



Digital Twin + AI: Control Room of the Future

IEEE TF on Digital Twin of Large-Scale Power System

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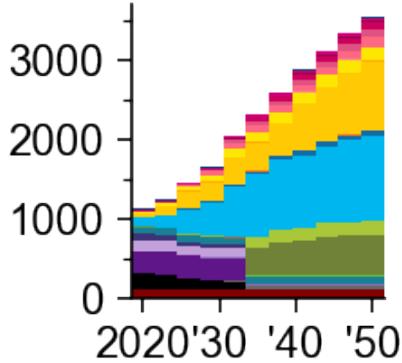
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Lower Colorado River Authority

May 2024

Control Room Decision Making

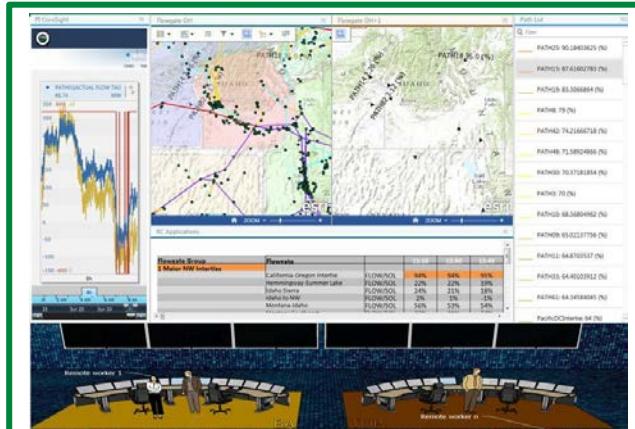
Problem Statement

Capacity [GW]



High DER penetrations and their operational impacts on the electric grid during the clean energy transition

Challenge



Lack of decision-making tools (too many displays & manual process)

Gap



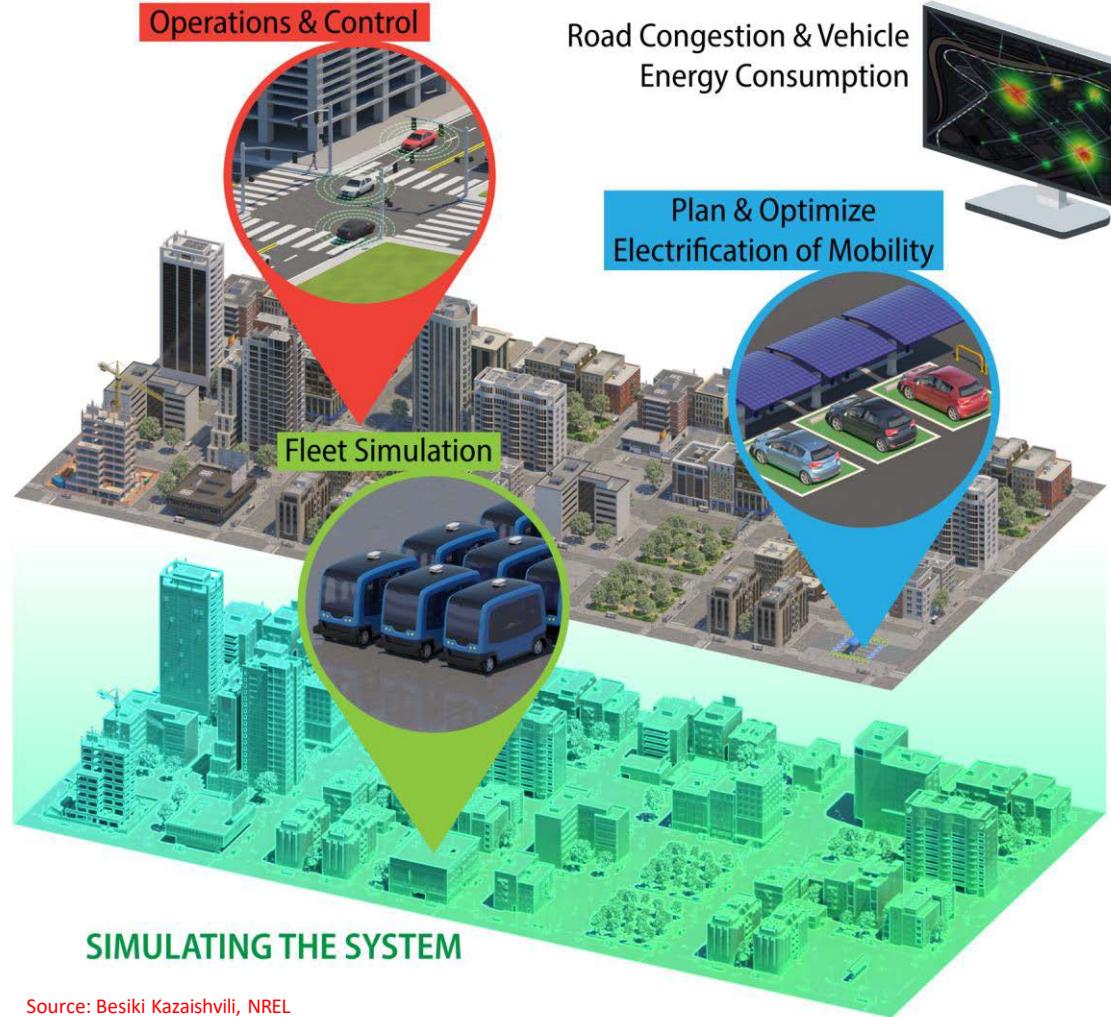
Image by DALL-E

Digital Twin + AI
=

Network Operator Virtual Assistant

Recommendation

Digital Twin in the Power Grid



Digital Twin: Decision-making support?

Simulation Real-Time Operation Remotely

Process Improvement in System of Systems (EMS-ADMS-DERMS-BTM)

Predictive Insight of Asset Maintenance

Proof-of-concept or What-if

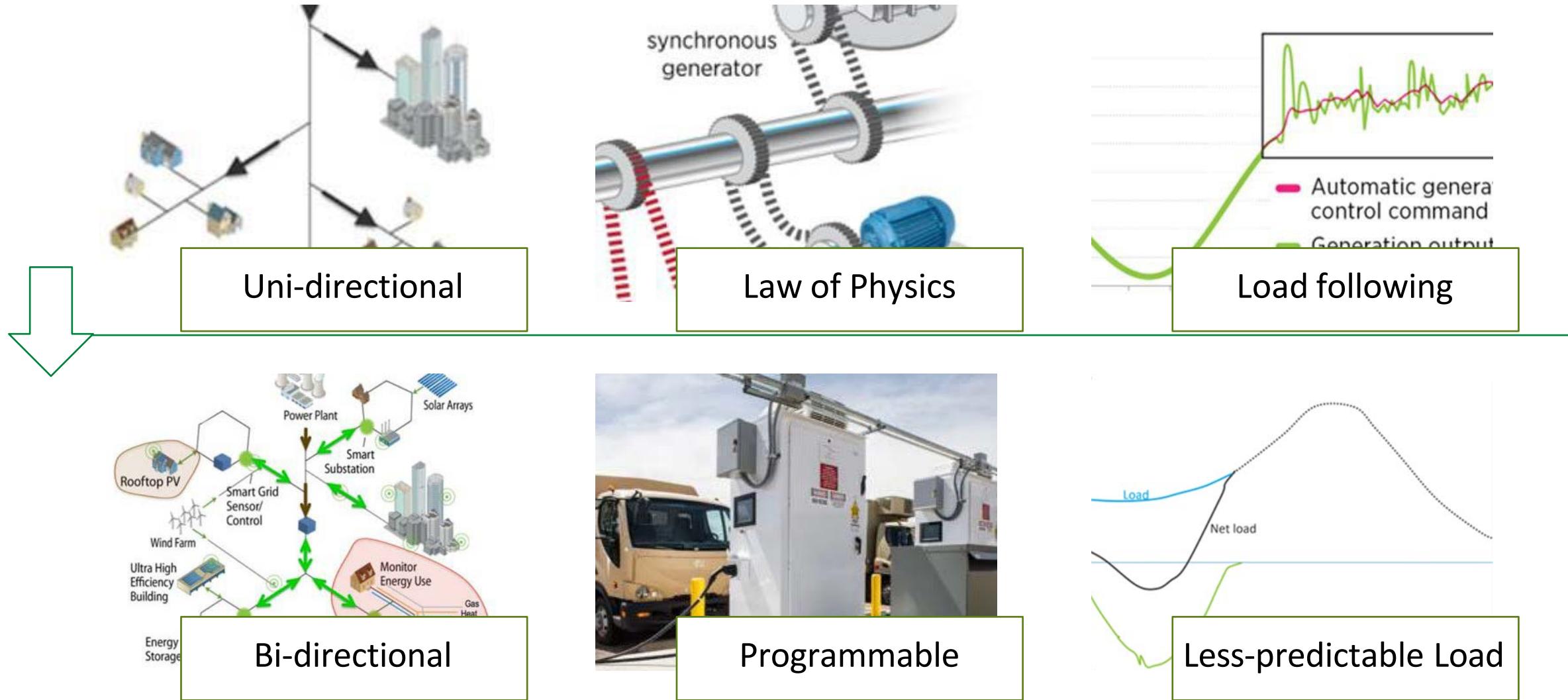
Digital Twin is a digital representation of the power network model and real-time measurement able to simulate scenarios.

