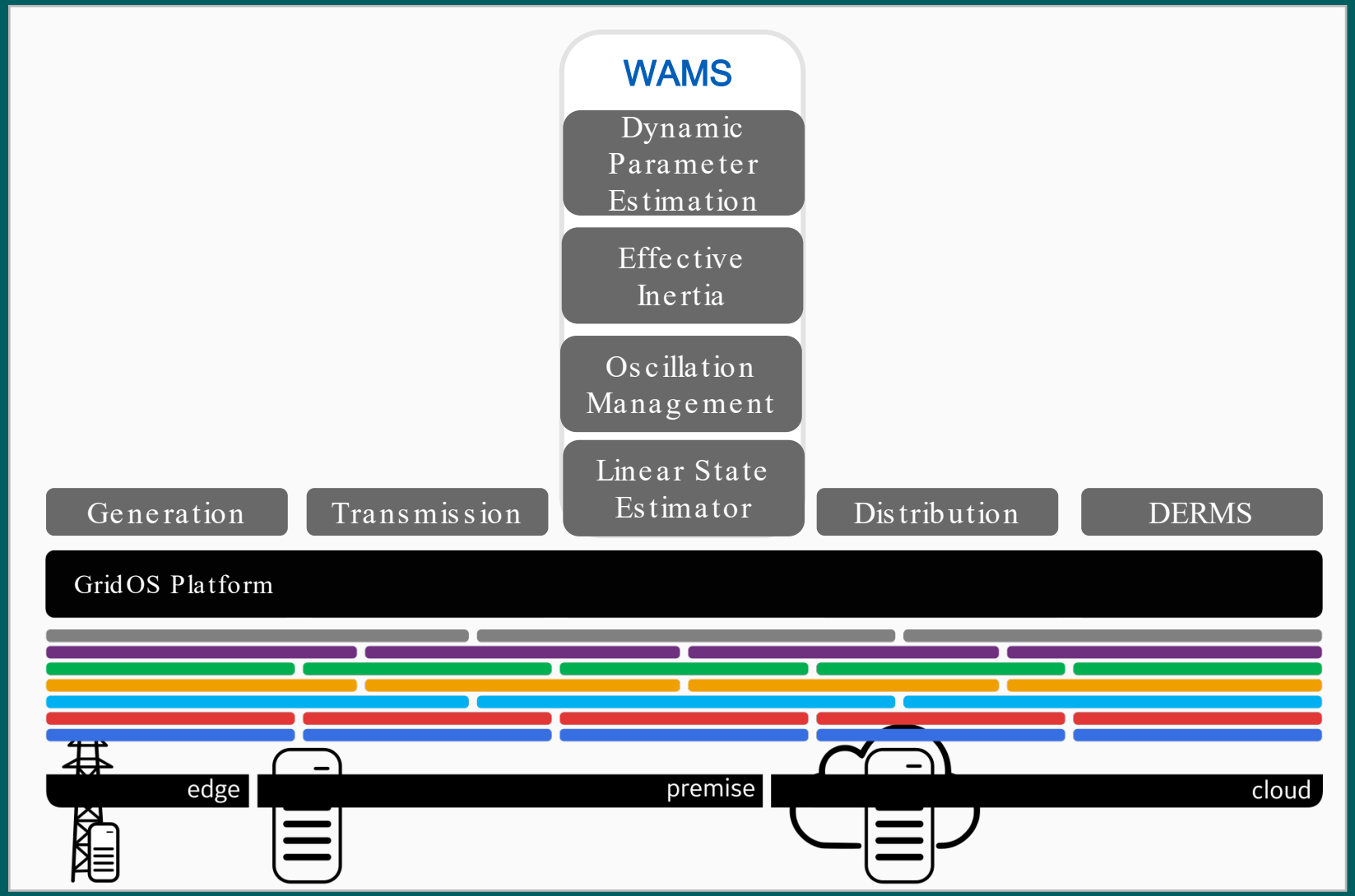
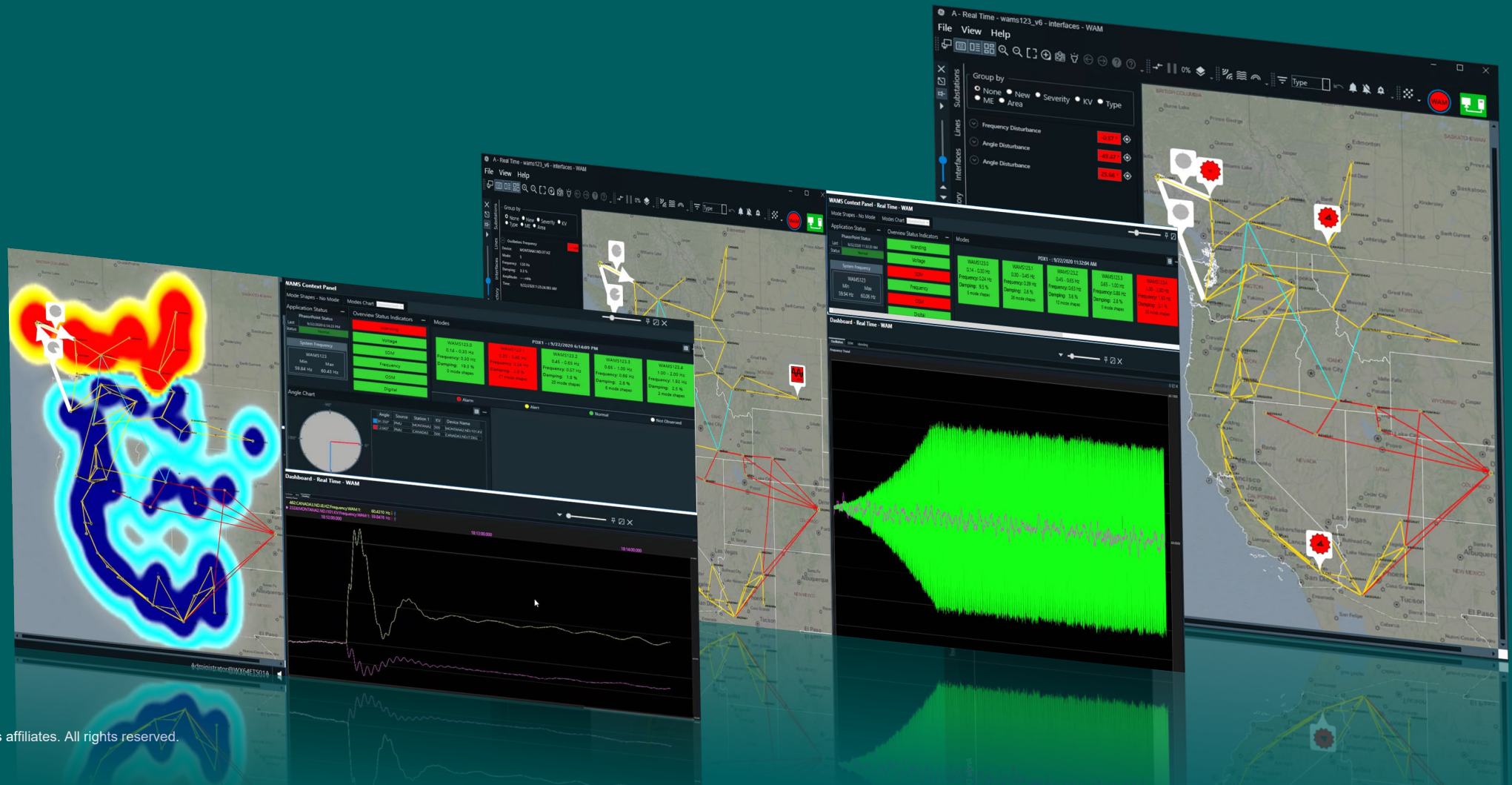


REAL-TIME APPLICATIONS

Islanding, Resynchronization & Blackstart
Oscillatory Stability Monitoring
System Disturbance Detection and Location



Major Oscillations in Recent Years

United States Eastern Interconnection
Forced Oscillation Event (Jan 11th, 2019)

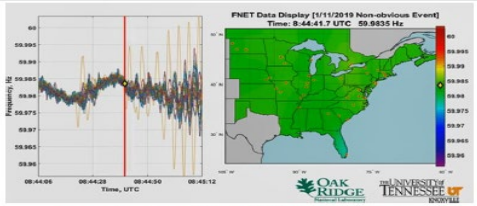


Figure 1.1: Beginning of Oscillation Disturbance [Source: UTK/ORNL]

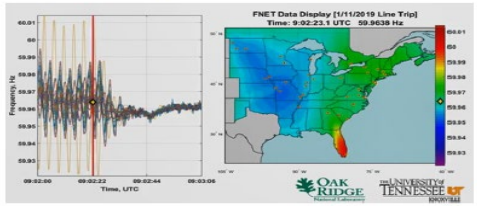
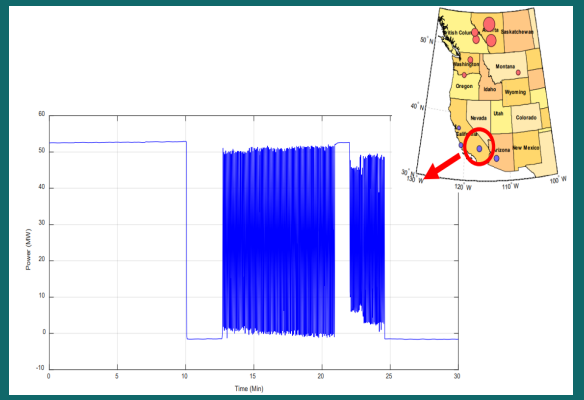


