



Digital Twin + AI: Control Room of the Future

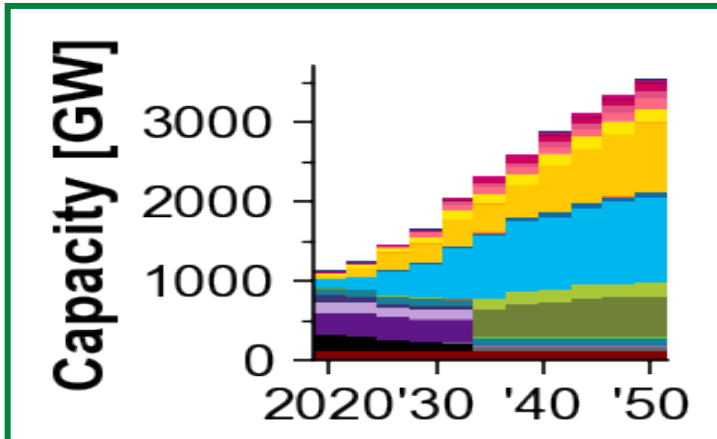
IEEE TF on Digital Twin of Large-Scale Power System

Seong Choi, Engineering Lead
Rishabh Jain, Senior Researcher
National Renewable Energy Laboratory

Hongming Zhang, SCADA EMS Supervisor
Lower Colorado River Authority

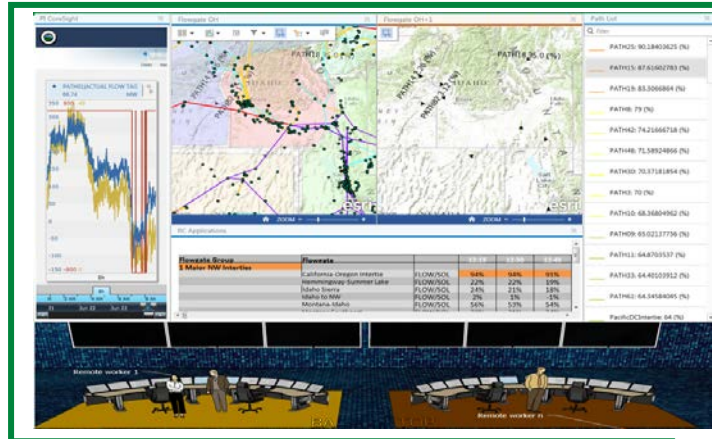
Control Room Decision Making

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

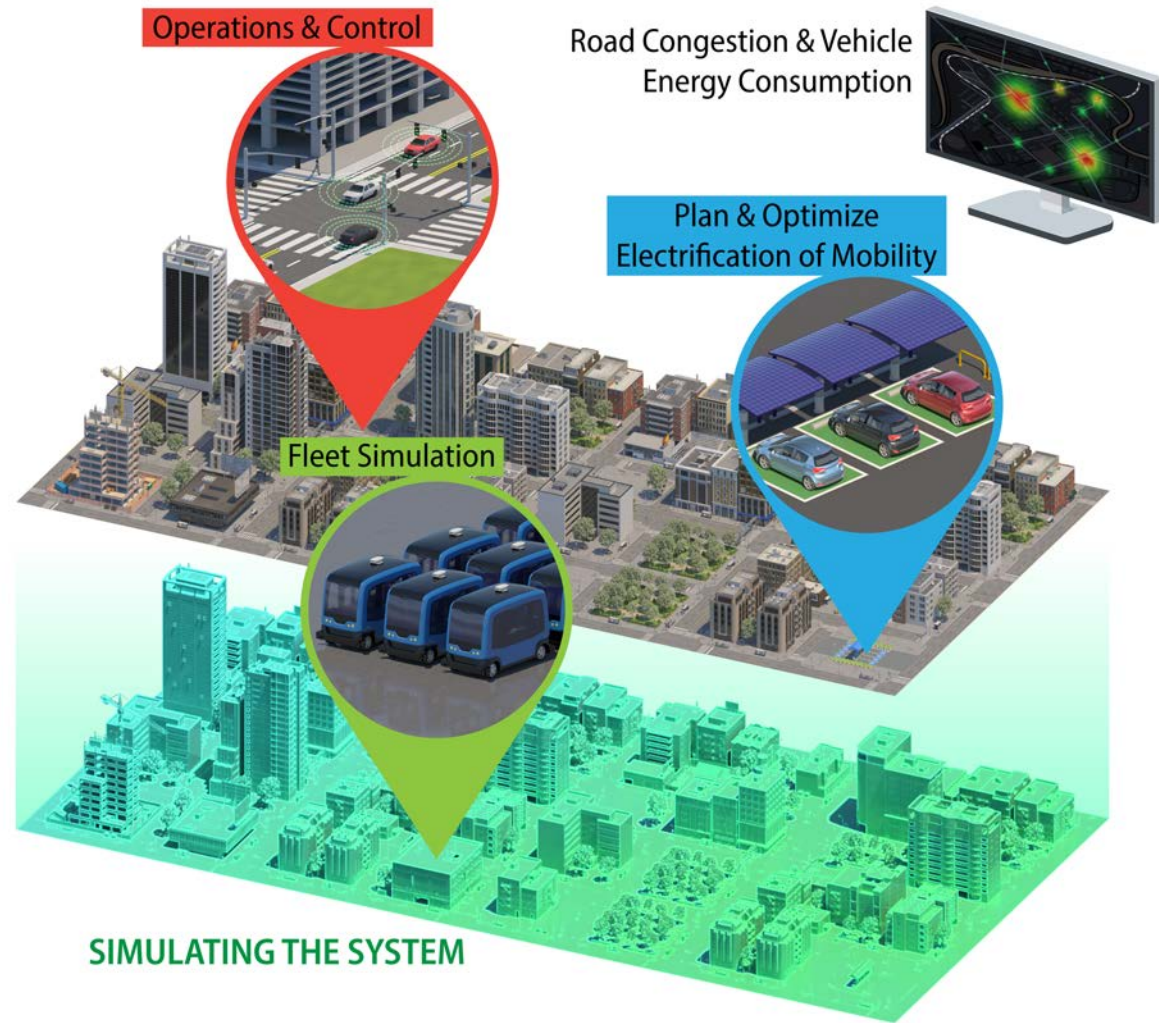


Source: DALL-E

Digital Twin + AI
=
Network Operator Virtual Assistant

Recommendation

Digital Twin in the Power Grid



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

Simulation Real-Time Operation Remotely

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

Predictive Insight of Asset Maintenance or Remaining Useful Life (RUL)

