



Digital Twin + AI: Control Room of the Future

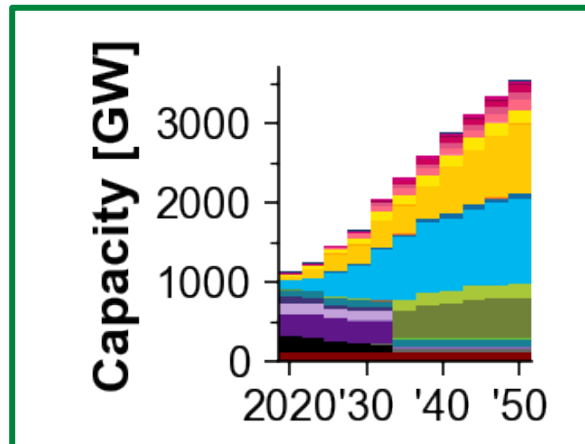
IEEE TF on Digital Twin of Large-Scale Power System

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National Renewable Energy Laboratory

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Lower Colorado River Authority

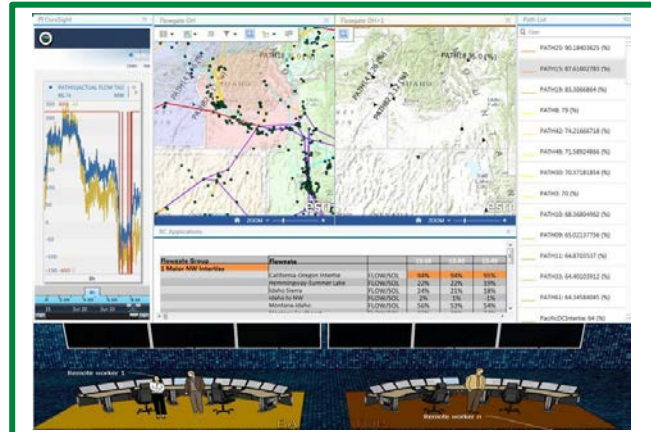
May 2024

Control Room Decision Making Problem Statement



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

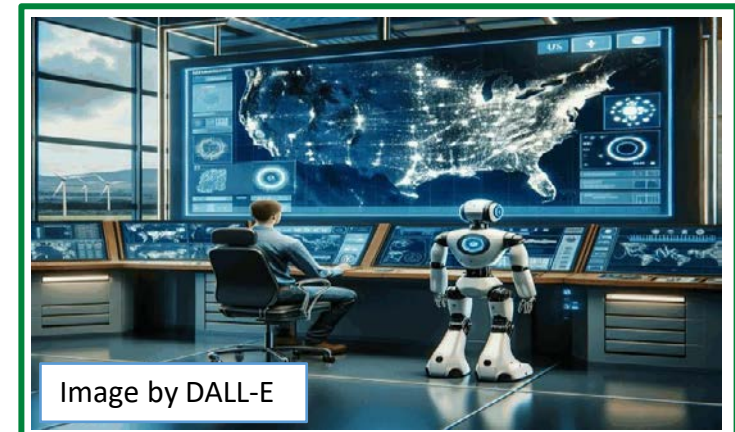
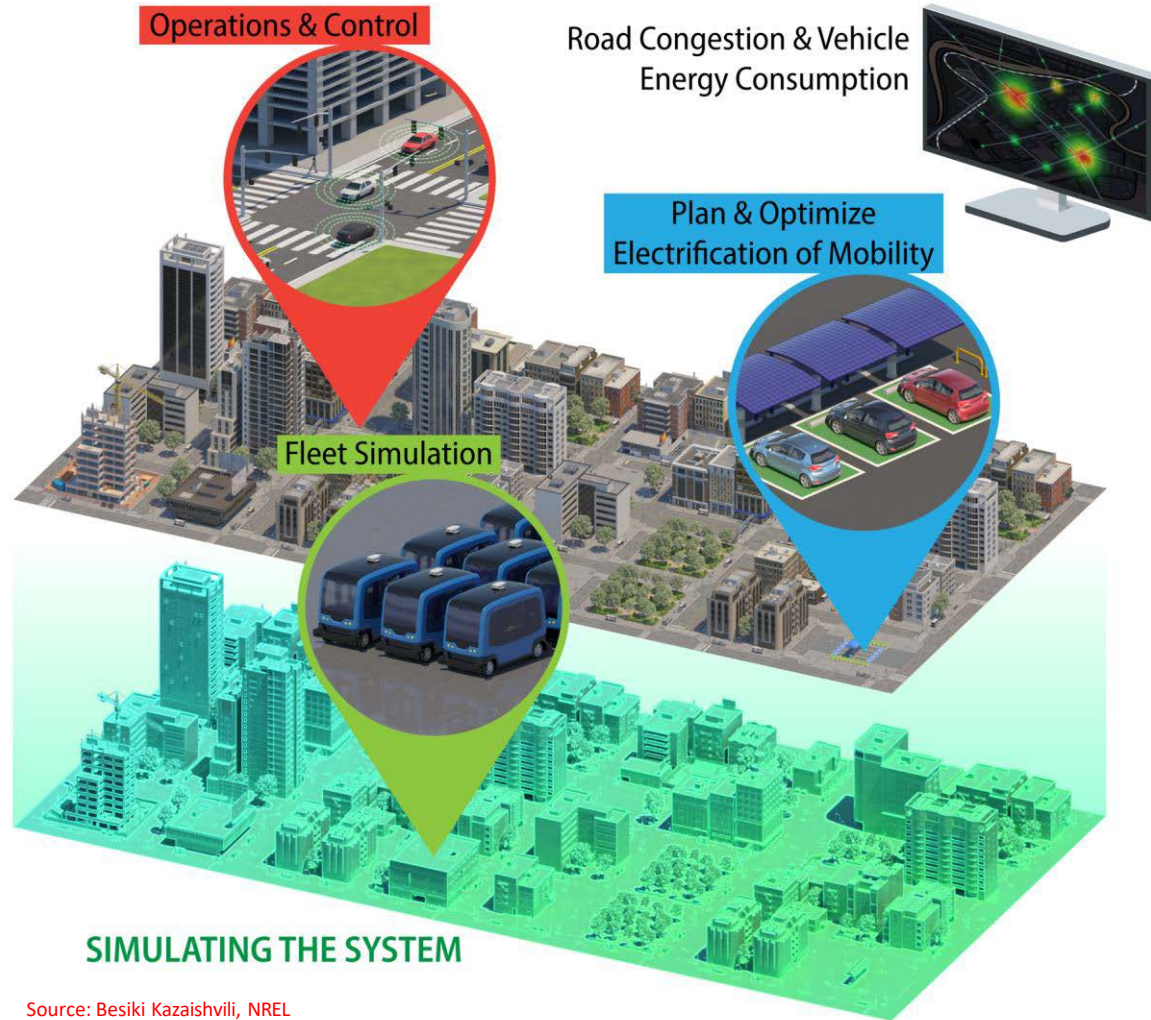


Image by DALL-E

Digital Twin + AI = Network Operator Virtual Assistant

Recommendation

Digital Twin in the Power Grid



Source: Besiki Kazaishvili, NREL

Digital Twin: Decision-making support?

Simulation Real-Time Operation Remotely

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

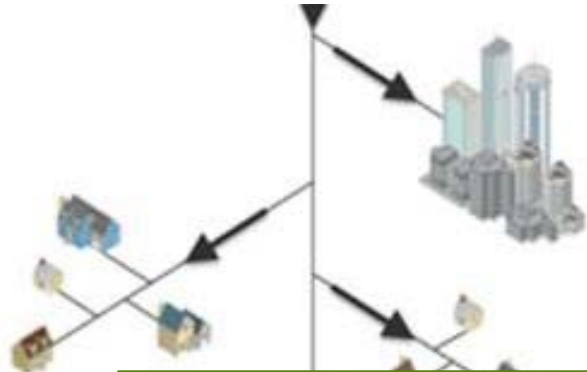
Predictive Insight of Asset Maintenance

Proof-of-concept or What-if

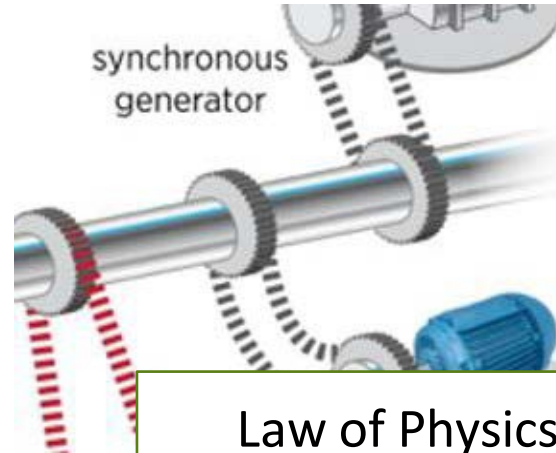
Digital Twin is a digital representation of the power network model and real-time measurement able to simulate scenarios.

ADMS: Advanced Distribution Management System
BTM: Behind-The-Meter
DERMS: Distributed Energy Resource Management System

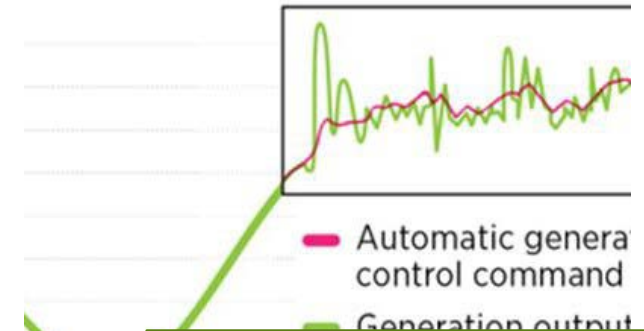
Power Grid Trends: Distributed, IBR & Weather



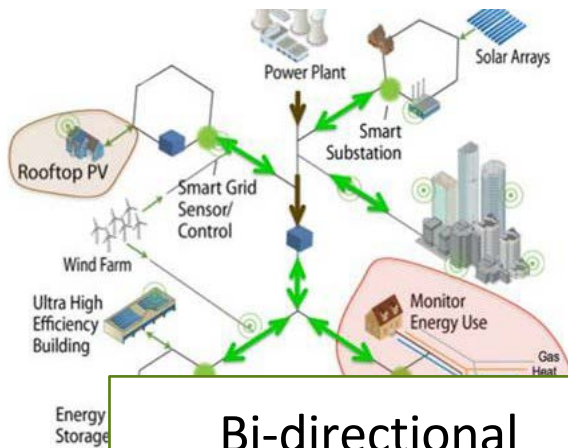
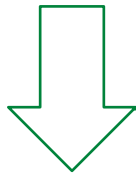
Uni-directional