Figure 1.2: End of Oscillation Disturbance [Source: UTK/ORNL]

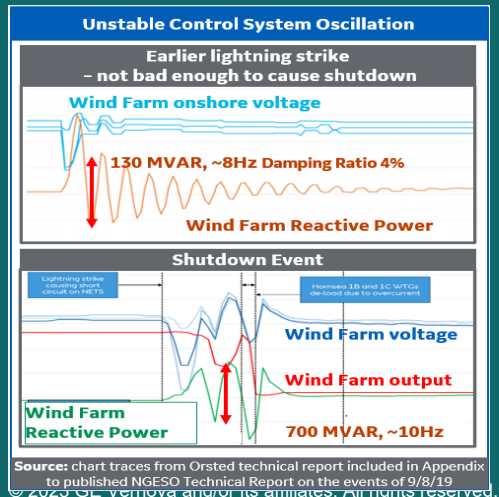
- **Faulty PT:** Errored voltage measurement
  - Imbalanced power load condition
  - Steam turbine of a combined cycle power plant
- **The 0.25 Hz forced oscillation interacted with the natural system mode causing the entire EI to experience the forced oscillation**

United States Western Interconnection
Forced Oscillation Event (Jan, 2022)



- Disturbance source was a battery storage system in Southern California
- Oscillation frequency, 0.25 Hz, close to NS-A mode
- Sustained oscillations last about 15 mins
- Oscillations interacted with system natural dynamics and observed throughout Western Interconnection

United Kingdom
Load Shed Event (Aug 9 th, 2019)

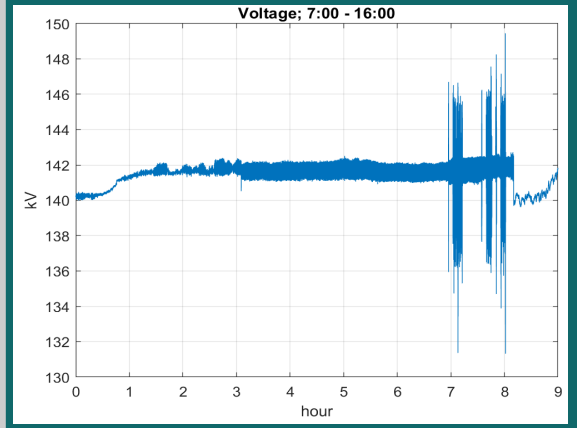


Source: chart traces from Orsted technical report included in Appendix to published NGESO Technical Report on the events of 9/8/19

- Wind farm shut itself down due to an **unstable control system response** to the disturbance.
- voltage dip -> WF acts to raise voltage -> oscillation develops
- Hornsea tested & modelled in line with Grid Code - no reason to suggest 9th August behavior.
- Issue already identified, but only expected when final unit connected.
- Control upgrade brought forward to resolve

Impact: Generator £4.5m "voluntary payment "

United States Local Oscillation
Forced Oscillation Event (Feb, 2022)



Voltage/MVars Oscillation Event Caused by IBR
and commenced when active power ramped up.

- Sustained oscillations last more than 5 hours until the magnitude got significant and plant was taken offline by operator action.
- Sustained oscillations were observed mostly in voltage magnitude and reactive power signals.
- Oscillation magnitude became significant with peak-to-peak values of 8 kV and 50 Mvar.

Oscillation Stability Management

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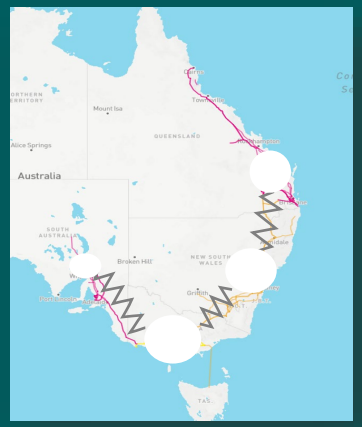


Reducing system inertia

Area inertia effects

Reducing synchronous generator PSS

Reducing System Strength

Resonances: Series Capacitor – Shafts – VSC/HVDC

0.002Hz

0.2Hz

4Hz

12Hz

50/60Hz

Governor Frequency Control

Rotor Angle Stability

Control Modes

Sub-Synchronous Oscillation

What 's New in OSM:

- **Extended Frequency Range** for Oscillation monitoring (up to 46Hz/54Hz)
- Oscillatory Monitoring also extending to **Voltage and MVAR measurements**
- **Oscillation Source Location** to identify source of Oscillation.

2021 IEEE-NASPI Oscillation Source Location Contest - GE 1st Place Winner!

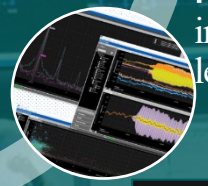
A Worldwide Contest! – 60+ teams registered

Effective Inertia

The **Inertia Challenges**

Area Effectiv e Inertia

Measuring Area-Inertia with WAMS



Forecasting area-inertia by machine learning

Inertia Measurement and Forecast

Solution Highlights

Expectations

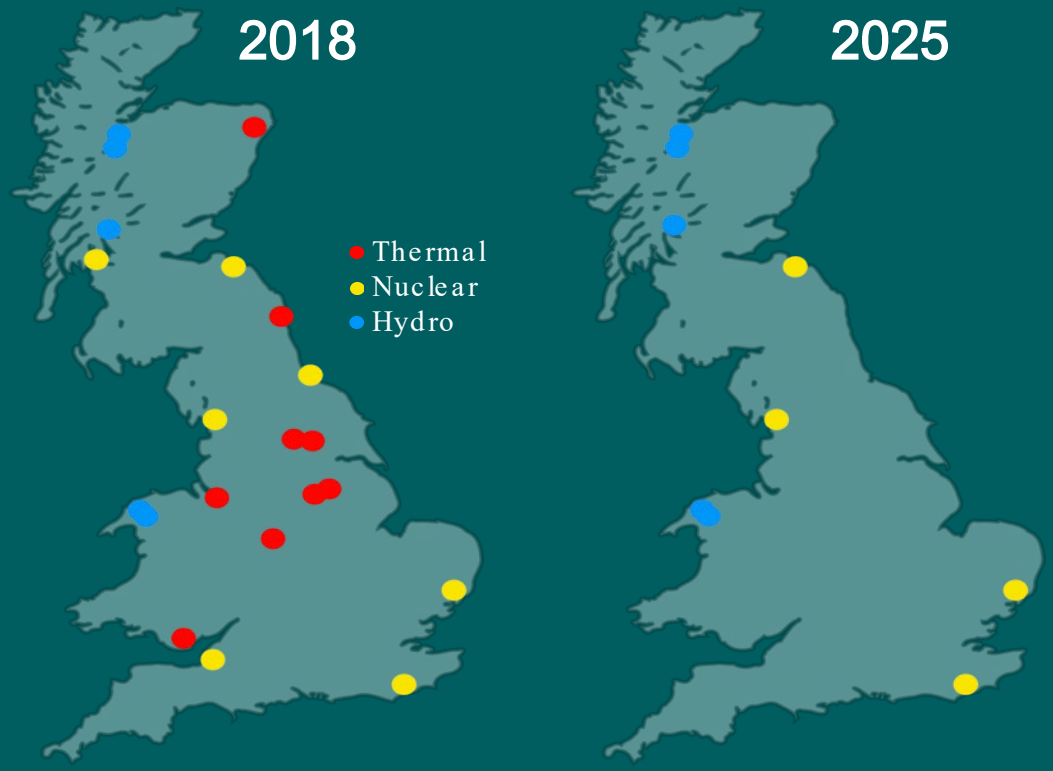
- Enable higher penetration of low inertia renewable generation.
- Reduce curtailment fees and penalties.
- Lower frequency response services.
- Increase network resilience; minimize risk of system separation.

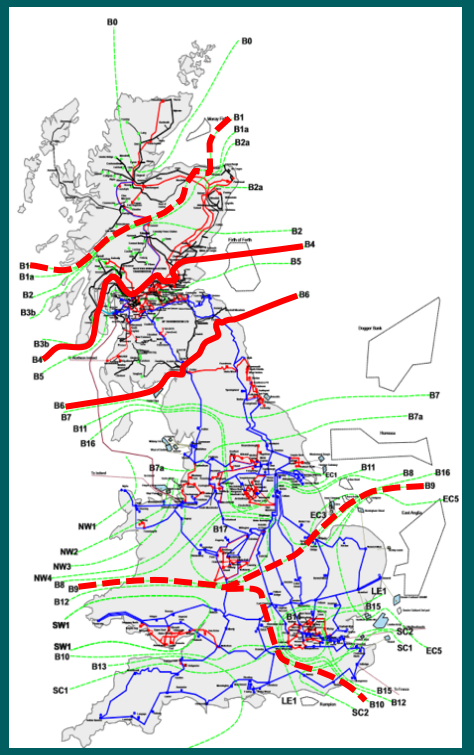
Effective Inertia

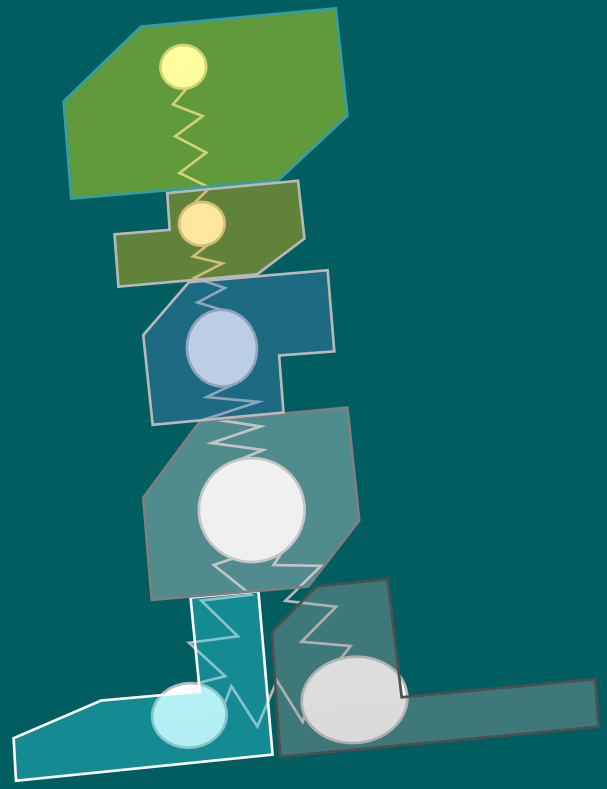
- Nonintrusive metering of “effective” inertia.
- No expensive hardware required; leverages existing WAMS investment.
- Regional and global real-time inertia measurements.
- Inertia forecast from AI/ML analytics.
- EMS and PMU/PDC agnostic.

