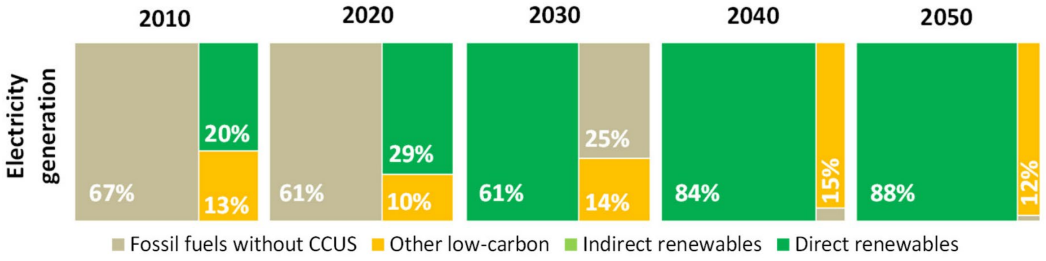
GE WAMS

Key Industry Drivers

Fast Renewable Integration

- ✓ 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)

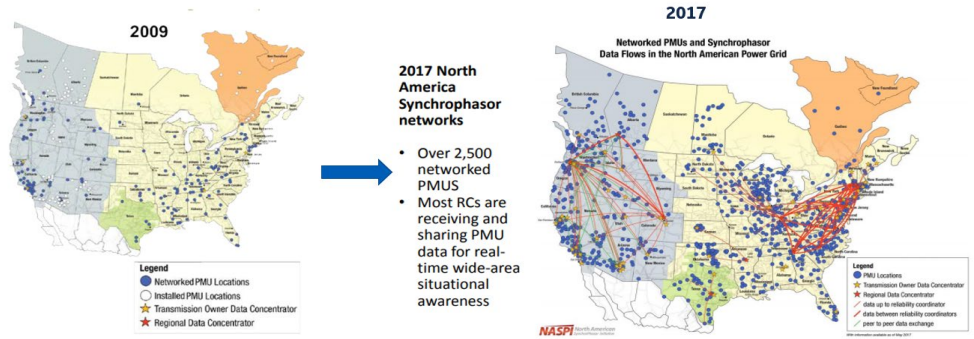


Source: Net Zero by 2050 International Energy Agency

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.

Changing Landscape



200 Sensors → 2500+ Networked Capable Devices

Future-Proof

Scalable

- ✓ Scale to manage the torrent of data
- ✓ Composable, bring together views, functions and data that may not be traditionally combined

High Performance

- ✓ Cloud-native, on-prem and hybrid
- ✓ Ready to be integrated to Energy Management and Distribution Management Systems

Integrated

GE Digital

Digital Energy

Smaller Total Cost of Ownership

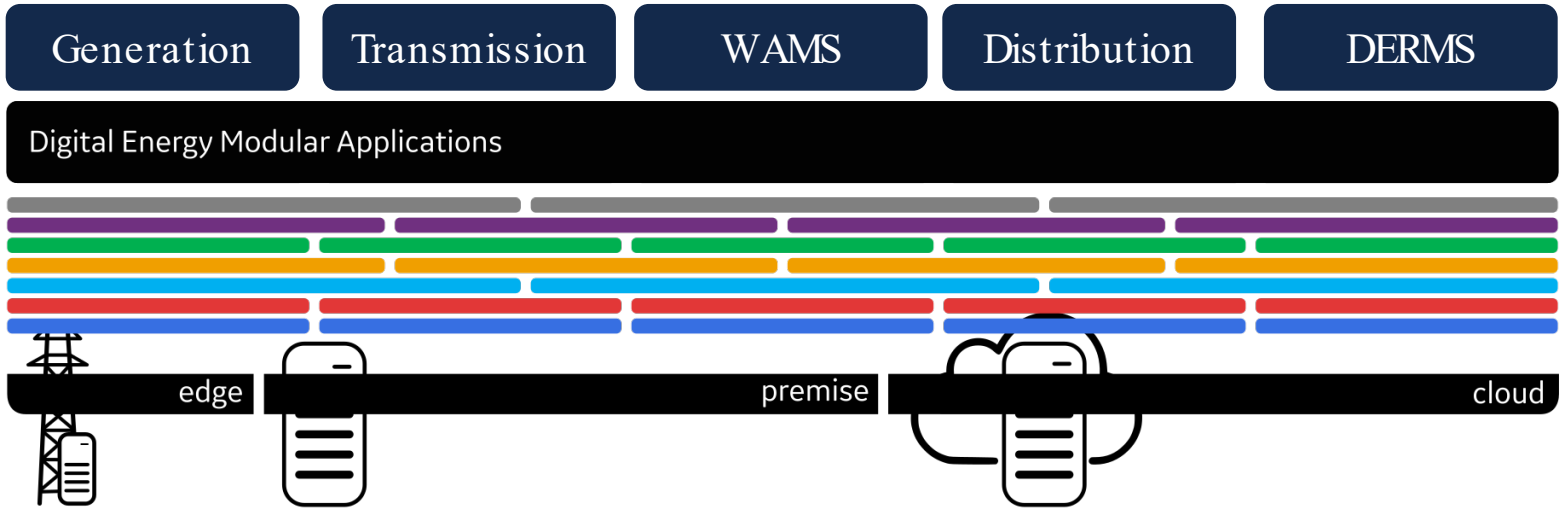
- Leverages Continuous Integration & Continuous Deployment
- Full Test Automation