Law of Physics



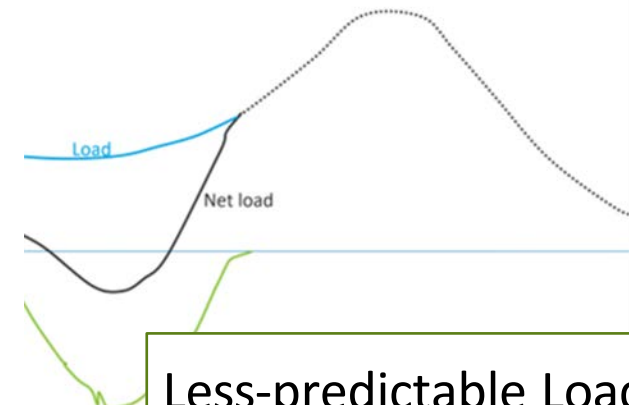
Load following



Bi-directional

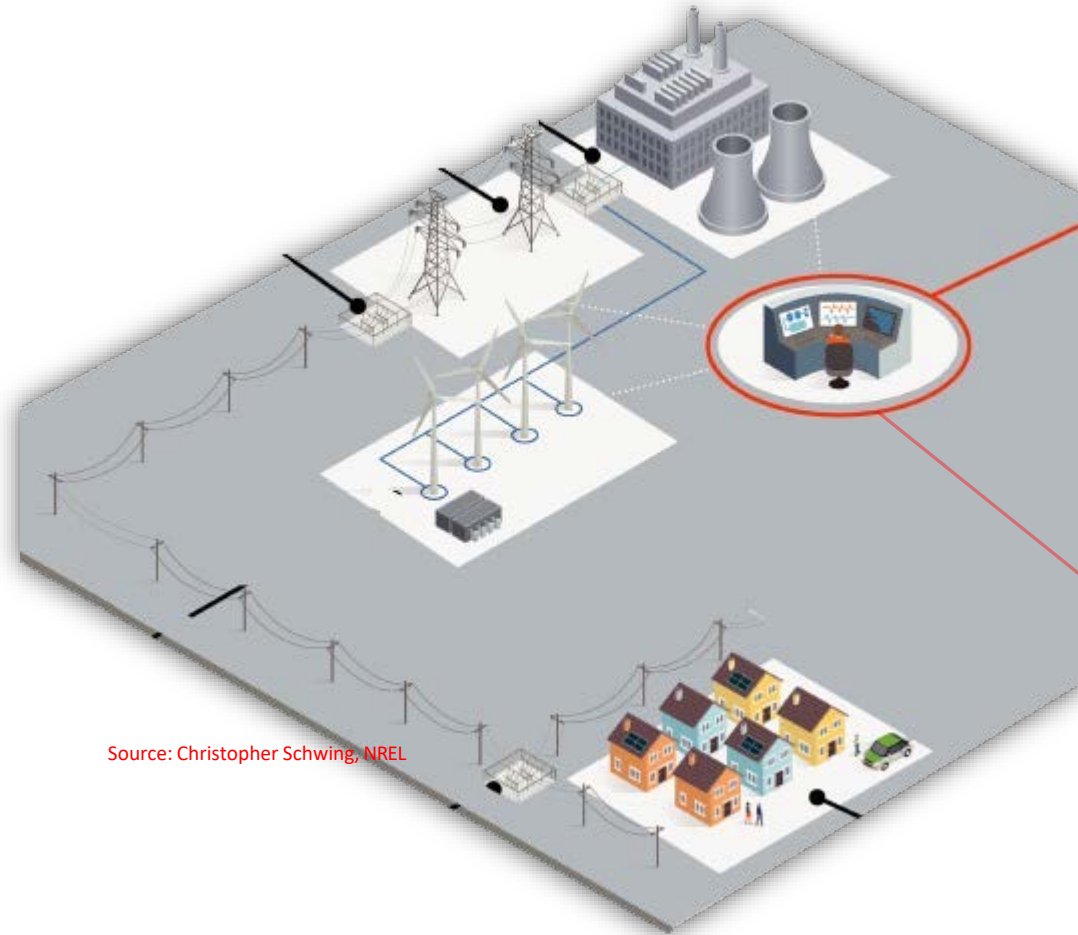


Programmable



Less-predictable Load

Decision making: Reliable Anytime 24 X 7 X 365



Source: Christopher Schwing, NREL

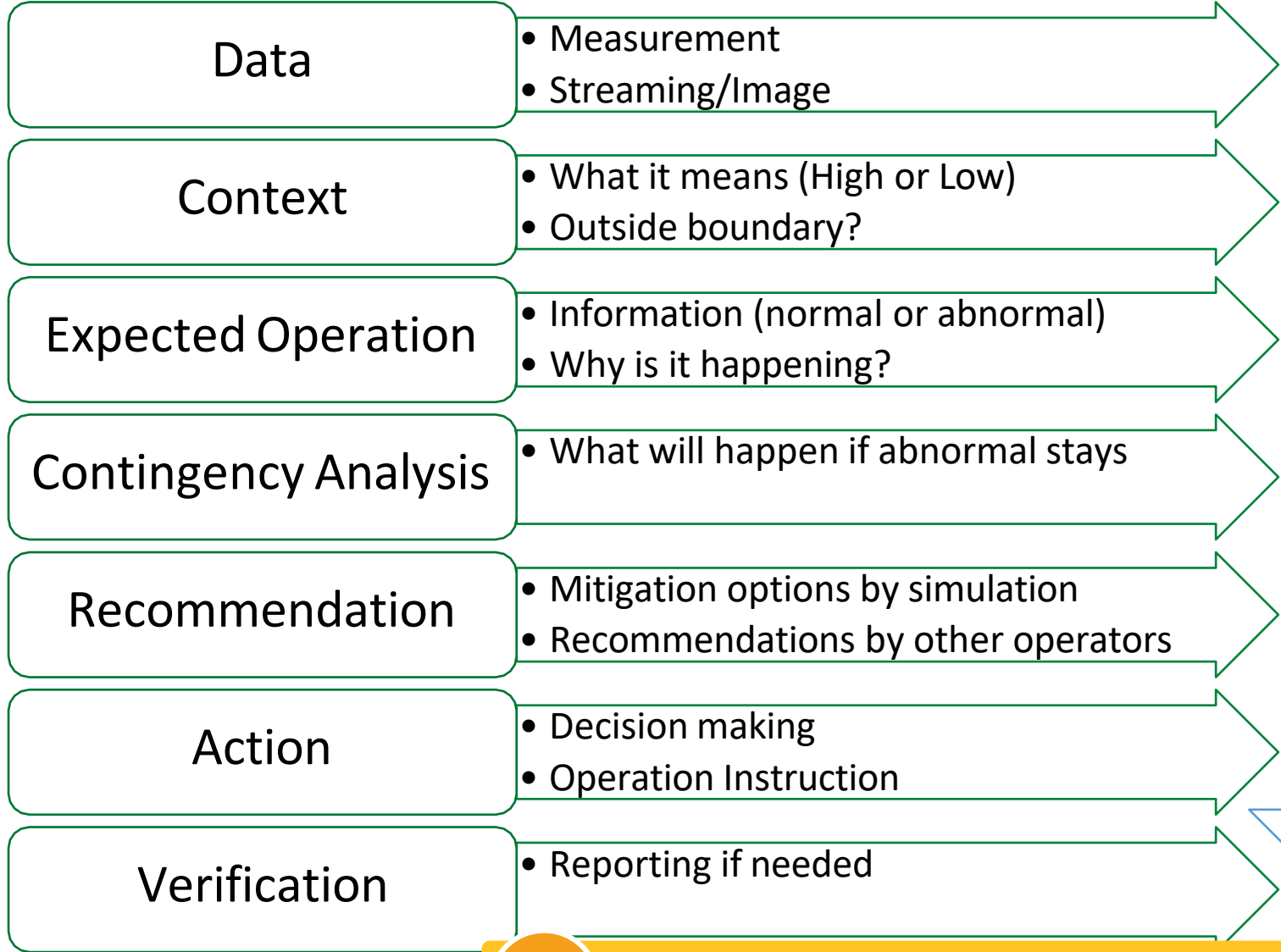


Operator must reliably balance generation & load (tug-of-war) via power line near 60Hz

Control Room Decision-Making Flow



Monitoring



Control

- Frequency Control
- Voltage Control
- Protection
- Switching
- Stability Control
- Load Management

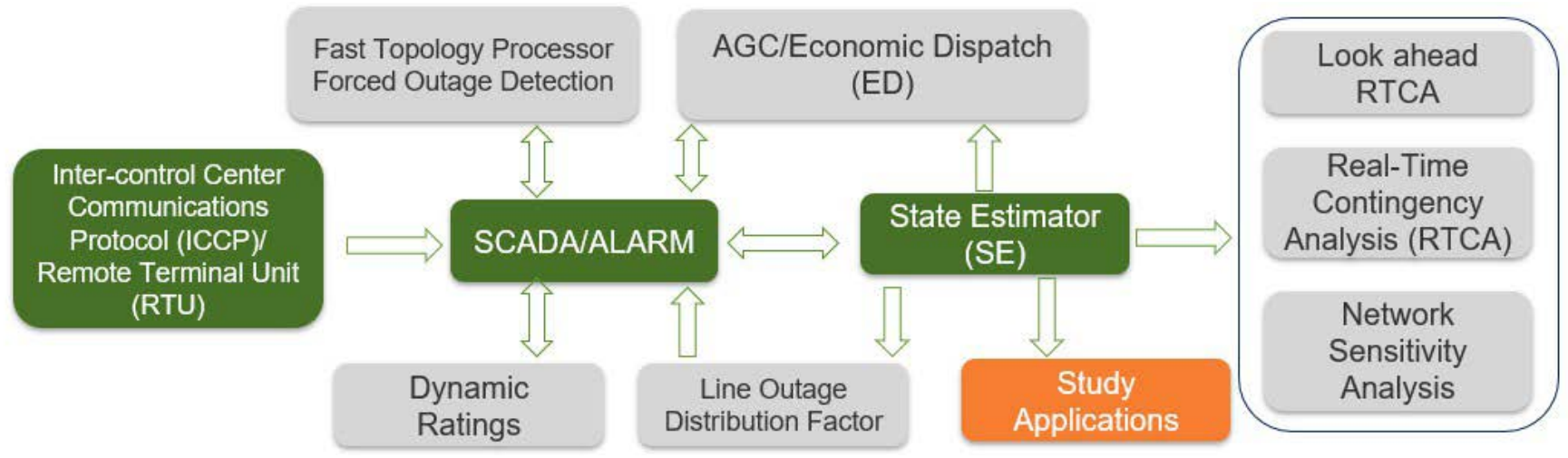
Decision-Making Belongs to Operators with NERC Certification

Operating's Decision-Making Input

Standard & Procedure

- DOE
- FERC
- NERC
- Regional Entities
- Cybersecurity

Control Room Tools



Operator Knowledge System

AD	ALARM	ACK	NOTES	NEW	Stahn	VIOL	TY	Voltage Class	CO	MONI	OP/ED_ELEMENT	Contingency Description
											ANST TAP	KEELET ALLSTON #1 500KV
											JPL 0115@LUNAFRM	HI_ALGO_TURQUINES 115 KV
											WSELI	KEELET ALLSTON #1 500KV