Meter and Forecast to Master High Renewable Integration

GB Example: Decreasing inertia, sparsely distributed







- ✓ Large inertia sources becoming extremely sparse, particularly in high renewable scenarios.
- ✓ Addressing the regional distribution of inertia key to frequency control and grid stability.

Effective Inertia

Linear State Estimator

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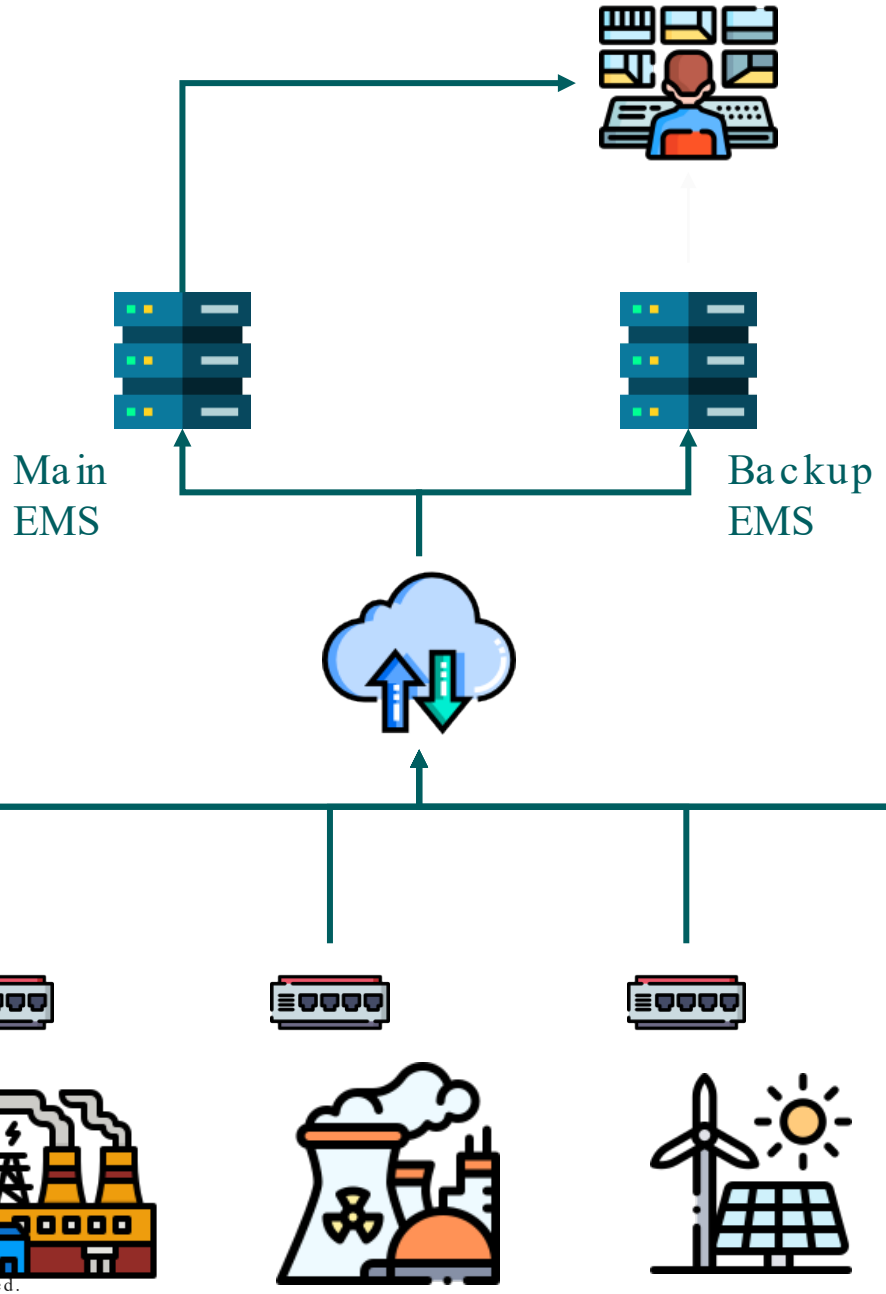
Solution Highlights

Comply with **NERC IRO-008 -2 R4 and TOP-001 -4 R13** as **back -up** to existing **EMS State Estimation** .

- Tertiary real-time assessment solution
  - Leveraging WAMS -> Independent of data from EMS
  - Solves at incoming WAMS data rate; built -in error processing to ensure solution robustness
- Extends WAMS observability beyond existing infrastructure
- Detect and correct for erroneous/missing WAMS data

Modular, IEC CIM based, state of the art UI/UX, cybersecure, HA, interoperable

Before LSE



Threats

Single RTU per Station (Lose RTU = Lose station visibility)
Backup EMS subject to same failures as Main EMS (convergence issues)