Proof-of-concept or What-if

more

Source: Besiki Kazaishvili, NREL

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

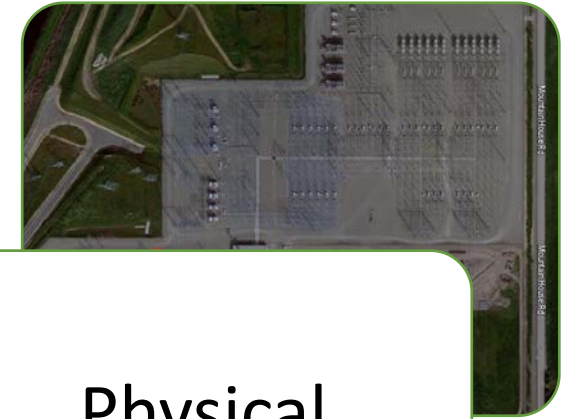
Digital Twin: Automation + Simulation



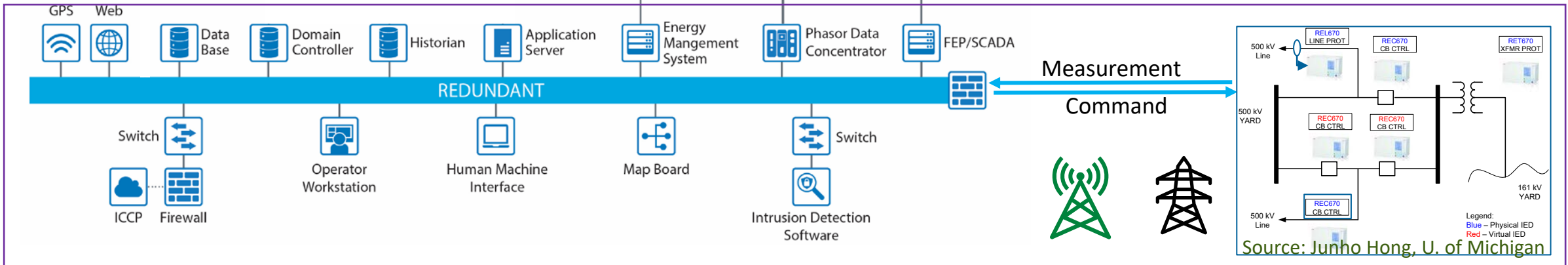
Dispatcher Training Simulator (DTS)
Training Network Model



Operation Model
SCADA Network Model
Real-Time Measurement

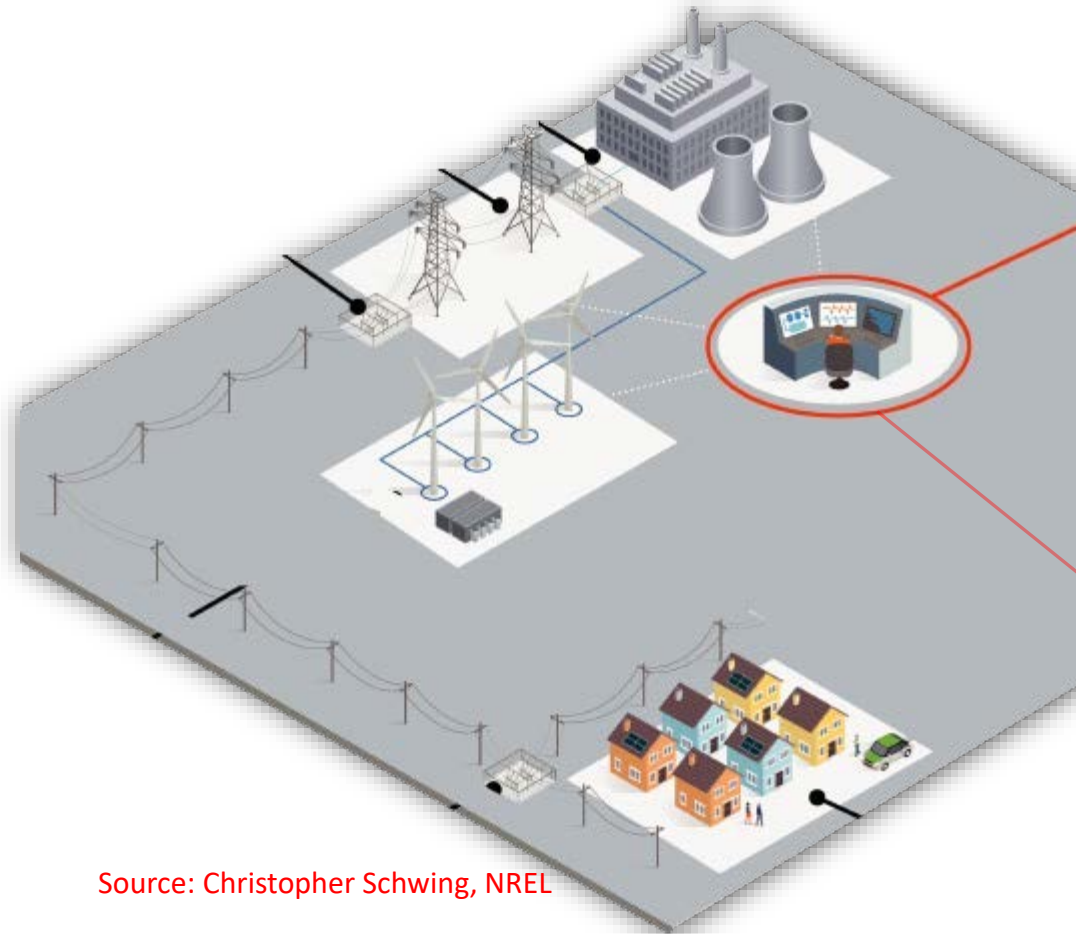


Physical Model
Real-Time Measurement



Decision making

Reliable Anytime 24 X 7 X 365



Source: Christopher Schwing, NREL

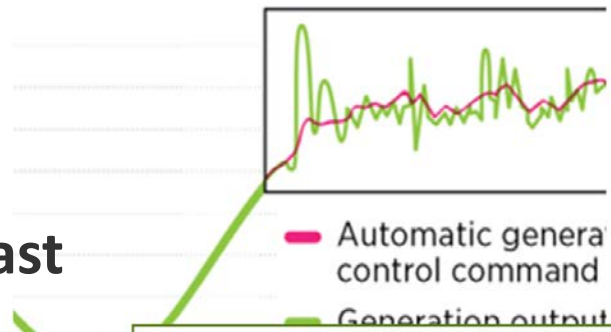


Source: Seong Lok Choi, NREL and DALL-E

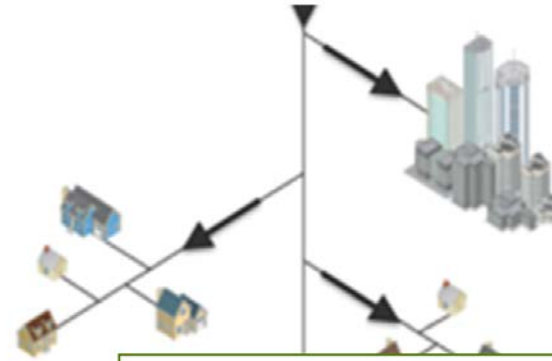
Operator must reliably balance generation & load (tug-of-war) via power line near 60Hz