ADMS: Advanced Distribution Management System

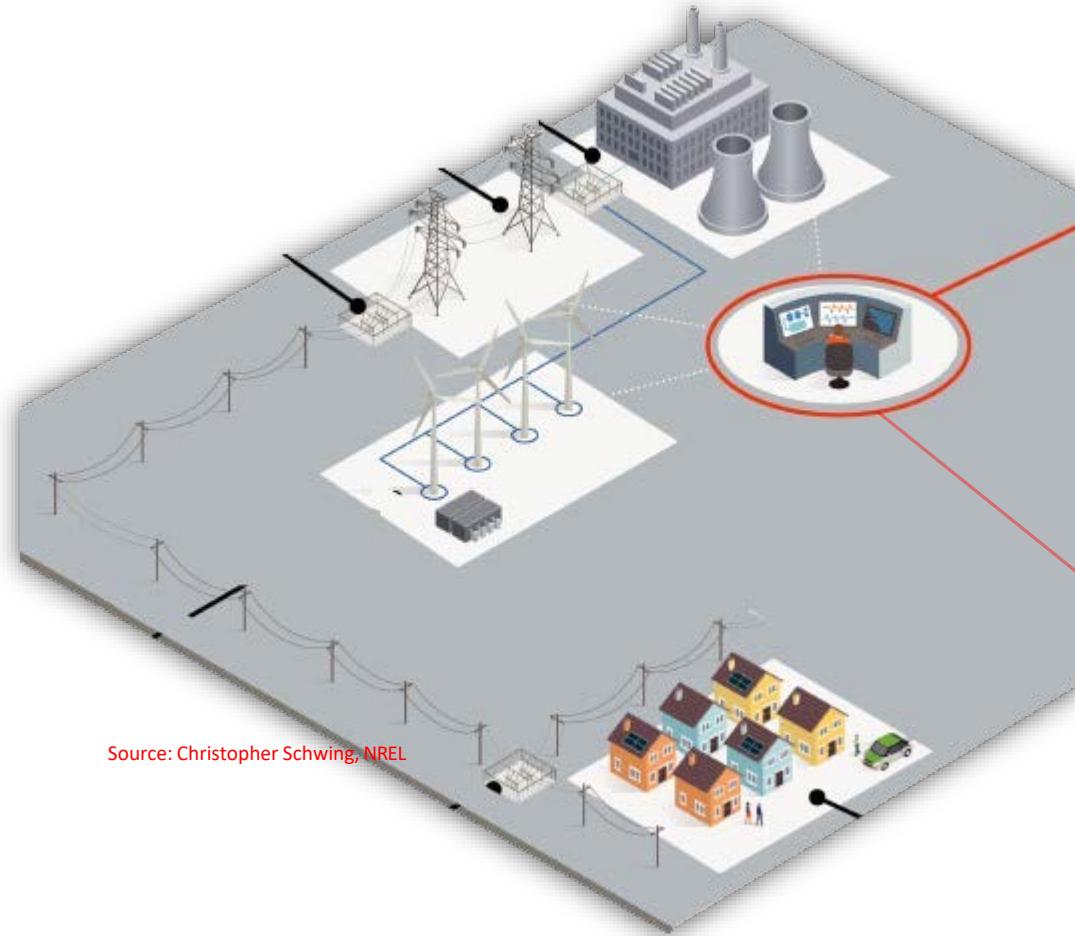
BTM: Behind-The-Meter

DERMS: Distributed Energy Resource Management System

Power Grid Trends: Distributed, IBR & Weather

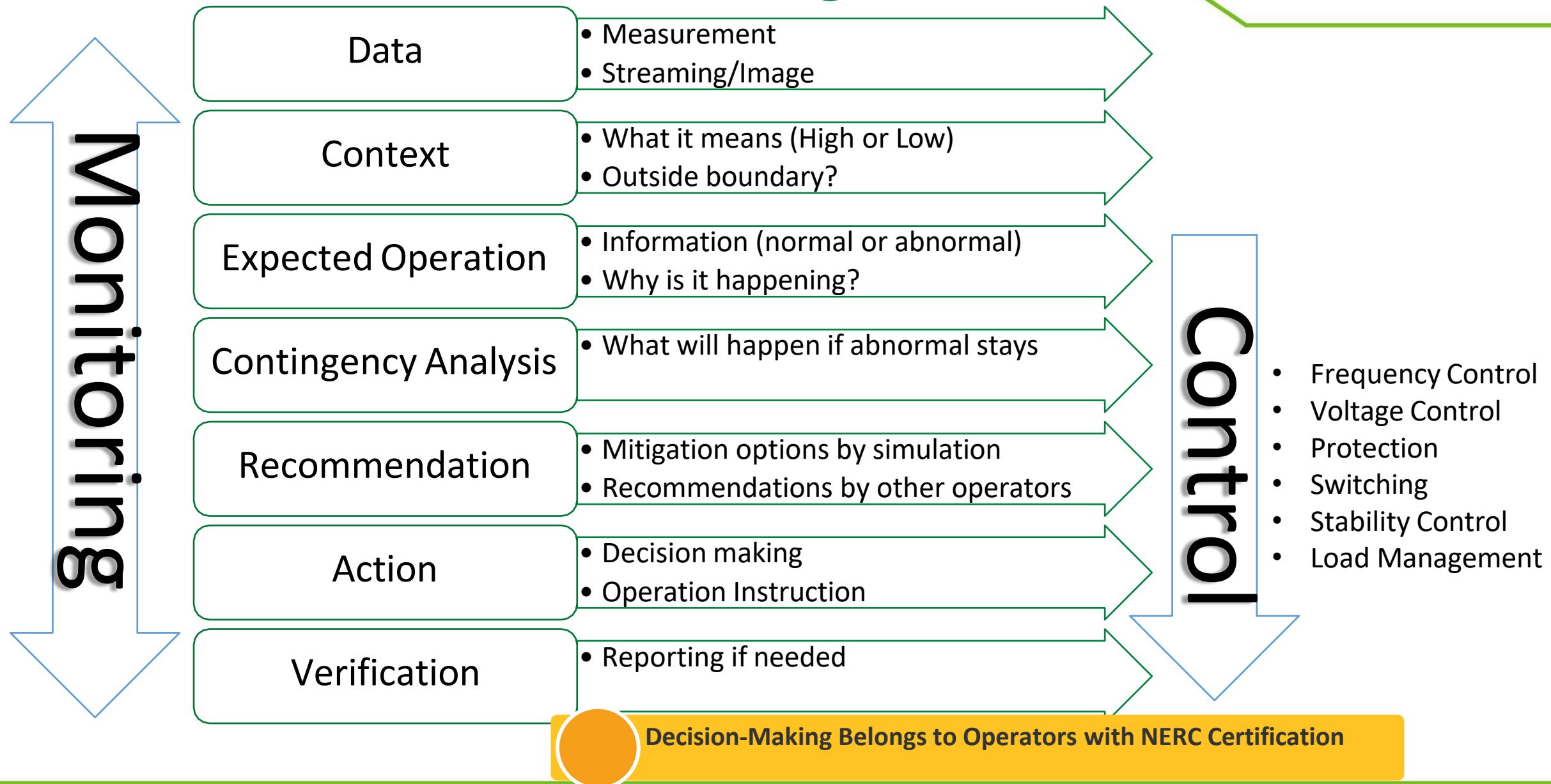


Decision making: Reliable Anytime 24 X 7 X 365



Operator must reliably balance generation & load (tug-of-war) via power line near 60Hz