Extra Resiliency with WAMS LSE

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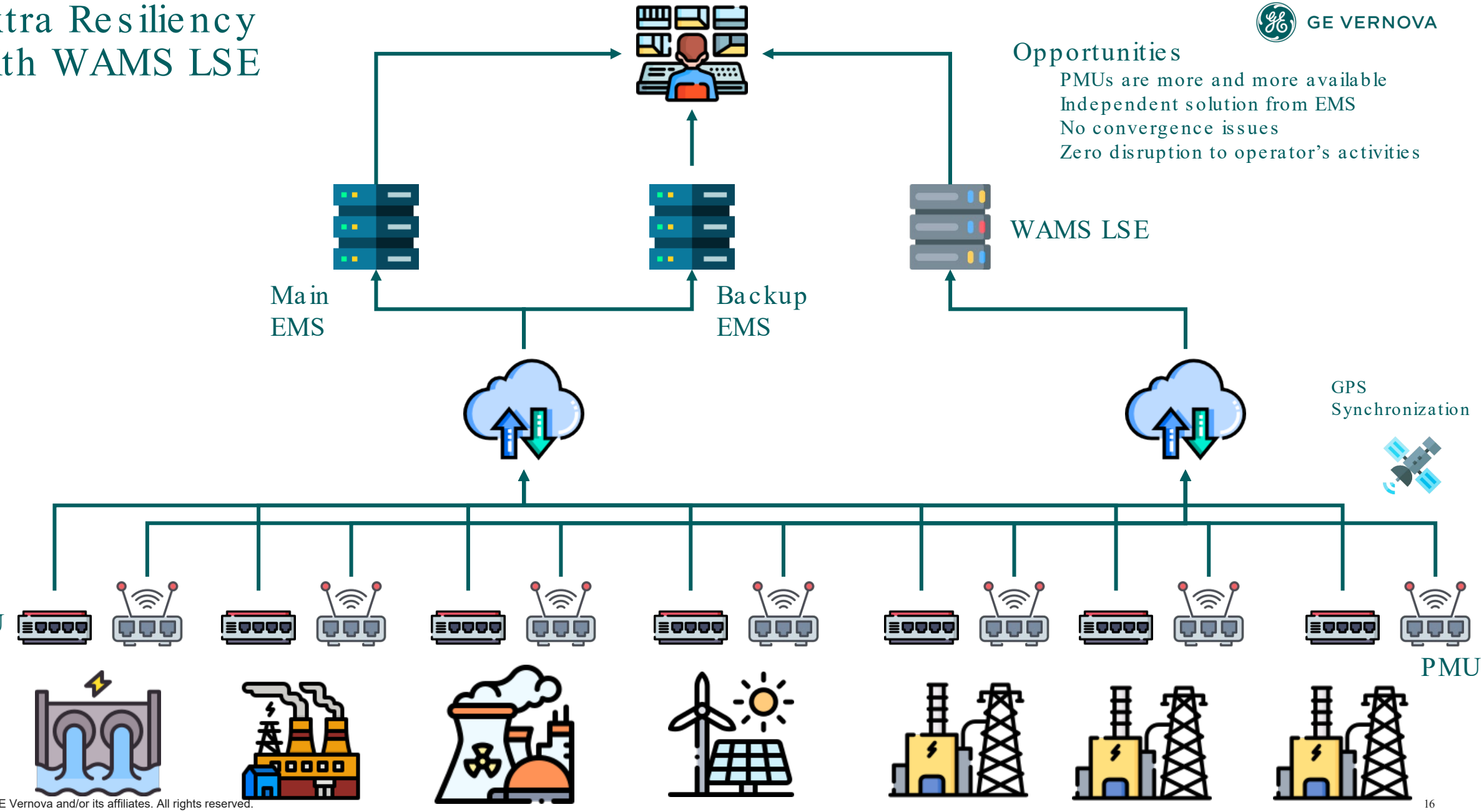
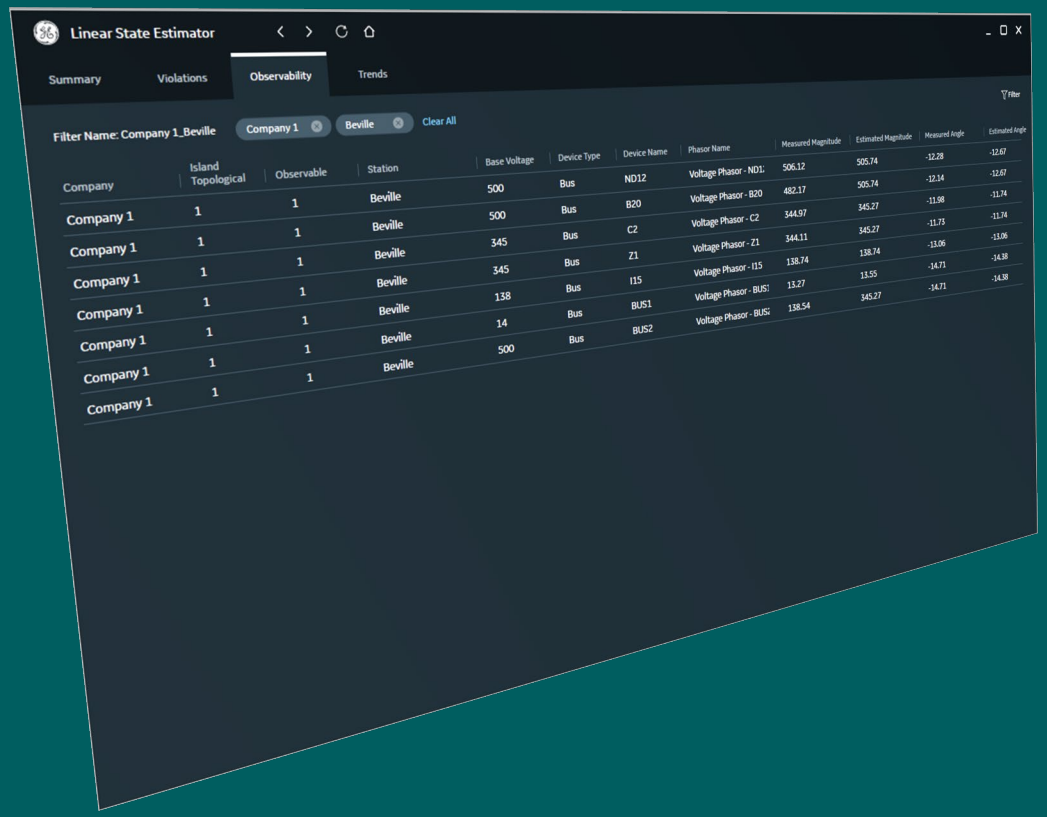
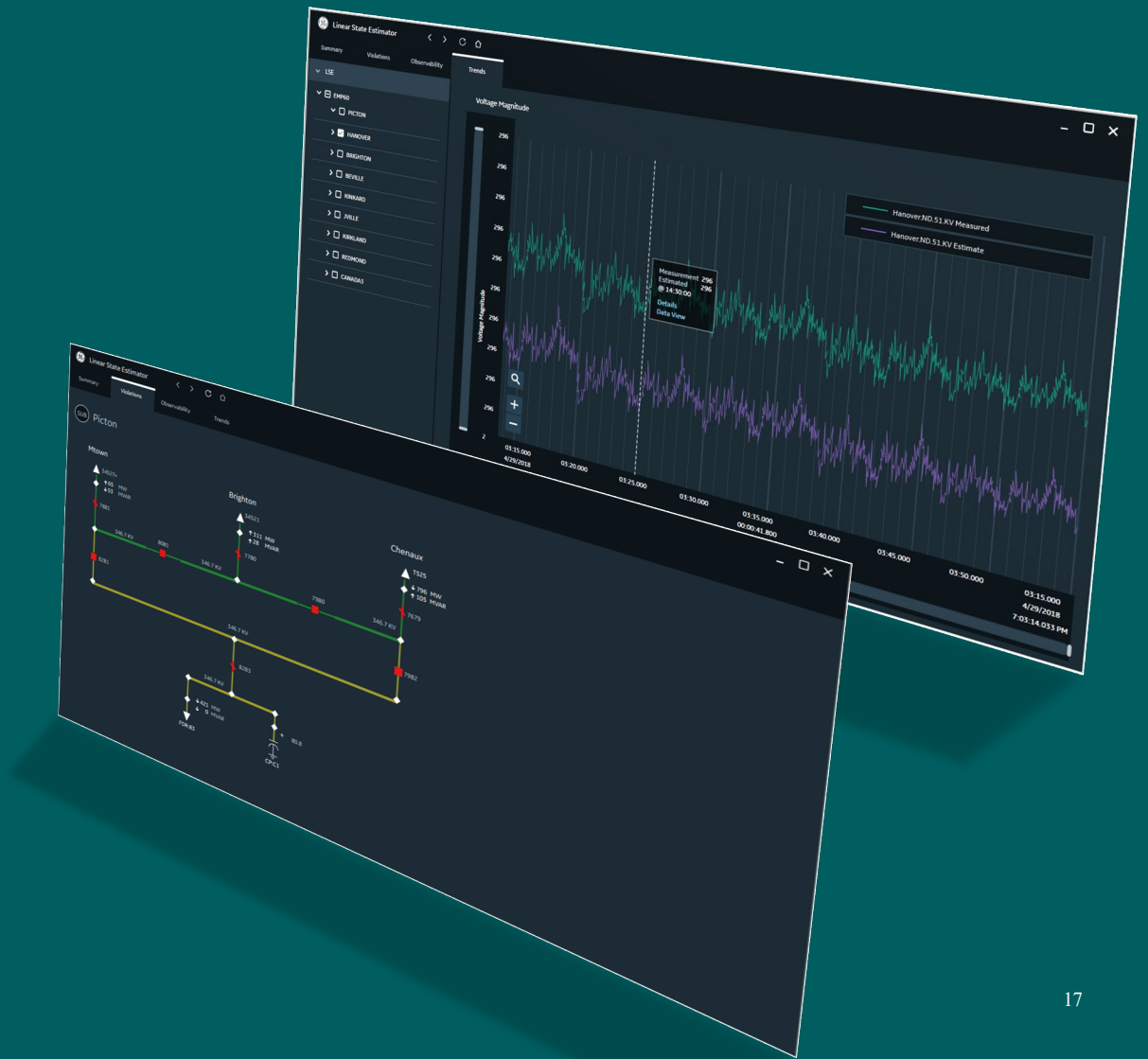
Opportunities

- PMUs are more and more available
- Independent solution from EMS
- No convergence issues
- Zero disruption to operator's activities



Sample LSE displays





ENGINEERING APPLICATIONS

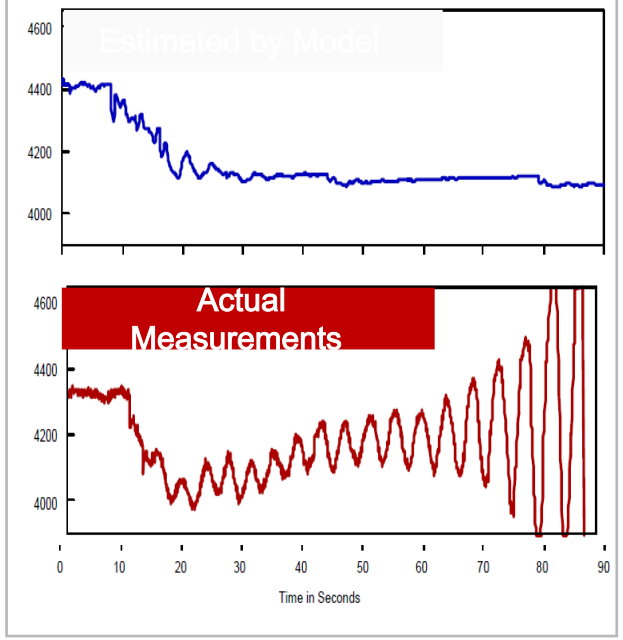
Dynamic Parameter Estimation

Challenges :

- **Inaccurate Dynamic & IBR Models** leading to inability to predict grid conditions.
- **Small Disturbance Testing not Sufficient** as this does not capture the large disturbance behavior.

Dynamic Models

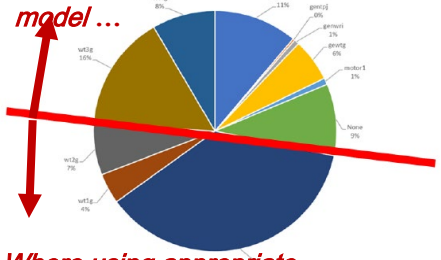
(US Western Interconnection August 10th, 1996 Blackout)



Inverter Based Resources

(WECC Base Case Review, August 2020)

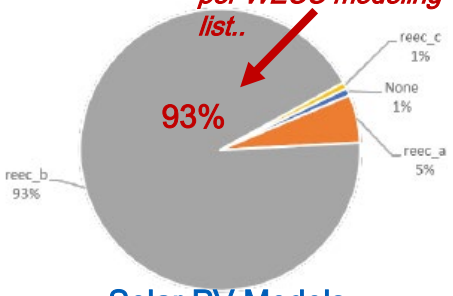
Everything above the line has incorrect, obsolete or no model …



Where using appropriate model default parameters widely used …

Wind Plant Models

Everything in grey is "not acceptable" per WECC modeling list..