Just the right bits

- Natively modular solution

Future proof

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



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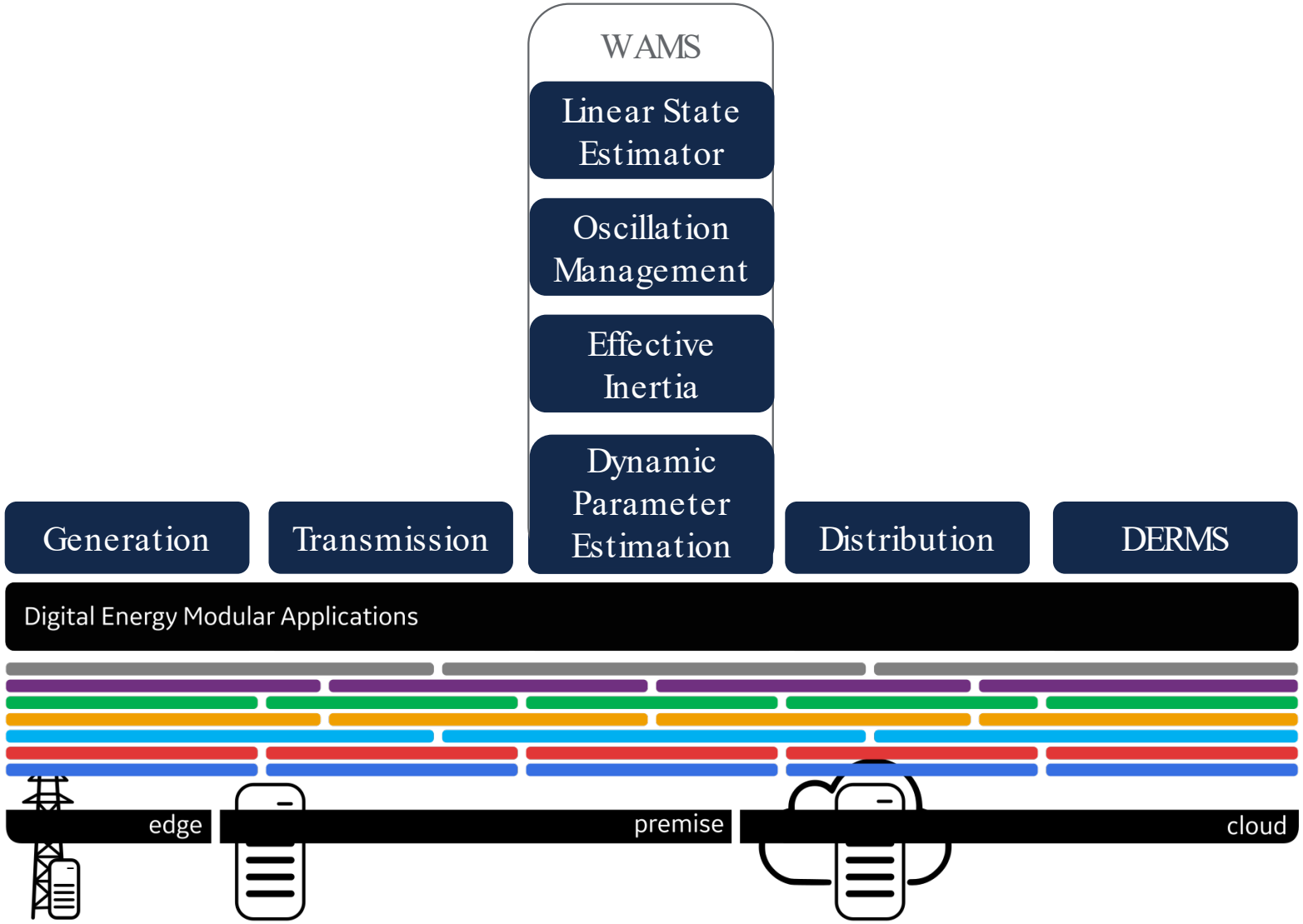


GE Digital

Digital Energy

User Interfaces and Experience

Reusable components across use-cases

Consistent and uniform experience

Optimized workflows

GE Digital

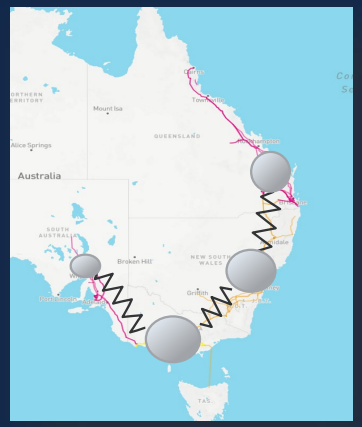
Linear State Estimator

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

Oscillation Stability Management



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.

