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Scalable Implementation and Deployment Of RTLSE and RTLSE-based Contingency Analysis for Transmission Systems

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Outline

- ✓ Introduction
- ✓ Real-time State Estimator
  - ✓ Overall view
  - ✓ Scalability and Robustness
  - ✓ Results and displays
- ✓ RTLSE complementary tools
  - ✓ Contingency Analysis
  - ✓ Optimal PMU Placement
- ✓ Conclusion

INTRODUCTION

Landscape Change- Need for Scalability and High-Performance Platforms

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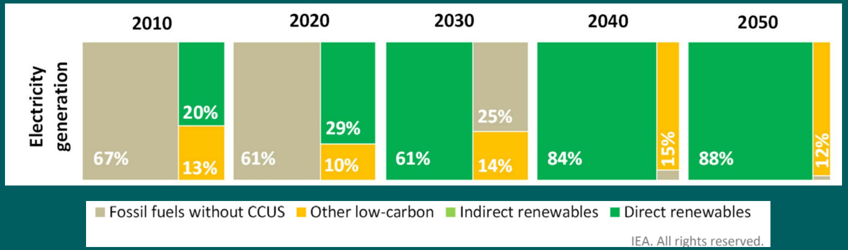
Higher Renewables Penetration

- ✓ 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)

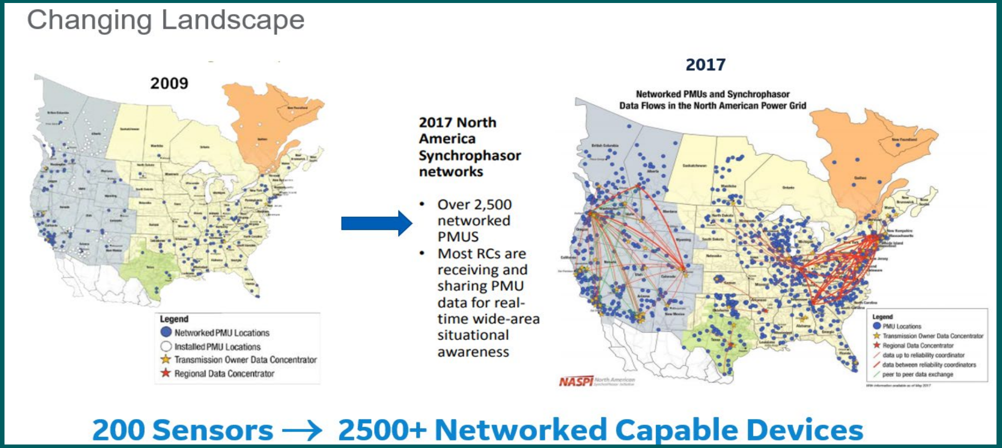


Source: Net Zero by 2050 - International Energy Agency

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.



There is a need for application with:

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

REAL-TIME STATE ESTIMATOR

Real-time Linear State Estimator

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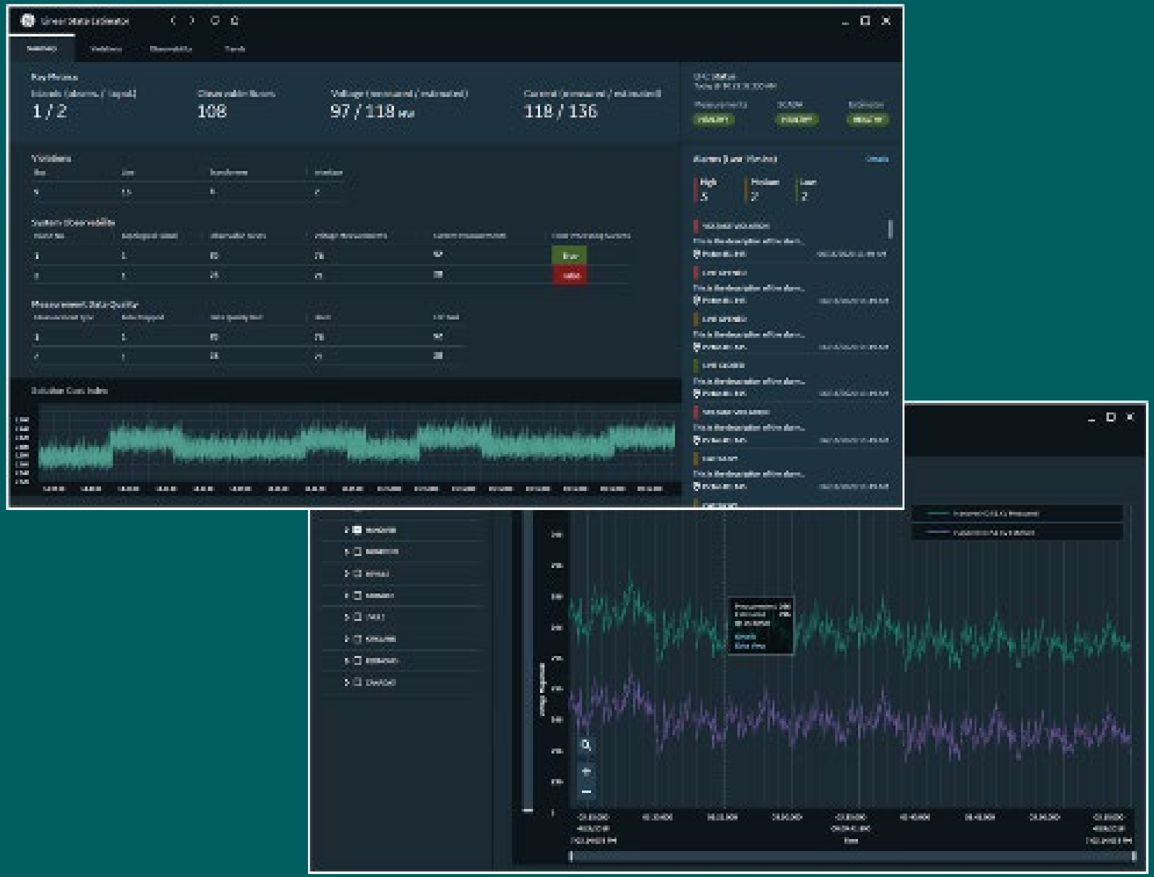
Comply with **NERC IRO-008-2 R4 and TOP-001-4 R13** as **back-up** to existing **EMS State Estimation**.