Power Grid Trends: Distributed, IBR & Weather

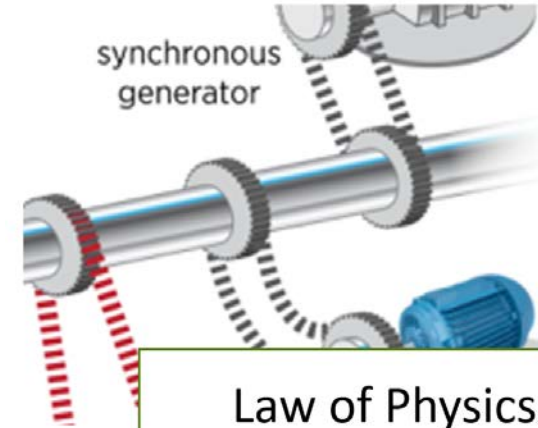
In the past



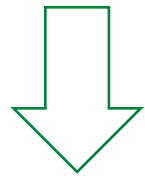
Load following



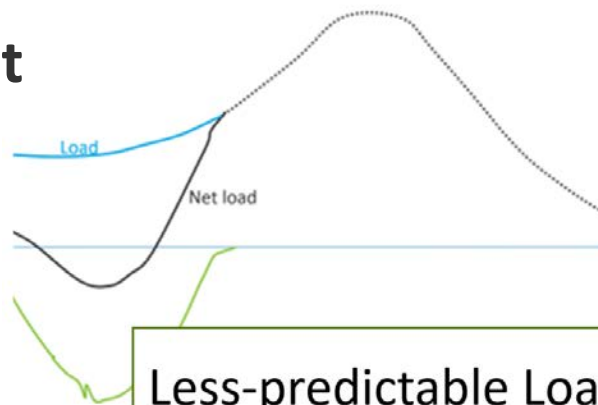
Uni-directional



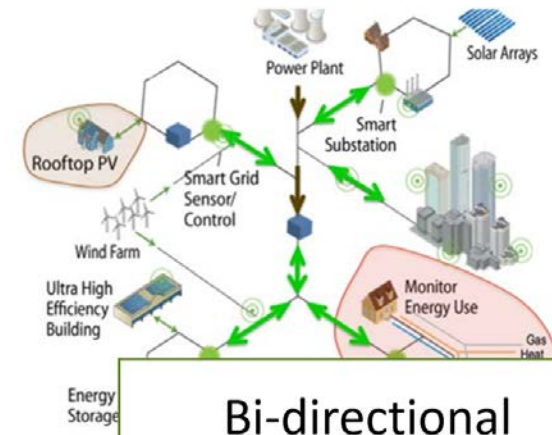
Law of Physics



Current



Less-predictable Load



Bi-directional



Programmable

Source: Ben Kroposki, NREL

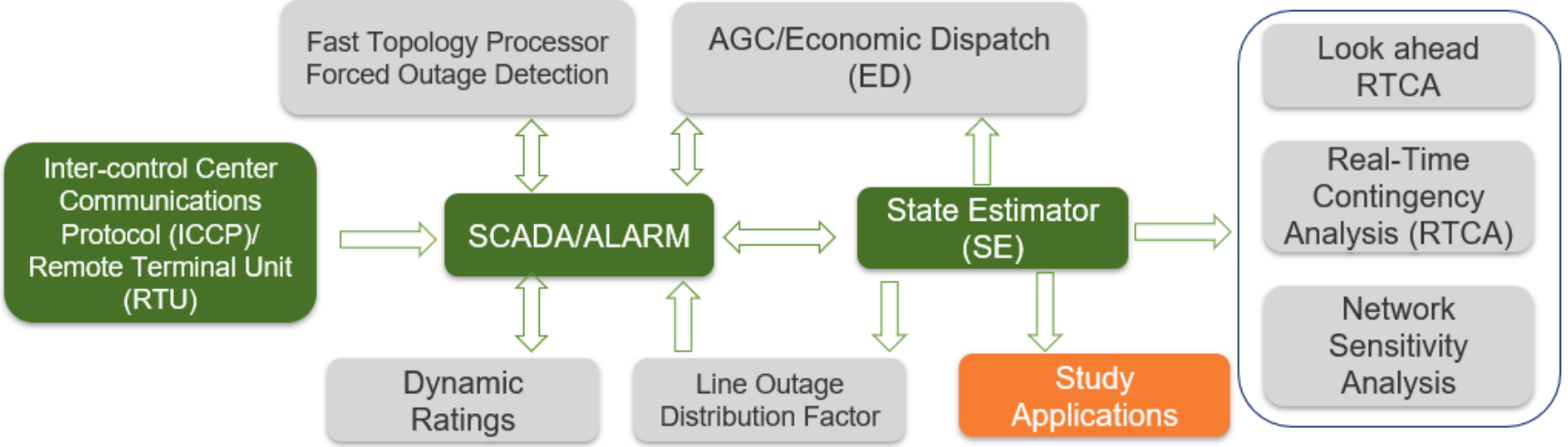
Operating's Decision-Making Input



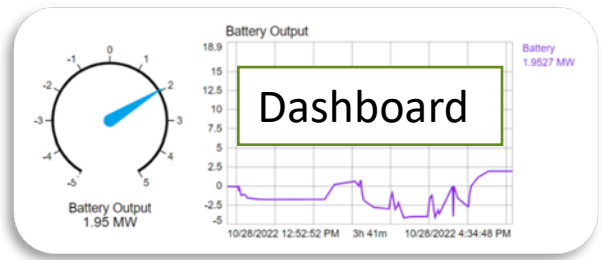
Standard & Procedure

- DOE
- FERC
- NERC
- Regional Entities
- Cybersecurity

Control Room Tools



Operator Displays



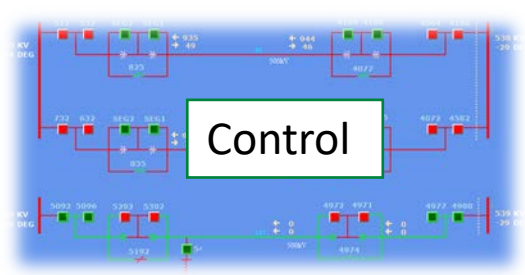
Alarms

Time	State	Message
04:26	🔔	ANACONDA MOLY 230 KV LN ANAC_RNDM_1230
04:54	🔔	ANACONDA MOLY 170 KV BUS 120KV
07:38	🔔	PATH MW WITH
07:30	🔔	PATH MW > 95
07:06	🔔	PATH MW WITH
06:50	🔔	PATH MW > LIM
06:42	🔔	SYSTEM PATH 66_76_ALM
06:30	🔔	SYSTEM PATH 66_ALM

Operator Knowledge System

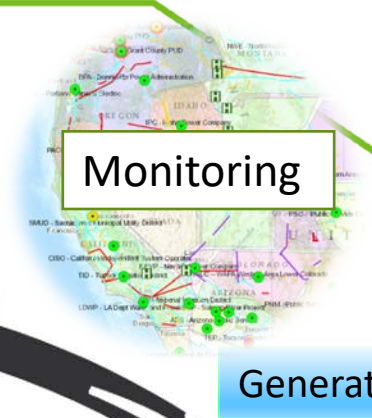
AD	ALARM	ACK	NOTES	NEW	Staten	VIOL	TYP	Voltage Class	CD	MONI	D/RED_ELEMENT	Contingency Description
					II		BR				ANST T1P	KEELER ALLSTON #1 500KV
					II		BR				JPL 8115@LUNAPPIM	HI ALGO-TURQUIMES 115 KV
											WISCEL	KEELER ALLSTON #1 500KV

Recognition-Primed Decision (RPD)



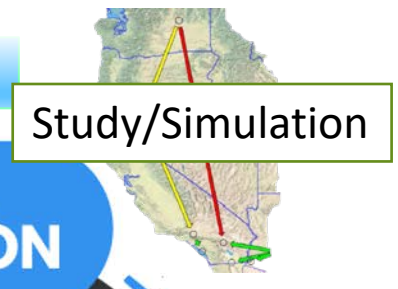
Control

Reassess situation



Monitoring

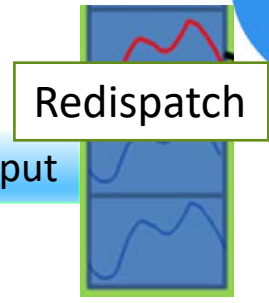
Generates



Study/Simulation



Will this work?