Operator Displays

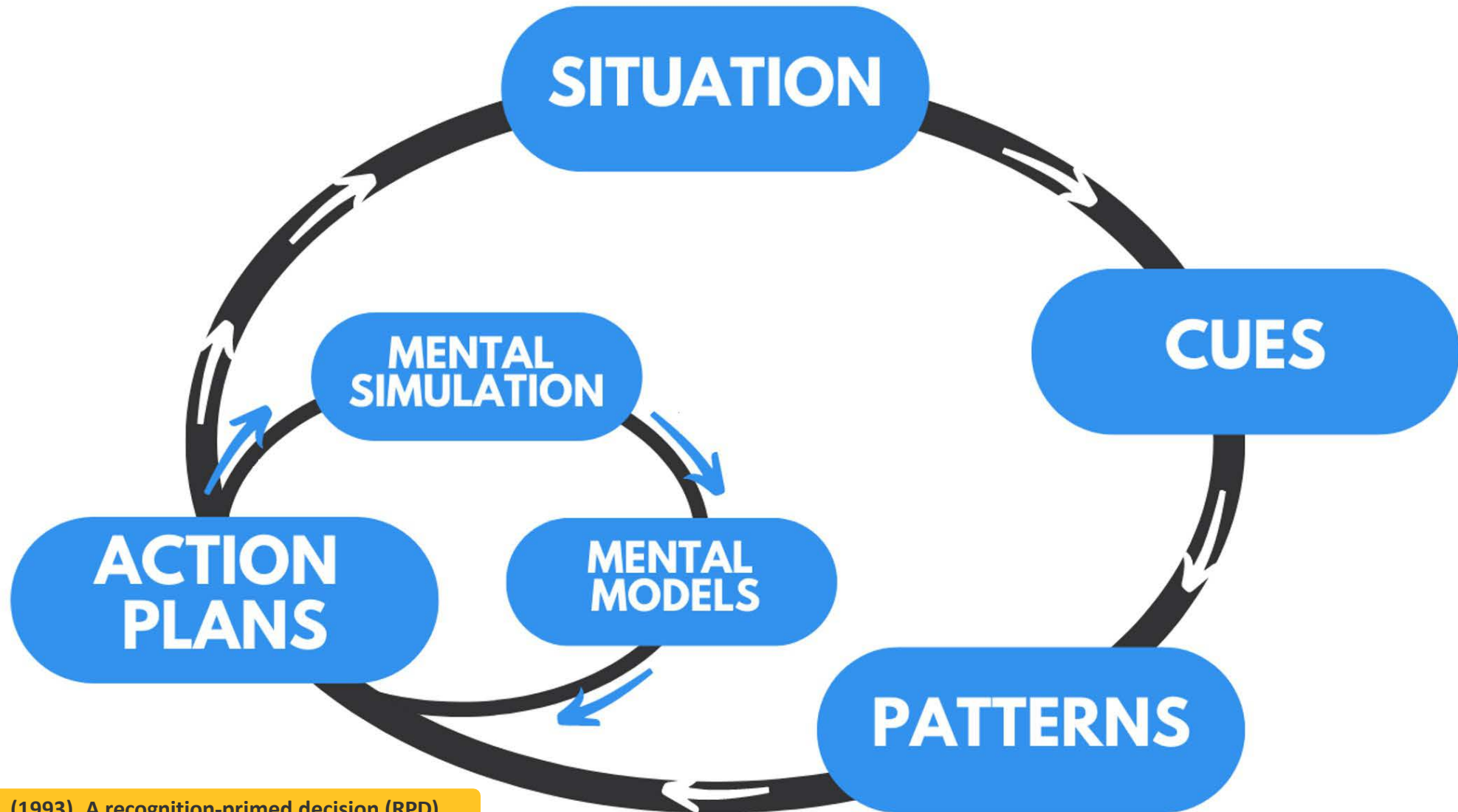
Monitoring

Dashboard

Alarms

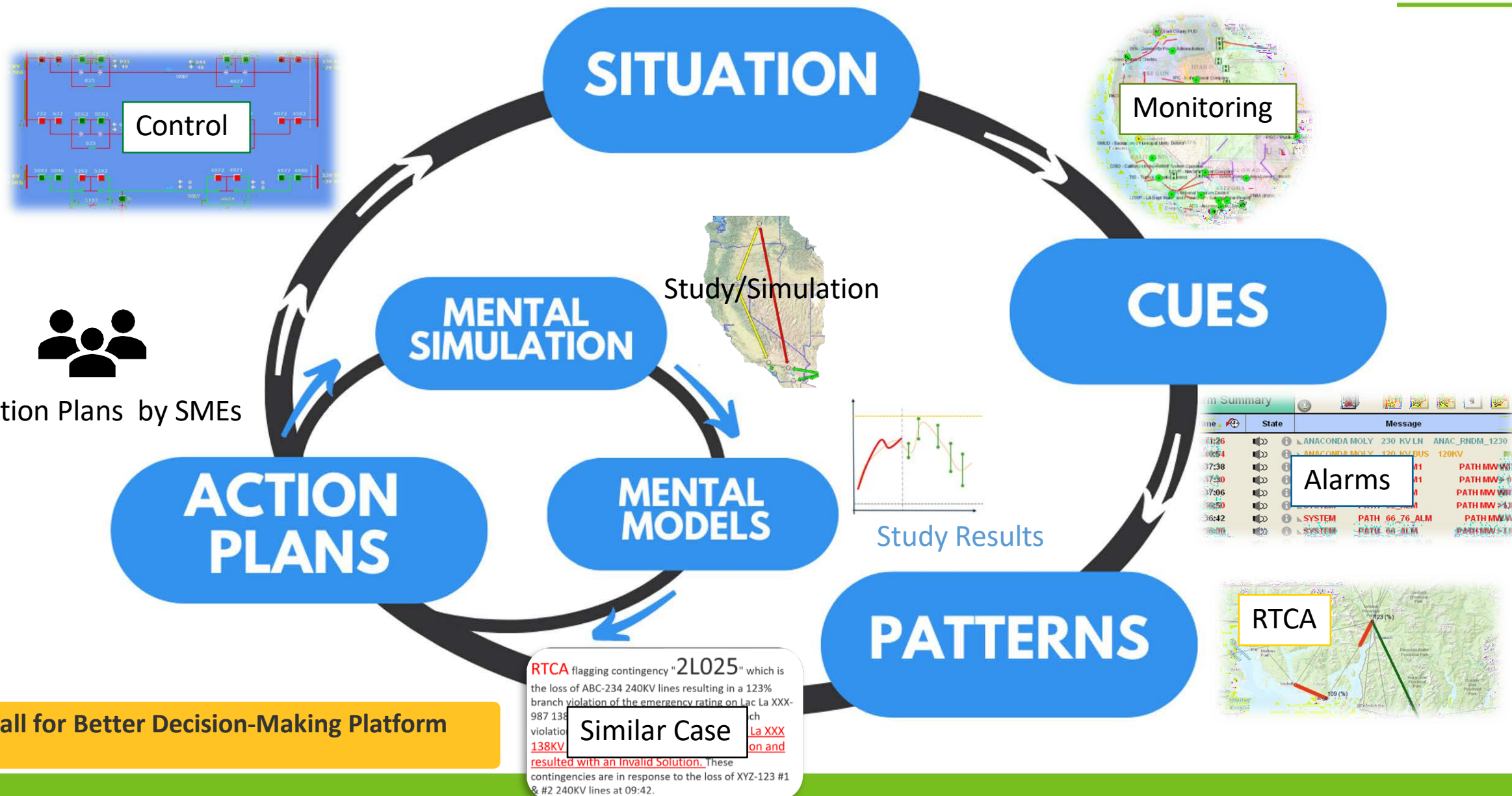
Time	State	Message
10:26		ANACONDA MOLY 230 KVLIN ANAC_RNDM_1230
10:54		ANACONDA MOLY 120 KVLBUS 120KV
17:38		SYSTEM PATH MW 5-1
17:50		SYSTEM PATH MW 5-1
17:06		SYSTEM PATH MW 5-1
18:50		SYSTEM PATH MW 5-1
16:42		SYSTEM PATH 66_76_ALM
16:30		SYSTEM PATH 66_ALM

Decision-making: Recognition-Primed Decision



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

Better Decision-Making Feasible?