- 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

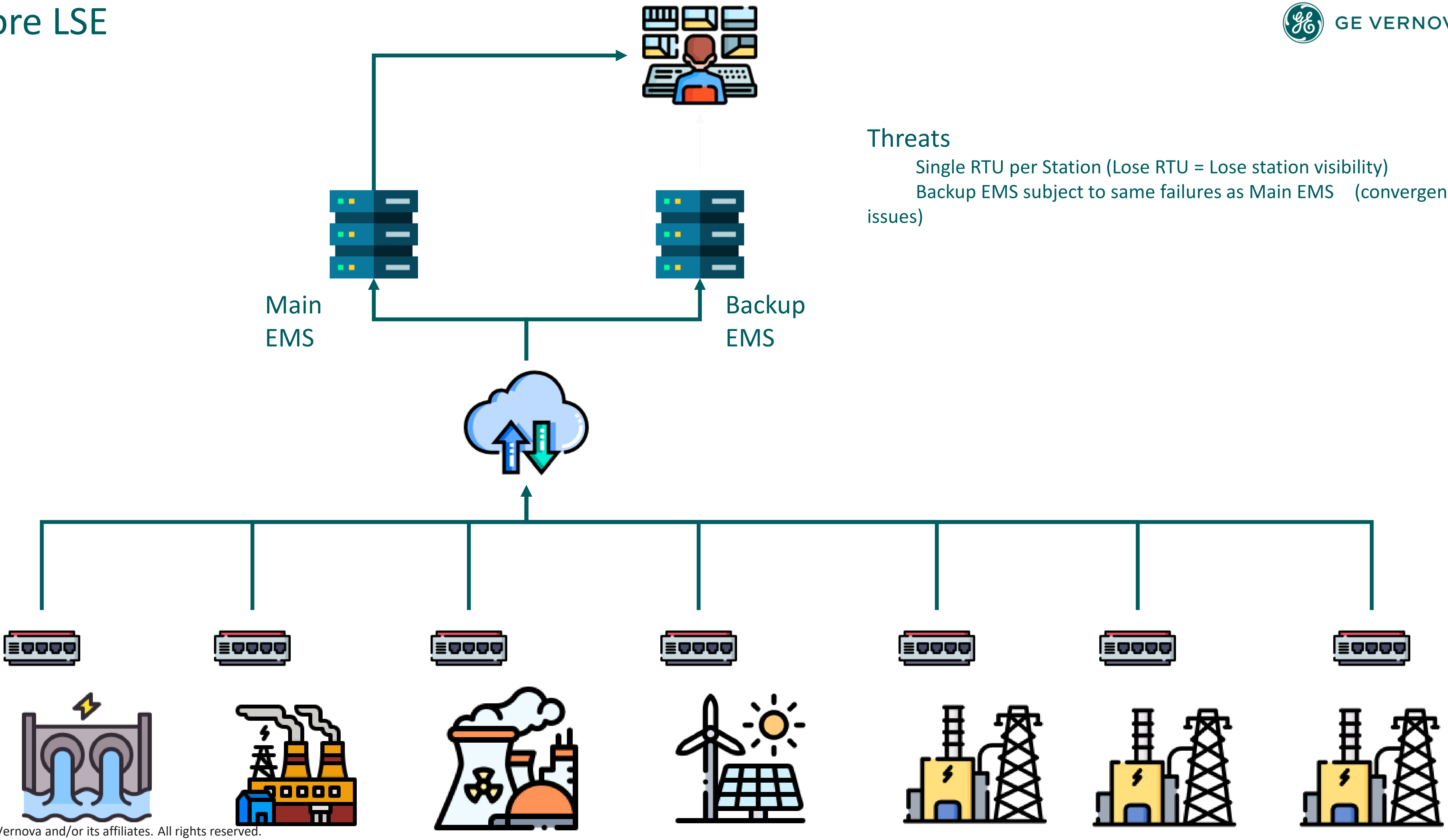


LSE versus Classic SE

Features	Linear State Estimator	Traditional State Estimator
100% Convergence	✓	
Linear Solution	✓	
Iterative Solution		✓
Sub-second results	✓	
Time synchronized measurements improving solution quality	✓	
Alternative data source for CA and Dynamic Stability Assessment	✓	
Official data source for CA and Dynamic Stability Assessment		✓