Redispatch

Modify input



Not appropriate



Appropriate action?

Time	State	Message
11:26		ANACONDA MOLY 230 KV LN ANAC_RNDM_1230
10:54		ANACONDA MOLY 120 KV BUS 120KV
10:38		PATH MW WITH
10:30		PATH MW > 95
10:06		PATH MW WITH
09:50		PATH MW > LIM
09:42		SYSTEM PATH 66_76_ALM PATH MW > LIM
09:30		SYSTEM PATH 66_ALM PATH MW > LIM

Alarms

Help to recognize



Contingency

activates

RTCA flagging contingency "2L025" which is the loss of ABC-234 240KV lines resulting in a 123% branch violation of the emergency rating on Lac La XXX-987 138KV violation on and La XXX on and resulted with an Invalid Solution. These contingencies are in response to the loss of XYZ-123 #1 & #2 240KV lines at 09:42.

Similar Case

Operating instructions

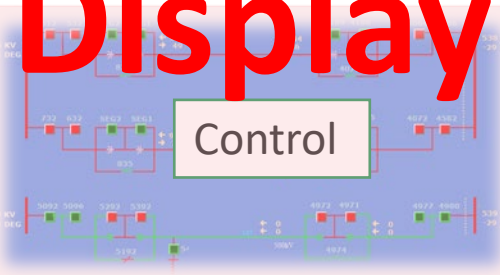
Goal achieved?



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

Recognition-Primed Decision (RPD)

Display



Control

Reassess situation

SITUATION



Monitoring

AI

Generates

Digital Twin

Will this work?

Study/Simulation

MENTAL SIMULATION



CUES

Operating instructions

Appropriate action?

Not appropriate

Modify input

Redispatch

ACTION PLANS

MENTAL MODELS

Time	State	Message
11:26		ANACONDA MOLY 230 KV LN ANAC_RNDM_1200
10:54		ANACONDA MOLY 120 KV BUS 120KV
17:38		PATH MW WITH
17:30		PATH MW > 95
17:06		PATH MW WITH
16:50		PATH MW > LIM
16:42		SYSTEM PATH 66_76_ALM PATH MW > LIM
16:30		SYSTEM PATH 66_ALM PATH MW > LIM

Alarms

Help to recognize

PATTERNS

Contingency

activates

RTCA flagging contingency "2L025" which is the loss of ABC-234 240KV lines resulting in a 123% branch violation of the emergency rating on Lac La XXX-987 138KV violation on and resulted with an Invalid Solution. These contingencies are in response to the loss of XYZ-123 #1 & #2 240KV lines at 09:42.

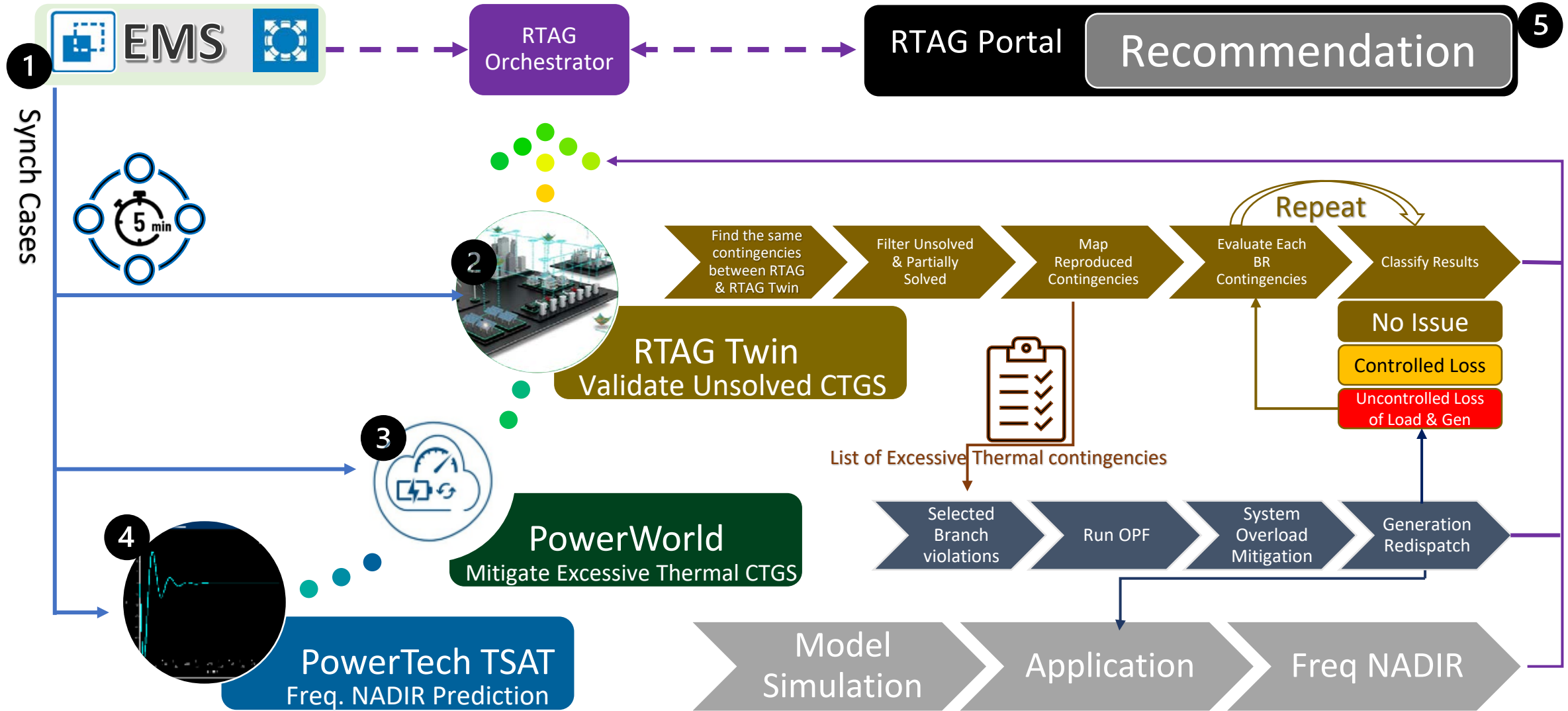
Similar Case



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

Real-Time Analytics for Grid (RTAG)

Data Flow



NREL Digital Twin Demo: Contingency Violation



Auto Validation

RTAG Primary (EMS) Pause Play Transfer Case to Twin

RUNNING
 Freq: 60.0159 Hz
 Gen: 98,492 MW
 Load: 93,310 MW
 Current Time: 28-Mar-2019 08:00:37

Violation Type	Basecase Violation	CTGs Violation
Island		
Branch	3	89
Voltage		44
Angle		0
Interface	2	6
Miscellaneous	0	