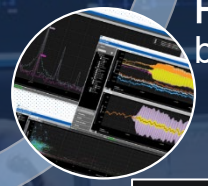
2021 IEEE-NASPI Oscillation Source Location Contest - GE 1st Place Winner!

A Worldwide Contest! –60+ teams registered

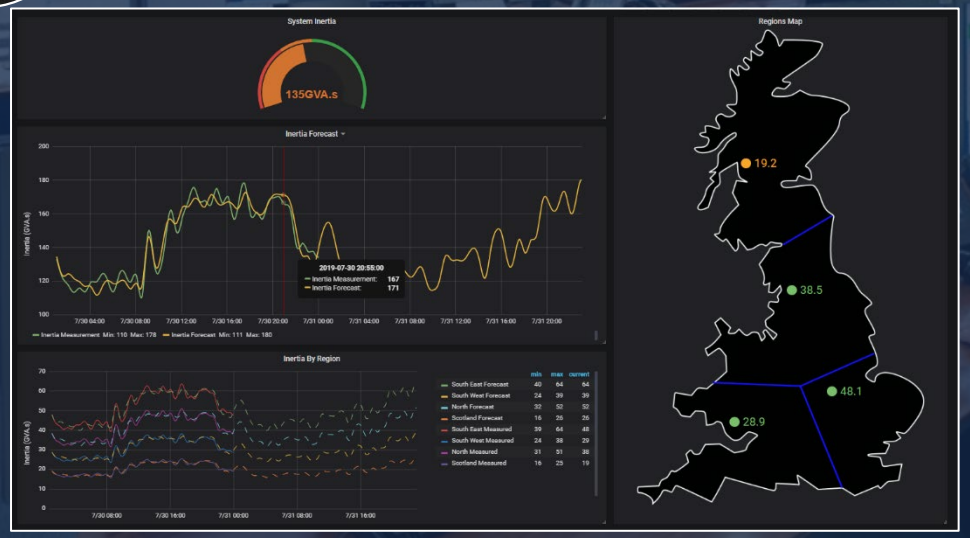
Effective Inertia

The **Inertia Challenges**

Measuring Area-Inertia with WAMS



Forecasting area-inertia
by machine learning



Inertia Measurement and Forecast

Solution Highlights

Outcome

- 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

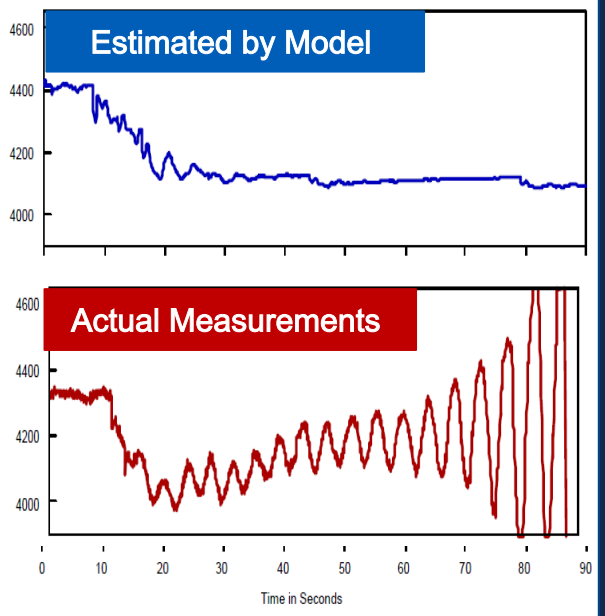
Dynamic Parameter Estimation

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

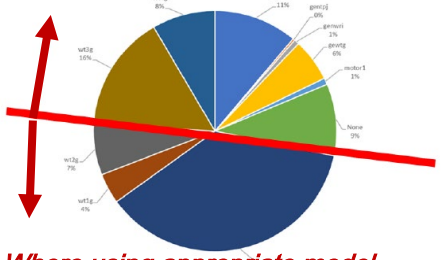
(US Western Interconnection August 10th, 1996 Blackout)



Inverter Based Resources

(WECC Base Case Review, August 2020)

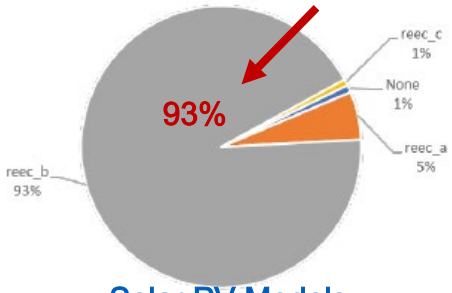
Everything above the line has incorrect, obsolete or no model…



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

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 & operator to verify generator models (turbine & excitation controls) on a periodic basi

Thank you