- Approximately 30~40% PMU coverage needed to achieve observability
- LSE can be restricted to observability pockets or grid voltage levels for lower PMU coverage

Before LSE



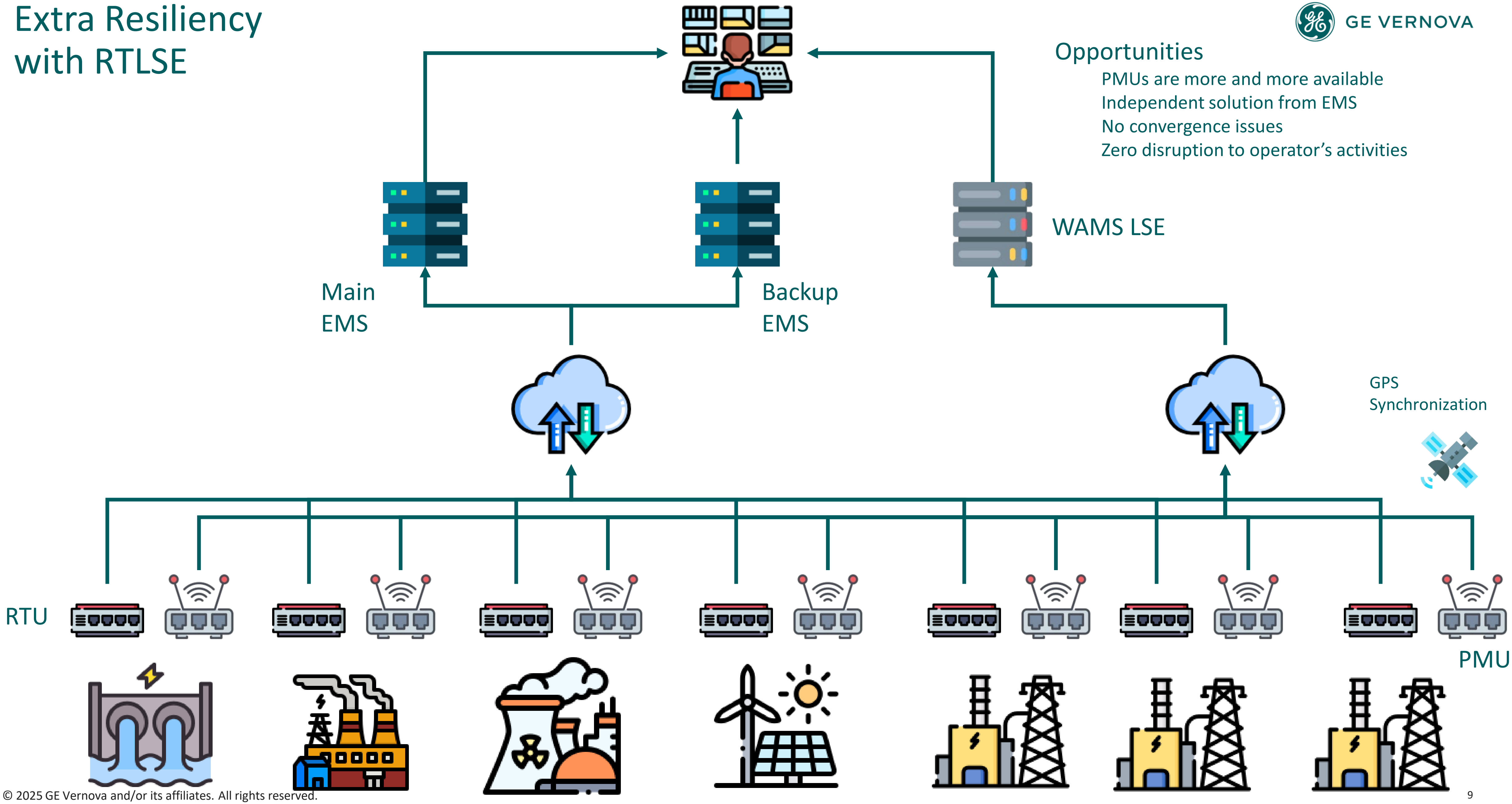
Threats

Single RTU per Station (Lose RTU = Lose station visibility)

Backup EMS subject to same failures as Main EMS (convergence issues)