Control Room Decision-Making Flow

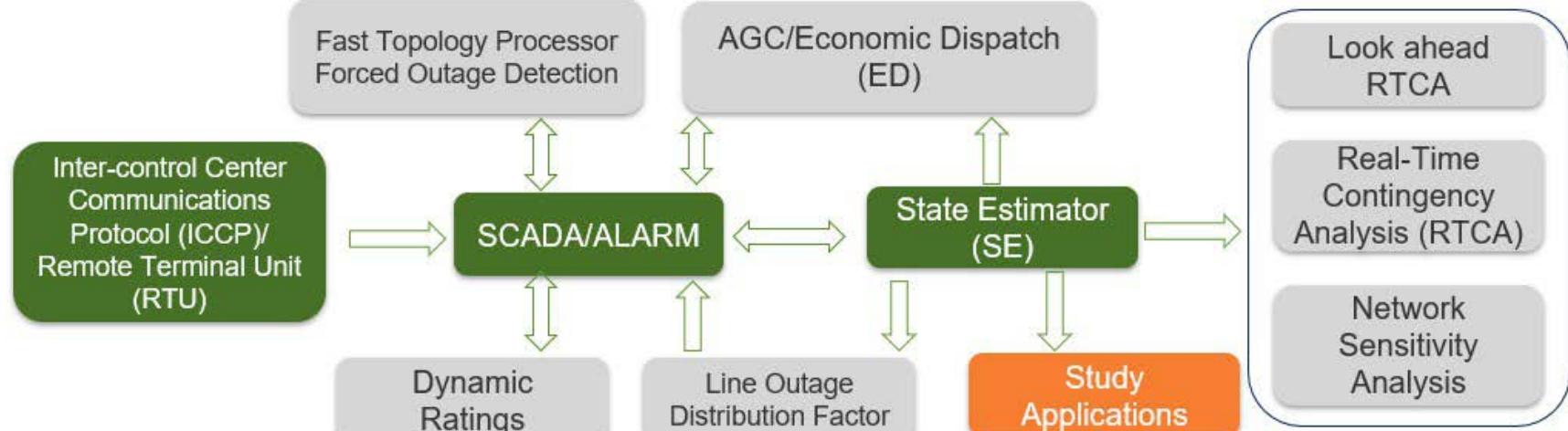


Operating's Decision-Making Input

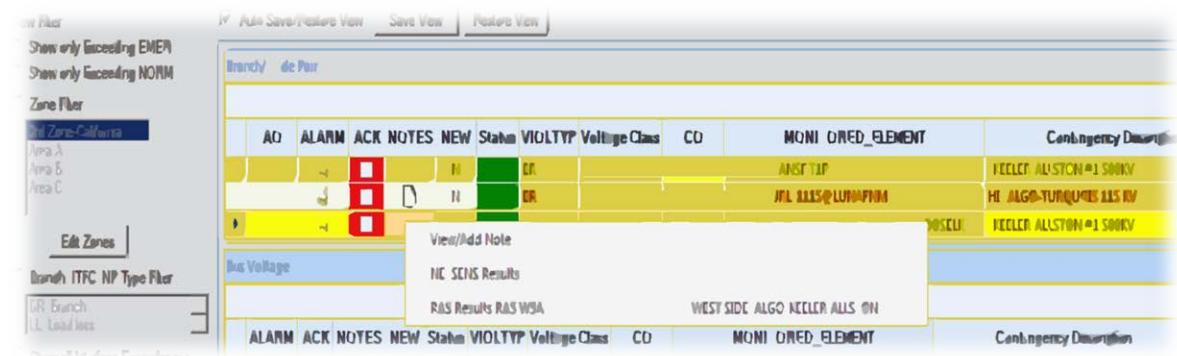
Standard & Procedure

- DOE
- FERC
- NERC
- Regional Entities
- Cybersecurity

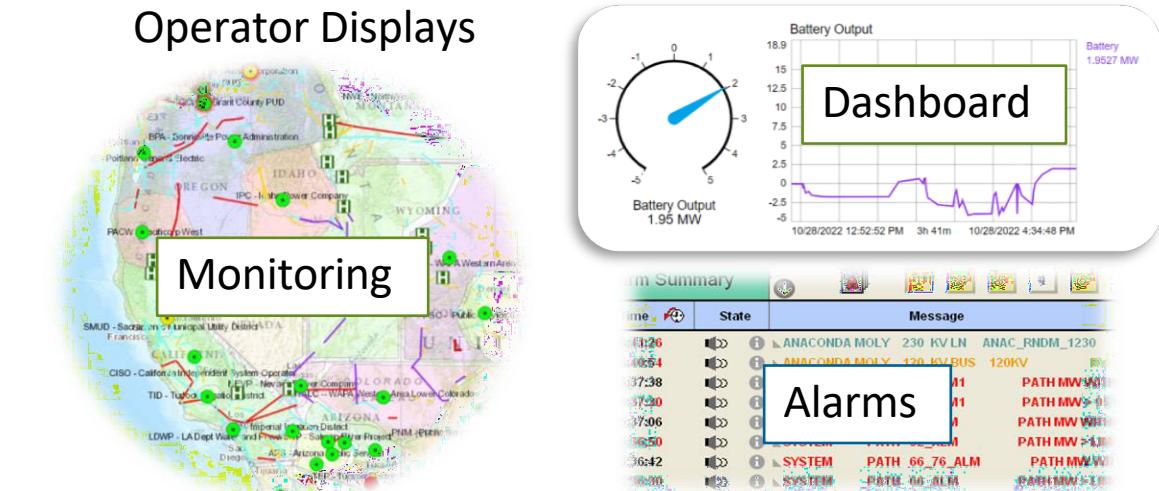
Control Room Tools



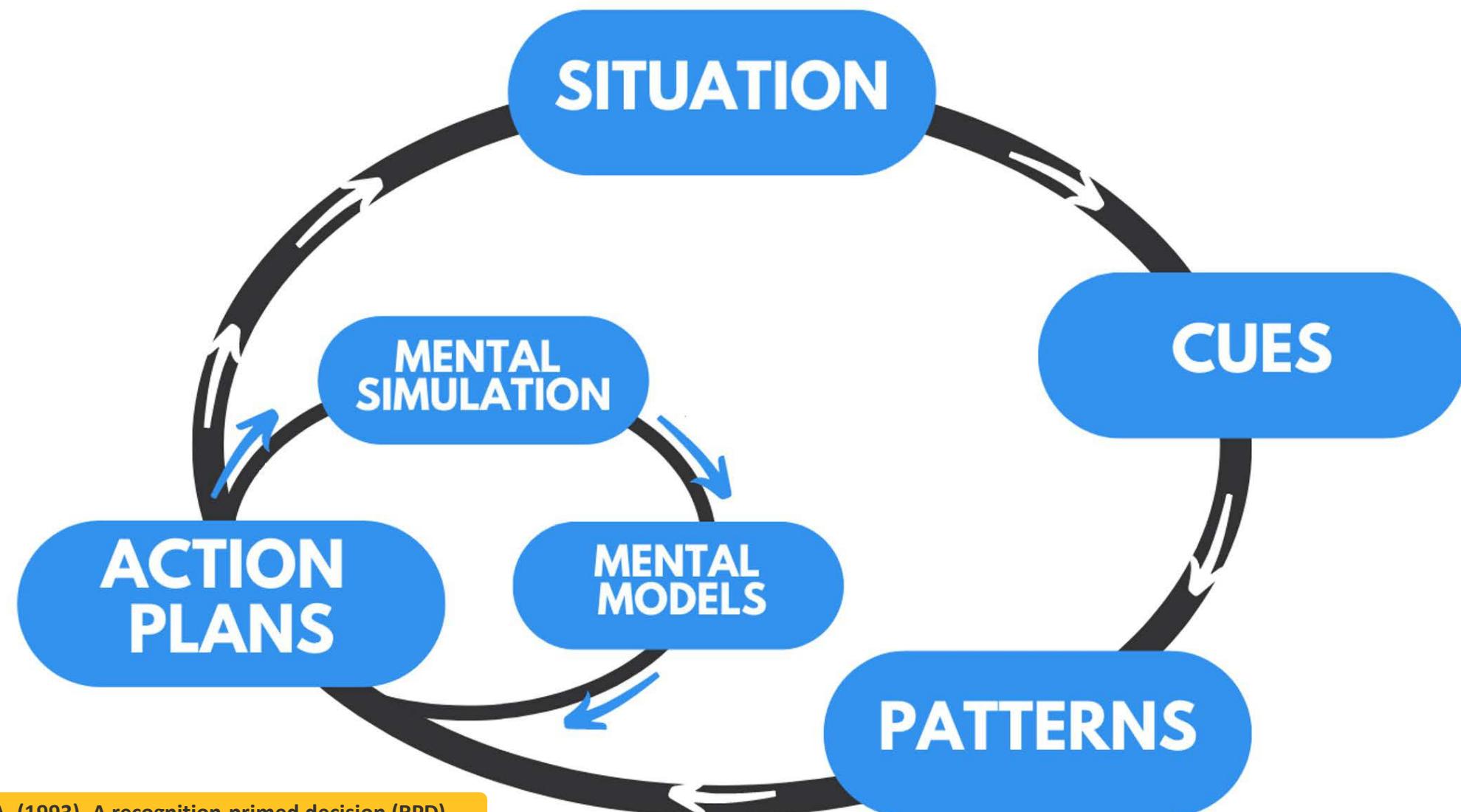
Operator Knowledge System



Operator Displays

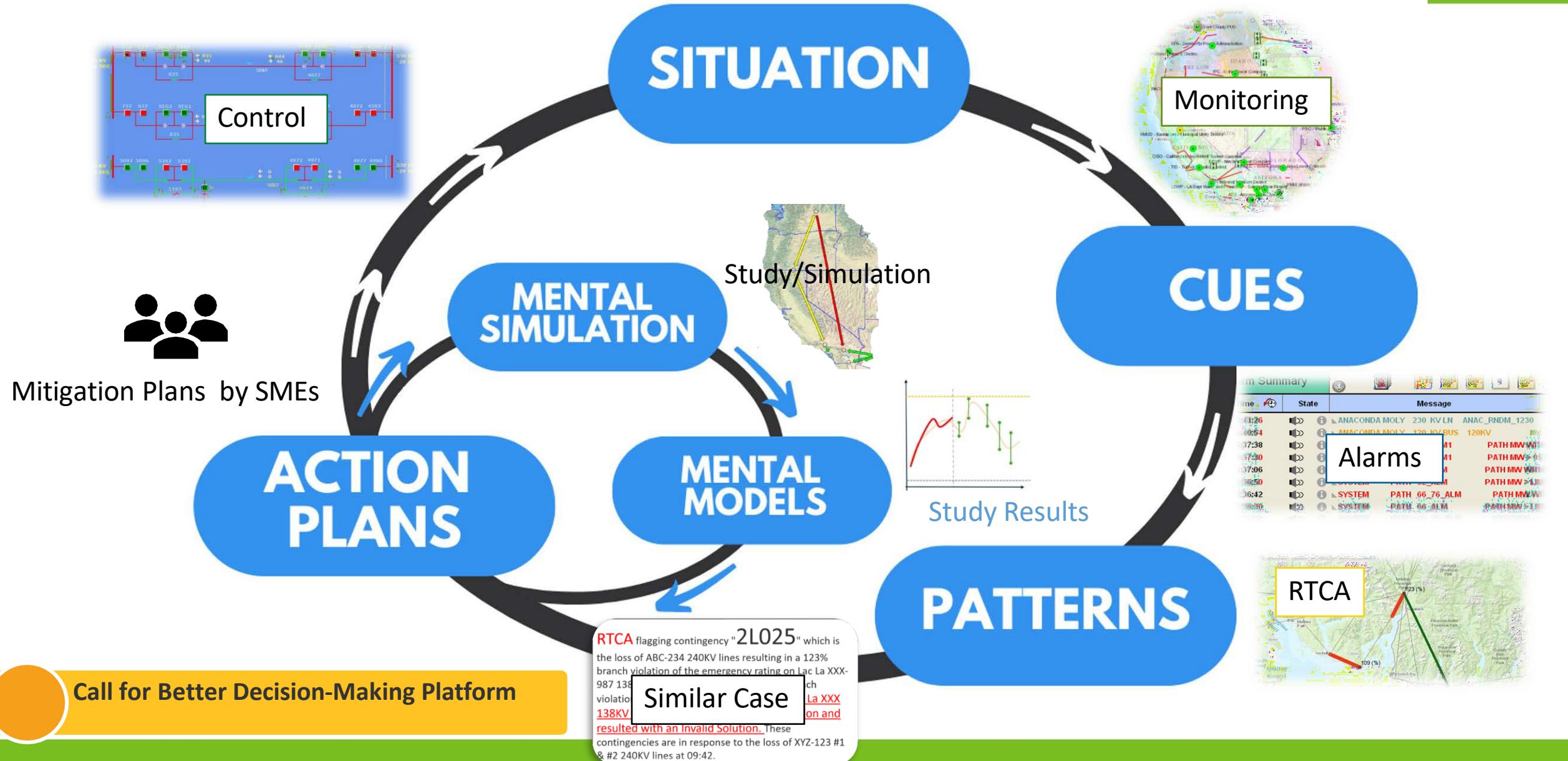


Decision-making: Recognition-Primed Decision

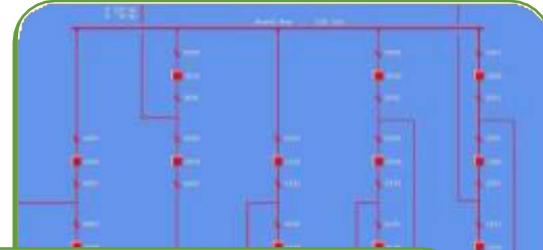


Klein, G. A. (1993). A recognition-primed decision (RPD) model of rapid decision making.

Better Decision-Making Feasible?

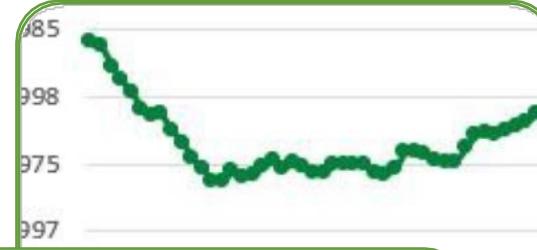


Digital Twin: Automation + Simulation



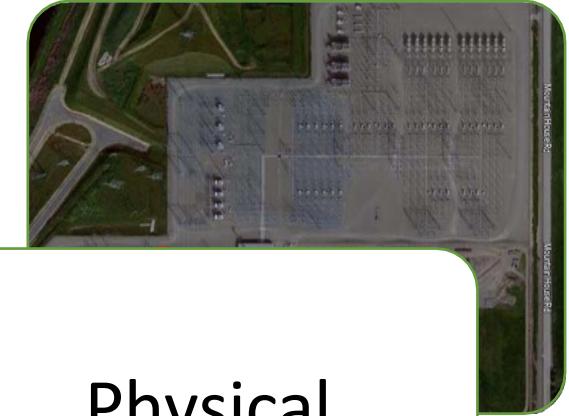
**Dispatcher
Training
Simulator
(DTS)**

Training Network Model



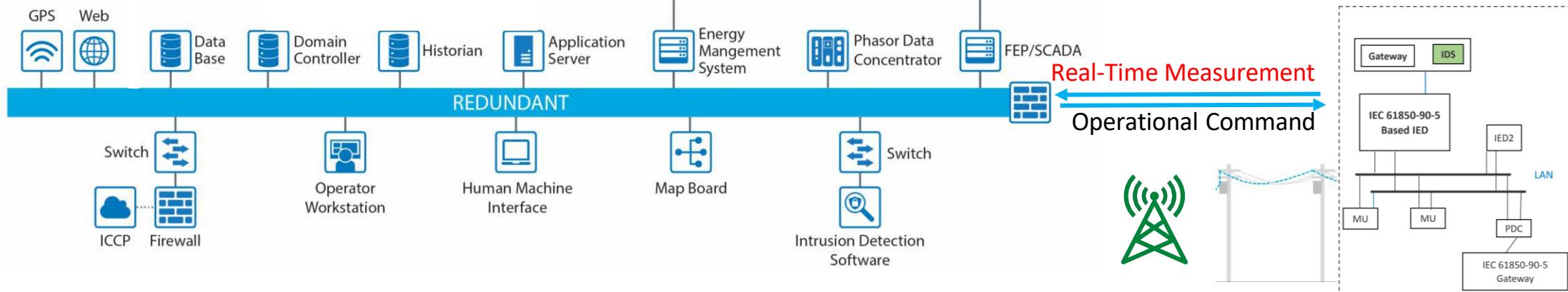
**Operation
Model**

Physical Network Model
Real-Time Measurement



**Physical
Model**

Real-Time Measurement



NREL Digital Twin Demo: RTCA Violation Auto Validation

RTAG Primary (EMS) Pause Play Transfer Case to Twin RTAG Twin (DTS) Pause Play EMS Synchronization



60.79 60.17

08:00 08:01:00 08:01:10 08:01:20 08:01:30 08:01:40

RUNNING
Freq: 60.0228 Hz
Gen: 98,492 MW
Load: 98,310 MW
Current Time: 28-Mar-2019 08:01:34

RUNNING
Freq: 60.0006 Hz
Gen: 97,825 MW
Load: 95,018 MW
Current Time: 28-Mar-2019 08:00:52 MDT
RTCA Time: 28-Mar-2019 08:00:20 MDT