RTAG Twin (DTS) Pause Play EMS Synchronization

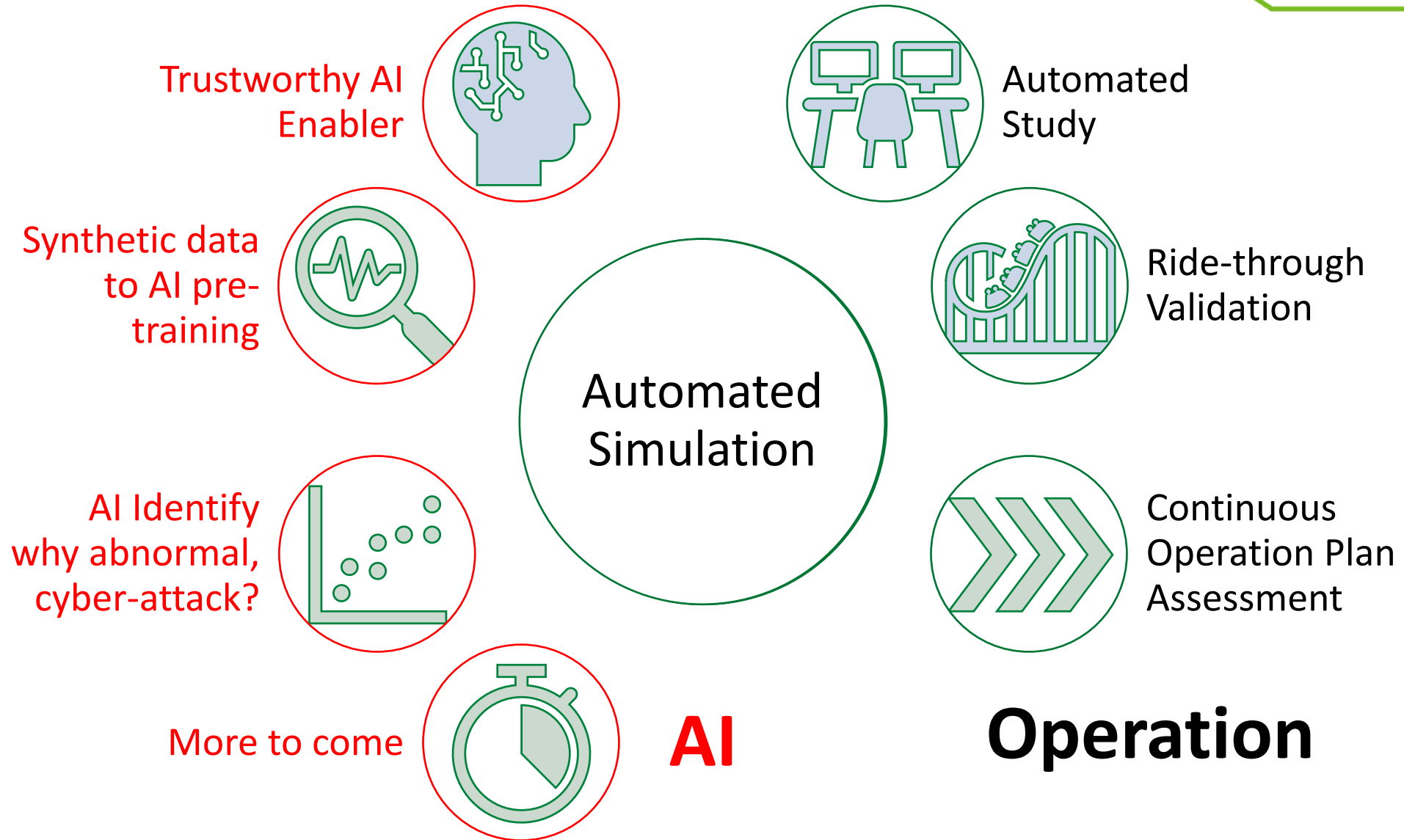
PAUSED
 Freq: 60.0165 Hz
 Gen: 97,506 MW
 Load: 94,917 MW
 Current Time: 28-Mar-2019 08:00:32 MDT
 RTCA Time: 28-Mar-2019 08:00:20 MDT

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

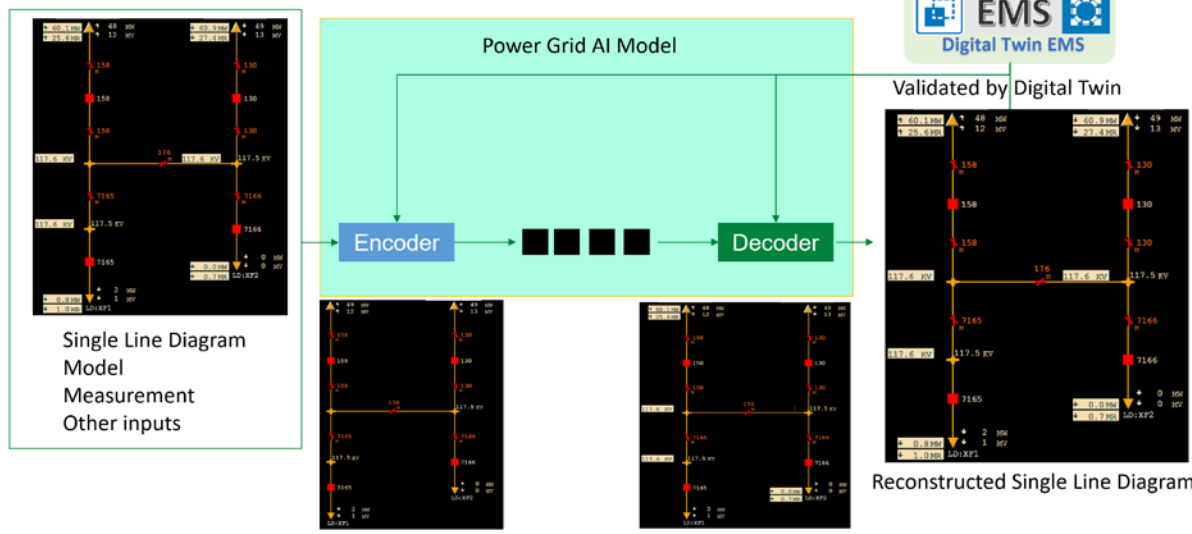
CTG ID	EMS RTCA	Twin RTCA Reproduced	Twin Validation Status	Twin Validation Detail
MUC5L076	UNSOLVED			

What Can We Do More With Digital Twin?