Solar PV Models

Solution Highlights

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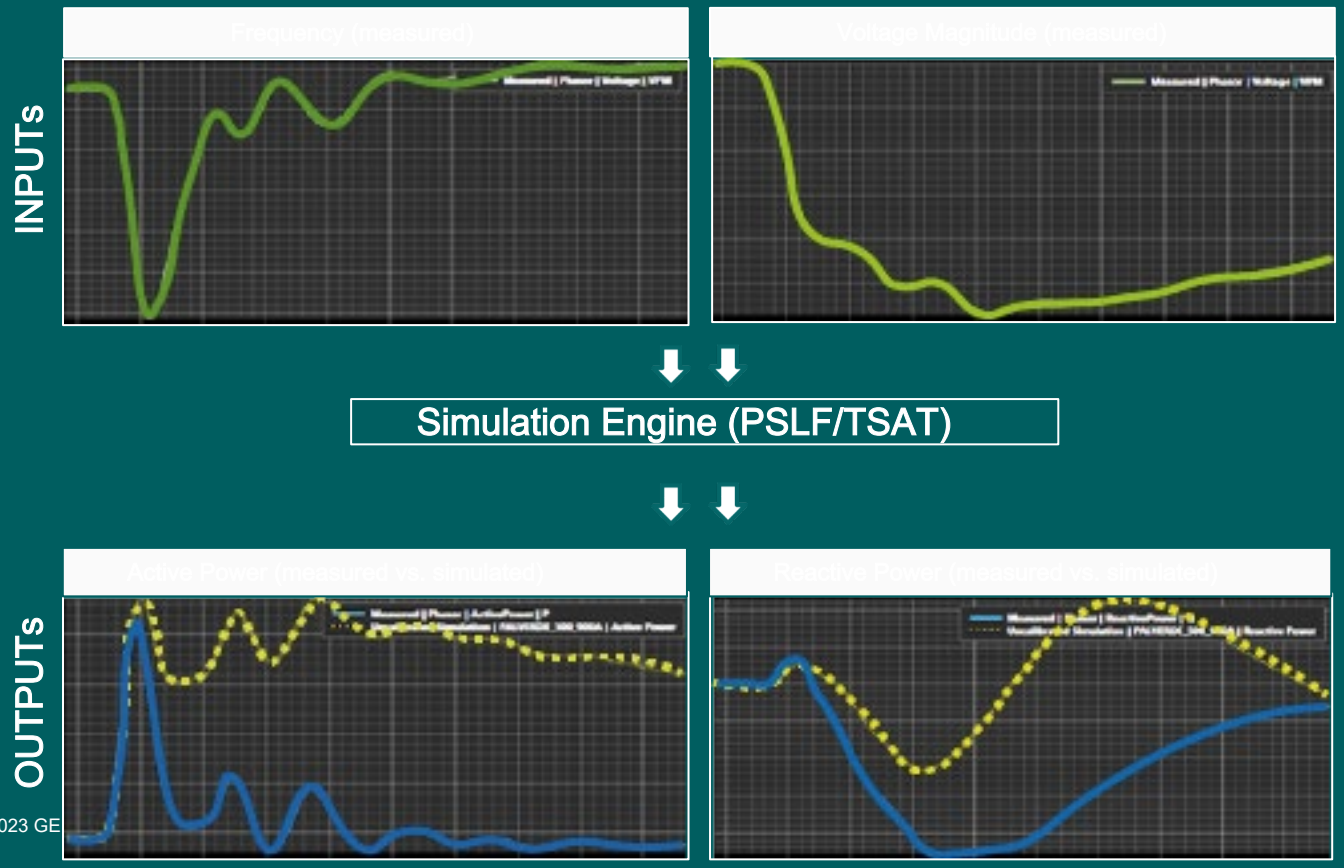
A Non-Invasive & Data-Driven Approach that is:

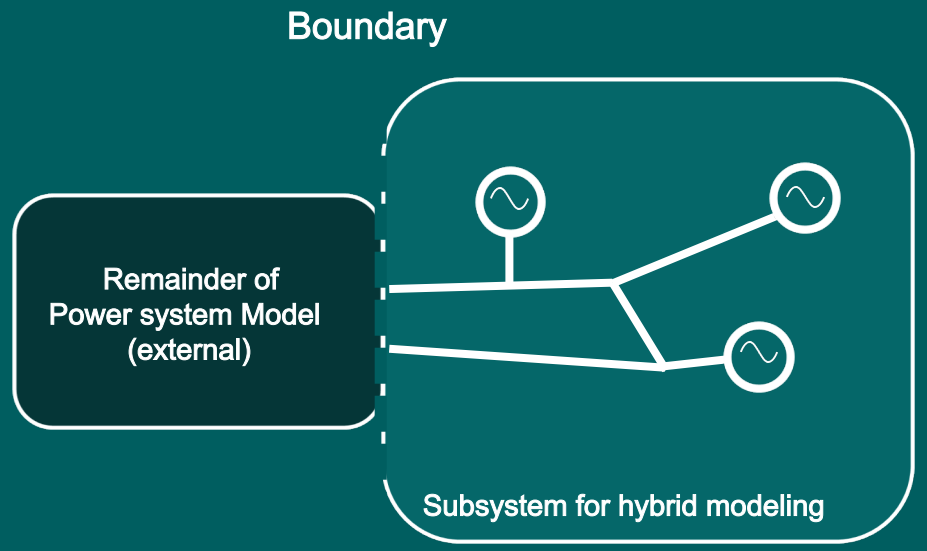
- **Cost-effective** method for TOs and GOs to **satisfy NERC Reliability Standards** .
- More accurate models for stability analysis => **Improved Reliability**
- More accurate calculation of system operating limits => **Better Asset Utilization**
- Works for **Conventional/Renewable Gens, Composite Load, System External Equivalent Network**

Compliance with NERC MOD -26/27 requiring transmission planners & operators to verify generator models (turbine & excitation controls) on a periodic basis.

Model Validation

- Run **Forced** Simulation using Measurements
- Compare measurements to initial model response