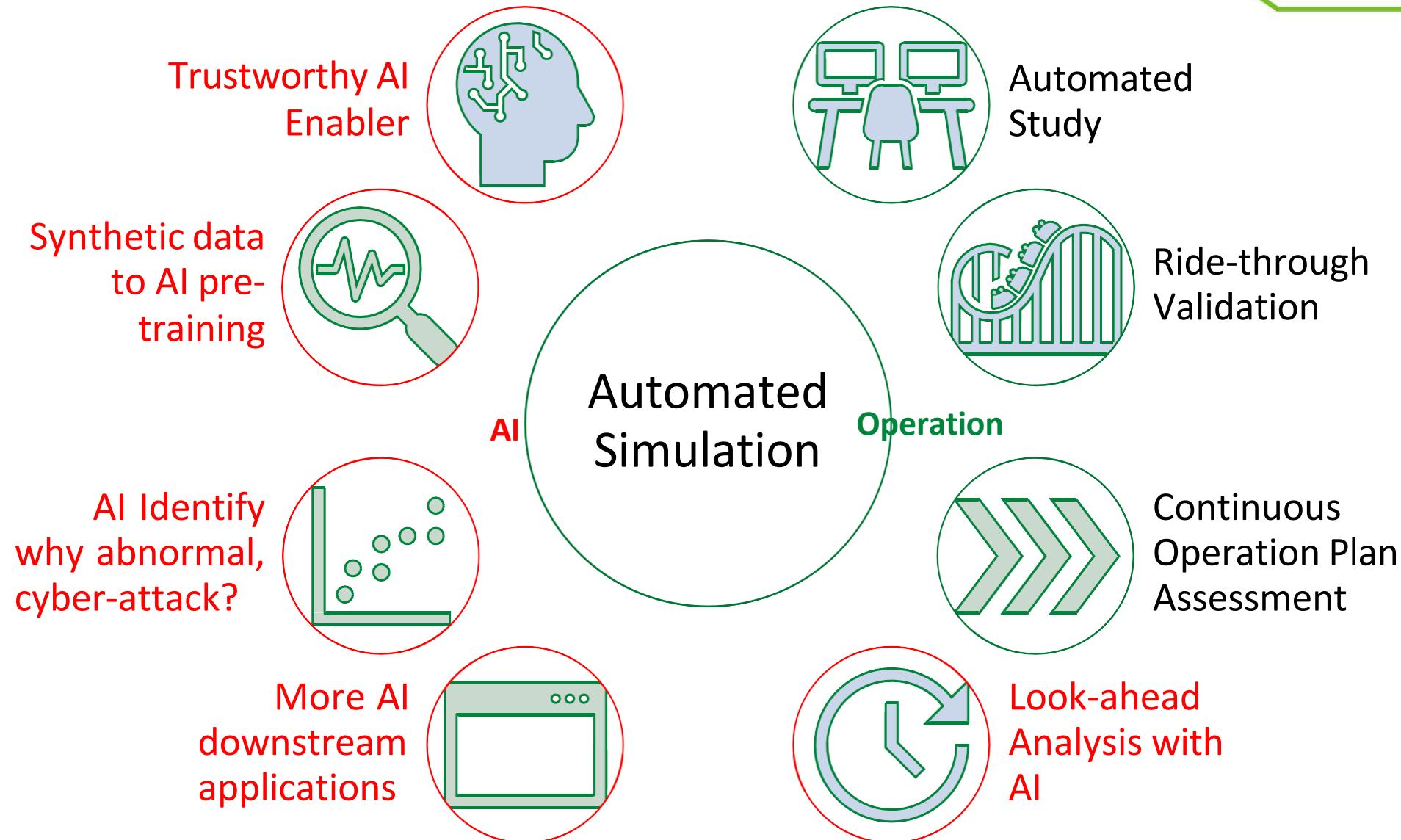
Violation Type	Basecase Violation	CTGs Violation
Island		
Branch	3	89
Voltage		44
Angle		0
Interface	2	8
Miscellaneous	0	

Violation Type	Basecase Violation	CTGs Violation
Island		
Branch	2	56
Voltage	2	171
Angle		2
Interface	2	3
Miscellaneous	0	

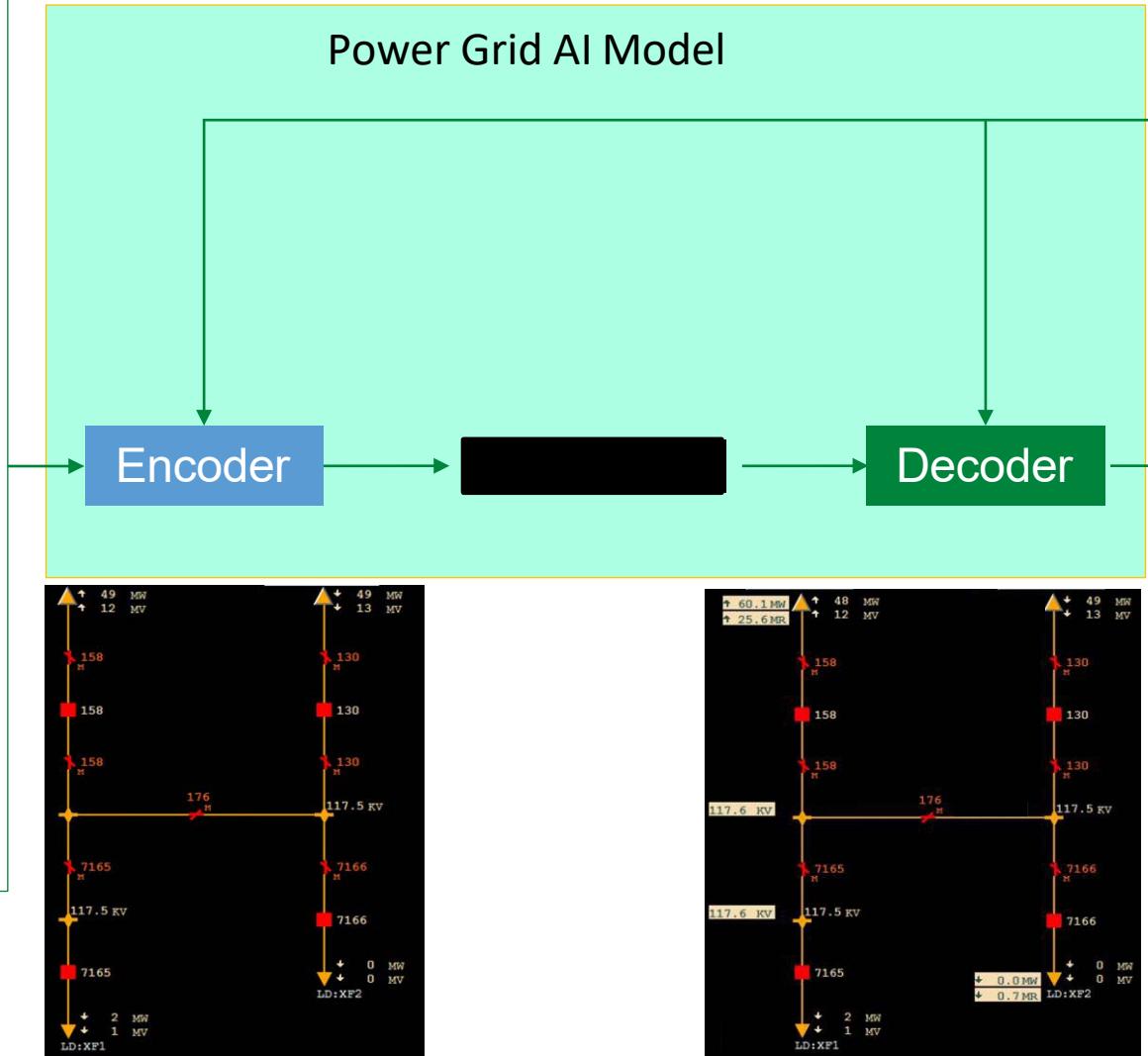
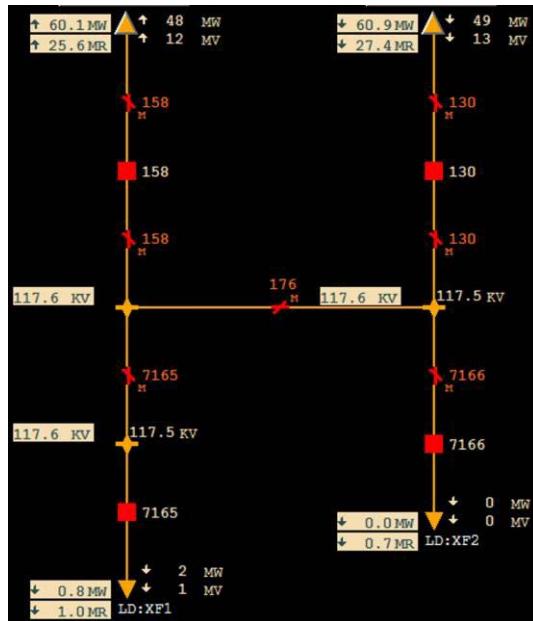
Verification & Validation of EMS RTCA Serious Violations

CTG ID	EMS RTCA	Twin RTCA Reproduced	Twin Validation Status	Twin Validation Detail
MUCSL076	UNSOLVED			

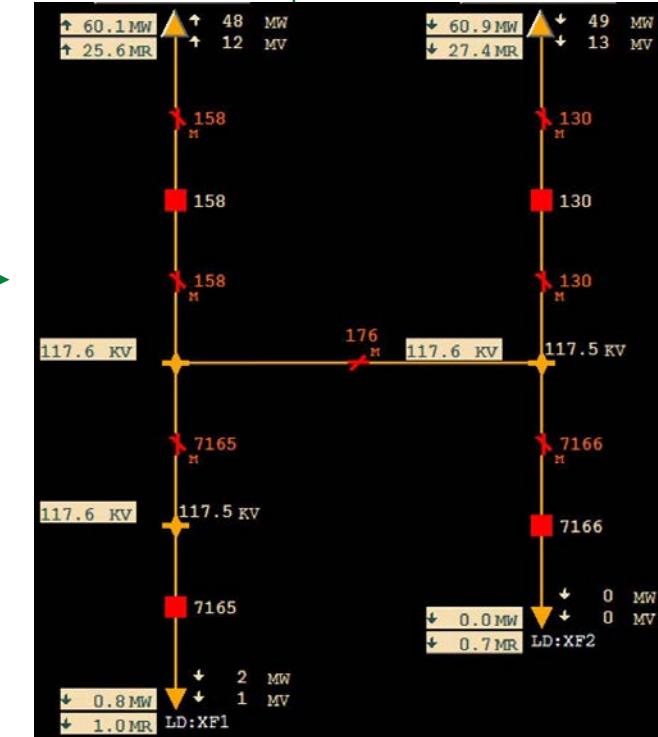
What Do We Do With Digital Twin?