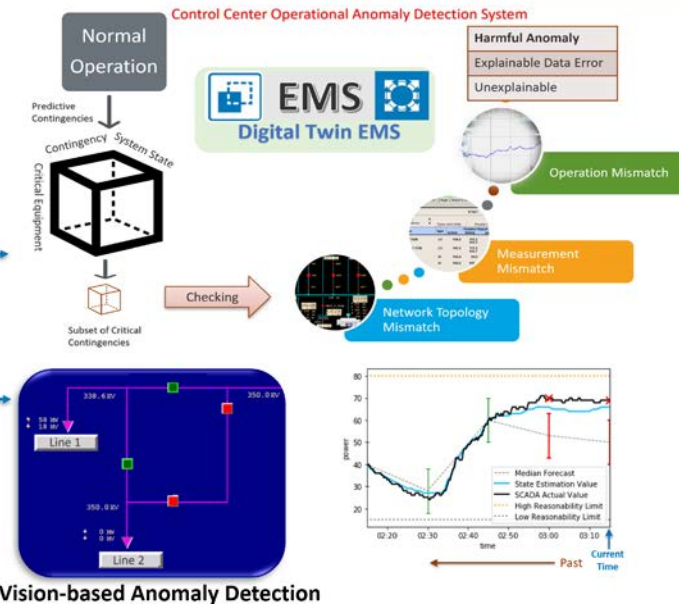
Digital Twin + AI in Decision Making

Trustworthy AI Enabler

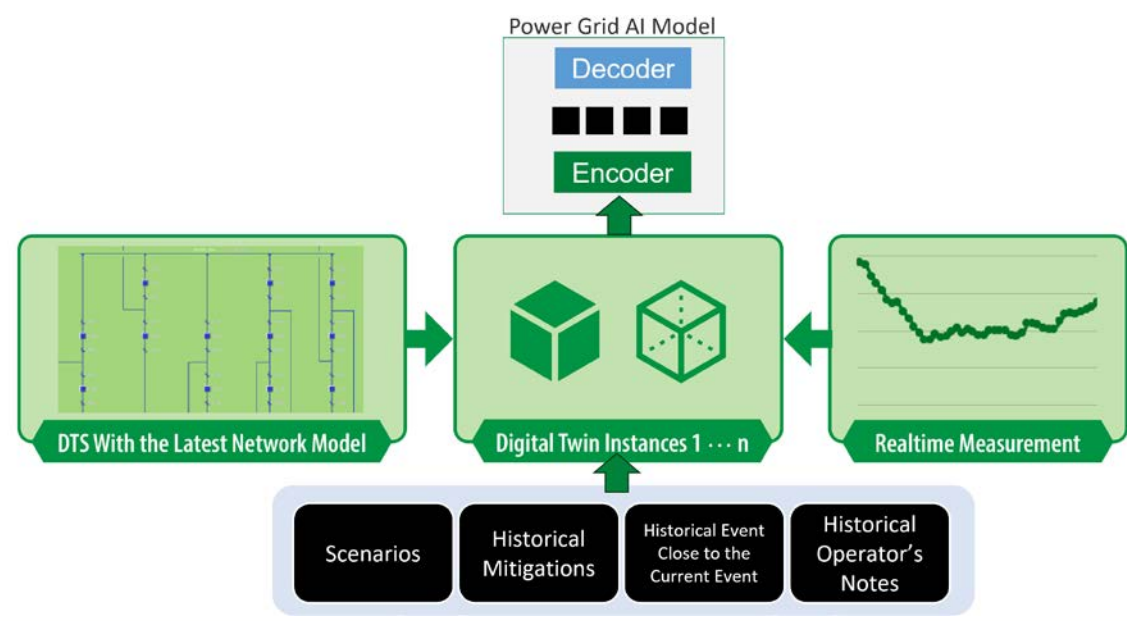


AI Identify abnormal, cyber-attack?