Call for Better Decision-Making Platform

Digital Twin: Automation + Simulation



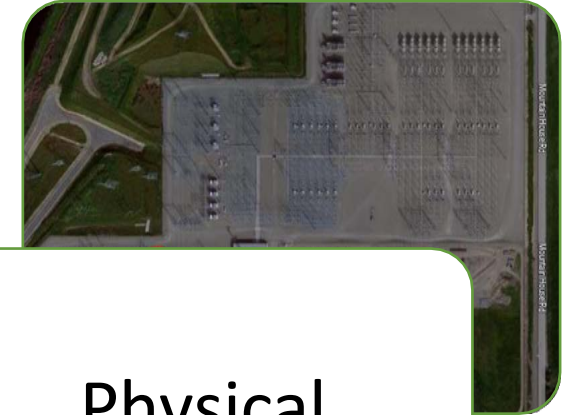
**Dispatcher
Training
Simulator
(DTS)**

Training Network Model



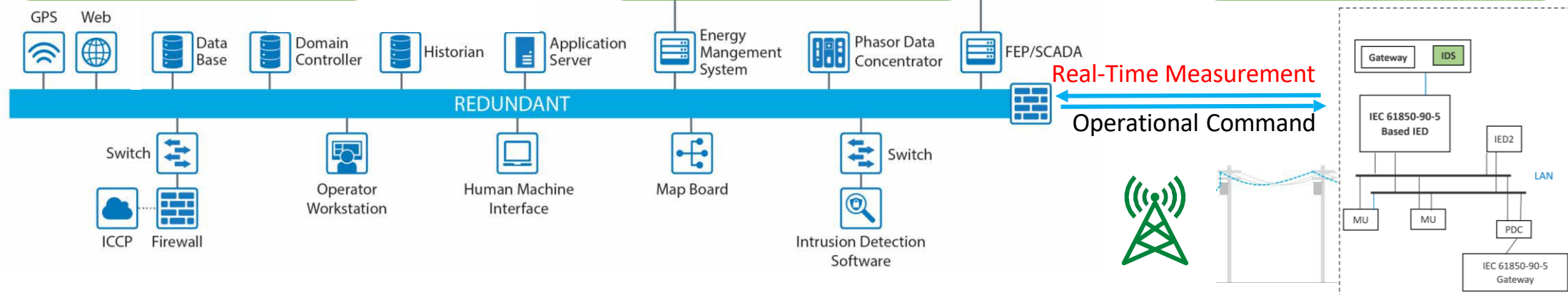
**Operation
Model**

Physical Network Model
Real-Time Measurement



**Physical
Model**

Real-Time Measurement



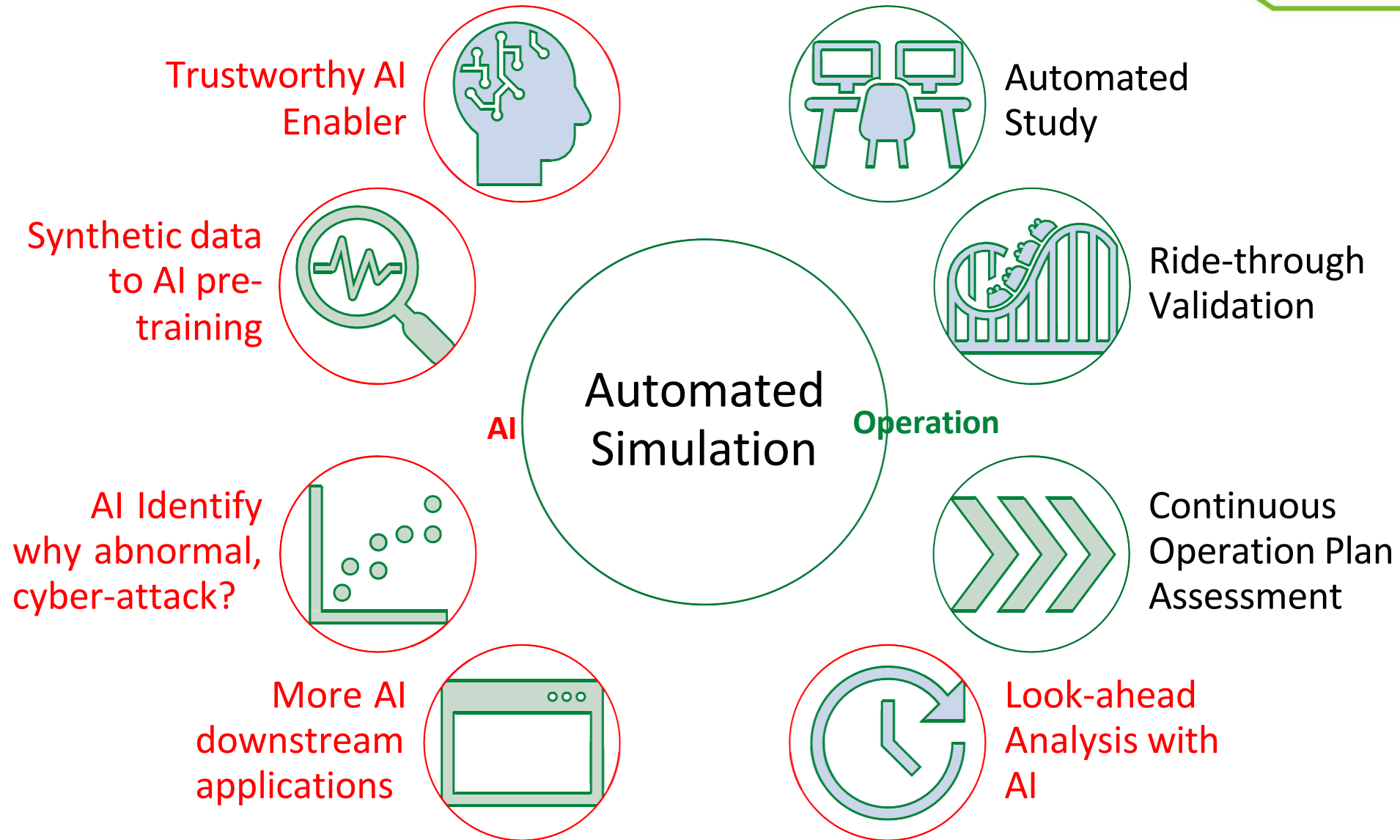
NREL Digital Twin Demo: RTCA Violation Auto Validation



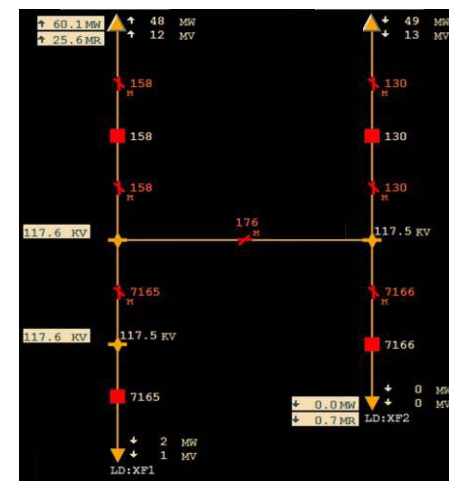
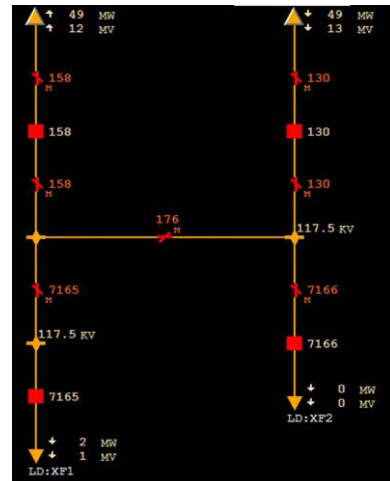
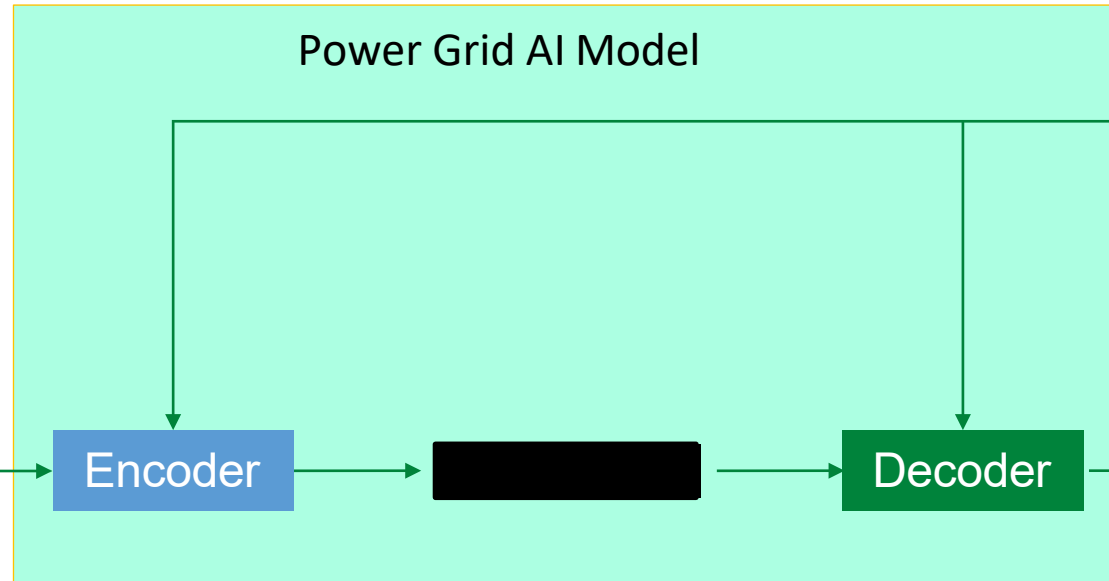
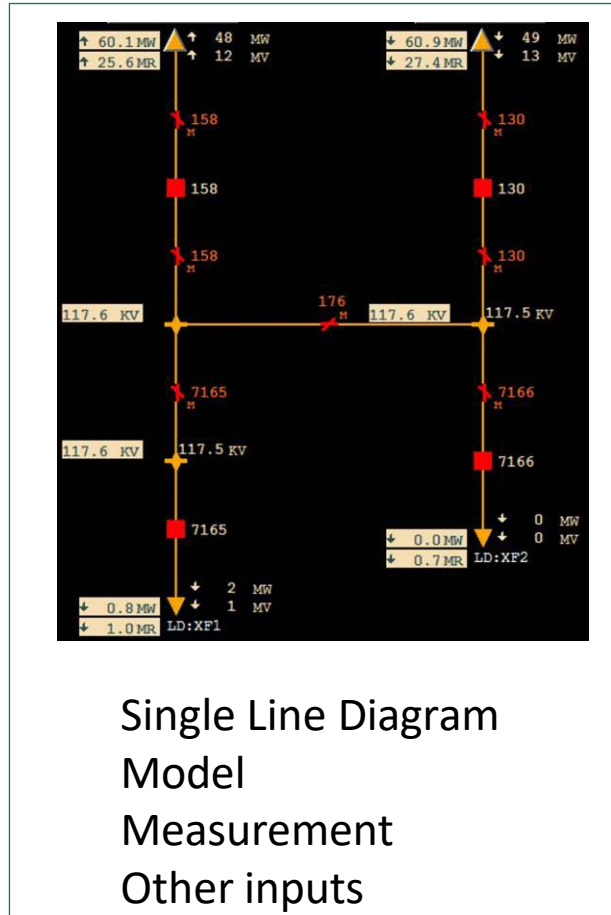
Verification & Validation of EMS RTCA Serious Violations

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

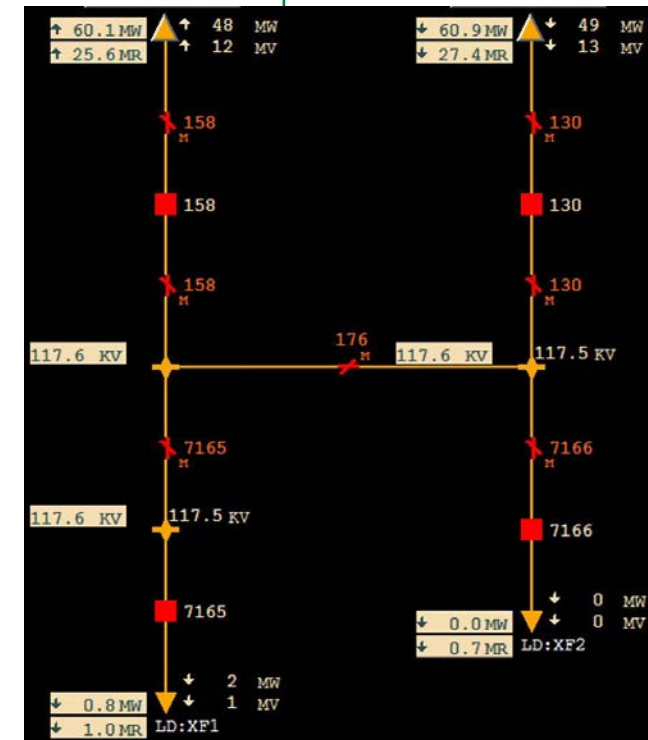
What Do We Do With Digital Twin?