Conceptual approach

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Disturbance Data

- V, f, P, Q PMU data at POI
- Network Model

Drivers

Inaccurate Dynamic Models
Reliability Standards

Calibration Report

Report estimated parameter values, confidence metrics

Model Validation

Stage I

Forced Simulation

Run Simulation Engine using Forced Simulation

Simulation Validation

Compare measurements to initial model response

Sensitivity Analysis

Stage II

Event Analysis

Determine events qualitatively different from previous events

Parameter Identifiability

Determine most identifiable set of parameters across all events

Model Calibration

Stage III

Optimization

Optimization based parameter estimation

Calibration Validation

Compare measurements to calibrated model response

MV&C Example

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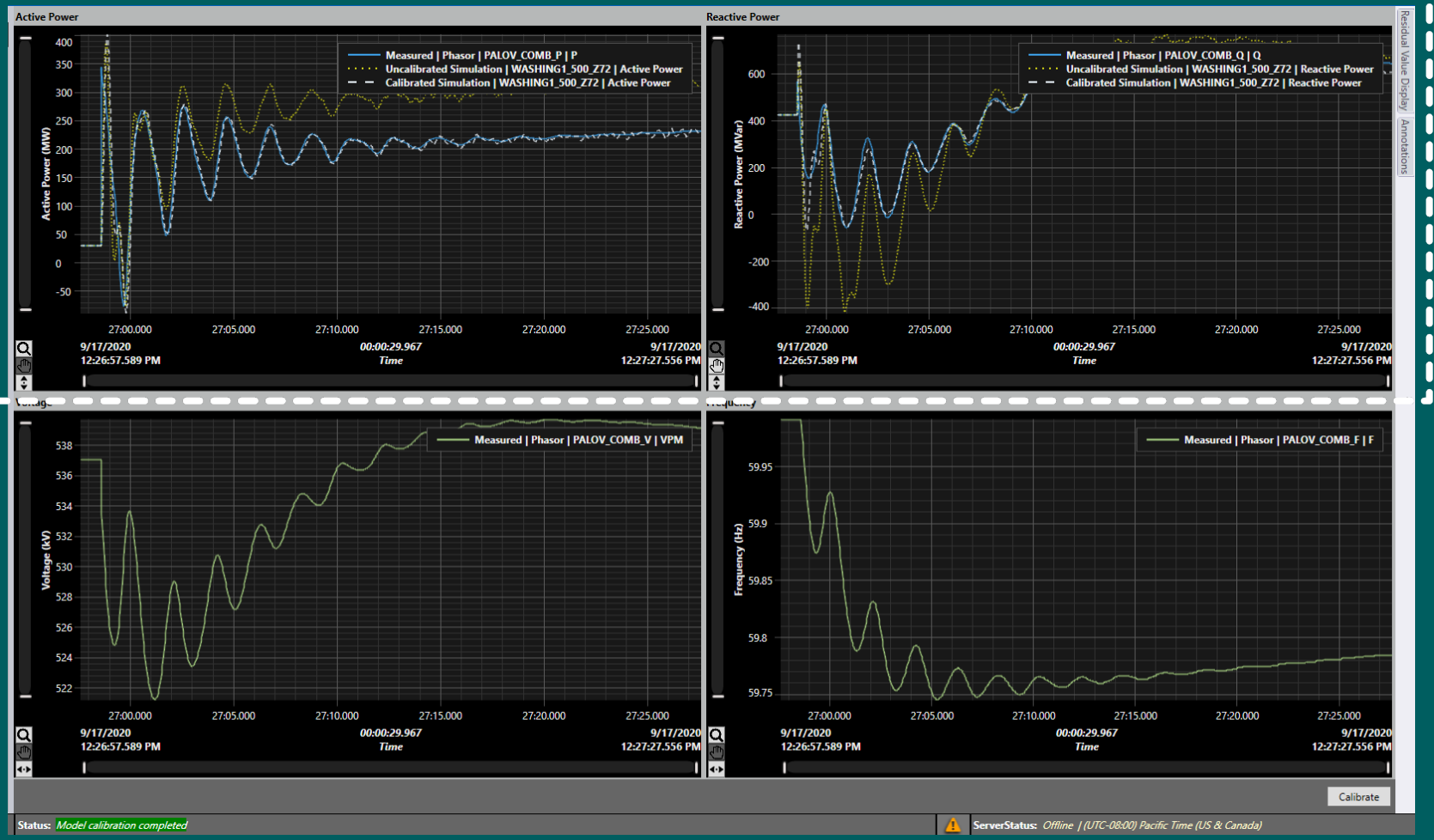
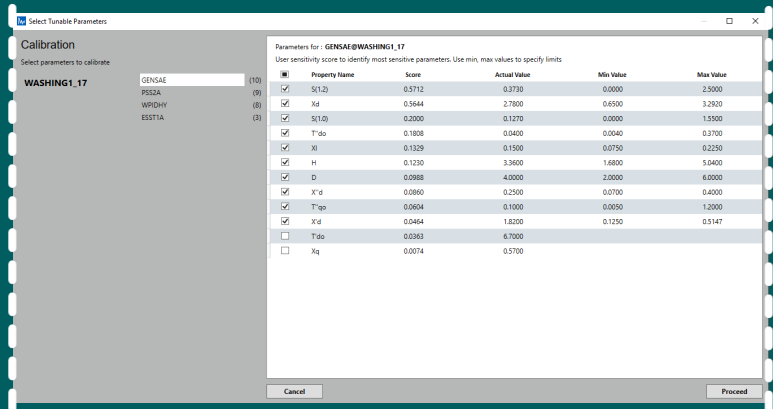
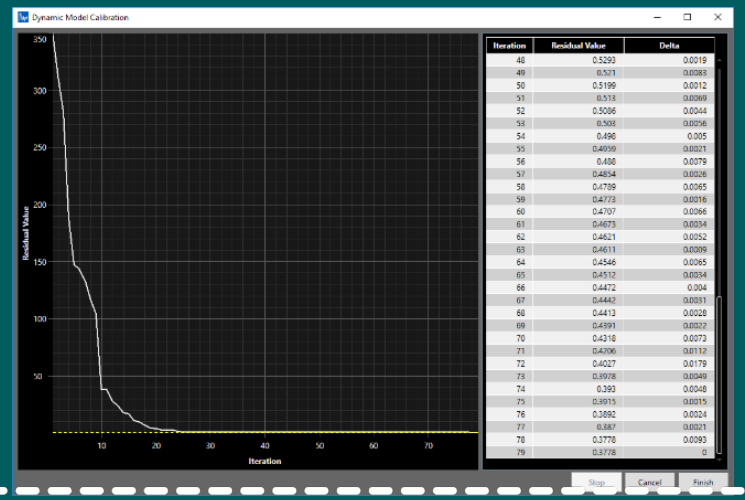
Model Verification

Model Calibration





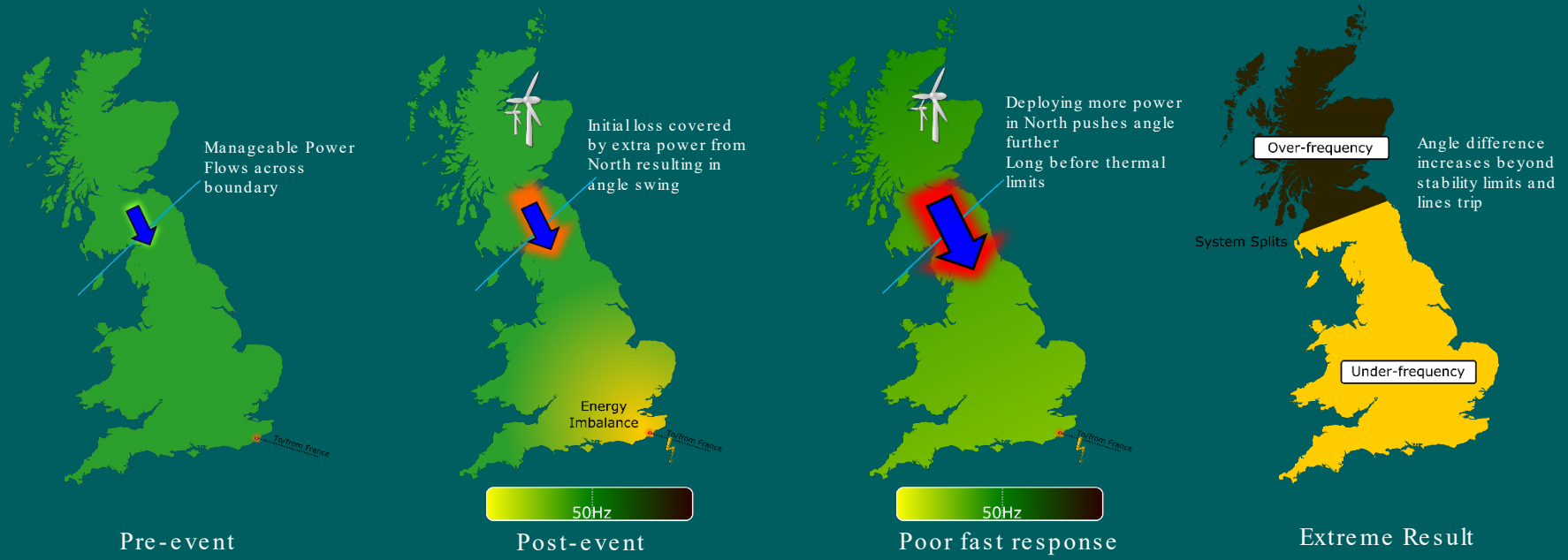


WIDE AREA CONTROL

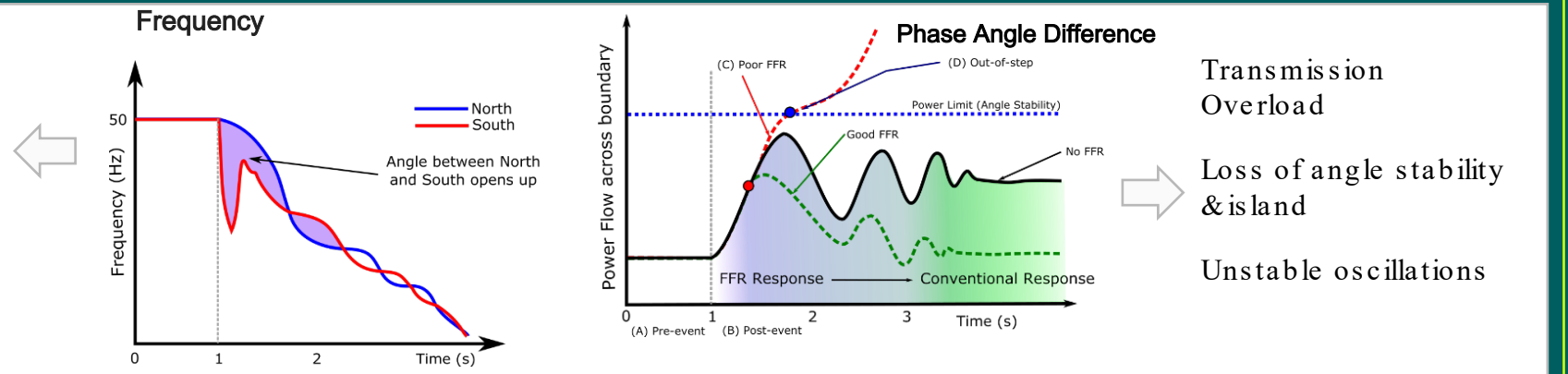
Product Offering

PhasorController	GE Power Gateway
Small form factor required within capability of device (e.g. distribution systems, DSR)	Large Form factor not an issue
Longer MTBF (if customer requirement)	Shorter MTBF (long MTBF not required)
SPDC for small scale (small number of PMUS, limits aggregation, outputs and standard data rates)	SPDC for larger number of PMUs, greater outputs from PDC, higher data rates or data manipulation (e.g. 100Hz or virtual phasors)
Control solutions which do not require high effort and utilise standard EMS/WAMS protocols	Advanced control which required high computation engine or intensive protocols (SV)
Simple, fast deployment, easily user configurable	Turnkey solutions, advanced operators/users, high levels of integration to existing substation equipment
Product diversity	