Digital Twin as Trustworthy AI Enabler

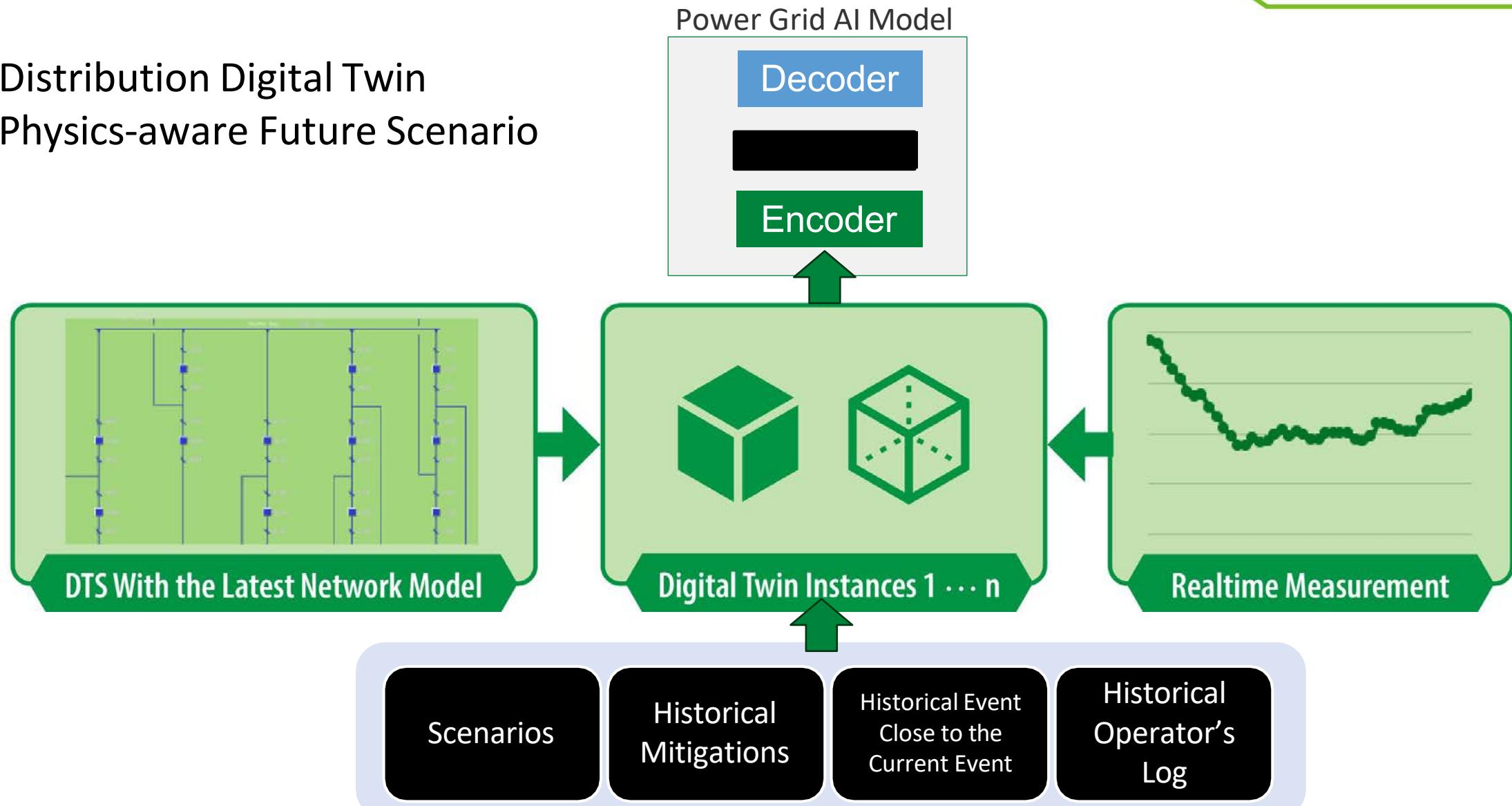


Validated by Digital Twin

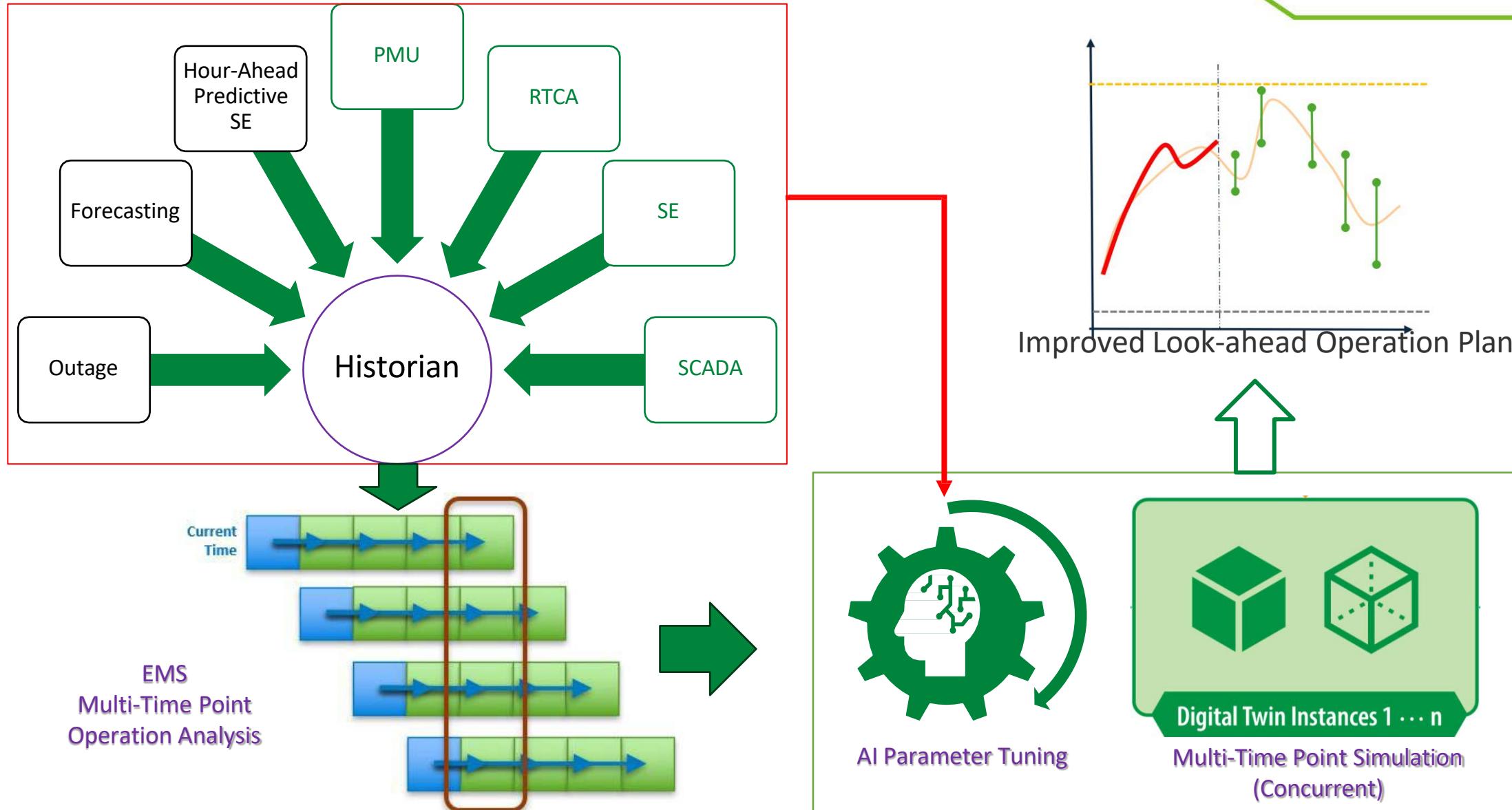


Digital Twin as AI Pre-training Data Provider

- Distribution Digital Twin
- Physics-aware Future Scenario

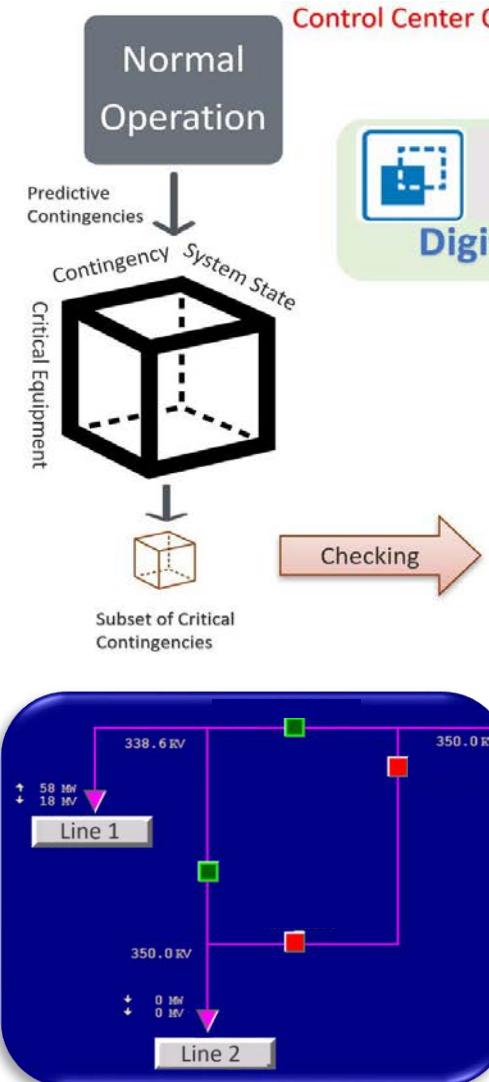
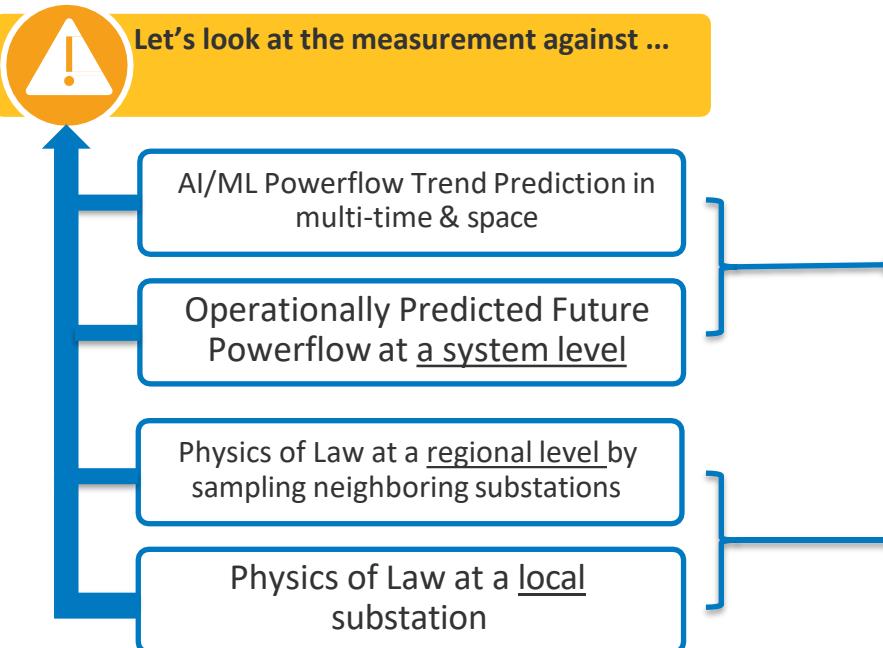


Look-ahead Analysis by Digital Twin + AI

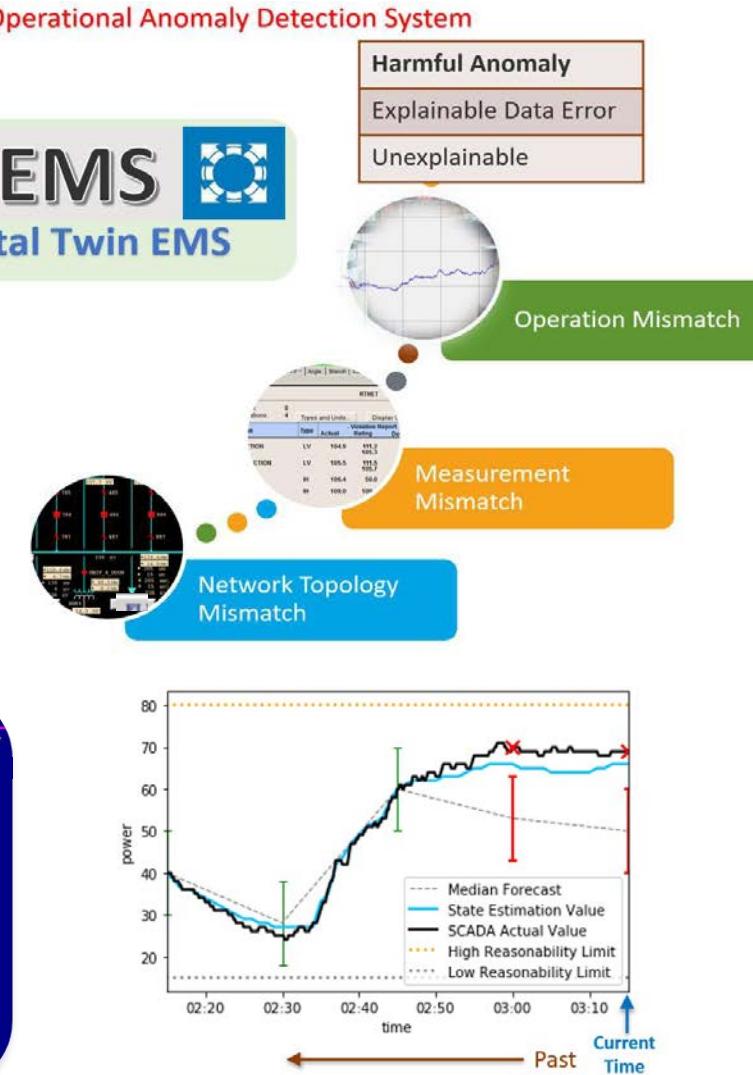


Digital Twin as Anomaly Detection

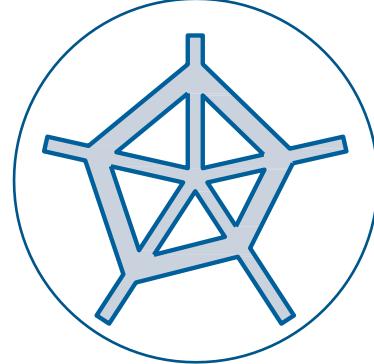
Let's look at the measurement against ..