Digital Twin as Trustworthy AI Enabler



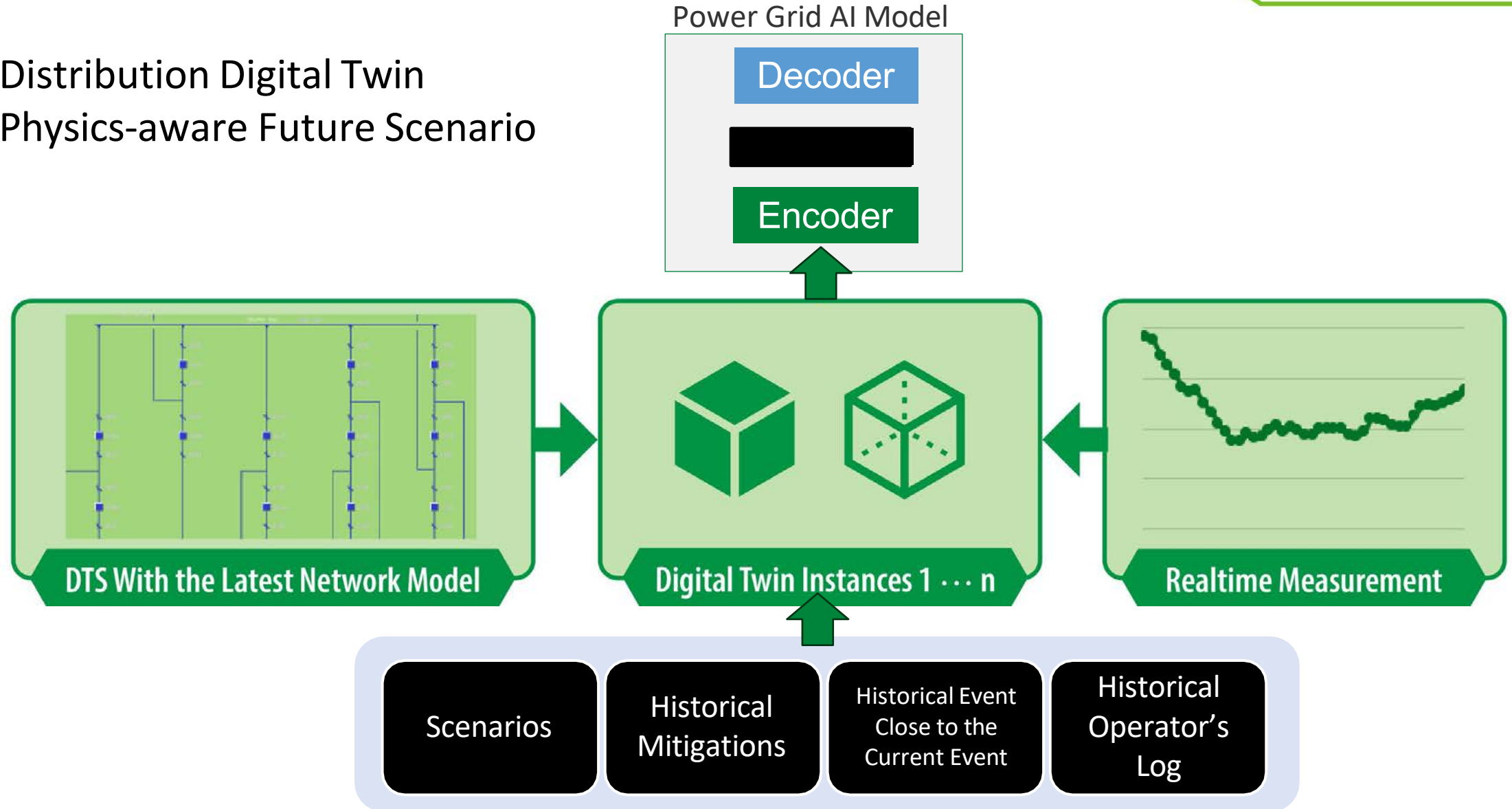
Validated by Digital Twin



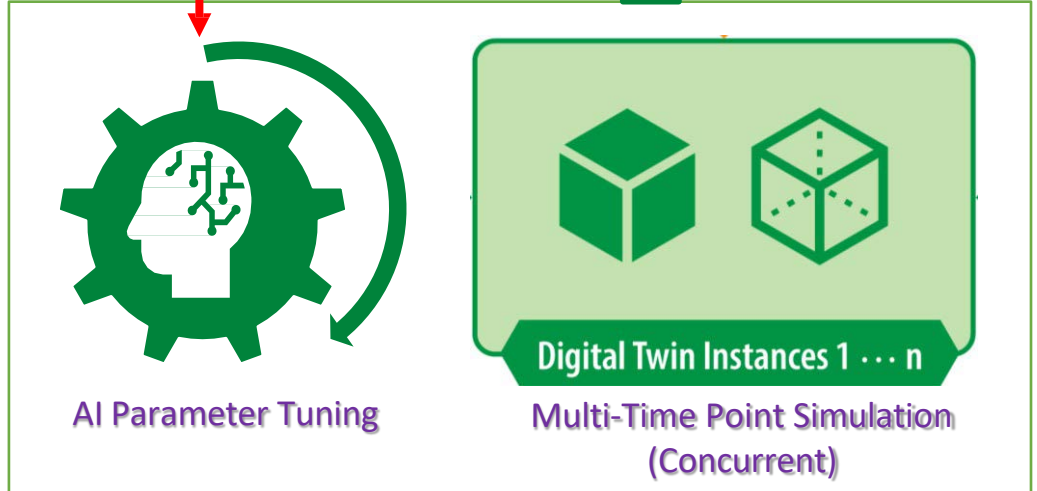
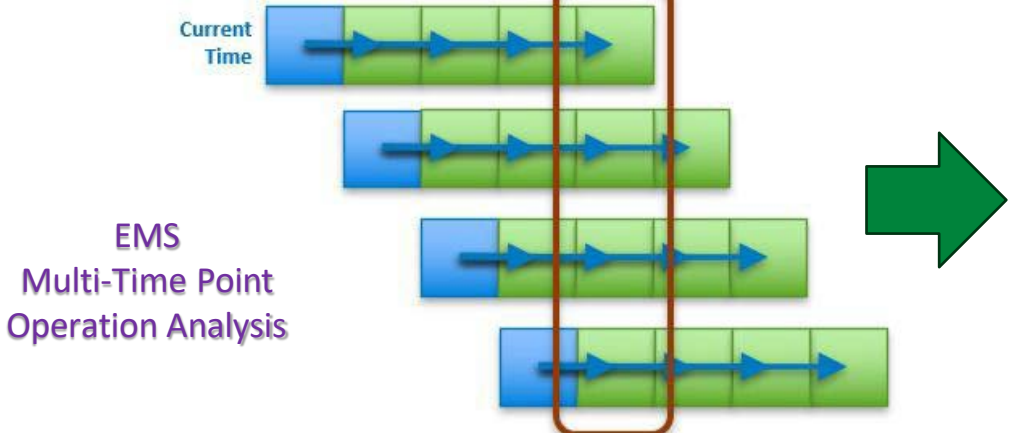
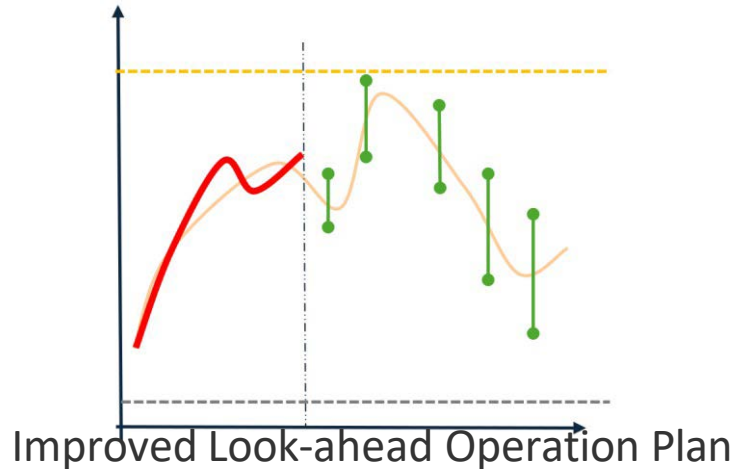
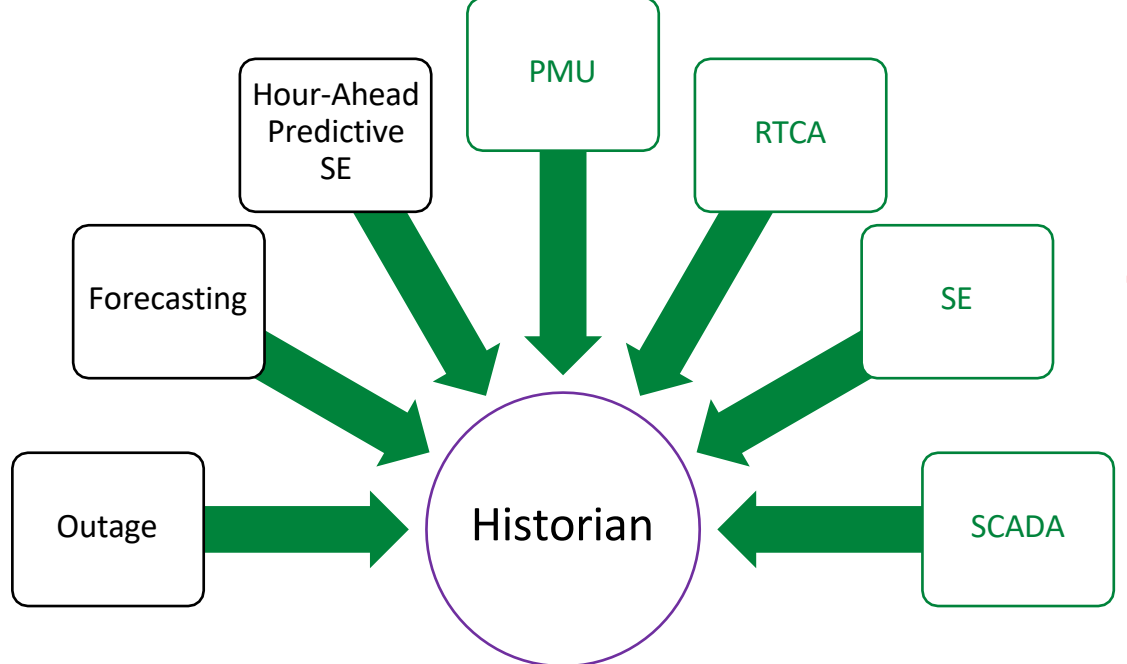
Reconstructed Single Line Diagram

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 ...