Result of Fast Response in Wrong Location



Pre-event | Post-event | Poor fast response | Extreme Result



DER Loss of Mains trips - cascade

Transmission Overload

Loss of angle stability & island

Unstable oscillations

Solution

Inject a step of power in the right area to reduce stress

…In proportion to the event

…Within ~1s to avoid load-shed

…Without risk of unstable oscillation

…Using existing resources

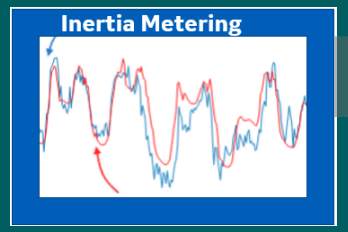
GE Vernova 's End-to-End Solution for Effective Inertia Management

Control Room

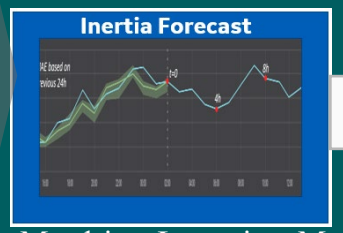
Zonal Control

Inertia Metering & Forecasting

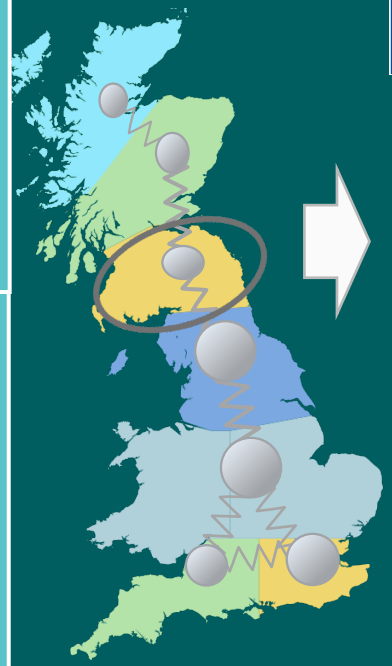
Control Room Operational Awareness



Pure WAMS sensing

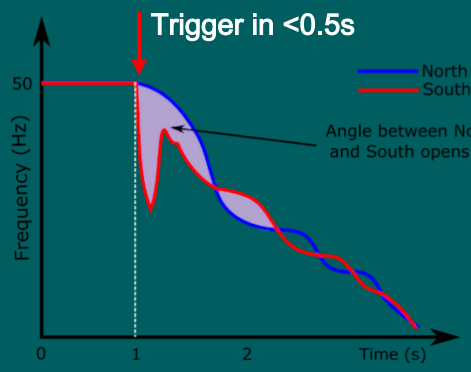


Machine Learning Model from Grid Analytics

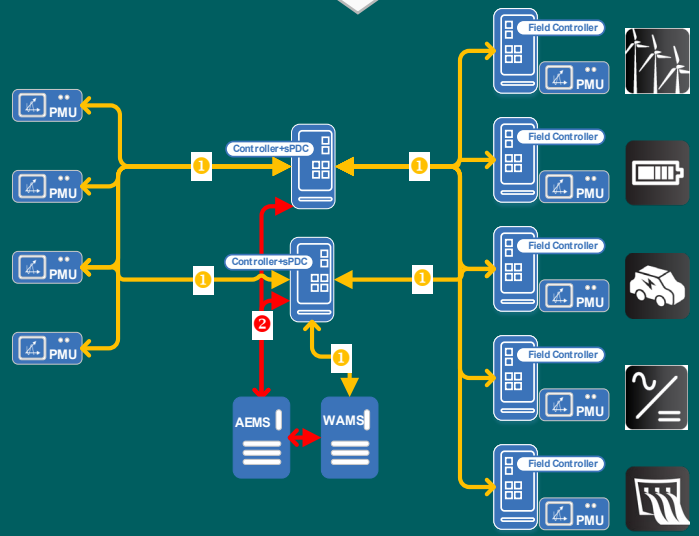


Locational Fast Balancing Response

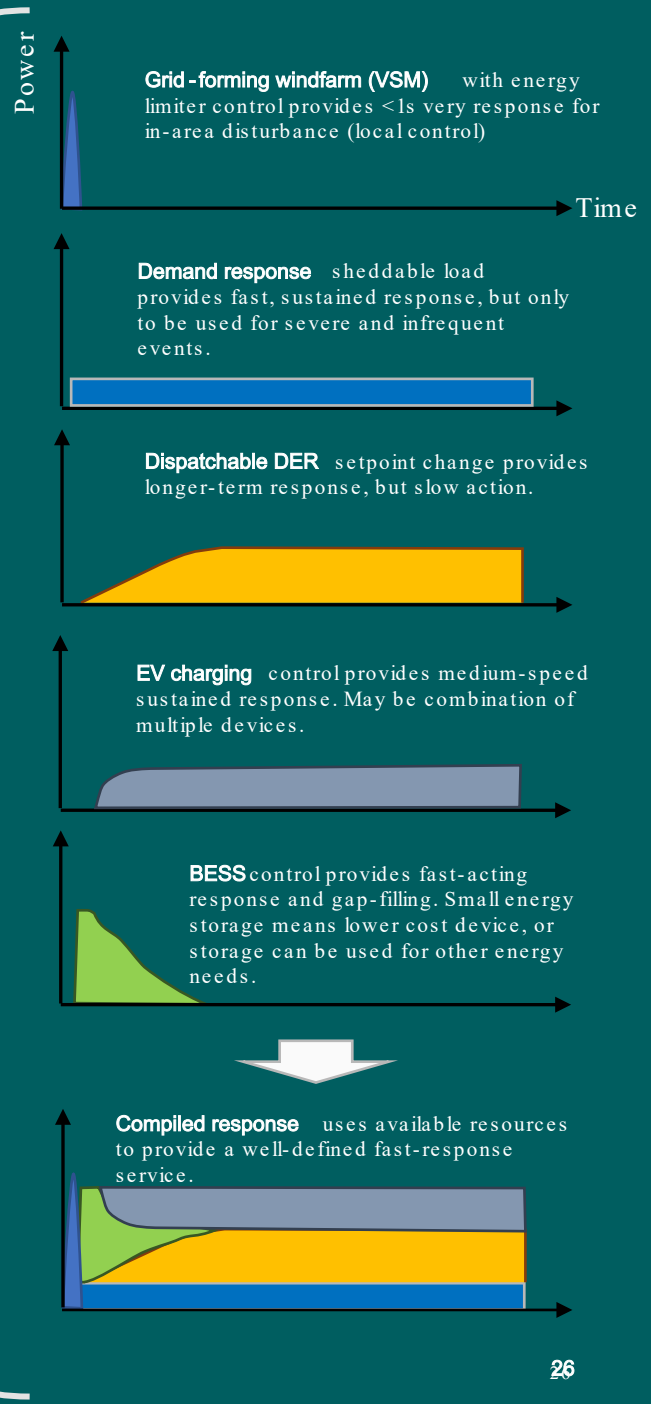
Automated Stability Support Services



Detect &extract size of disturbance



Fast dispatch of available resources to match event trigger



Distribution Blackstart

Challenge

- Blackstart-capable central generation is retiring, so the conventional service is compromised and remaining resources expensive
- Fossil fuel generation remains in service to provide blackstart, slowing the energy transition
- Resilience of system reduced due to reduced blackstart service availability
- Emerging regulatory standards for blackstart require a new approach

Solution Highlights

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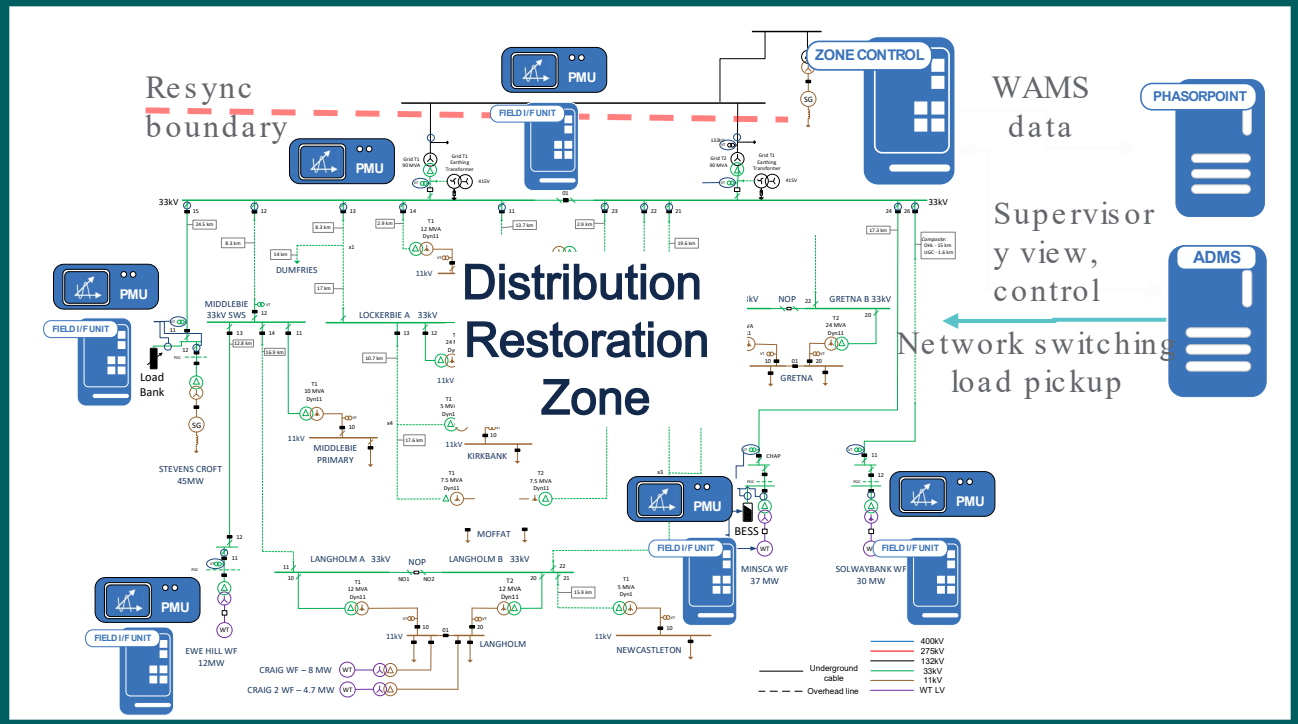
- Energise &run distribution network island with multiple DERs
- Merge fast &slow balancing, frequency droop, resync control capabilities
- Customers restored early
- Island can run as long as required
- Restoration zones can be connected
- Transmission energised from distribution restoration zone
- Resilience improved, blackstart service cost reduced
- Control infrastructure available for other services