Extra Resiliency with RTLSE

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



LSE Solution Workflow

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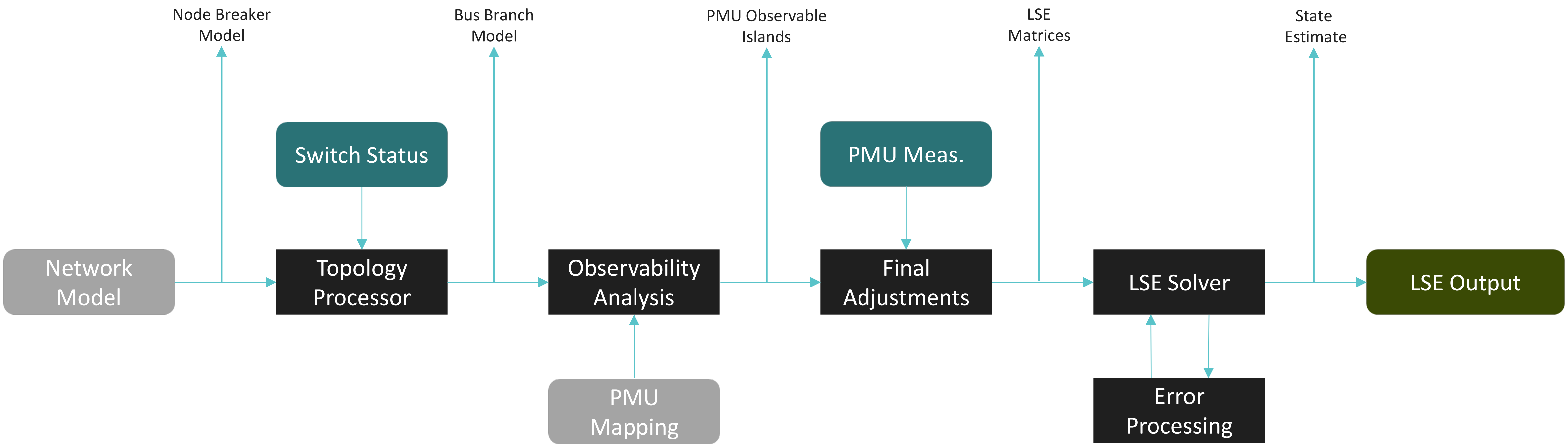
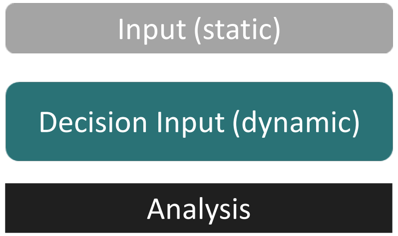


Generic LSE Solution Workflow



- ✓ Utilizes phasor measurements from PMUs
- ✓ Linear Problem, non-iterative solution
- ✓ State estimates obtained at sub-second intervals

Scalability and Robustness

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Architecture

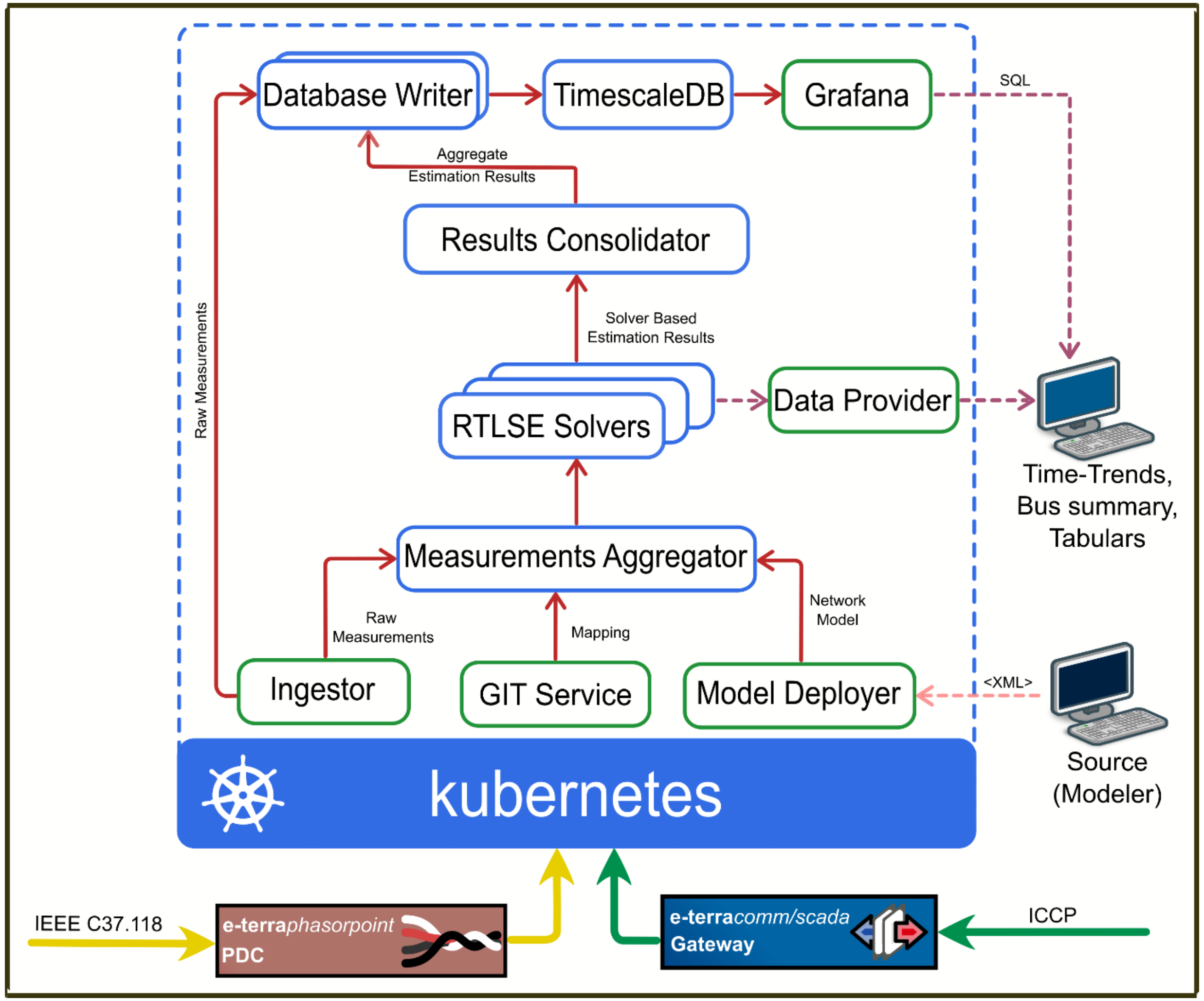
- Solution offered as a set of microservices
- Orchestration of services is handled by Kubernetes
- Horizontally scalable, individually upgradable
- Parallelization