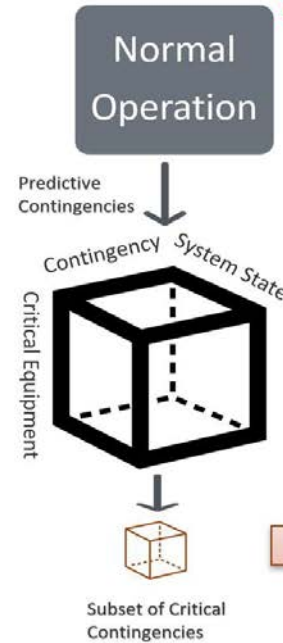
AI/ML Powerflow Trend Prediction in multi-time & space

Operationally Predicted Future Powerflow at a system level

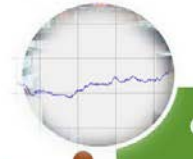
Physics of Law at a regional level by sampling neighboring substations

Physics of Law at a local substation

Control Center Operational Anomaly Detection System



Harmful Anomaly
 Explainable Data Error
 Unexplainable

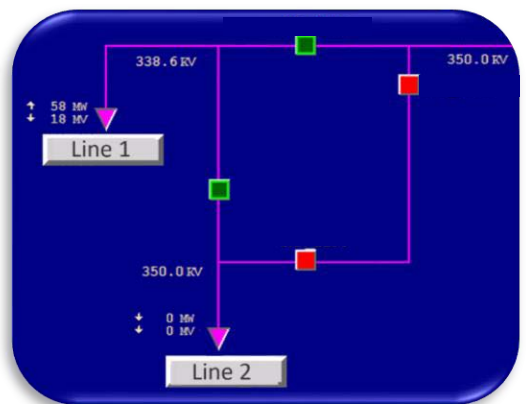


Operation Mismatch

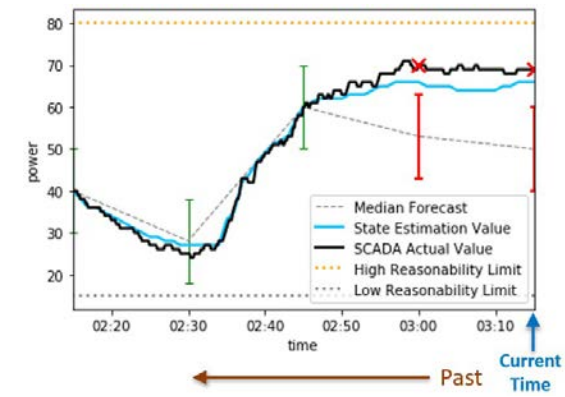


Measurement Mismatch

Network Topology Mismatch

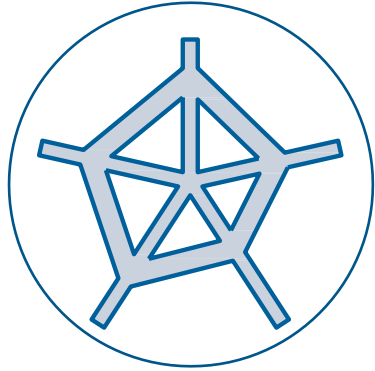


Vision-based Anomaly Detection



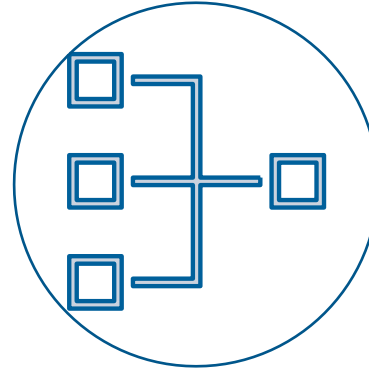
DT confirms
 Operation
 & Network
 Topology
 Mismatch

Decision Making and AI



Forecasting

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



Data & Model

- Network
- Optimization
- Protection
- Anomaly Detection



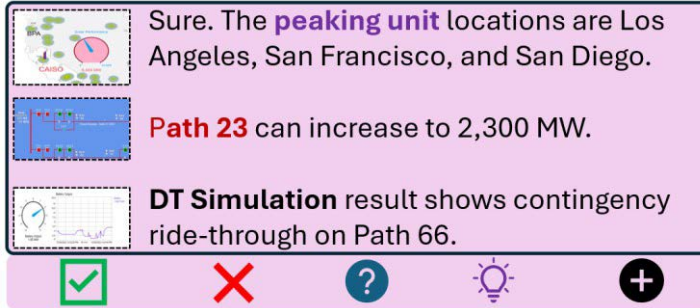
Recommendation

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

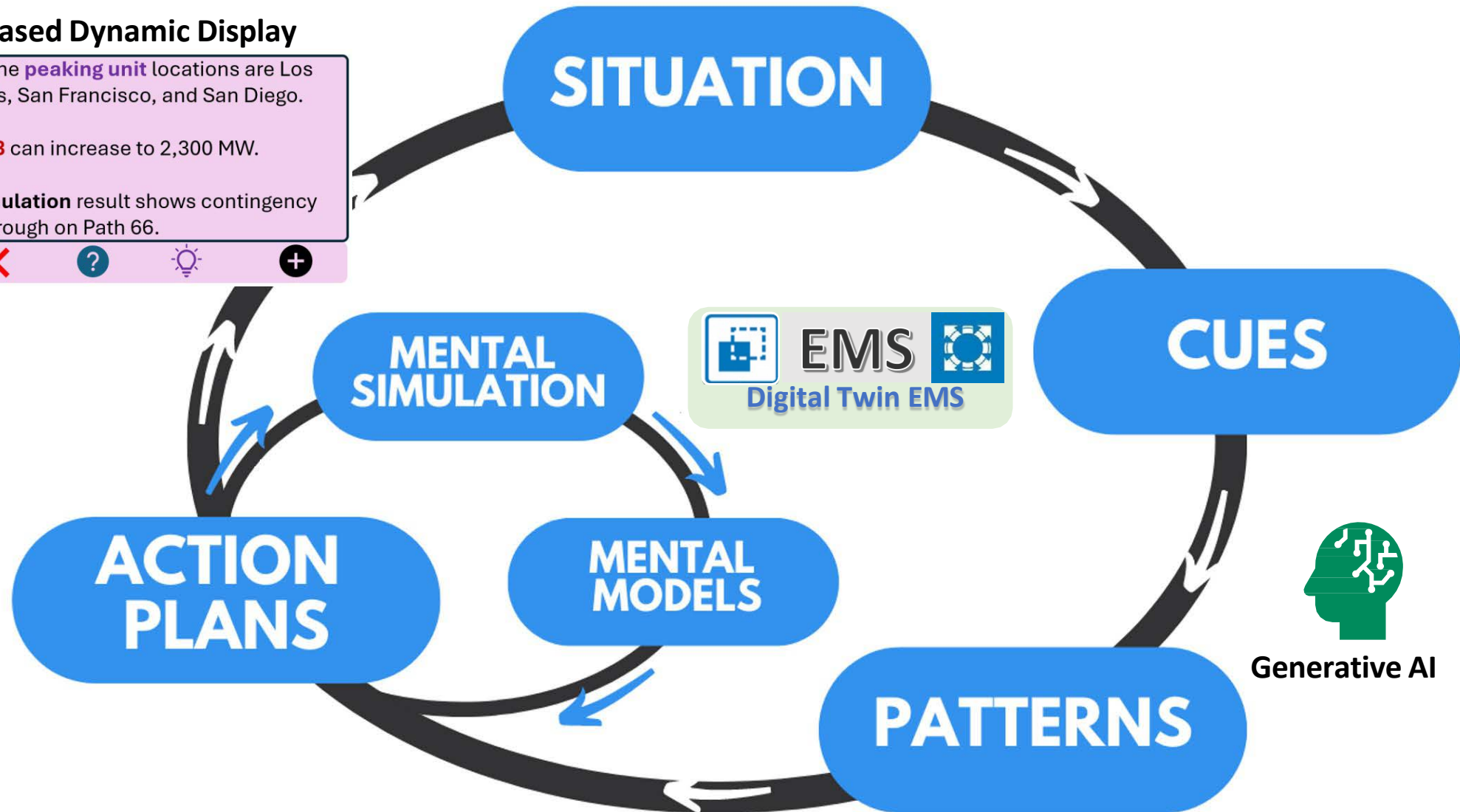
Final Decision Belongs to Operator, Not AI

Digital Twin + AI + Dynamic Display

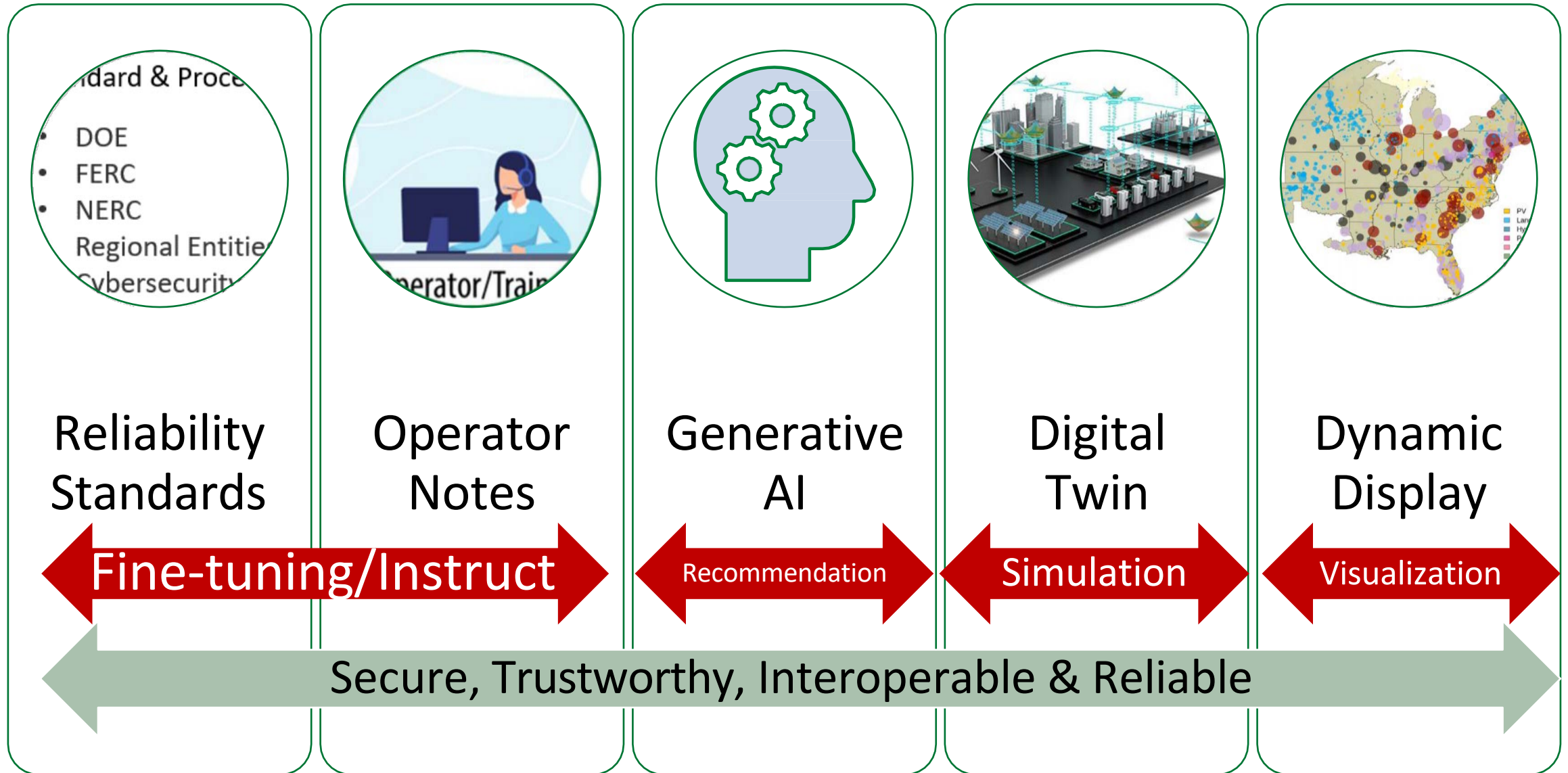
Prompt Based Dynamic Display



The UI mockup shows a pink background with three data visualization panels. The first panel shows a map of California with a red dot and the text 'Sure. The peaking unit locations are Los Angeles, San Francisco, and San Diego.' The second panel shows a line graph with a red peak and the text 'Path 23 can increase to 2,300 MW.' The third panel shows a line graph with a red peak and the text 'DT Simulation result shows contingency ride-through on Path 66.' Below the panels is a navigation bar with icons: a green checkmark, a red X, a question mark, a lightbulb, and a plus sign.