Distributed Restart
Balancing an Island with Diverse Control Resources

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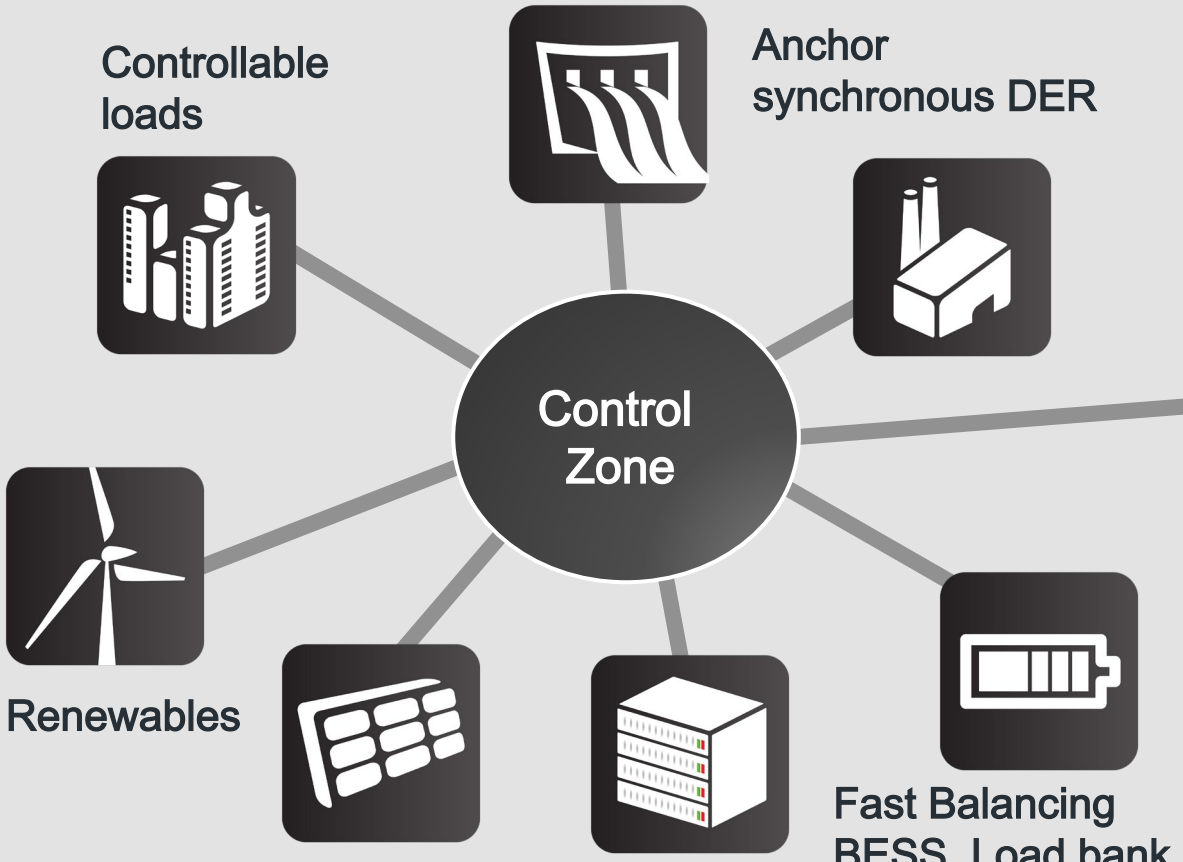
Innovation Project

ELECTRICITY RESTORATION ZONE



Blackstart service

Zone self-balances
Frequency stabilised
Controlled reconnect

Fast balancing service

Aggregated fast power response
Trigger/inhibit based on location

TRANSMISSION SYSTEM

Blackstart Progression

- Energize out to transmission
- OR Resync to live transmission
- OR Synch to neighboring zone

Grid-connected fast balance

- Step-change of power from zone
- Delivers single block of response
- Trigger <0.5s by system event
- Improves grid stability

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ROADMAP

GridOS WAMS roadmap &opportunities

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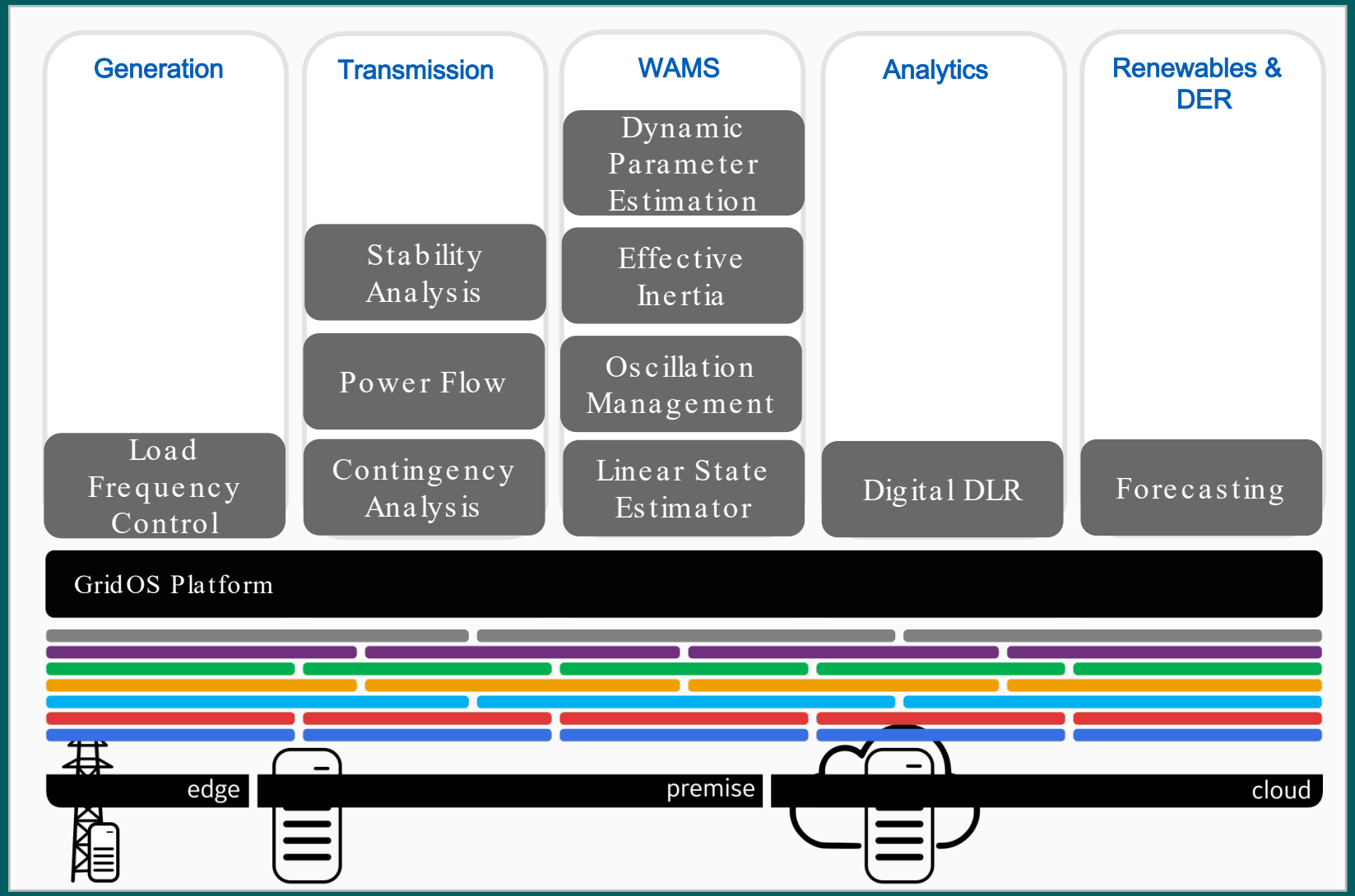
New opportunities in 2024

By adopting any GridOS application, customers get ready to receive any released GridOS application due to its common design and native integration.

Both GridOS EMS and GridOS WAMS are based on the CIM16 model of the network.

Customers who upgrade to GridOS WAMS and adopt Linear State Estimator will be able to feed licensed GridOS EMS applications with LSE results obtaining a fully redundant EMS based on PMU/WAMS technology.

The first GridOS EMS applications are becoming available in 2024, and the full GE EMS apps will become GridOS native in the coming years

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