Vision-based Anomaly Detection

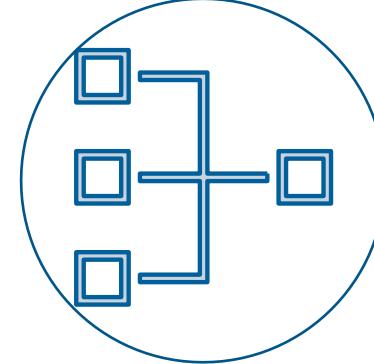


DT confirms Operation & Network Topology Mismatch



Forecasting

- Weather
- Load
- Variable Renewable Energy
- Asset Remaining Useful Life



Data & Model

- Network
- Optimization
- Protection
- Anomaly Detection



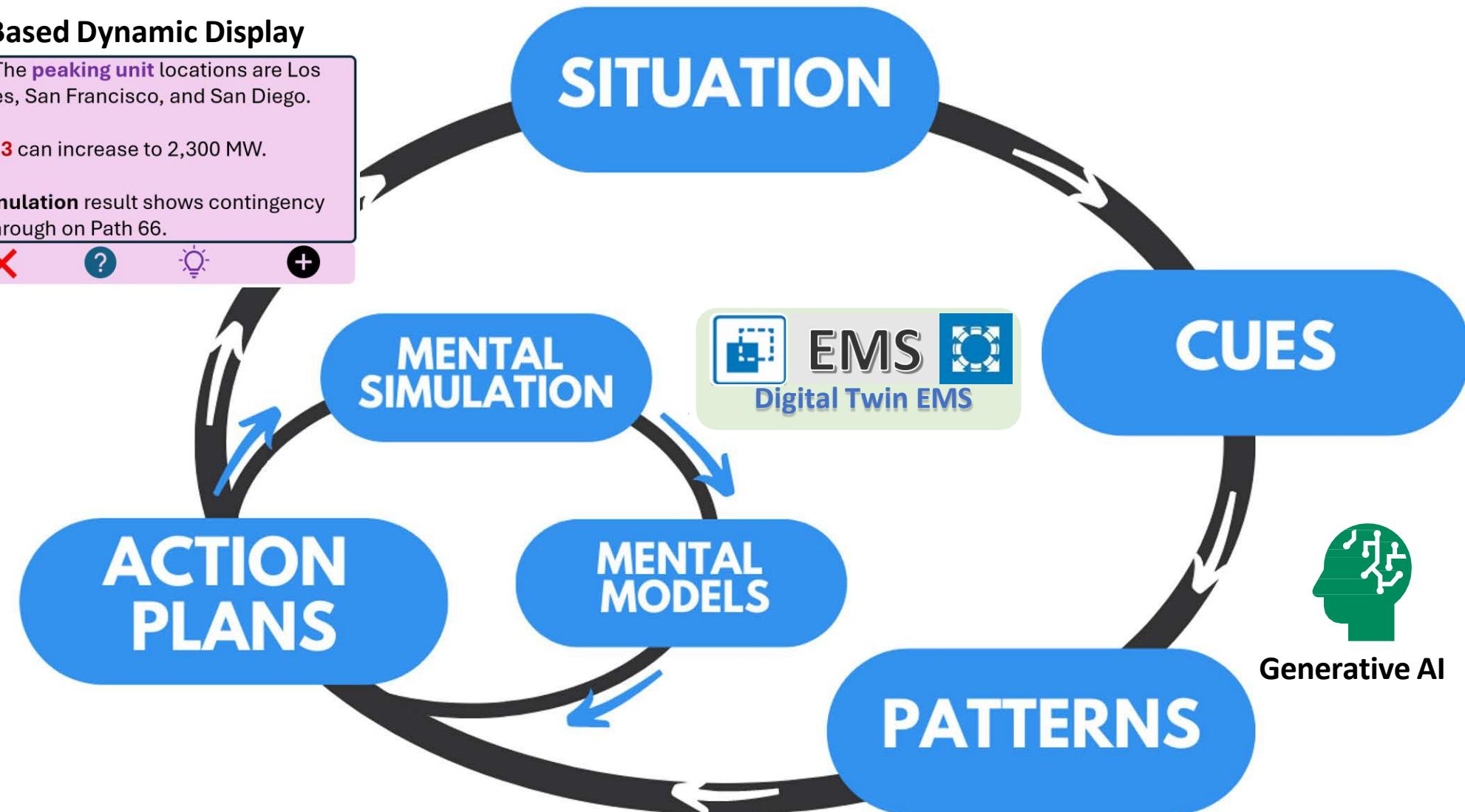
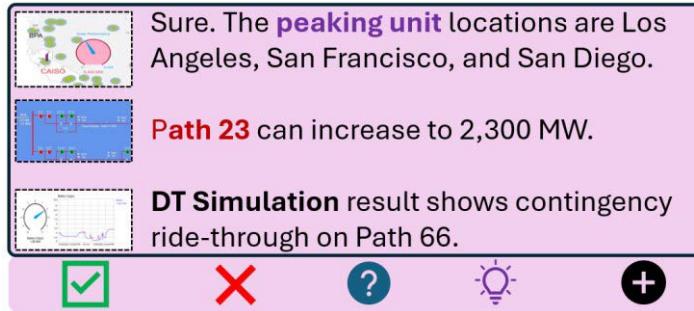
Recommendation

- Operation Strategy
- Operator Log Processing
- SCADA Alarms
- Resilient

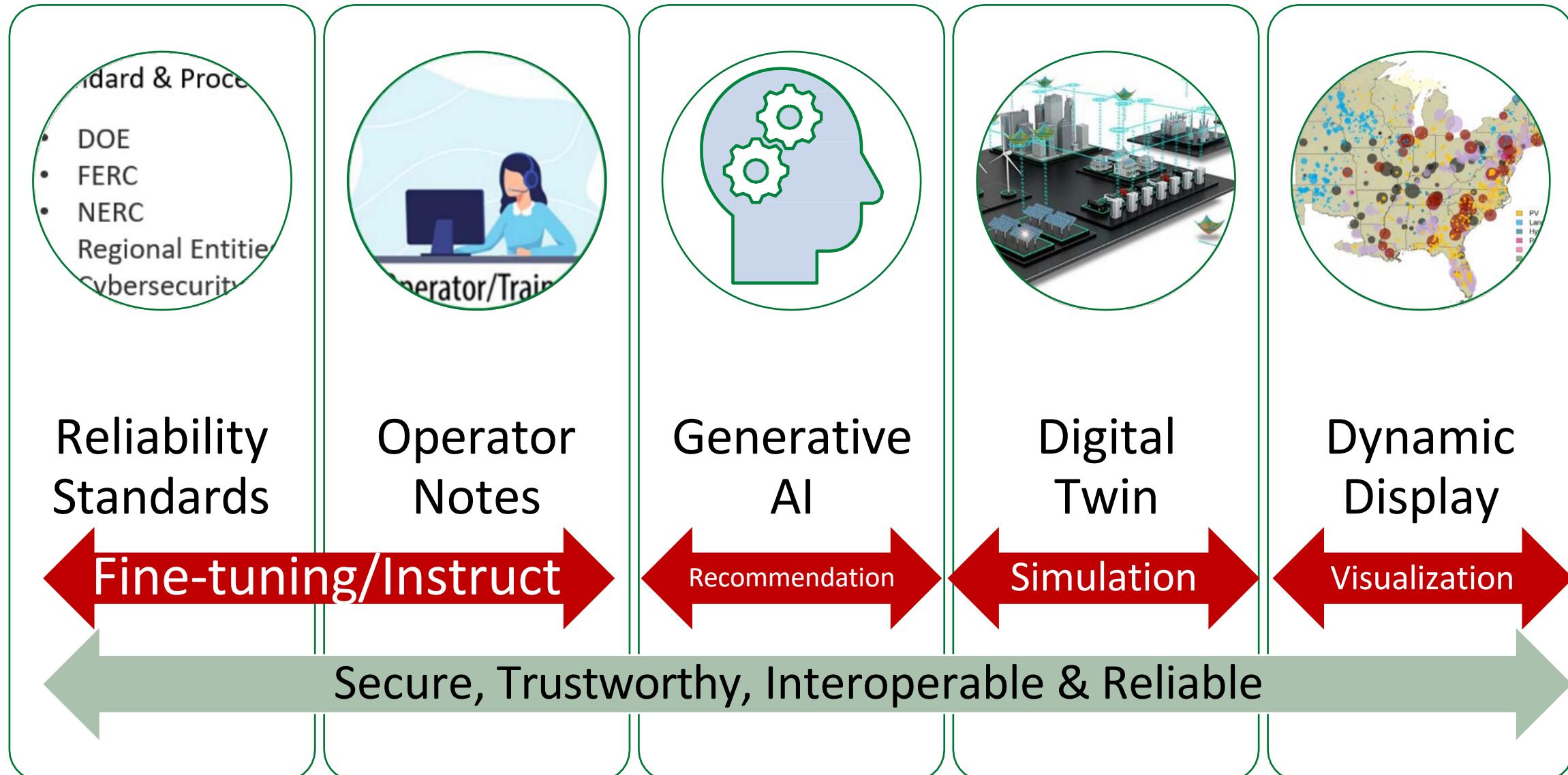
Final Decision Belongs to Operator, Not AI