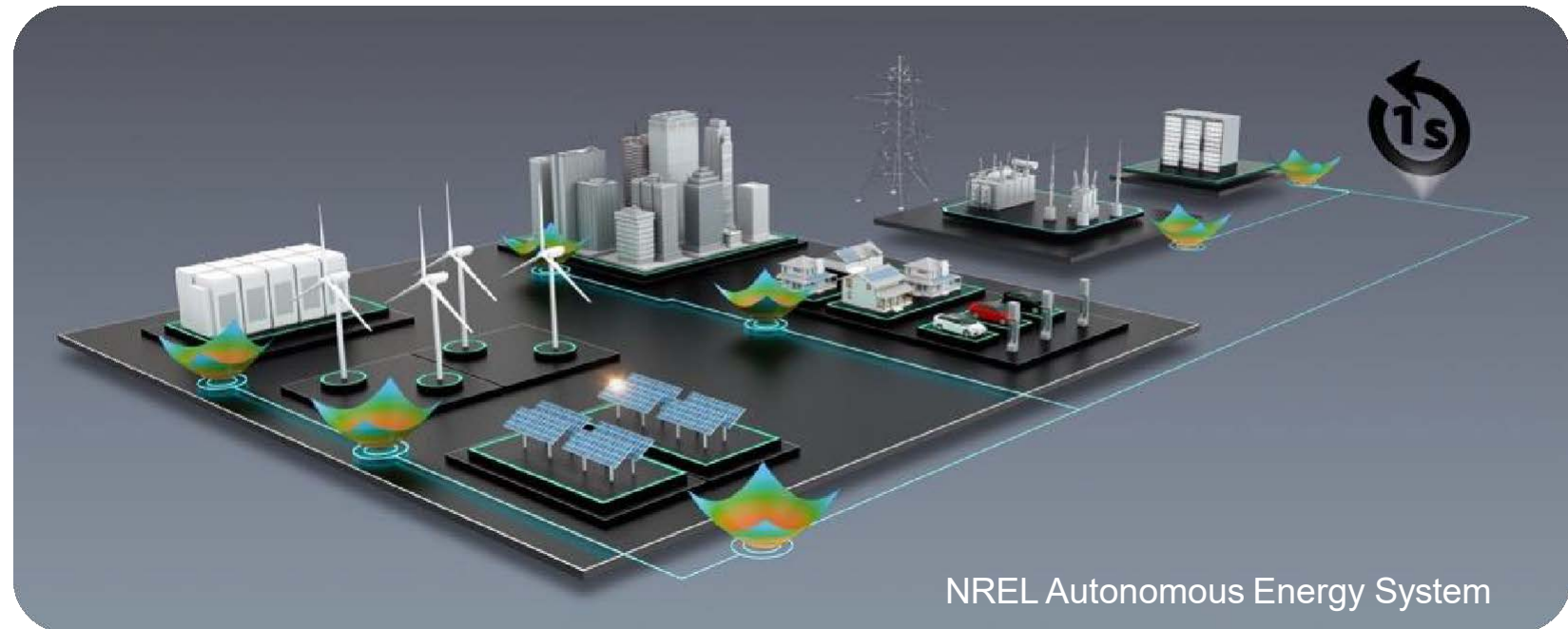
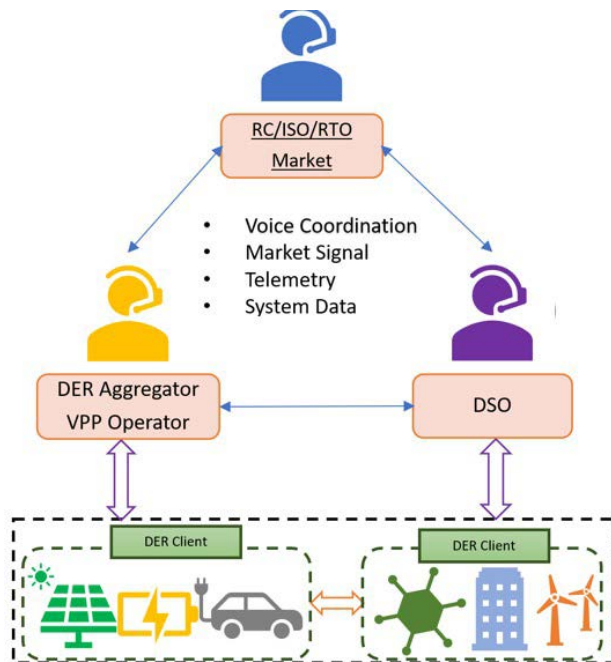
NREL Decision Making Platform



Digital Twin Expanding Scale: T&D + DER

Digital Twin's Role

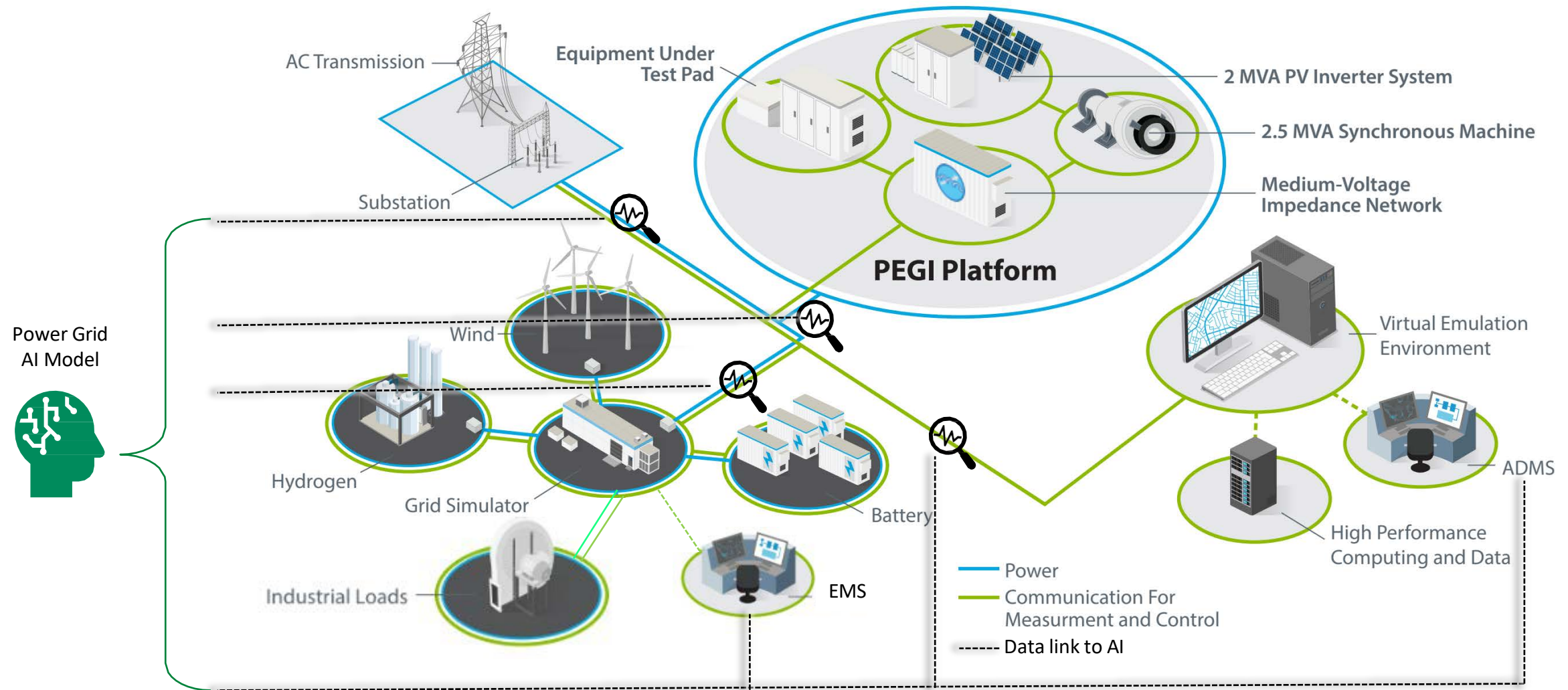
- Expand to Distribution where measurement lacks, and modeling is challenging
- Coordinate T&D with the grid participants including DER customer per FERC Order 2222



NREL T&D Digital Twin Validation at Scale



Draft for Power Grid AI Model Training

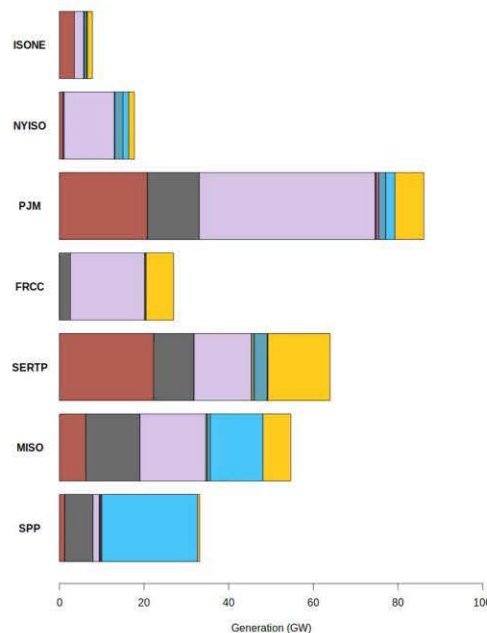
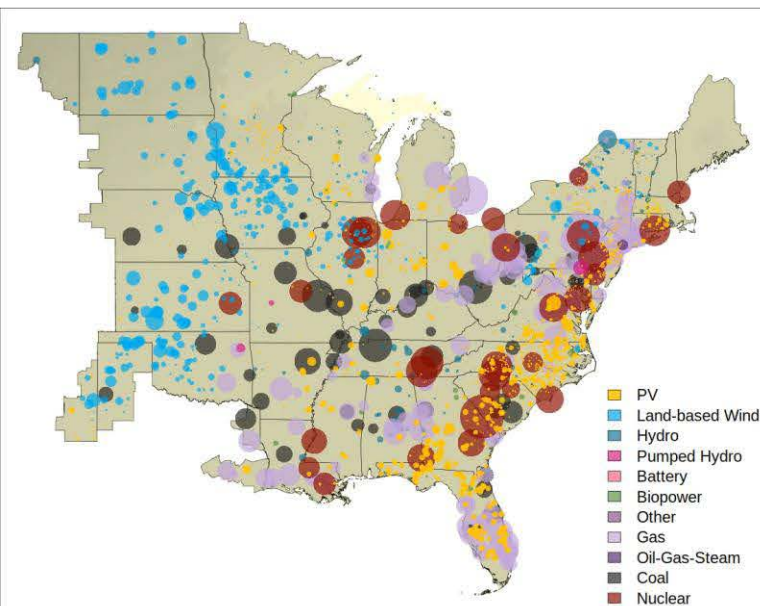