- 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



Synthetic data to AI pre-training



NREL Decision Making Platform: eGridGPT

- Standard & Process
- DOE
 - FERC
 - NERC
 - Regional Entities
 - Cybersecurity

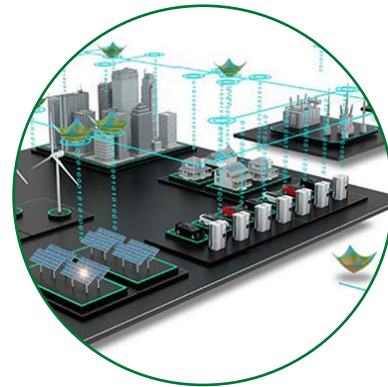
Reliability
Standards



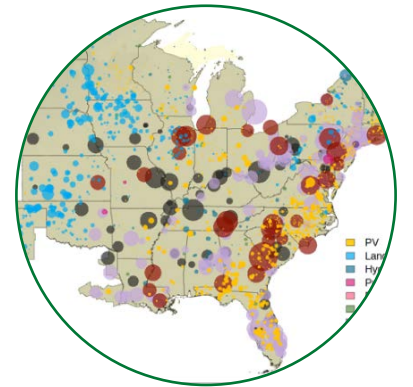
Operator
Notes



Generative
AI



Digital
Twin

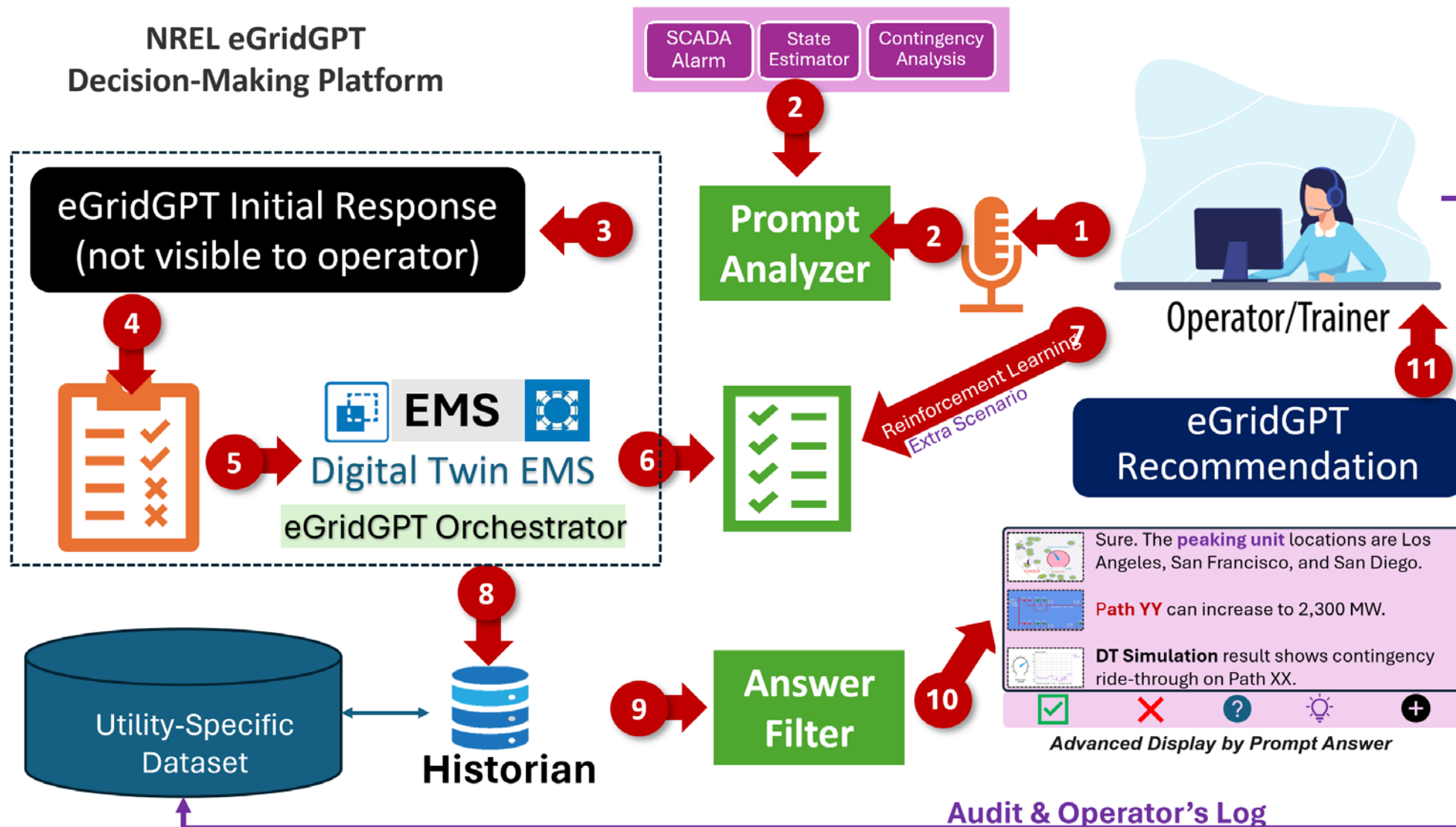


Dynamic
Display

Secure, Trustworthy, and Reliable

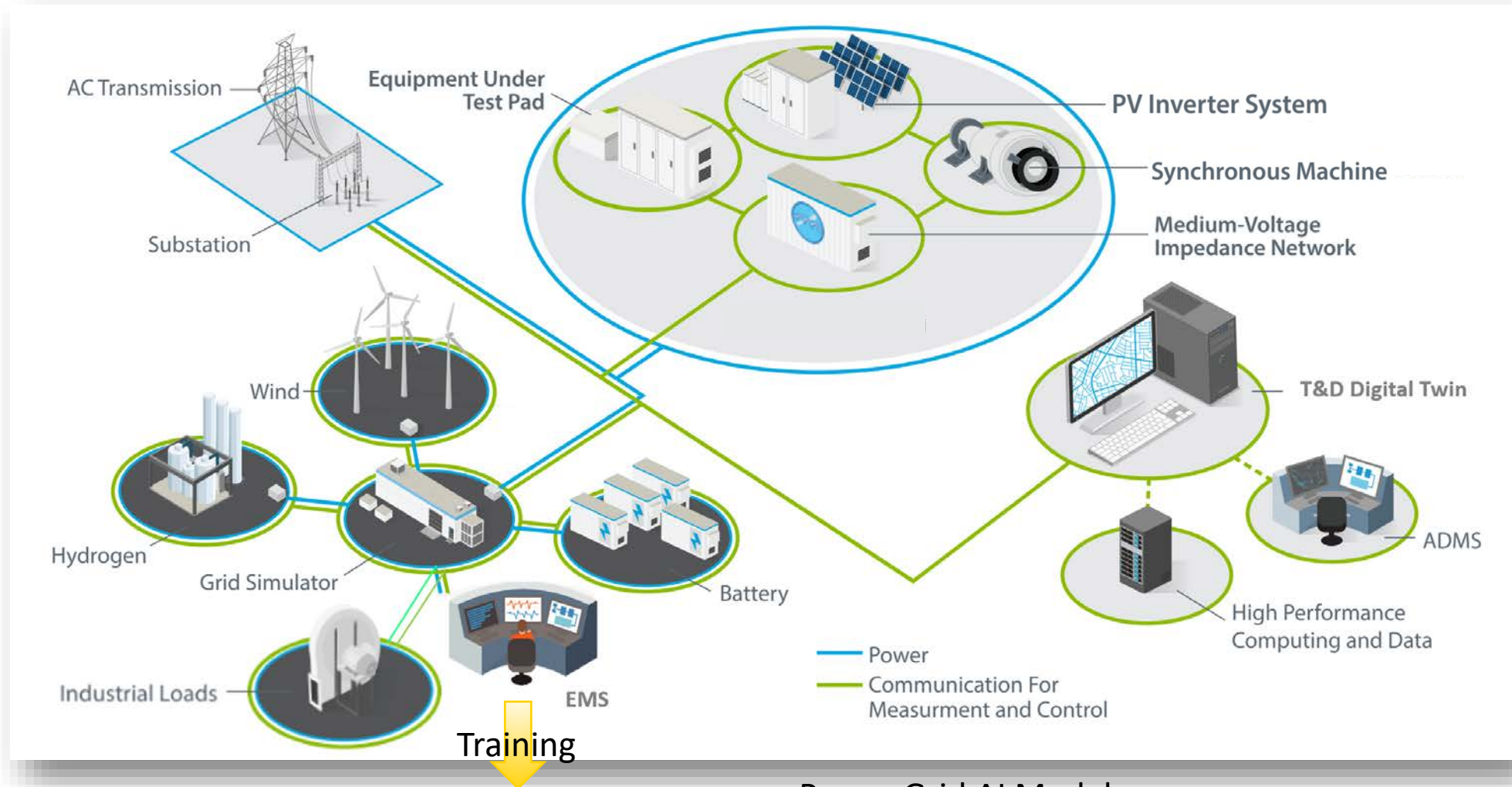
NREL Decision Making Platform: eGridGPT

NREL eGridGPT Decision-Making Platform

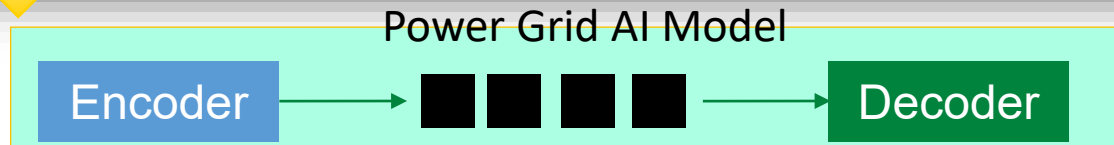


(Draft) NREL T&D Digital Twin Future

Power Grid AI Model Training & Validation



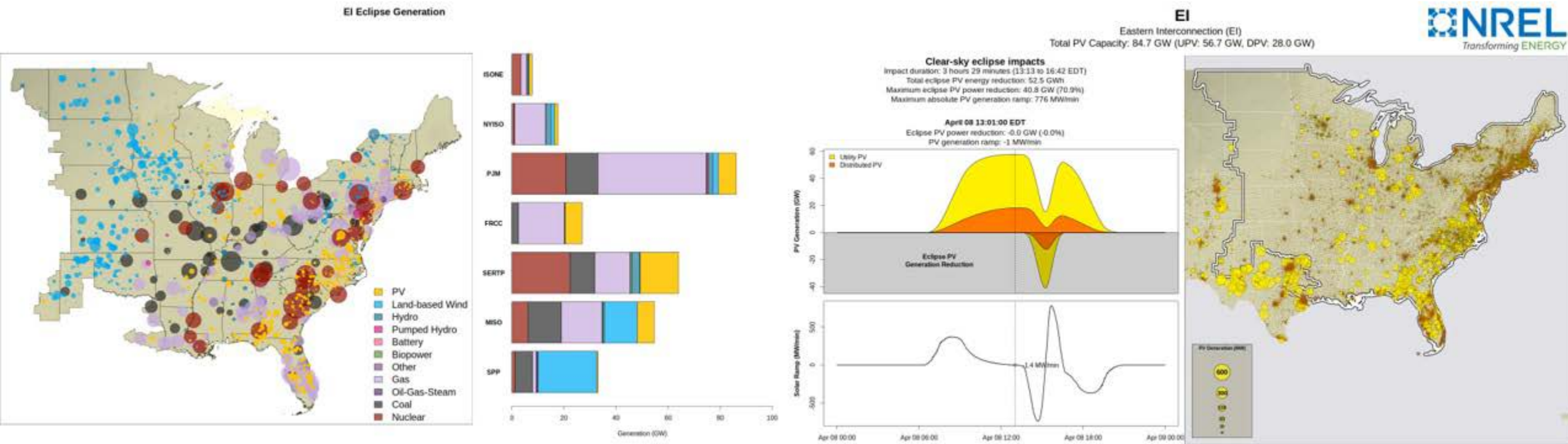
Source: Barry Mather, NREL



Validation

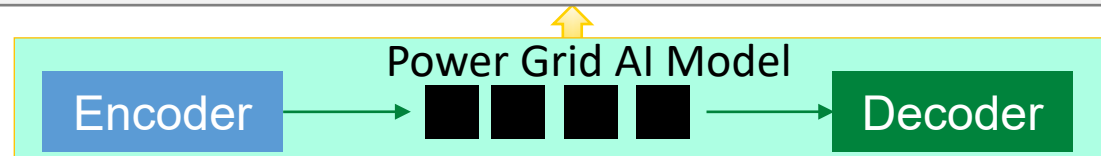
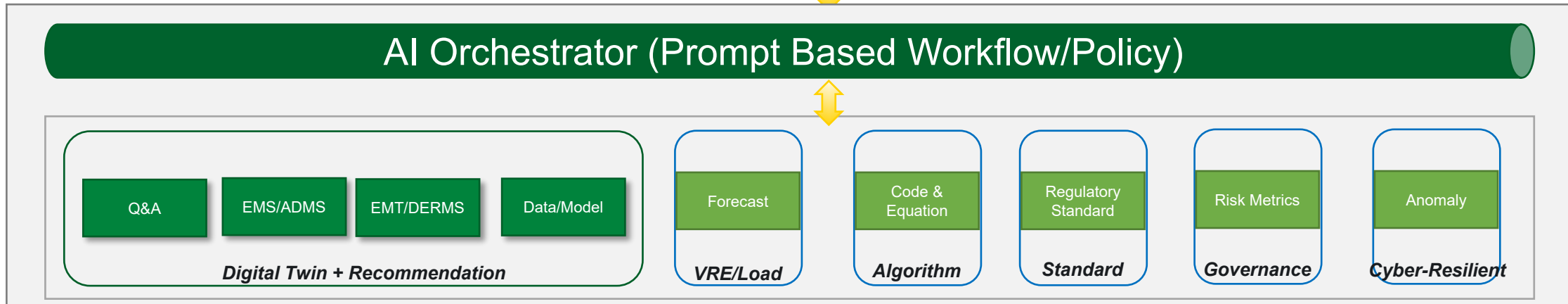