Digital Twin + AI + Dynamic Display

Prompt Based Dynamic Display



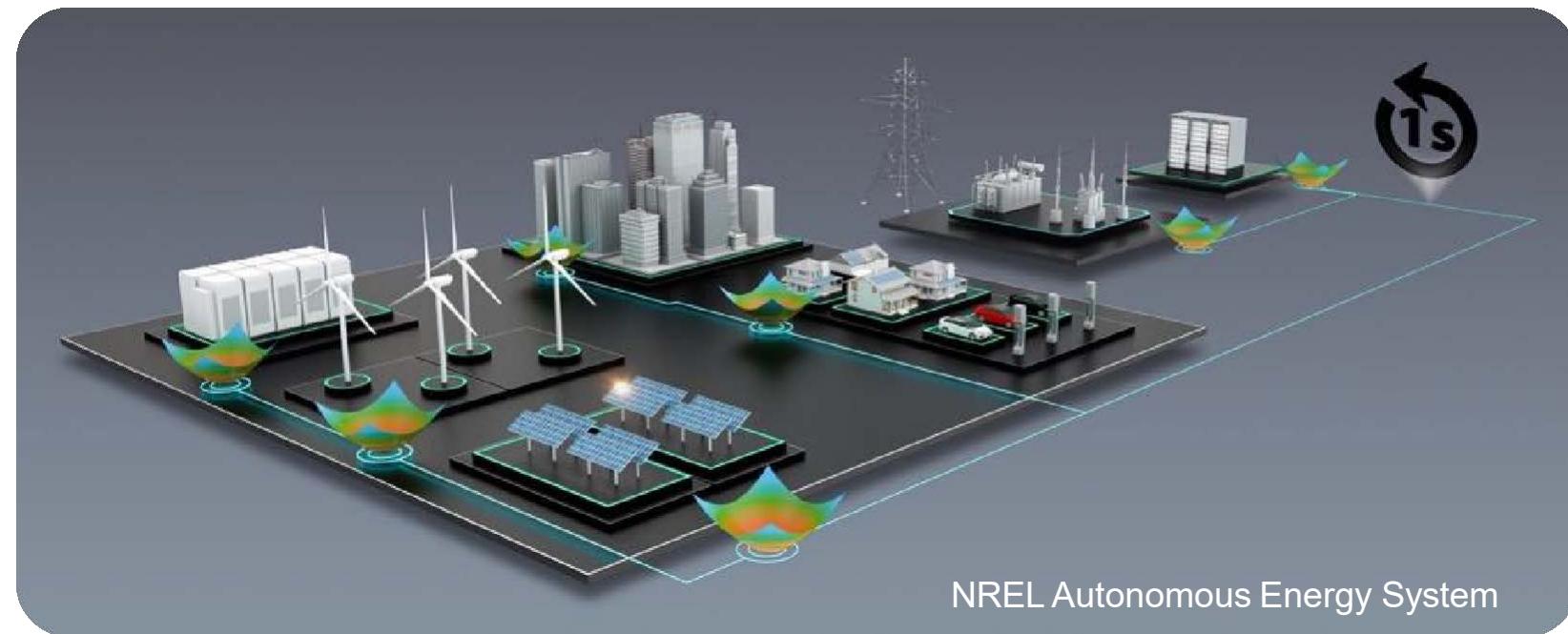
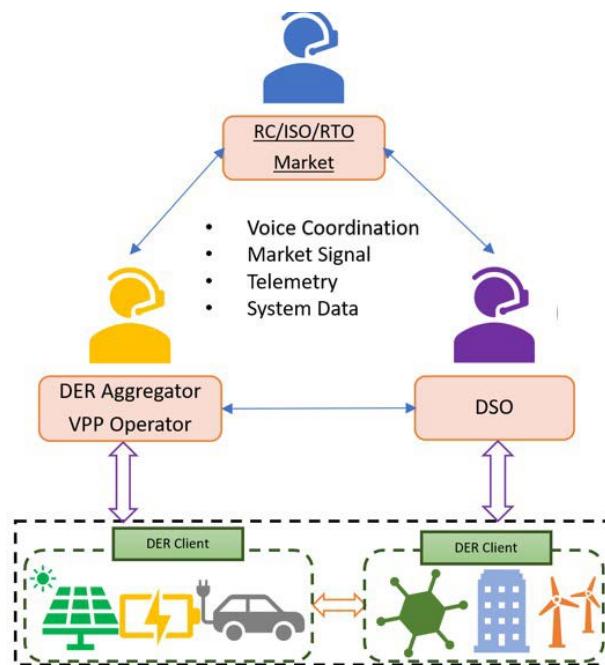
NREL Decision Making Platform



Digital Twin Expanding Scale: T&D + DER

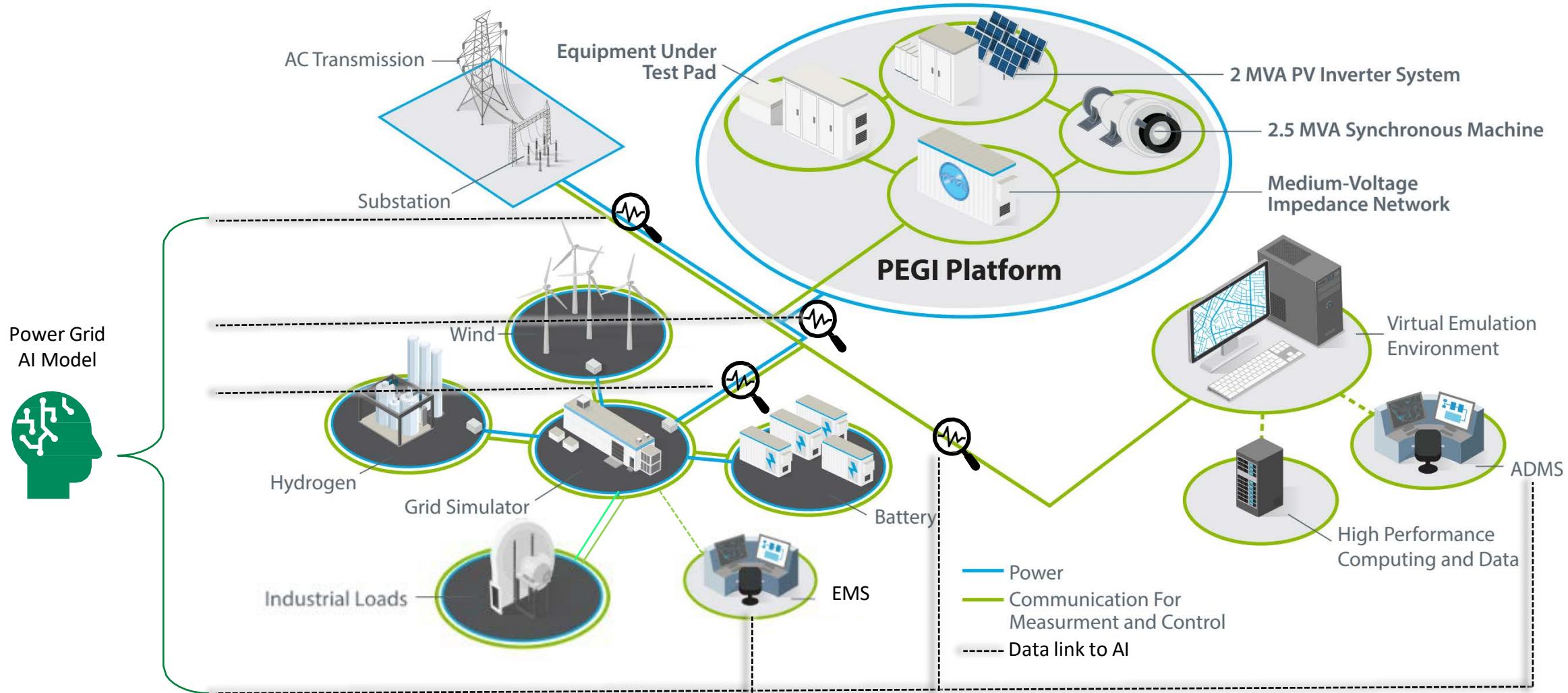
Digital Twin's Role

- Expand to Distribution where measurement lacks, and modeling is challenging
- Coordinate T&D with the grid participants including DER customer per FERC Order 2222



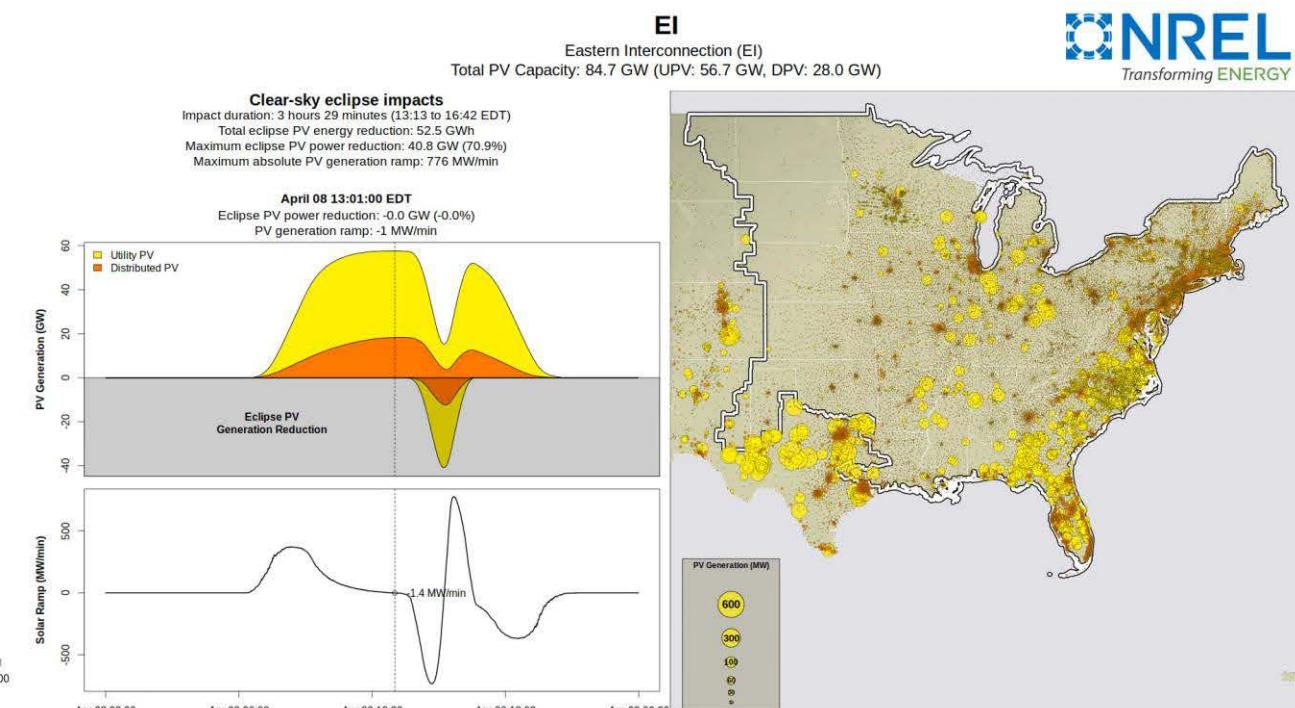
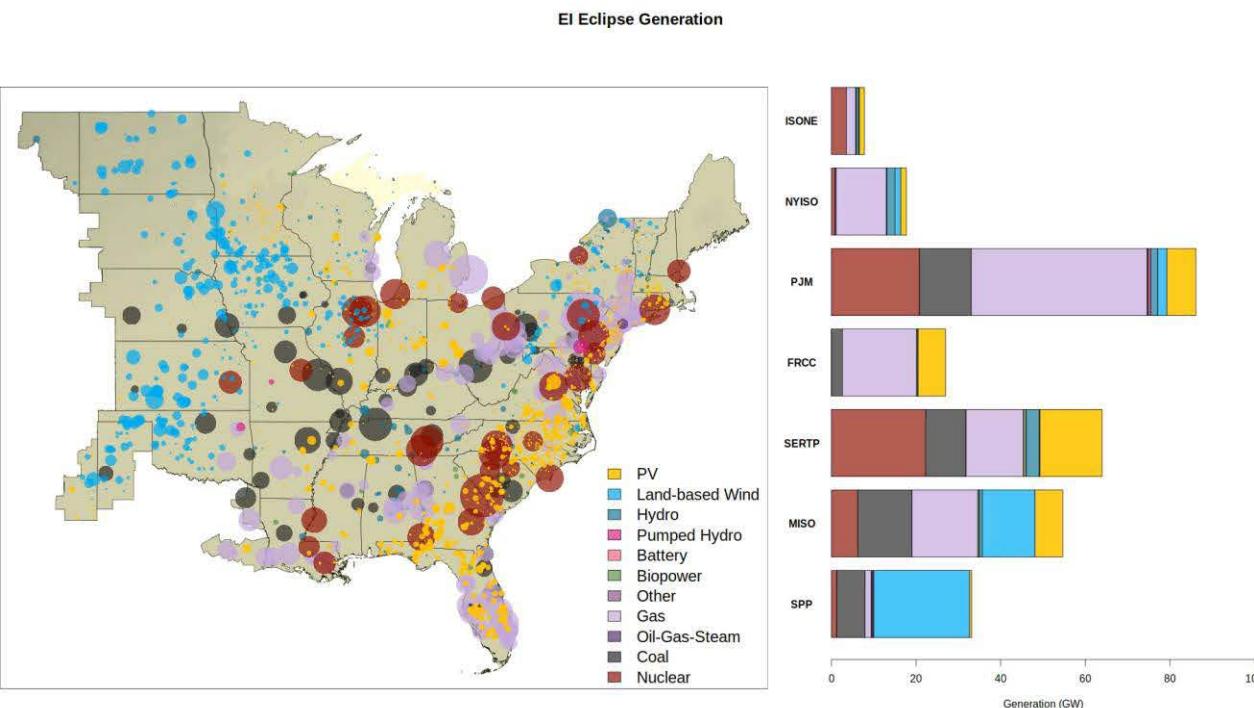
NREL T&D Digital Twin Validation at Scale