Source: Barry Mather, NREL

Dynamic Display

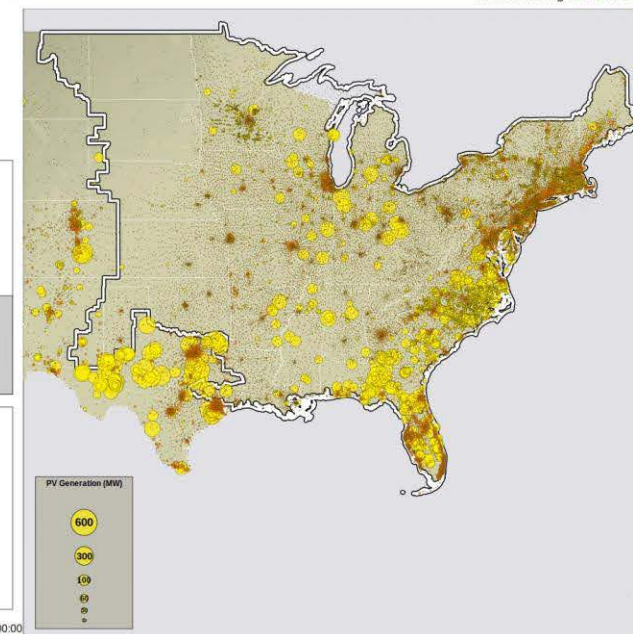
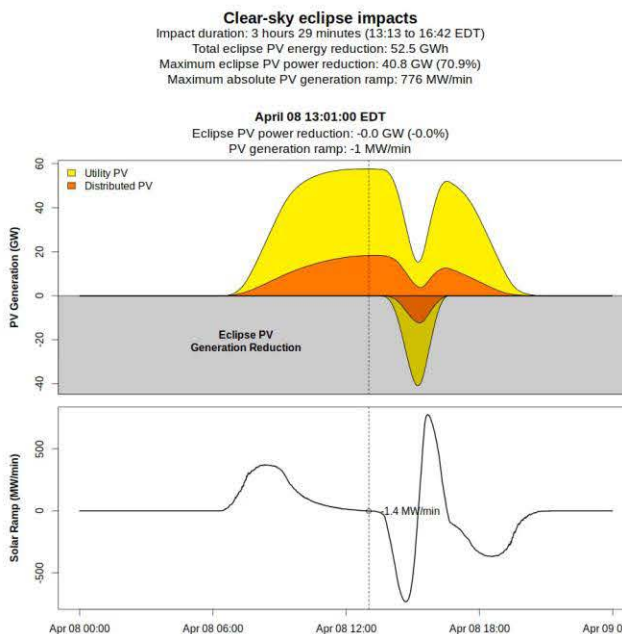
Prompt: During the solar eclipse, animate PV reduction/increase while ramping up/down by other generation sources to meet the demand

EI Eclipse Generation



EI

Eastern Interconnection (EI)
Total PV Capacity: 84.7 GW (UPV: 56.7 GW, DPV: 28.0 GW)



Source: Kenny Gruchalla, NREL

Prompt Based Digital Twin + AI Orchestration

Telecom Weather Other Energy

Operator/Trainee

Sure. The **peaking unit** locations are Los Angeles, San Francisco, and San Diego.

Path 23 can increase to 2,300 MW.

DT Simulation result shows contingency ride-through on Path 66.

✓ ✗ ? 💡 +

Interdomain Coordination by Operator

Dynamic Display by Prompt Answer

AI Orchestrator (Prompt Based Workflow/Policy)

Q&A EMS/ADMS EMT/DERMS Data/Model

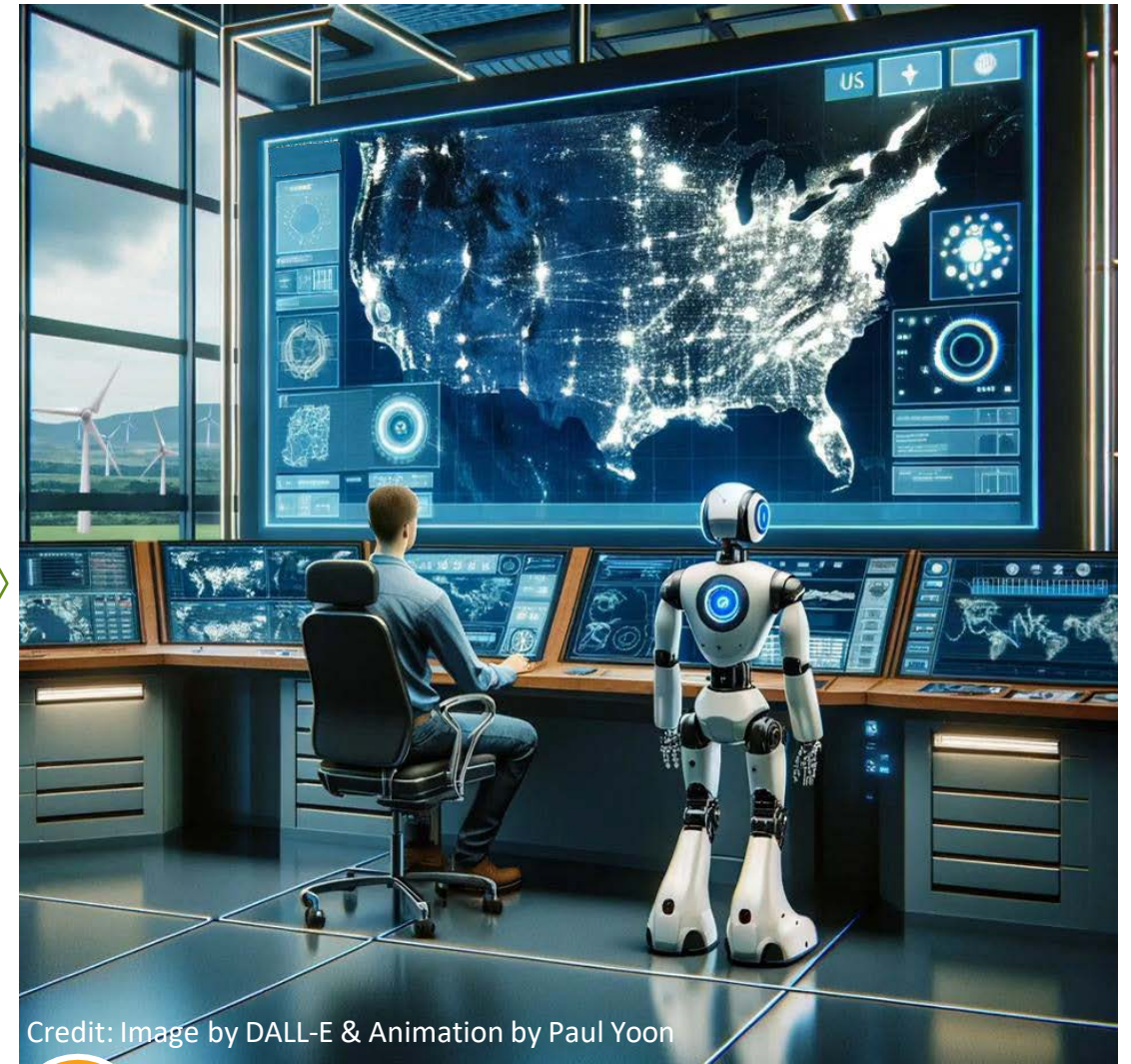
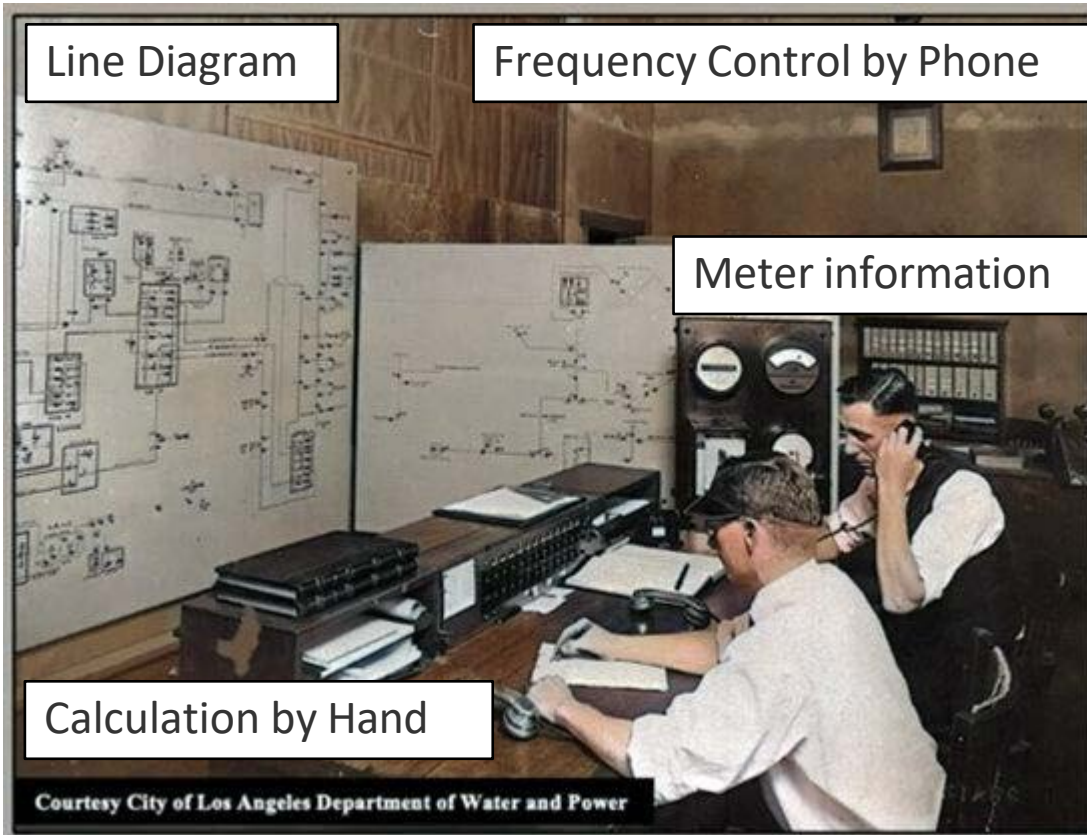
Digital Twin + Recommendation

Forecast Code & Equation Regulatory Standard Risk Metrics Anomaly

VRE/Load Algorithm Standard Governance Cyber-Resilient

Power Grid AI Model

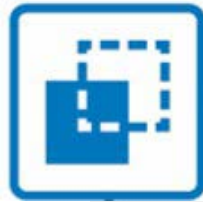
Digital Twin + AI + Dynamic Display



Julie Cohn: The Grid: Biography of an American Technology

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

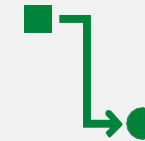


Dynamic Display must be dynamic to Operator's request.

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



Better Decision Making



Recommendations



Trustworthy

NREL/PR-5D00-89725

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