Highlights

- Speed : Keeping up with real-time PMU streaming rate
- Robustness : Efficient and thorough error processing
- Backup to EMS classic State Estimator

Performance:

- Successfully validated sub-second performance with large-scale utility model.
- Deployed (and in process of deployment) for multiple customers
- Parallelization- Scale up LSE solvers to keep up with increasing PMU deployments
- Different Run-Time Optimizations



RTLSE Architecture

RT-LSE Results (major US ISO)

PMU Datasets

Three datasets were created based on provided PMU data –

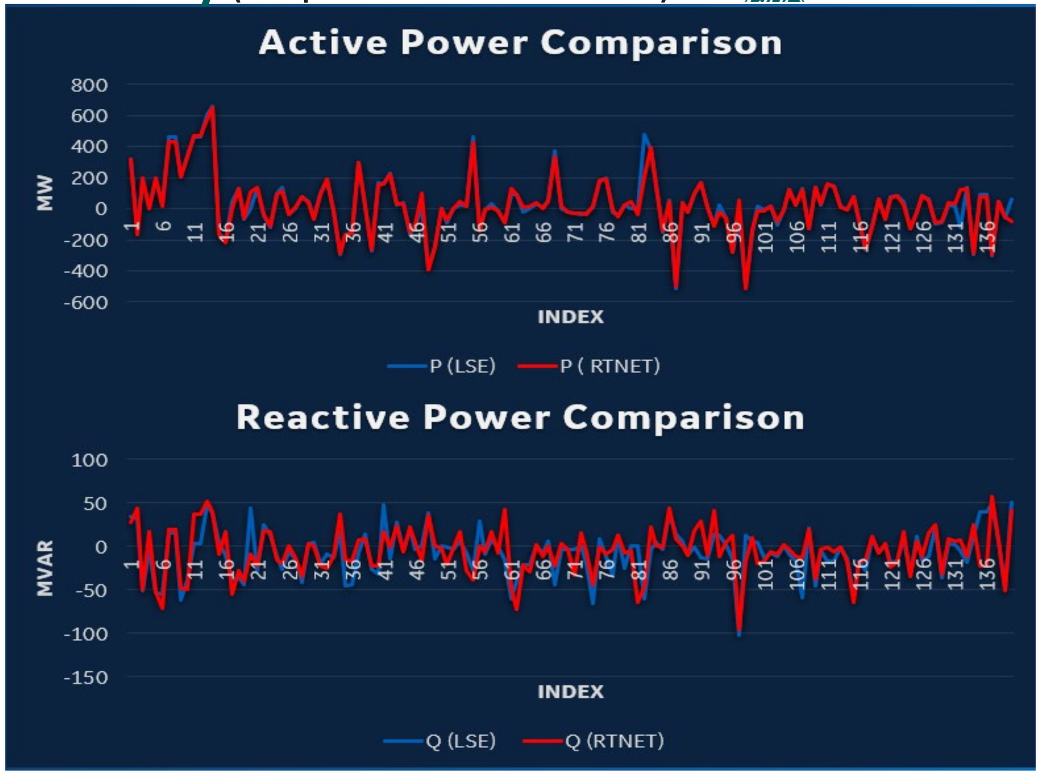
- **Set A:** PMU Data As Is
- **Set B:** Cleaned data after removing 14 phasors with highest number of gaps
- **Set C:** Subset of data (timestamp based) with no data quality changes

Performance

Dataset	Set A	Set B	Set C
No. of input phasors	396	382	396
Total Time	783.335 (s)	520.460 (s)	297.115 (s)
Avg. Time / Cycle	43.542 (ms)	28.930 (ms)	16.515 (ms)
Avg. Cycles / Second	22.966	34.566	60.551

Machine Specifications → Operating System: Windows 10 Pro, Processor: Intel® Xeon ® E-2176M CPU @ 2.70 GHz 2.71 GHz, Installed Memory (RAM): 64.0 GB

Accuracy (Comparison of LSE with EMS SE)