Draft for Power Grid AI Model Training



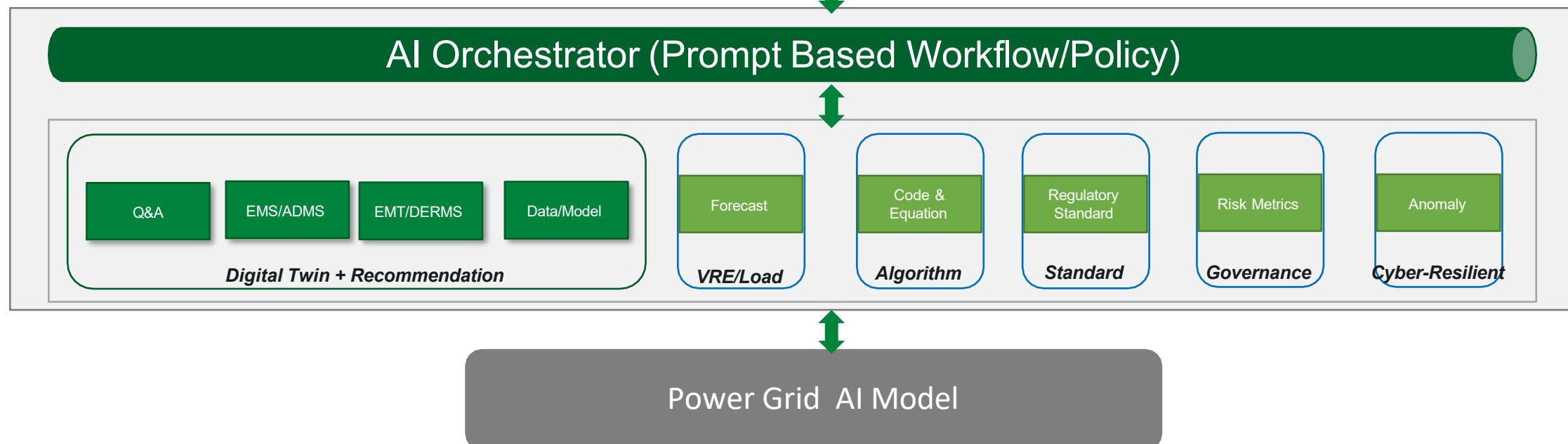
Dynamic Display

Prompt: During the solar eclipse, animate PV reduction/increase while ramping up/down by other generation sources to meet the demand

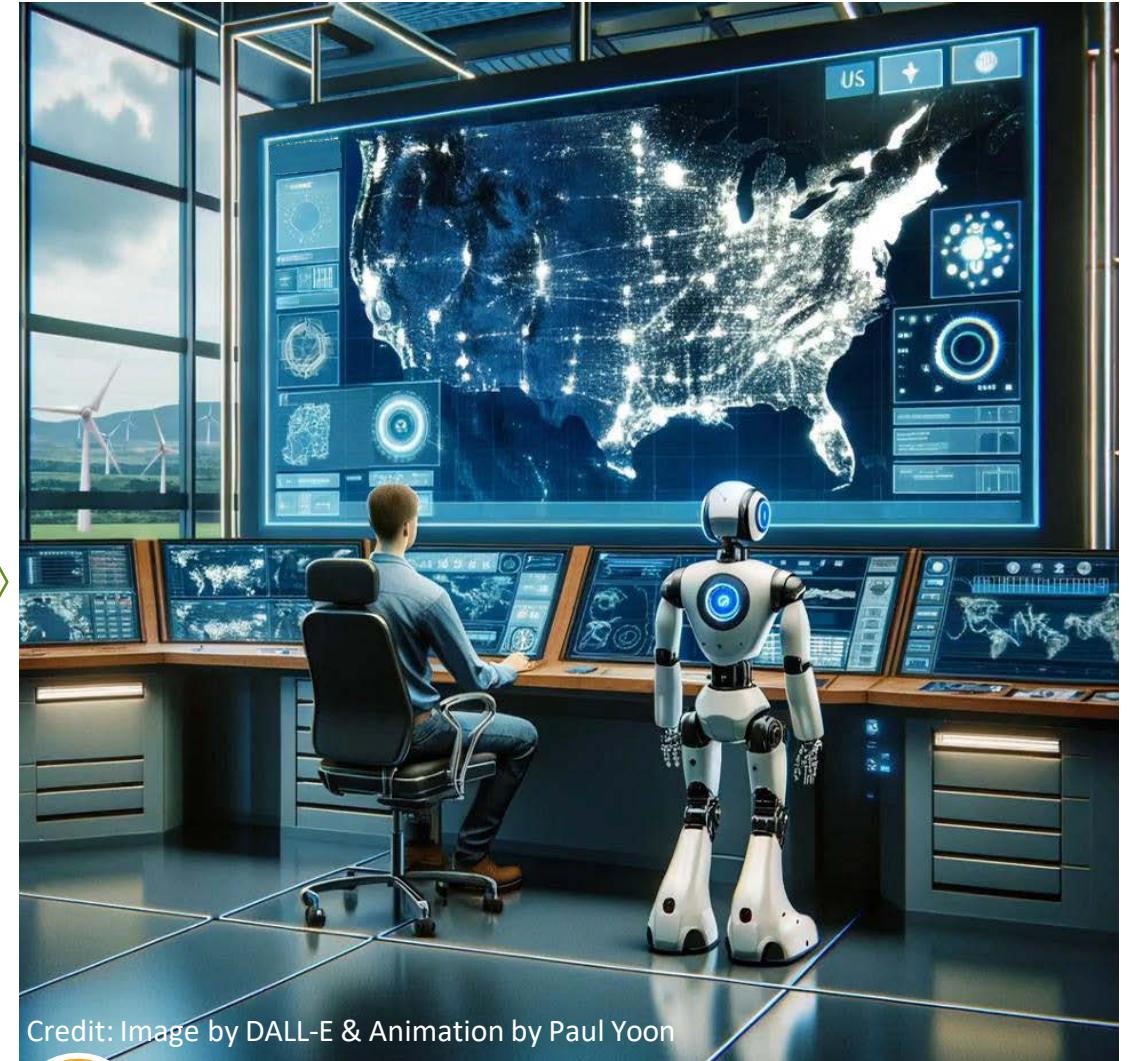
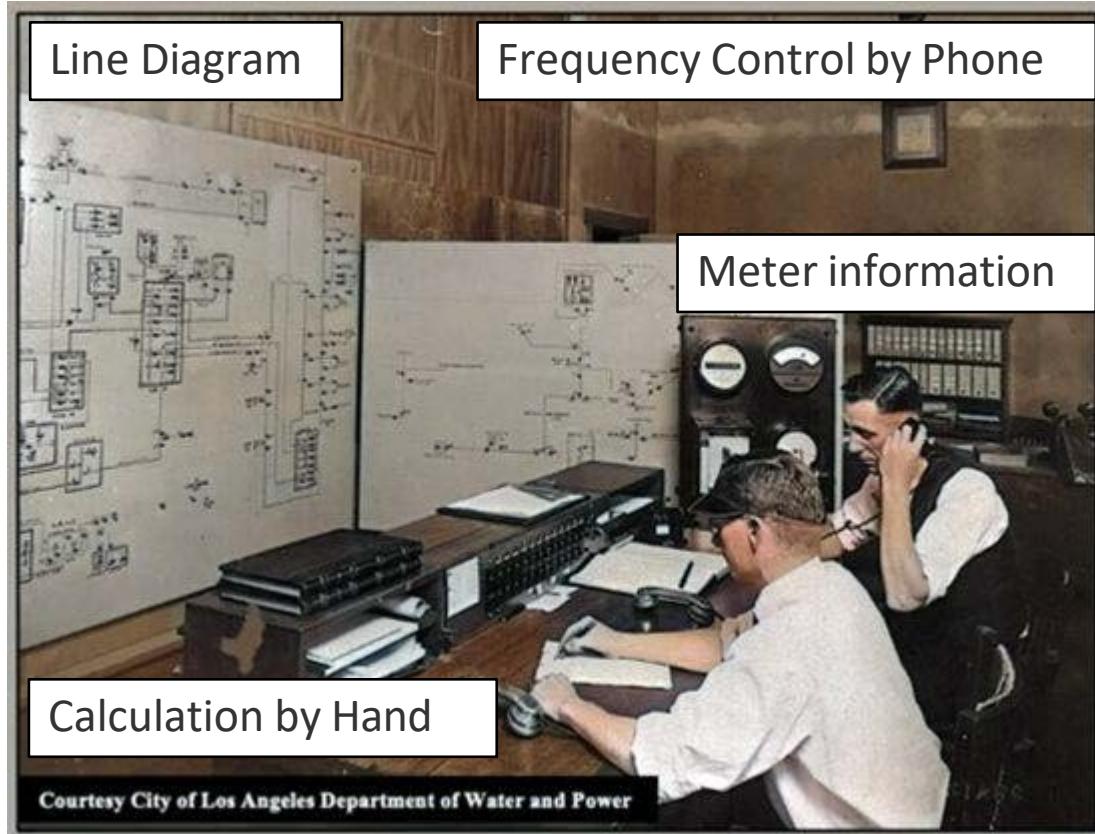


Source: Kenny Gruchalla, NREL

Prompt Based Digital Twin + AI Orchestration



Digital Twin + AI + Dynamic Display



Julie Cohn: The Grid: Biography of an American Technology

Credit: Image by DALL-E & Animation by Paul Yoon

Key Takeaway: AI's role is increasing, even to Robots

Digital Twin + AI + Dynamic Display

Control Room of the Future



Digital Twin with Automated Simulation.

- Reduce manual process
- Scenario runs concurrently



AI as a Virtual Assistant.

- Additional recommendation with reference
- Orchestrate tool coordination based on prompts



Dynamic Display must be dynamic to Operator's request.

- Prompt based display
- Provide triggering (or pop up) display if meaningful



Operator/Train

Better Decision Making



Recommendations



Trustworthy

NREL/PR-5D00-89725

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