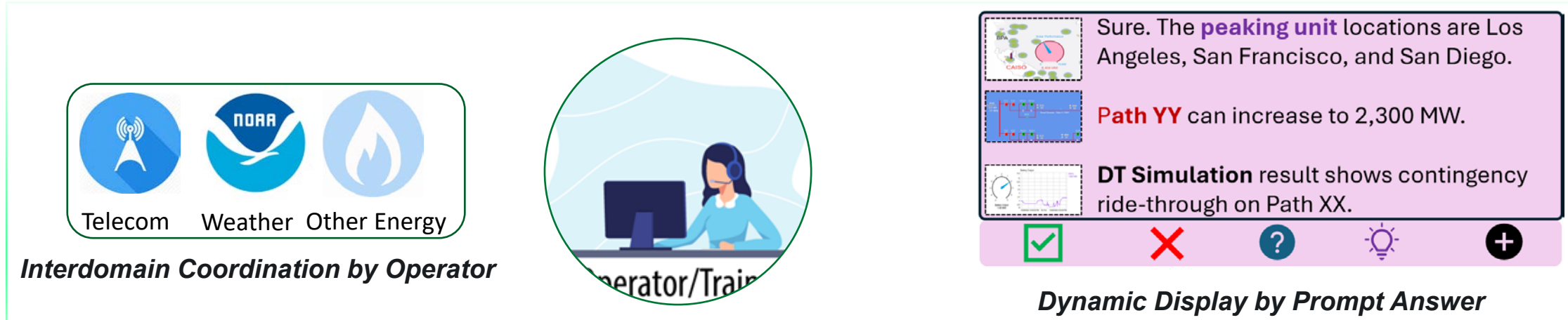
(Draft) Prompt Based Dynamic Display

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

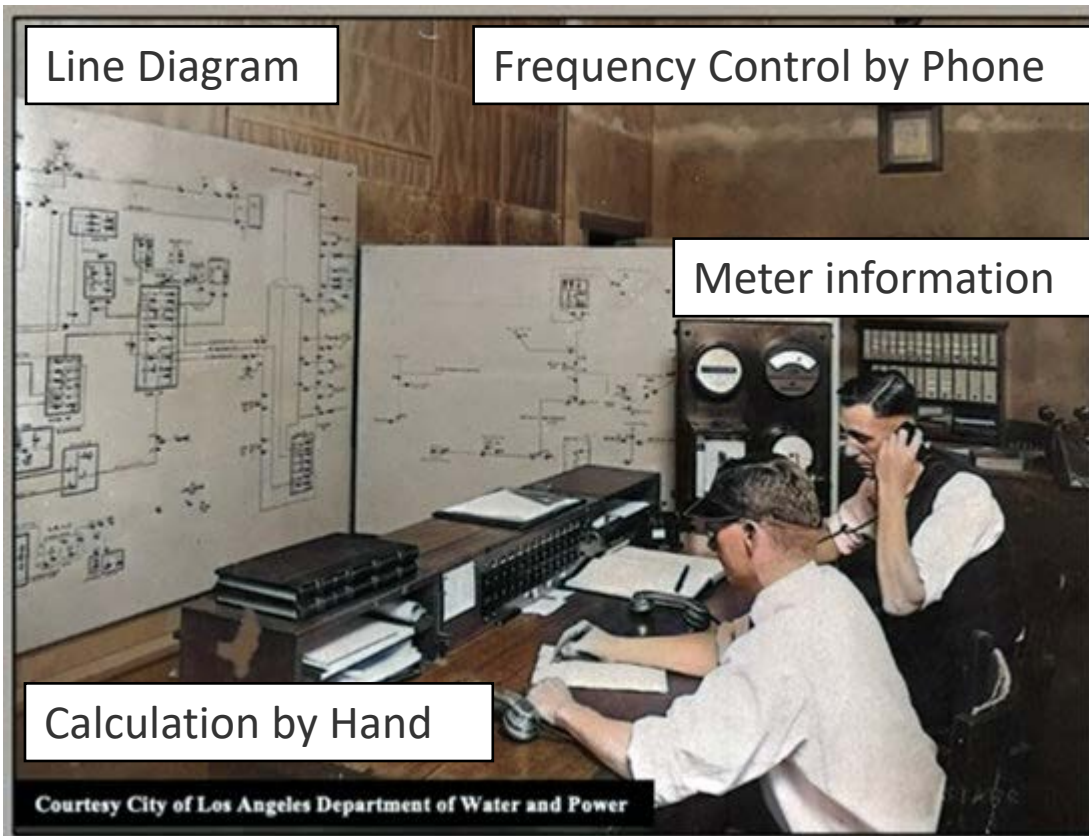



Source: Kenny Gruchalla, NREL


(Draft) Prompt Based Digital Twin + AI Orchestration



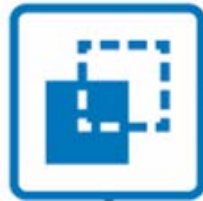
Digital Twin + AI + Dynamic Display



 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 to Automate Simulation.

- Reduce manual process
- Scenario runs concurrently



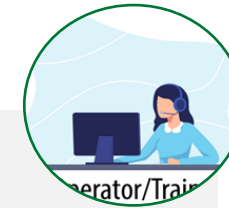
AI as a Virtual Assistant.

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

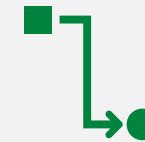


Display dynamically to Operator's request.

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



Better Decision Making



Recommendations



Trustworthy

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