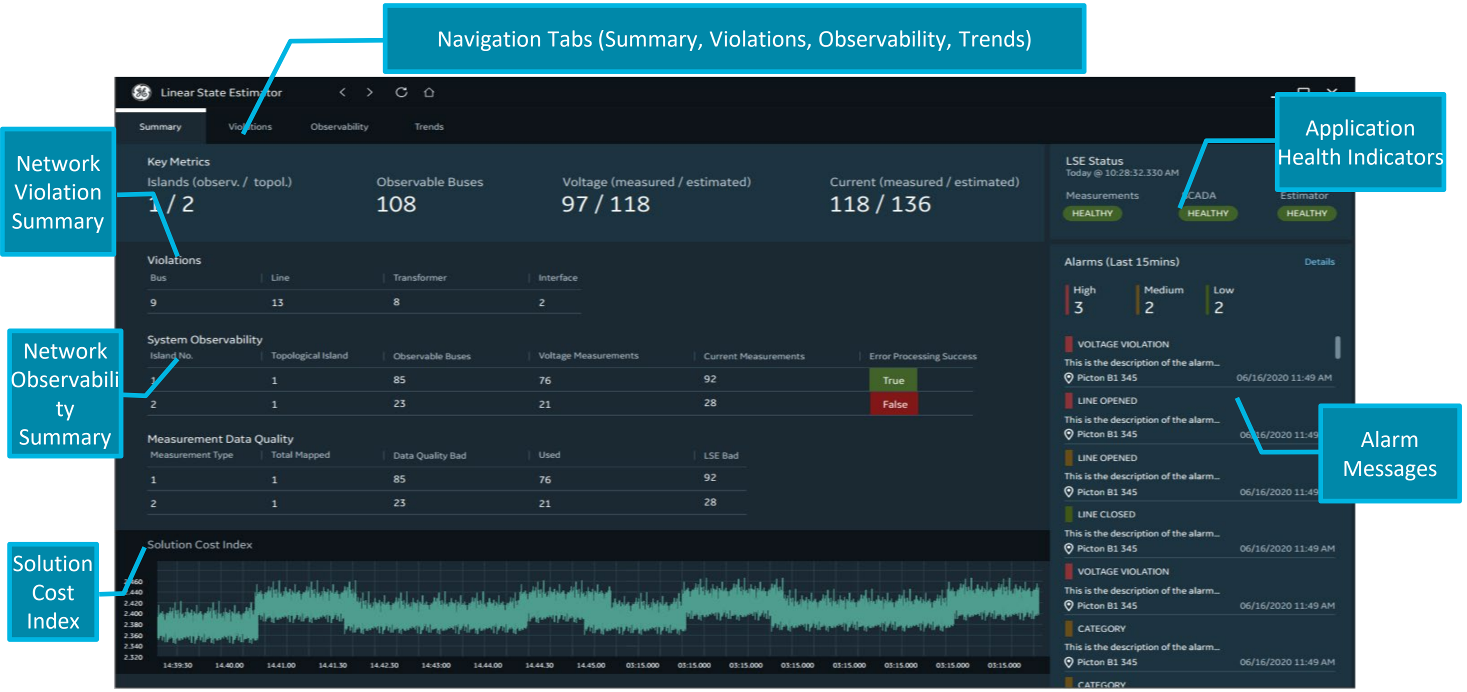
Customers with RTLSE in their GridOS WAMS Portfolio:

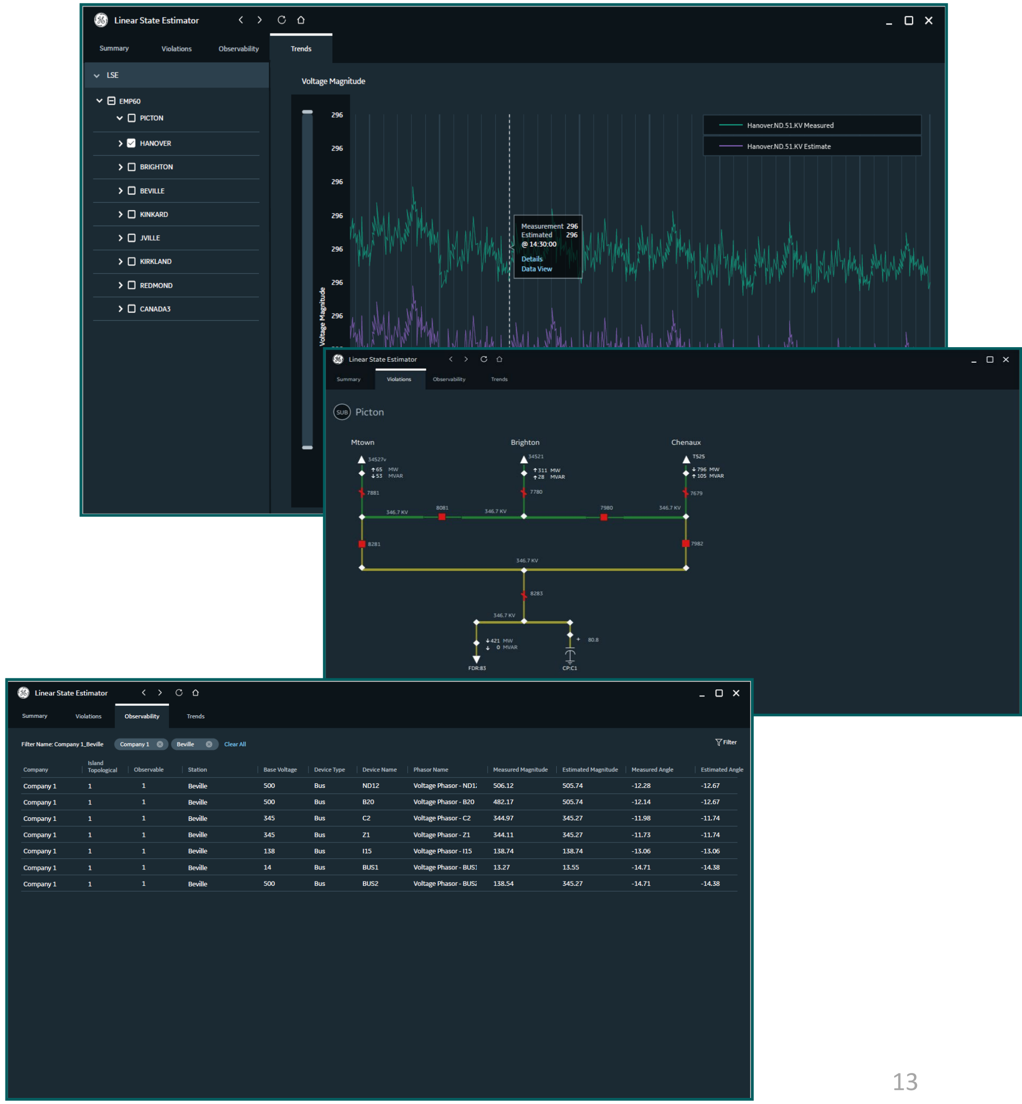
NESO National Energy System Operator

elering

FPL

LSE Displays





RTLSE COMPLEMENTARY TOOLS

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RT-LSE Based Contingency Analysis

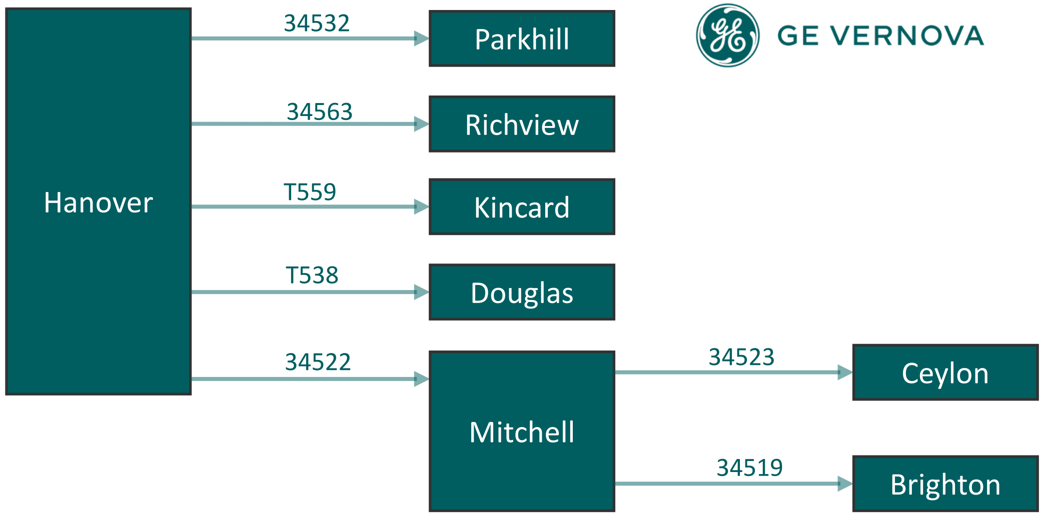
Key Challenges

- Limited PMU based observability – Often, only high KV level network observable
- Leads to incomplete basecase for traditional full Contingency Analysis
- Heavy network equivalencing needed to run CA → negative impact on the quality of the solution

Solution

- Sensitivity based contingency analysis
- No need of network equivalencing
- Automatically adjusts to PMU-observable region of the network

Local Network Connectivity



Results Comparison for Contingent Line 34532

Observed Element (Line)	Pre-Contingent MW Flows	Post-Contingent MW Flow		
		RT-LSE + Sensitivity Based	Power Flow Result	Delta (%)
34563	38.71	84.35	83.9	**0.53**
T559	-324.94	-324.94	-319.7	**1.61**
T538	-185.52	-185.52	-188.1	**-1.39**
34522	-131.12	-84.91	-83.9	**1.19**
34523	96.31	121.25	122.1	**-0.70**
34519	-227.58	-206.31	-206.1	**0.10**

All flows are reported on FROM side.

RT-LSE Based Contingency Analysis

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Home › Dashboards › LODF Results

LSE - LODF

Results

LODF Results

timestamp	contingency_equip	monitored_equipment_id	pre_mw	lodf	post_mw	observable	violation_level	violation_	last_topology_run	model_version
2025-04-04 12:45:00	ddbe7d9b-89cf-4ce7-	81b10d9a-217f-4dc2-80b9-4f044a46a6	531	-0.0600	503	true	EMERGENCY_LOW	600	2025-04-04 08:45:11.	WamsCommonModel_
2025-04-04 13:21:00	81b10d9a-217f-4dc2-8	ddbe7d9b-89cf-4ce7-a855-59ae76712	-450	-0.0903	-497	true	LOADSHED_LOW	300	2025-04-04 08:45:11.	WamsCommonModel_
2025-04-04 13:21:00	81b10d9a-217f-4dc2-8	ddbe7d9b-89cf-4ce7-a855-59ae76712	452	-0.0903	405	true	UNKNOWN	0	2025-04-04 08:45:11.	WamsCommonModel_
2025-04-04 13:21:00	81b10d9a-217f-4dc2-8	d1c9f5c5-4f06-4f2e-aef3-e852921727	-195	0.0449	-171	true	LOADSHED_LOW	500	2025-04-04 08:45:11.	WamsCommonModel_

Contingency List

Contingency Elements

mrid	composite_id	name	type
81b10d9a-217f-4dc2-80b9-4f044a46a615	NEPOOL.EAST.T559.1	1	AC_LINE_SEGMENT
ddbe7d9b-89cf-4ce7-a855-59ae767122a2	NEPOOL.NORT.34532.1	1	AC_LINE_SEGMENT

Observable elements

Monitored Eleements

mrid	composite_id	name	type
072bff3f-87f7-4924-9f0c-e9293f90dfd8	NEPOOL.EAST.34591.1	1	AC_LINE_SEGMENT
81b10d9a-217f-4dc2-80b9-4f044a46a615	NEPOOL.EAST.T559.1	1	AC_LINE_SEGMENT

Optimal PMU Placement

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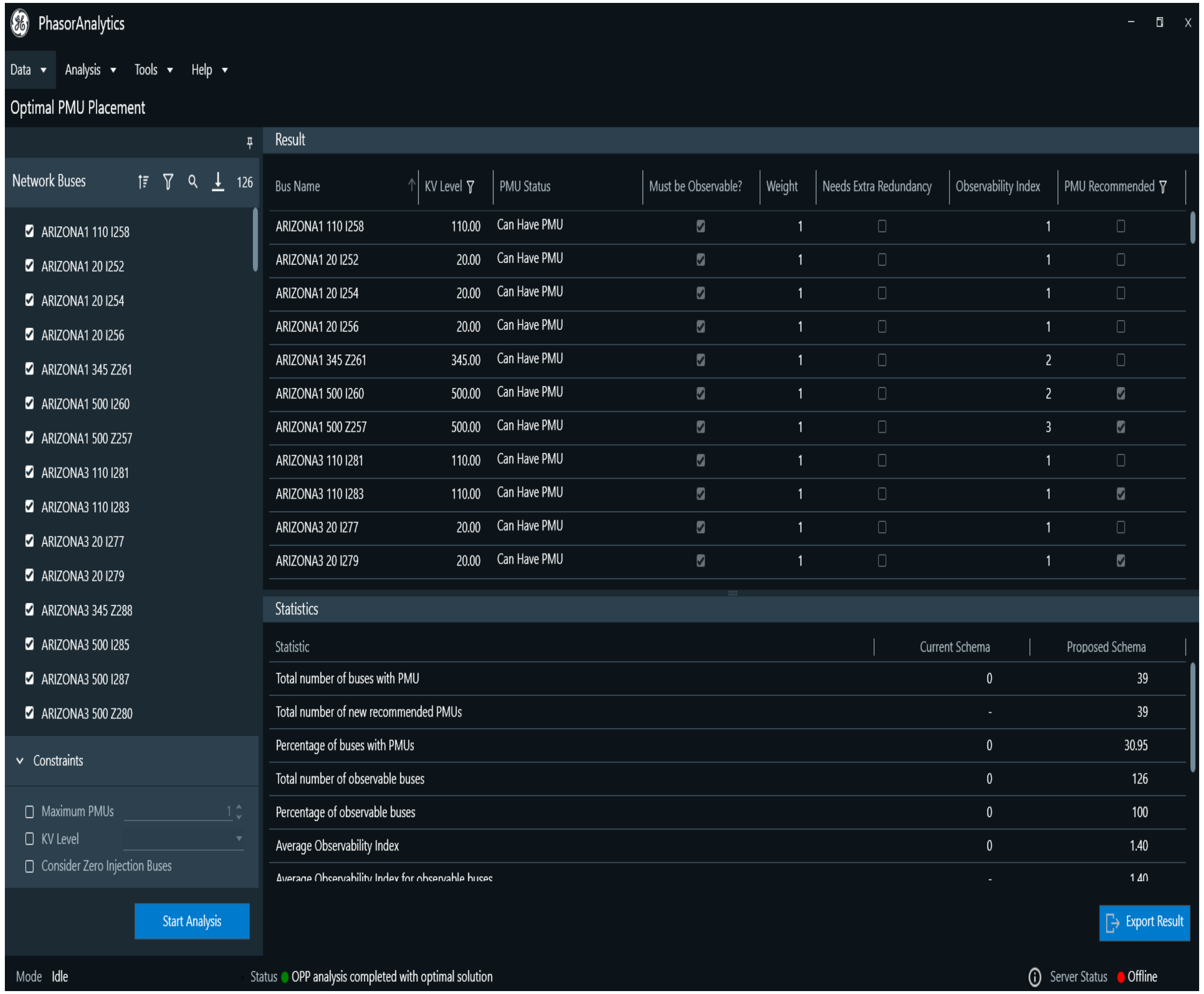
- Aims to achieve complete power system network observability with minimum number of PMUs
- Considers existing PMU placement in the solution process *(or prohibited buses)*
- Considers additional conditions like required level of redundancy for a particular network equipment
- Inputs:
  - Network Model (CIM16/PSSE)
  - Existing PMU deployment mapping information
- Output:
  - Number and location of new PMUs for complete system observability



Conclusion

- The increasing number of deployed PMUs highlights the need for scalable and high-performance applications in modern power systems.

- RTLSE can serve as a backup to the traditional EMS state estimator, offering enhanced visibility and reliability.

- A scalable and high-performance implementation of RTLSE can be achieved through a Kubernetes-based microservices architecture, enabling flexibility and efficient resource utilization.

- RTLSE has been tested and is either deployed or in the process of being deployed by various utilities and ISOs.

- Complementary tools such as contingency analysis and optimal PMU placement further enhance the value and effectiveness of RTLSE.

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THANK YOU!

QUESTIONS?